Institutional Change and Institutional Inertia: Auctions and Quotas and the Illiquidity of Water
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Abstract

There is ample evidence that institutions governing human relationships are persistent over time. I explore a particular historical episode, irrigators communities in Mula (southern Spain), that went from a market institution (auctions) to a non-market institution (fixed quotas) in the 1960s. I show that by focusing only of the distribution of power or the efficiency of each available institution we are unable to explain the institutional change. One institution is a market mechanism while the other requires a ban on trading. Depending on the parameters of the model one mechanism is more efficient than the other. Moreover, each mechanism could achieve full efficiency under some parameters. The non-market mechanism requires an egalitarian distribution of property rights. I use this fact to show that a transition into a more efficient (and more equal) institution may not happen because of commitment problems when the new institution requires the owners of property rights to sell them to other agents with limited liability. Hence, the model predicts that an existing institution will persist, even though the new institution could be adopted without any cost, and the old institution is both less efficient and less egalitarian. I show how the role of collateral, due to the increase in savings of the farmers, solved the commitment problem and lead to a change to a more efficient institution.

“There is nothing more difficult to arrange, more doubtful of success, and more dangerous to carry through, than to initiate a new order of things.” N. Machiavelli, The Prince.

1 Introduction

Institutions governing human relationships, and specially those related to economic issues, are influenced by the environment around them and restricted by initial (historical) conditions. Historically determined initial conditions affecting current institutions are usually considered as given, a factor outside of the scope of the model, not an intrinsic part of it. The aim of this paper is to consider historical factors as part of the framework and analyze where and how historical factors will affect current institutions.

We can interpret the problem of institutional building and the lack of institutional change as a misalignment of incentives. There is a group of people (elites) who has the power to decide which institution will be in place. There is another group of people (citizens) that have no political power but are affected by the institution in place. If these two groups of people were only one single agent there will be no problem. The institution that maximizes the payoff for this single agent will be put in place. However, these

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two groups may have conflicted interests: the elites may prefer some institution that do not maximizes the payoffs of the citizens. These conflicted interest might be so important that they produce an overall inefficient institution: what the elites are gaining is less than what the citizens are losing. In this situation we want to understand under which circumstances can we get rid of this trap, that is, when would the elites and the citizens be able to reach an agreement such that the chosen institution maximize the total payoff of both groups.

It is not only important to understand when we will expect to see the efficient institution being the chosen one, but also equally important to understand how the transition from an inefficient to an efficient institution can take place. One explanation might be that the citizens gained political power. Since now all the citizens have political power there is no distinction between elites and citizens and hence, the efficient institution will be in place. This is the approach take in the Political Economy (PE) literature.

Another explanation might be that there is a technological change that makes the losses of the citizens (gains of the elites) so big (small) under the inefficient institution that whatever mechanism that prevented the citizens from getting their preferred institution is not sufficient anymore and hence, the change happened. This is the approach taken in the New Institutionalism Economics (NIE) literature. See Menard and Shirley (2005) for a broad discussion.

There is yet a third approach. If there is an institution that can increase the sum or the payoffs of the citizens and the elites, then in an economy with perfect contracts we will always expect this institution to be in place. The transition would be simple. The winners (citizens) under this new institution should compensate the losers (elites) and, since efficiency has increased, the payment asked by the losers is less than the gains of the winners. An implication of this statement is that, if we do not see the efficient institution in place, this implies that in this economy there are no perfect contracts. If the potential winners under the new institution can credibly commit to compensate the losers, then we will observe a change in institution. If the potential winners cannot commit to this payment, then we will observe that an inefficient institution persist over time. This can happen even if all the players understand that the institution is indeed inefficient. The third way in which we can explain institutional can change is after an increase in the commitment ability of the winners.

In an economy without political or technological change, we cannot use the first two (standard) explanations of institutional change. Hence, we need to use the third approach. The key ingredient for this explanation lies in the commitment power of the parties involves. Both PE and NIE have used the role of commitment in explaining the sustainability of institutions but in a different way.

In the case study presented here, the new institution is more efficient than the old institution but it requires a specific allocation of property rights. In order to achieve this re-allocation, the winners under the new institution should compensate (pay) the losers. In a world with perfect commitment, this compensation process is trivial. Since the new institution is more efficient than the old one, the increase in efficiency could be divided between the winners and the losers in such a way that all of them are better off. Hence, any change towards a more efficient institution will be Pareto Efficient. However, if the potential winners cannot commit (ex-ante) to compensate the potential losers, the losers will oppose the change. If the potential losers are the ones with political power (elites) they could effectively block the change. The potential winners can commit to compensate the losers by paying upfront part (or all) of the compensation. Hence, a change in the institution will happen if and only if the potential winners can make a sufficiently high upfront payment to the potential losers. The potential winners are penniless (and thus suffer from limited liability, the transition, although efficient, will not take place, because they cannot commit (ex-ante) to a payment (ex-post).

Notice that the transition will happen in the absence of any technological change. The new institution could be more efficient than the old one and the inefficiency gap will remain for centuries while the
commitment problem is not solved. Notice also that the reason that the potential losers prevent the change is not because they want the potential winners to remain poor or to keep the power, but rather that they demand a fair compensation for the losses they will suffer under the new institution. If the new institution is just a reallocation of property rights, the losers are only claiming to be paid for the property they are “selling”.

This paper analyzes a very particular setting, with a specific set of institutions and one important change in the environment. In the 13th century the Christians conquered the Kingdom of Murcia from the Muslim rulers. The towns and cities in the Kingdom were then settled with Christians from northern Spain (mainly from the Castille and Aragon Kingdoms). In this environment, all the communities in each town faced a similar problem: how to allocate the water from the river among the farmers? The new settlers had to create new institutions to allocate water from scratch. However, different towns adopted different solutions. In some places they adopted a market mechanism (auctions) and in other places they adopted a non-market mechanism (quotas). From the 13th century until the end of the 15th there was some experimentation in many towns (Totana, Librilla, Beniajan, Cartagena) switching back and forth with both mechanisms (see Rodriguez Llopis (1998)). By the end of the 16th century the institutions that were in use in every place remained unchanged until the 20th. Only the cities of Mula and Lorca kept the auction mechanism, and did not change until the second half of the 20th century. In the 1960s the cities of Mula (1966) and Lorca (1961) switched to the quotas mechanism.

The fact that most of the towns experimented with both institutions and farmers in those towns knew the existence of other allocation mechanisms means that Old Institutionalism (OI) (Schotter (1981)) theories cannot explain the evolution of institutional design in the present setting.

In Mula, the prices of water began to rise in the 1950s, more than a decade before the change in the institution took place. However, prices began to fall few years before the change took place. But even if water was becoming more valuable, unlike North and Thomas (1973) and Libecap (1978), the new institution produced a weakening of the definition of property rights, because it required a ban on water trading and a joint ownership of water and land.

The history of Spain, from the 16th century onwards is plagued with wars, changes in law and borders and political instability. Political instability increased during the 19th century and the first half of the 20th century until a civil war (1936-39) ended with the victory of the fascist party who imposed a long-lived dictatorship (1939-1975). Hence, in the 1960s Spain was experiencing the most peaceful period in its history and most stable political regime in centuries.

Each mechanism (auctions and quotas) has been continuously used in each town for centuries. Also, in most towns both institutions have been in place at some point in their history. However different, what both institutions have in common in that both are self-governed and self-regulated. The farmers got together and allocated the water through one mechanism or the other without the intervention of a third party. Moreover, the farmers, under each regime, establish their own courts and appoint their own judges. Elinor Ostrom (1990) has extensively studied the benefits of self-governed institutions like the one I am studying here, unlike most scholars that rely on a Hobbesian Leviathan. The Hobbesian legal centralism theory has been criticized by Ellickson (1991) among others. That is, there are situations in which people are not constrained by formal legal institutions (see Posner (2000)), but according to some (commonly agreed) social norms. This point of view about social organizations is consistent with the point I am making here.

Moreover, the internal institutional norms (Ordinances) that the farmers in Mula had before and after 1966 are both consistent with the eight points required by Ostrom (2005) for a self-governed institution to be robust. This literature is of little help when deciding which of the two self-governed institutions will survive. Thus, the literature in self-governed institutions is useful to understand the persistence/optimality
of the self-governed characteristics of the institution but it is mute about the optimality or adequacy of markets.

1.1 Literature Review

NIE (see Menard and Shirley (2005) for a detailed survey) emphasizes studying the micro-foundations of contract-enforcement institutions (Williamson (1985)) and the inter-relationships between the polity and the economy (North and Thomas (1973)). According to Williamson, it is the tradeoff between a cheap form of production (markets) without any commitment from the seller and another (more expensive) form of production (firm) with perfectly aligned incentives that determines both the organization structure of the firm and its mere existence.

According to North (1990) institutions fail to adjust in response to exogenous changes due to sunk costs, coordination costs and network externalities. I will argue that commitment problems are at least as big a concern as any of these costs. The inability to commit to a future payment can be interpreted as a greater risk premium asked by the lender. The question, then, is not whether the borrower will pay or not, but the probability that the borrower will pay back and the risk premium associated with that probability. The lower the probability that the borrower will pay, the greater is the premium asked by the lender and thus, the greater are the gains in efficiency for a transition to take place. Hence, one could interpret the model presented here as an attempt to endogenize some type of transaction costs.

What Eggerston (1990) calls the “naïve” theory of NIE view of the world focuses on the efficiency of each contractual arrangement, here: market, hybrid or firm, and in which cases each of them will be the most efficient (cheapest) form of production. It implicitly assumes that there is only one planner and that the objective function of the planner is to maximize efficiency (minimize costs). Less naïve theories of NIE have no such narrow view, but they still focus on efficiency and neglect the conflicts that can arise between different groups of people with different interests. However, as political economists emphasize, the identity of the planner will matter if players do not have the ability to commit or if the players affected by the change in the institution are not the same player with the power to change the institution. Technology or production alone is not sufficient to explain the survival of an institution for more than seven centuries and its abrupt end in the 1960s.

Mass and Anderson (1978) claim that the two institutions (quotas and auctions) can be ranked in terms of efficiency and equality, auction being the most efficient and unequal allocation system. According to this theory, we observe both systems because the less efficient systems are also simpler and easier to maintain (lower operational costs). This hypothesis predicts that we will observe auctions in places where water is extremely scarce. Although this is a very appealing hypothesis, it has some flaws. The size of the land used for irrigation is (at least partially) endogenous. Farmers could, and actually did, increase the land designated for irrigation (regadio) if needed. Moreover, the first settlers could have imposed limitations on the size and the number of the parcels assigned to the newcomers, as farmers did in the American frontier. Hence, “scarcity” is also endogenous. Ruiz-Funes (1916) also shares this skepticism.

The PE view of institutional change is best exemplified in Acemoglu and Robinson (2008). They see the world as a zero-sum game (or negative-sum game in case of a revolution). The elites have the political power (decision rights) and are concerned only about their revenues, regardless of the overall efficiency in the society. Hence, all that matters is how the society divides the cake. The size of the cake does not change with different institutional arrangements. This hypothesis is very appealing because it explains why inequality persists over time and why the elites did not want the institutions to change. Actually, it might be the reason why, in the first place, Mula and Lorca ended up with private property rights on water and other cities did not. Politics might have been very different in these two towns in the 13th–16th centuries due to their strategic position in the border between a Christian and a Muslim kingdom and the
fact that both town were originally ruled by military orders.

However, this hypothesis is not able to explain why the situation changed in the 1960s, and not before, given that the border disappeared in 1492 with the unification of Spain. PE models will predict an institutional change to happen after (and only after) a revolution or the threat of a revolution. Political instability was the rule and not the exception in Spain during the 19th century and the first third of the 20th after the civil war ended in 1939 with a long-lived dictatorship. Hence, by 1966 the citizens of Mula had enjoyed 25 years of political stability for the first time in almost two centuries and the threat of a revolution was not in the minds of anyone at this time. Another flaw of this theory is shown in Espín-Sánchez (2012). When a farmer accused another farmer of stealing water, the fine was substantially greater when the defendant was a “Don” than when it was a regular farmer. There is no relation between the defendant being a “Don” and the probability of being found guilty. This suggests that the institution was intended to minimize crime, imposing bigger fines in individuals that are wealthier. The fine was also smaller when the accuser was a “Don”. This means that the institution serves as redistributive rather than “extractive” mechanism.

Along the same line, some authors (see Garrido (2011b)) have claimed that auctions were used in places where the local elite has a lot of power. Auctions then may create both inefficiency and inequality. We will expect a quotas system only when/if the local elite is not so powerful. This way of thinking was the main point of view of (mainly 19th century) contemporary observers as Juan Subercase (Cited by Muñoz (2001)), Aymard (1864) and Brunhes (1902). This literature properly criticizes the flaws of the NIE view. Their main point is that auctions are a bad way to allocate water. Compared with quotas, auctions will produce higher inequality and mild or no increases in efficiency. It is so because very few people own all the water, and the tradable water rights may even increase inequality over time. The Waterlords (owners of water rights but not land) are a minority in power and will not abandon their right without resistance.

However, this view fails to provide a proper model of minority resistance and institutional persistence. It implicitly assumes that the farmers (minorities) are unable to commit to a future payment to the Waterlords (elites) after the institution has changed. In the micro-setting I am presenting here the commitment ability of the players is not exogenous. Moreover, if the auction is such a “bad” mechanism to allocate water, and a better system was in use in the surrounding towns, why did it survive at all? If a system with quotas produces greater output and more equality (than auctions) in any place that it is established (Pareto Improvement), the Waterlord could have signed a contract with the farmers and sold the water to them. With the increased output the farmers will be able to pay at a higher price than the value the Waterlords are obtaining with the auction system. But this change did not happen until the 1960s. I will argue that the Quotas and the Auction systems need not be ranked in terms of efficiency. Each of them fits best in a different environment. Hence, I agree with the NIE that different environments would shape different institutions. However, the existence of an institution that will increase efficiency is only a necessary condition but not sufficient to trigger institutional change. Without the commitment to payback the new acquired property rights, an increase in efficiency will not produce the change in the institutions. We need to identify the winners and the losers under the new regime and whether the winners could credibly compensate the losers.

No technological shock happened in 1966 that caused the change in institutions in Mula. On the contrary, a slow process that began in the previous decades, of improvement of financial institutions and the welfare of the farmers was the cause of the institutional change, by solving the commitment problem. To the best of my knowledge Greif (2006) is the only attempt towards a theory of endogenous institutional change. He proposes an endogenous change based on commitment ability and unintended consequences of previous institutional arrangements. Although my approach is different, what both approaches have in common is that it is not a change in the payoffs or the available set of actions of the players what makes
a new institution possible.

Although not directly related to the Institutions or Institutional Dynamics literature, this paper is also related to the literature in auctions with budget (or liquidity) constrained bidders as in Che, Gale and Kim (2012). Same as here, Che, Gale and Kim (2012), find that a mix between Market and Quotas is better than markets or quotas alone. They find also that Markets alone dominate Quotas alone. However, in this setting there is no strict rank between Market and Quotas. The reason is that they assume that agents can consume only only unit of the good, with linear utility in their type, while I let agents consume as much as they want, with concave utility.

The result that collateral can be used to improve the efficiency in the allocation of resources is not new in the literature in Finance. Moreover, there is recent and active research area in Finance/Mechanism-Design that deals precisely with the problems that arise when the agent is penniless (limited liability) and how to enforce the optimal (or efficient) dynamic contract (see De Marzo and Fishman (2004) and De Marzo and Sanikov (2007) among others). This paper also aims to contribute to the short but growing literature in empirical studies in institutional change. A good review and a explicit path for research is found in Alston, Eggerstsson and North (1996). Finally, the paper is consistent with the comments and findings of both contemporaneous (Diaz Cassou (1889) and Brunhes (1902)) and current historians (Gonzalez-Castaño (1991)) that have look extensively at the traditional organizations of the Huertas in Murcia and southeastern Spain (Passa (1844), Glick (1967), Gil-Olcina (1994) and Garrido (2011b)).

2 Case Study

"A majoribus tradita, et apud nos deposita - Recibida de nuestros mayores y conservada entre nosotros", ("Received from our elders, and preserved among us"), Epigraph of the Preamble of the Ordinances of Mula, 1853.

In this section, I discuss the situation in Mula and the particular characteristics of the situation before, during and after its transition from a market institution to a non-market institution for water allocation. Geographical, historical and social conditions at the time the Christians conquered the Kingdom of Murcia, may have had an important impact on the way these institutions where originally set up. There is evidence of experimentation with other systems and some towns did, indeed, switch back and forth from a market to a non-market system before the 15th century (see Rodriguez Llopis (1998)).

2.1 Environment

In this area, the exploitation of the farm is made at the individual or family level (more than 90% of the parcels are smaller than 1ha). None of the plots are big farms (all owners have less than 5ha and most less than 1ha). The first explanation that comes to mind is that the technology/environment here makes the moral hazard problem so important that a bigger exploitation scale would not be profitable, even though it would alleviate the problems derive with the water scarcity. The same argument appears in Hoffman (1996).

2.1.1 Geography and weather

The coastal strip of southeast Spain is the most arid region of all continental Europe due to the "Foehn Effect". It is located right to the west of the mountain chain Prebaetic System, which includes the

1 A Foehn wind is a type of dry downslope wind which occurs in the lee downwind side of a mountain range. It is a rain shadow wind which results from the subsequent adiabatic warming of air which has dropped most of its moisture on windward slopes see orographic lift. As a consequence of the different adiabatic lapse rates of moist and dry air, the air on the leeward slopes becomes warmer than equivalent elevations on the windward slopes.
Mulhacen (the second highest mountain in Europe). The annual rainfall is less than 300 mm. The rainfall frequency distribution is skewed. The majority of years are dryer than the yearly average. The summers are dry with a secondary winter minimum appearing; Autumn is the only relatively wet season. However, in rainy days, in 70% of the cases, less than 1 mm falls and in 90%, less than 10 mm. The number of torrential rain days is not very high but when they occur, they can reach high intensity (for examples, 681 mm of water fell in Mula on one day, 10th October 1943, while the yearly average is 320 mm). Insolation is very high, more than 3000 hours of solar exposure per year, the highest figure in Europe. Arid conditions are found in relation to the marginal situation of southeast Spain to the circulating air movements found in the occidental Mediterranean area and to the Atlantic-origin storms.

2.1.2 History and Origins

After the fall of the Caliphate of Cordoba in 1031, the Kingdom of Murcia passed under the successive rules of the powers seated variously at Almería, Toledo and Seville. In 1172 it was taken by the Almohades, and from 1223 to 1243 it briefly served as the capital of an independent kingdom.

The Castilians, with forces led by King Alfonso X, took the city at the end of this period of autonomy, whereupon large numbers of immigrants from north northern Spain resettled the town. As with much of the Spanish Reconquest, these Christian populations were brought to the area with the goal of establishing a Christian base here, one that would be loyal to the Crown of Castile and whose culture would supplant that of the subjugated Moorish peoples. In 1296, control over Murcia and the surrounding region was transferred to the Kingdom of Aragon and, in 1304, was finally incorporated into Castile under the Treaty of Torrellas.

Every king since Alfonso X has respected the customs that farmers have in Murcia and in every town of the region. He also gave them the right to self-govern as “farmers’ communities”. It is worth noticing that the ruler opinion, for this particular situation, was that it is better to let the people make their own economic decisions and charge a (somewhat) low distorting tax, rather than appropriate the rights of exploitation and create a monopoly.

After the capital city (Murcia) surrendered to the Christians there were still three fortresses in the kingdom to be considered: Mula, Lorca and Cartagena. The leaders of these cities claimed rebellion and did not accept the terms of surrender agreed in the capital. Soon the Christian army was at the gates of Mula (the closest city to Murcia among the three) and the place was taken by force. After this victory the remaining cities of Lorca and Cartagena surrendered without resistance. This event had as a consequence stronger reprisals were taken against the (mostly Muslims) citizens of Mula, which increased the local demand for new Christians colons. The Muslims were then exiled to the adjacent village of La Puebla. Hence, the new Christian settlers in Mula had to start *tabula rasa* and made new institutional arrangements.

The need for more Christians induced families from other parts of the peninsula, mainly from the kingdoms of Castile and Aragon, to migrate to Mula. The *Concejo* (City Council) would give every family a piece of land (*parcela*) and a quota on the water of the river (*tanda*). After some years due to war, illness and other reasons, some of the *parcelas* were abandoned. The *Concejo* claimed property rights over those lands and the water associated with them. The drought increased the demand for irrigation. The demand for land does not vary with rainfall. Since this was still a land-surplus economy, a drought would create a great demand for water but not for land (since population was already below-average).

In other circumstances, the solution would be to increase the time given in the *tandas*. However, Mula was a frontier-city between a Christian kingdom and a Muslim kingdom. Although the general situation was of relatively peace, the documents from this age (centuries 13th to 15th) indicate repeated small skirmishes between frontier militias and raids intended to capture slaves or to steal cattle. All of
Table 1: Spain’s Political History

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<tr>
<td>13th Century-1492</td>
<td>Crown of Castille</td>
<td>1873-1874</td>
<td>1st Republic</td>
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<td>1492 century until 1701</td>
<td>Habsburg Monarchy</td>
<td>1874-1923</td>
<td>Bourbon Restoration</td>
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<td>1701 until 1808</td>
<td>Bourbon Monarchy</td>
<td>1923-1930</td>
<td>Primo de Rivera’s Dictatorship</td>
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<td>1808-1813</td>
<td>Napoleonic war</td>
<td>1931-1936</td>
<td>2nd Republic</td>
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<td>1813-1867</td>
<td>Bourbon Monarchy</td>
<td>1936-1939</td>
<td>Civil war</td>
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<td>1868-1869</td>
<td>Revolution</td>
<td>1939-1975</td>
<td>Franco’s Dictatorship</td>
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<td>1870-1873</td>
<td>Savoy Monarchy</td>
<td>1978-...</td>
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this meant that the city hall was always in need of money. The solution adopted was to “sell” the water and earn some cash. After a while, and responding to the demand of the farmers, the Concejo permitted the separation of ownership of water and land and eliminated the ban imposed on water rights’ trading. There is not a exact date for this process for the city of Mula, although this probably happened during the middle third of the 13th century, since the first document that talk explicitly about auctions dates from this time.

After that, the Waterlords (Waterlords) were clearly different persons than the land-owners (farmers). A well functioning cartel was established. The Waterlords themselves began to run the auctions. In the 19th century this cartel was made formal and legal and received the name “Heredamiento de Aguas”. The land-owners were small proprietors, with family-size plots, who created their own association, “Sindicato de Regantes”. The aim of this association was, for one side, to regulate themselves and settle disputes that arose between neighbors. Also, this association was created to keep balance the power in the market for water.

2.1.3 The production system

I refer here to the traditional production system, present in the southeast of Spain from 13th century until the last third of the 20th century. As reported by Anderson and Maass (1978), in each of the two systems for allocating the water (quotas and auctions), the production structure is based on small (family-size) units. Since the land is owned individually but the water irrigation system (the river, the dam and the channels) have to be managed jointly, these farmers had to create an institution to manage the common resource.

However, in neighboring areas the structure is radically different. Powerful landowners hire seasonal workers to work in large estates and pay them wages just above their survival needs. These large estates are used to grow cereals and are not irrigated. The production function is different: scale effects are important (hence the big estates), the crop is homogeneous (cereals) and, thus, there is no need for specific human capital investment or proper incentives for effort: quantity is easy to verify and contract, quality not so much. The argument for the optimality of the contract on land is consistent with Hoffman (1996).

The goods produced in the huertas are also different than in the large estates. Huertas produce mainly vegetables and fruits. They were also the main producers of white mulberry leaves during the silk boom in the 19th (and 16th) century as well as saffron and other high quality products. However, large estates produce mostly grain and fodder. Olives and grapes (wine) are produced in both systems.

The first thing to remark is that huertas produce goods that are heterogeneous in quality, while large estates produce homogeneous goods that bring low profit per acre. The former products (citrus, peaches,

\footnote{In economic terms, the trade-off between cash today and cash in the future (or consumption vs. investment) faced by the citizens of Mula was biased toward more cash today. In this situation, the best response is not the same as in times of peace, i.e. in times of peace we will expect greater investment/savings than in times of war. Hence, the original institutions in every town will be different, since it will be the best response to a different environment.}
etc) are very sensitive to weather conditions and require constant and close attention. Also, products cultivated in *huertas* required a high level of specific human capital. Things like pruning, fertilizing, selective harvesting (and seeding) or animal caring require a level of specific human capital higher than average. This accumulation of human capital will take several years and is transmitted mainly from father to son. However, things like reaping are easily learned and poorly paid.

All the attributes mentioned in the previous paragraphs are determined by technological constraints. What about the economic structure? Goods that are heterogeneous in quality, for which production a high level of specific human capital is needed and which are subject to shocks and specific needs only observed by the farmer, have a severe moral-hazard problem in a principal-agent setting. Monitoring cost are prohibitively high. Critz, Olmstead and Rhode (1999) showed that “whereas wheat required about 9 man-hours of labor per acre in 1939, lemons required 286.” The optimal mechanism in this environment will be to “sell” the firm to the agent. Garrido (2011a) and Garrido and Calatayud (2011) show that this was indeed the case in eastern Spain. They also show that all the contracts in this type of environment require that the farmer owns the land or that the farmer has a long-term contract with the Landowner with compensation for all the improvements, which is roughly equivalent to the farmer owning the land.

In a static environment, the wage-worker will not pay much attention in taking care of the crop. He will have incentives to report bad weather and will not work as much as needed in some circumstances. All these problems could be solved by some incentives mechanisms, such as a piece wage instead of an hourly wage, adjusting the payment to some quality measure if needed. However, any of those mechanisms is unlikely to solve the problem of investment in specific human capital or the selective harvesting (and seeding) issue. Moreover, any other specific investments will only be carried out if the farmer can get the entire surplus produced by the investment, such as experimenting with new crops/methods or irrigating at night.

### 2.1.4 Market and Non-Market Institutions

In this sub-section, I will describe two different institutions/mechanisms used in South-Eastern Spain to allocate water from the river, among farmers. Each of them is used in several cities of South-Eastern Spain.

**Tandas (Quotas)** This institution is the one that contemporaries considered the fairest. Every *tanda* will last three weeks. Water ownership is tied to land ownership. Every plot of land has assigned some amount of time of irrigation during each *tanda*. The amount of time allocated to every farmer depends on the plots he owns. The time allocated is roughly proportional to the area of the plot. However, plots with better quality receive more irrigation time (they also contribute a greater share to the cost of the channel maintenance). Parcels placed in elevated lands also get some more irrigation time, because they will receive less water when irrigating during the same time, due to the differences in the pressure of the water flow.

This system has the advantage that every farmer gets some “fair” amount of water once in a while, so it is especially desirable during a drought. Another important feature is that because of the insurance property of this institution, farmers have security enough to carry out risky investment... like trees. A tree will take several years to be fully productive, but it can die if it does not get enough water in a given year. Vegetables grow faster, and need no waiting time. Other crops like corn last three months to grow and be harvested, while the farmer will incur no losses (besides the seeds) in case of a drought. Hence, a farmer with a secure supply of water is more likely to plant trees, and get a higher expected profit from them.

However, without such security, a farmer may not make the investment. I will argue that a market
system, like auctions, might not achieve social optimum because of this. Credit constrained farmers will
not be able to pay (in cash) for the water they need in case of drought. Imperfect financial institutions
will make such investment non-viable.

**Subastas (Auctions)** Technically, the units sold in the auction refer to the right to use the water flowing
through the river at a specific date and time. The property rights of water and land are independent:
some people are the Waterlords (that is, they own the right to use the water flowing through the channel)
and some people are the land-owners. The Waterlords form a (legal) cartel. They will meet once a week
and decide how many units of water are going to be sold.

In Mula, water property rights were well established and were divided into 832 shares. The functioning
of the cartel was very similar to a modern corporation: votes were proportional to shares and these shares
were marketable.

### 2.2 Possible Explanations

Traditional explanations for this institutional diversity have been focused mainly on geographical differ-
ences between Mula and Lorca and the rest of the region. The argument goes as follows. These two
towns were (are) specially dry, much more than the rest of the region, thus they have auctions. Some
authors (Anderson.., in line with NIE) claim that auctions are always more efficient than quotas but are
more costly to manage, hence, auctions will only be use when the water (asset) is very scarce/valuable.
Other authors, mostly historians like González-Castaño (1992) in line with PE, claim that auctions (or
private property rights of water), is just another way in which the local elite can exert their power over
the peasantry. Auctions will only be used in places were water is scarce and, by controlling the water, the
local elite can control the non-elites. I will show that both arguments are wrong simply because they rest
on an incorrect fact: Mula and Lorca are not specially drier than other towns that have quotas.

The relative dryness can take two forms: Either towns with auctions are drier because they have lower
average rain (or same average rain but greater variance), or they are drier because the ration between
available water and irrigable land is lower. We can see in Table 2 Mula and Lorca are not especially
dry, nor especially humid. The table present a comprehensive sample of the province of Murcia for towns
that have irrigators communities. The most reliable source for Mula and Lorca comes from their dams
and, as we can see, they are around the median, not in the top of the table. If the argument was
correct we would expect towns like Ulea, Fortuna or Alguazas (all of which had the quotas system) to
run auctions, or even the capital Murcia. As Garrido (2011b) points out, there is not a real correlation
between weather/geography and private property rights of water.

The other argument for relative dryness comes from the fact that different towns have different amount
of water from their river and different sizes of irrigable land areas. Although this is true, towns with
auctions had less water available for every hectare, the causality is reversed. As Garrido (2011b) shows,
the biggest increased in irrigable land that took place in Lorca and other towns happened after they have
the auctions and not before. The argument is simple, if the owners of the water and the owners of the land
are the same people, they will restrict the size of irrigable land in order to maximize the average or total
output. If the owners of the water are not the owners of the land, they will increase the size of irrigable
land beyond the point that maximize total output, in order to maximize revenue. They will increase the
size of the irrigable land until the point in which marginal output equals average output.

This argument, however, is not as powerful as Garrido suggests. While it is true that the irrigable
land in Alicante and Lorca (both with auctions) quadrupled and tripled respectively between the 15th and

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\[\text{In this region not all land can be irrigated. Land that can be irrigated receives the name of regadío and land that cannot be irrigated receives the name of secano.}\]
the 19th century, the irrigable land of Murcia (with quotas) also tripled during the same period (Chacón
Jiménez et al (1979)). This suggest that the main reason for this increase in irrigable land was due to
improvement in irrigation technology.

Hence, there is no evidence to support the claim that Mula and Lorca were intrinsically different than
other towns around them. Also there is only little evidence suggesting that the environment in Mula and
Lorca changed dramatically due to the auction, i.e. it is hard to argue that the irrigable land in Lorca
and Mula would have been much smaller had the auctions not been in place. These facts suggest that
if there was some path dependence after they switch to auctions its main channel would be through the
institutional channel rather than the physical one. They also hint that the reason for them to switch might
lie either in different macro institutions in these towns or in some external shock that affected Mula and
Lorca in a different way than it affected the other towns.

There are several plausible hypotheses that can explain why Lorca and Mula switched (before the 15th
century) to an institution in which land and water ownership are independent (auctions), even if this was
not efficient, based on an external temporary shock. After this change in the institution to adapt to the
temporary shock some towns were able to go back to the efficient institutions and some others did not.
One explanation is related to the Black Death. After the epidemic disease, and due to the decrease in
population, the community faced a situation in which some of the land (and the water tied to it) is not
being used. In such a situation and during a drought, it will always be optimal to make use of the water
tied to the unused land. One way to make use of this land is by public auction by the municipality, and
to use the revenues to improve/repair the irrigation system. Once it is agreed and understood that the
city hall is using these water rights, the new settlers will only receive land, without water rights. In this
situation, some of the owners of water and land might want to sell part of their water rights and some of the
new settlers might want to buy them. After the City Hall has accepted private trading in water property
rights, it might also decide to sell the water rights that it initially claimed and let the private owners run
their own auctions. With free trade of water property rights, there is no reason to think that equality will
remain constant. Moreover, Gonzalez-Castaño shows that inequality in water ownership increased during
the 16th – 19th centuries.

Another explanation has to do with risky investments in silk. Before 1492, the Muslim Kingdom of
Granada was the main port for silk in Europe. It also had a big industry for silk fabrics. After 1492 with
the conquest of Granada by the Catholic Kings, and the expulsion of the Muslims afterwards, there was
an excess of demand for silk in Spain and Europe. The artisans in the neighbor region of Murcia rapidly
took over it. They built new factories and demanded white mulberry leaves from the local farmers. The
farmers uprooted the vines, olive and fruit trees that have been there for years (centuries) and planted
white mulberry trees to satisfy the increasing demand. Then, by 1570-1580, a crisis emerged in Europe,
due to the Wars of Religion. Silk is a luxury good and it is of little use both in war or famine, the demand
for silk plummeted. The consequences were disastrous for the region (see Lemeunier and Pérez Picazo
(1984)). Farmers had to uproot the useless white mulberry trees and plant vines, olive and fruit trees,
or just wheat, to survive. Some of these trees take five or more years to become productive. Hence, the
farmers were in a real desperate situation. In such a situation, it is sensible to think that the farmers
agreed to untie the ownership of land and water, sell their water rights and keep their land. With the
cash received in exchange for their water rights they could feed their families while the new trees grew up.
Although inefficient, this new system was far better than to starve. Since Mula and Lorca were both big
cities, each of them the capital of their county and both in the border with Granada, it is plausible that
these cities were more specialized in the silk industry and, hence, they suffered more from the silk crisis

4They both were run by military orders in the years following the Christian conquest, unlike Murcia an other mayor
towns.
than smaller towns or cities closer to the sea. Hence, only in these full-specialized cities did the system change, and not in other towns.

If a new economic institution could substantially increase the output of a given society, in the absence of transaction costs, one would expect that the new institution would be put in place. If the elites are worse off under the new institution, the winners could compensate then to prevent the elites from blocking the change. However, one problem that can arise is lack of commitment. The Waterlords could sell their rights to the farmers. Farmers would then make better (non-distorted) decisions and, thus, increase output. This result is standard in moral hazard problems (“sell” the firm to the agent). However, farmers are penniless and could only buy the water rights (not the water) with a promise of future repayment.

One option would be to use the land as collateral. However, the farmers might be reluctant to do so. On one hand this would imply that farmers should carry a lot of risk, since they can lose “everything” during a drought. On the other hand, it would be hard for the Waterlord to take over the land and it would also be hard for him to sell it so someone else since maybe most farmers are in the same financial situation. Finally, the Waterlord is not a farmer, just a financial speculator; hence, it would be even harder for him to grow the land by himself. In the data, 97.35% of the parcels are cultivated by their owner, which reinforces the idea that the production function is intensive in labor and requires a lot of “know-how”. In any case, due to the scarcity of water, the value of a plot of land is much lower than the value of the water rights needed to irrigate it properly, so even if the farmers are willing to use the land as collateral it will not cover 100% of the purchase.

A debt contract will also create inefficiencies in production, due to the risk that the farmer is bearing, even if the farmer is risk-neutral. Hence, contractual/commitment problems can delay or make impossible an institutional transition. In such situation, the “only” way to achieve full efficiency is to “give” the water rights to the farmers (“give” the firm to the agent).\footnote{This is exactly the same policy followed after the American civil war. The congress ordered that the former slave owners should “give” one mule and 40 acres of land to each freed slave. This policy established explicitly that the former slave owners should “give” one mule and 40 acres of land to their freed slaves, not that they should “sell” a mule and 40 acres to the slaves.}

Not surprisingly, this was the proposition of the government in 1931 when the new Dam was build (see \footnote{This is exactly the same policy followed after the American civil war. The congress ordered that the former slave owners should “give” one mule and 40 acres of land to each freed slave. This policy established explicitly that the former slave owners should “give” one mule and 40 acres of land to their freed slaves, not that they should “sell” a mule and 40 acres to the slaves.}). The government made an offer to the Water owners of 4.2 million pesetas for all the water rights of the Mula river. After the purchase, the government will allocate water rights to the farmers in proportion to their land, for free, and the water will be tied to the land. Hence, the commitment problem would be solved and the more efficient institution will be adopted. The Waterlords took the offer very seriously. They printed a small book with the details of the offer and the opinion of the president and other members as well and some of the conclusions during previous meetings, before the voting in the general assembly. The opinion of the water owners was divided in three groups. The group of small owners (1 or 2 shares) was in favor of the sell, at any price. Since all of them were farmers with a small amount of water shares they will benefit greatly from the change. Not only they will receive money from their shares, but they will also be awarded more water rights than they have before. The group of middle owners (3 or 4 shares) were also in favor, they will received the same amount of water rights that they have now, but they would be paid for the water they own. The group of big owners (5 or more shares) was in favor of the offer only if the price offered was sufficiently high and the payment was made in cash. The offer of 4.2M was a “fair” price according to most of the big owners; the offer was accepted as adequate by the Waterlords. However, the sale was not completed because the Waterlords wanted the payment to be in cash, but the government (the new established 2nd Republic of Spain) could not afford to make the payment in cash. The government was unable to make a credible promise of future payment. The concerns of the Waterlords were justified since in 1936 a civil war erupted. The civil war ended with the defeat of the supporters of the Republic and the establishment of a 40-year long dictatorship. Had the Waterlords accepted the offer from the government, they would not have been repaid.
Table 2: Rain in Several towns in the region (Average and Standard Deviation).

<table>
<thead>
<tr>
<th>Town</th>
<th>From</th>
<th>To</th>
<th>Average Rain</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>ULEA</td>
<td>1961</td>
<td>1966</td>
<td>150</td>
<td>201</td>
</tr>
<tr>
<td>LORCA, C. H. S.</td>
<td>1933</td>
<td>2007</td>
<td>212</td>
<td>276</td>
</tr>
<tr>
<td>FORTUNA</td>
<td>1952</td>
<td>2010</td>
<td>228</td>
<td>286</td>
</tr>
<tr>
<td>ALGUAZAS</td>
<td>1933</td>
<td>1981</td>
<td>234</td>
<td>300</td>
</tr>
<tr>
<td>MURCIA, C. H. S.</td>
<td>1933</td>
<td>2007</td>
<td>236</td>
<td>297</td>
</tr>
<tr>
<td>JUMILLA</td>
<td>1912</td>
<td>1930</td>
<td>242</td>
<td>259</td>
</tr>
<tr>
<td>LORCA, CASTLE</td>
<td>1948</td>
<td>1978</td>
<td>243</td>
<td>360</td>
</tr>
<tr>
<td>LIBRILLA, C.H.S.</td>
<td>1934</td>
<td>2010</td>
<td>260</td>
<td>350</td>
</tr>
<tr>
<td>YECLA</td>
<td>1935</td>
<td>2010</td>
<td>261</td>
<td>289</td>
</tr>
<tr>
<td>MULA, DE LA CIERVA DAM</td>
<td>1933</td>
<td>2010</td>
<td>262</td>
<td>362</td>
</tr>
<tr>
<td>LORCA, VALDEINFIerno DAM</td>
<td>1933</td>
<td>2010</td>
<td>268</td>
<td>338</td>
</tr>
<tr>
<td>TOTANA</td>
<td>1913</td>
<td>2010</td>
<td>269</td>
<td>344</td>
</tr>
<tr>
<td>MULA, DIPUTACION</td>
<td>1954</td>
<td>1977</td>
<td>271</td>
<td>311</td>
</tr>
<tr>
<td>MULA, C. H. S.</td>
<td>1953</td>
<td>1978</td>
<td>274</td>
<td>343</td>
</tr>
<tr>
<td>MURCIA, INSTITUTE</td>
<td>1863</td>
<td>1955</td>
<td>275</td>
<td>344</td>
</tr>
<tr>
<td>BLANCA</td>
<td>1945</td>
<td>2008</td>
<td>278</td>
<td>331</td>
</tr>
<tr>
<td>RICOTE</td>
<td>1944</td>
<td>2010</td>
<td>290</td>
<td>353</td>
</tr>
<tr>
<td>PLEGO</td>
<td>1954</td>
<td>2010</td>
<td>306</td>
<td>394</td>
</tr>
<tr>
<td>MORATALLA</td>
<td>1933</td>
<td>2010</td>
<td>308</td>
<td>356</td>
</tr>
<tr>
<td>LORCA, “CASA IGLESIAS”</td>
<td>1916</td>
<td>1978</td>
<td>406</td>
<td>589</td>
</tr>
</tbody>
</table>

Source: Own elaboration with data from the AEMET. Sorted by average rainfall. Monthly rainfall data measured as (mm/m²). C. H. S. refer to measures by the Confederación Hidrográfica del Segura, a public regulatory agency. Towns in bold letters (Mula and Lorca) had auctions while all the other towns had quotas.

Figure 1: Offer made by the government for the full ownership of the water. Pages 10-11.
This was quite an unfortunate course of events. Before 1895, when a new book of “Ordenanzas” (civil law) was approved and printed, the system established a democratic (rather than corporatist) voting rule: one man one vote, regardless of the number of shares each member owns. After 1895, the rule established that a man with 1-4 shares will have 1 vote; a man with 5-8 shares will have 2 votes and so on. Had the old “Ordenanzas” been in place in 1931 the outcome might have been different.

During the 1950s and 1960s the foreign policy of the government began to change. Borders were open and trade contracts were made with EU and US. This situation produced an unprecedented boost in the Spanish economy. This boost was especially important for the farmers in southeastern Spain because they take advantage of it and exports of fruit and dry fruit grow exponentially. For the first time in their history, the farmers of Mula could produce enough output to create a surplus that can be storage. Improvements in the financial sector and a state policy concern with increasing local savings and provide easy access to credit for small business created the perfect environment for savings. By 1966 the savings accumulated by the farmers in Mula were enough to provide the local financial institutions and the Waterlords with a credible promise of future payments. After several centuries of history the auction mechanism came to an end.

2.3 Liquidity shocks

“The destruction of the inducement to invest by an excessive liquidity-preference was the outstanding evil, the prime impediment to the growth of wealth, in the ancient and medieval worlds.”, John M. Keynes, The General Theory of Employment, Interest and Money (1935), Book 6, Chapter 23, p. 351.

The findings of Garrido (2011a) and (2011b) and especially those about the paradox of Maas and Anderson (1973) data are also consistent with the existence of liquidity shocks. In 1964 the crop which provided the highest “full production net return/ha” in Alicante was the tomato, which allowed farmers to obtain 60,000 pesetas per year per hectare. So why were tomatoes only planted on 4.5 per cent of the huerta? (Maass and Anderson 1978, 144-145). If wheat and almonds only yielded 15,000 and 28,800 pesetas per hectare, respectively, why did they take up 20.5 and 24.6 per cent of the irrigated area? In eastern Spain as a whole, the crop with the highest net return was the orange (80,000 pesetas per hectare, p. 99), which was the monoculture of most of the huertas without a water market (Garrido 2011b).

2.4 Transition

In 1966, the auction mechanism ended. The farmers’ association (Sindicato de Regantes) reached an agreement with the cartel (Heredamiento de Aguas) and the auction was substituted by a bargaining process. They agreed on a fix price for all the water flowing through the river. The price will be revised every six months. The Sindicato the Regantes allocated then the water among the farmers using Tandas (quotas). Moreover, from 1966 the farmers’ association starts buying each of the shares from the original owners. By 1981 the association owned all the shares and formally changed the legal status of the water. Since then, the water of the Mula River is also tied to the land, in the same way as it is in other towns in Murcia.

This fact and other anecdotal evidence show that the cartel, although a private (and arguably profit-maximizing) firm, usually took into consideration the effects that its actions may have on the farmers. In the late 17th century, and right after a plague, the Dam of Mula was broken due to a big flood. Most of the members of the cartel were dead or bankrupt. The citizens of Mula agreed that the Town Hall should

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pay for the Dam to be re-built, with tax collected money. They understand that, even though it was a private endeavor, it was essential for the survival of the city. In any case, the Town Hall reserved the right to use 5% of the water for public usage.

In 1868, Spain suffered one of the most severe droughts of modern history. The Waterlords in Lorca, after listening to the complaints of the farmers, decided to sell any amount of water demanded by farmers, at the minimum price paid in the last auction. After two days they had to stop this direct sale, since the dam was virtually empty. However, this shows that (myopic/static) non-profit-maximizing actions intended to help the farmers are not so uncommon. These actions could just be the responses to a concern that farmers will lose their crops and their trees (even their lives), and this will in turn reduce future demand for water. One could argue that this is a desperate measure when facing the threat of a (violent) revolution. In any case, this flexibility is, in my opinion, one of the keys to the success and survival of the system.

These examples of non-profit-maximizing actions together with the evidence found in Espin-Sanchez (2012) suggest that even if the market mechanism is inefficient due the existence of liquidity shocks, in the real world, both the farmers and the Waterlords took action to alleviate these effects, especially during severe droughts or floods. Even if the cartel was a private enterprise whose aim was to maximize profit, it survival depended on its role of insurance of last resort.

3 Model

In this section I present the model. I first present the assumptions in the environment and then solve for the equilibrium in the auction system. I also compute the outcomes in both the auction system and the quotas system.

Let there be an economy in which there is one Waterlord and a continuum of farmers of mass equal 1. All players are risk neutral. Time is discrete and there is an infinite horizon. All players discount the future with a common discount rate \( \beta \). Only farmers can produce goods. There is only one output good in this economy, food, with price normalized to 1. Individual output is perfectly observable by all players. The production function of food depends on two factors: water \( w_{it} \) and effort \( e_{it} \), and in some random technology parameter \( A_{it} \) which probability distribution is common knowledge. Effort \( e_{it} \) is chosen by farmer \( i \) and is only observable by him. Each farmer is entitled with some irrigation rights \( \theta_i \).

For simplicity, I assume that the amount of water available for irrigation is the same every period, hence, \( \int_0^1 \theta_i \, di = \theta \). This assumption is not important for the results but will simplify the analysis.

Water comes from two sources: rain and irrigation, i.e. \( w_{it} = r_{it} + \gamma_{it} \). Rain \( r_{it} \) is a random variable and has a finite mean every period \( \frac{1}{0} r_{it} \, di = R_t \), while the total amount of irrigating water is \( \theta \). The production function of food is then \( f(w, e) \), with \( f(0, 0) = f(w, 0) = 0 \). This function is increasing and concave in each argument, i.e. \( f_w, f_e, \geq 0 \) and \( f_{ww}, f_{ee} \leq 0 \). A farmer working on a plot will receive a (dis)utility from effort equal to \(-e\). Inada conditions (marginal productivity is infinite at zero and is zero at infinite, for each factor) are sufficient to guarantee an interior solution if there is a market for water.

It is important to distinguish between aggregate uncertainty and idiosyncratic uncertainty. Aggregate uncertainty measures the differences in the total rain that farmers receive every period \( r_t \). Idiosyncratic uncertainty measures the differences in individual rain among farmers for a given period. The rain that every farmer receives in every period can then be decomposed into two components: the aggregate component \( r_t \) and the idiosyncratic component \( \epsilon_{it} \) such that \( r_{it} = r_t + \epsilon_{it} \). I assume that the upper bound of \( r_{it} \) is such that there is never too much rain in any plot, i.e. \( r_{it} < r_t + \theta \). This assumption implies that

\[ This assumption is not crucial for the results. Whenever one farmer has so much rain, he would just sell all his water.\]
there is not a corner solution, so that one farmer has too much (rainfall) water, and he would like to sell some of this (rainfall) water.

The random variable \( r_t \) can take only two values at every period:

\[
\begin{align*}
  r_t = \begin{cases} 
  r_H & \text{with prob. } q \in [0,1] \\
  r_L & \text{with prob. } (1-q) \in [0,1]
  \end{cases}
\end{align*}
\]

The random variable \( \epsilon_{it} \) comes from a distribution with density function \( h(\epsilon) > 0 \), \( E_{it}(\epsilon_{it}) = 0, \forall t \) and \( Var(\epsilon_{it}) = \sigma^2 \). The distribution function \( h(\epsilon) \) is the same every period (otherwise it will not represent pure idiosyncratic shocks) and is the same for all farmers.

At every period \( t \) a farmer is hit with a “liquidity shock” with probability \( \pi \in [0,1] \).\(^8\) I assume that a liquidity shock is uncorrelated with the rainfall that a farmer receives. A liquidity shock can be thought as any unexpected situation (independent of the rain) that affects the ability of the farmer to make payments: a cow died, his son got ill or he lost the previous harvest for any reason. This assumption is very conservative. If I assume that it is only the rain that affects the ability to payback of the farmer, it would be like assuming perfect correlation between the liquidity shock and the idiosyncratic shock. In this situation, the financial exposure of the farmer would be much worse: in periods when rain is low he needs more water, but those would be precisely the periods in which he cannot buy water. In other words, the inefficiency cause by the inability of the farmer to buy water would be worse in the case when the liquidity shock and the low rain periods are positively correlated, because the average unmet needs of water will be greater-than-average during the low rain periods. When both shocks are independent, the unmet needs of water will be equal to the average, given \( \theta_i \). The average is taken across periods.

This probability \( \pi \) is equal for all farmers. If a farmer is hit with a liquidity shock, she cannot buy any water during this period. She could still sell some water if she chooses to. This means that, for farmers that are financially constrained, the amount of water they can use is also limited, i.e. \( w_{it} = w_t = r_t + \theta_i \). It should be noticed that, because there is a continuum of farmers with mass equal 1, the parameters \( \theta \) and \( r_t \) refer to both the total amount and the average amount, per farmer.

### 3.1 Market Mechanism: Auctions

In this section, I solve for the equilibrium when there is a market for water and discuss under which parameters a market institution will achieve efficiency. If there is no market for water, the individual production in every period is \( f(r_{it} + \theta_i, \epsilon) \) and there are no decisions to be made. This could be clearly inefficient. Since \( f \) is concave, a necessary condition for efficiency is that the marginal value of water is the same for all farmers: \( w_{it} = w_t = r_t + \theta_i \). Hence, a market for water will always increase efficiency with respect to the case when no market for water is available.

The initial distribution of water rights \( \theta_i \) has probability density function \( g(\theta_i) > 0 \), cumulative density function \( G(\theta_i) \), mean equal to \( \theta \) and finite variance \( \sigma^2_\theta \). When \( \sigma^2_\theta = 0 \) the distribution of property rights is degenerate, i.e. \( \theta_i = \theta, \forall i \). In this case I say that the distribution of water rights is equalitarian.

Let \( \pi > 0 \) be the probability that a given farmer is facing a liquidity constraint. A constrained farmer cannot buy any amount of water in the market. This probability is independent of \( \theta_i \). The equilibrium in this case is fully characterized by a price \( p_t \) and an neutral farmer \( \tilde{\theta}(\pi) \) such that:

\[
\begin{align*}
  p_t(\pi) = f_w\left(r_t + \tilde{\theta}(\pi), \epsilon^*\right)
\end{align*}
\]

\(^8\)The assumption of a liquidity shock is introduced to be consistent with the speech of 19th century historians about the negative consequences of the auction in the “illiquid” farmers as well as for simplicity, since we can summarize the inefficiency in a single parameter. The whole analysis as well as all the results will not change qualitatively if we assume that there are no liquidity shocks but the farmers are risk-averse.

\[\text{rights and the remaining farmers will have the same amount of water for irrigation.}\]
• All (constrained or not) farmers with \( \theta_i > \hat{\theta} (\pi) \) will sell water and all non-constrained farmers with \( \theta_i < \hat{\theta} (\pi) \) will buy water. The farmer with \( \theta_i = \hat{\theta} (\pi) \) will not buy nor sell water. Moreover, the final allocation of water is the same among all farmers that are not constrained and constrained farmers with \( \theta_i > \hat{\theta} (\pi) \). Constrained farmers with \( \theta_i < \hat{\theta} (\pi) \) will not buy nor sell water.

**Proposition 1.** The equilibrium in this case is fully characterized by \( \hat{\theta} (\pi) = G^{-1} \left( \frac{1}{2 - \pi} \right) \).

*Proof: See Appendix.*

**Lemma 2.** The equilibrium price is decreasing in \( \pi \).

*Proof: See Appendix.*

Notice that without liquidity constraints \( (\pi = 0) \) we have \( \hat{\theta} (0) = G^{-1} \left( \frac{1}{2} \right) \): the indifferent farmer is the median farmer. With \( \pi > 0 \) there is a mass of farmers equal to \( \pi G \left( \hat{\theta} \right) = \frac{\pi}{2 - \pi} \) that will not trade although they would like to buy water. Since \( \hat{\theta} (\pi) \) is increasing in \( \pi \), the price that clears the market is decreasing in \( \pi \). A greater value of \( \pi \) means that there are more people that cannot buy water and, hence, the indifferent farmer has a greater endowment of water rights. The price is determined by the indifferent farmer. Decreasing returns of water implies that the equilibrium price is decreasing in \( \pi \). Notice also that the inefficiency is increasing in \( \pi \). The case with \( \pi = 1 \) coincides also with the case in which trading water is forbidden, hence, the inefficiency is maximal.

**Definition.** The distribution \( H (\cdot) \) is second-order stochastic dominant (SOSD) over \( G (\cdot) \) if and only if \( S_h (\theta_i) < S_g (\theta_i) \) for all \( \theta_i \in (0, 1) \) and \( S_g (1) = S_h (1) \), where \( S_g (\theta_i) = \int G (t) \, dt \) and \( S_h (\theta_i) = \int H (t) \, dt \).

**Lemma 3.** Let \( \pi > 0 \), and let \( H (\cdot) \) SOSD \( G (\cdot) \) or let \( G (\cdot) \) be a mean-preserving spread of \( H (\cdot) \). Efficiency will be greater under \( H (\cdot) \) than under \( G (\cdot) \).

This result is a direct consequence of the concavity of the production function. Reducing inequality implies that there are fewer farmers in the lower tail, i.e. with very few water rights, and those are the farmers that would suffer the most from a liquidity shock.

**Lemma 4.** When there are idiosyncratic shocks to farmers, i.e. \( \sigma^2 \neq 0 \) and farmers face financial constraints, i.e. \( \pi > 0 \), allowing for water markets will increase efficiency.

Even though allowing for water markets will increase efficiency (with respect to the no-trade situation), the planner will do better (actually, he will do best) by expropriating the irrigation rights of the farmers and imposing the egalitarian distribution of water\(^9\). The expropriation of property rights with no monetary compensation is, however, not realistic and would introduce legal insecurity.

**Proposition 5.** The Auction system is inefficient if \( \pi > 0 \).

*Proof: See Appendix.*

Although the proposition requires no idiosyncratic shocks, i.e. \( \sigma^2 = 0 \), since the result is strict, by continuity, when the idiosyncratic shocks are small, i.e. \( \sigma^2 \approx 0 \), the result is still true. Depending on the relative size of \( \sigma^2 \) and \( \pi \) one system will be more efficient than the other.

**Definition.** The total value of the water, in each period, when \( \pi > 0 \) is:

\[
I \equiv I (\pi) = \eta p_H (\pi) + (1 - \eta) p_L (\pi) = q f_w \left( r_H + G^{-1} \left( \frac{1}{2 - \pi} \right), e^* \right) + (1 - q) f_w \left( r_L + G^{-1} \left( \frac{1}{2 - \pi} \right), e^* \right)
\]

\(^9\)This was the solution adopted in Lorca and Mula in times of extreme drought, the water owners were later partially compensated with money coming from taxes.
3.2 Non-Market Mechanism: Quotas

In this section I present some results that I have already sketch in the previous section. I show under which circumstances it will be more efficient to have a Quotas system than an auction system and under which circumstances a quotas system will achieve full efficiency.

A Quotas system is just a mechanism in which there is a ban on trading both water and water property rights. Hence, in every period, each farmer can only use the water that comes from rain and from her property rights, \( w_{it} = r_{it} + \theta \). The ban on trading water property rights is needed to ensure that in every period the “initial” distribution of property rights is always egalitarian. The following result is useful to understand the specific role of each element in the present analysis.

**Proposition 6.** The Quotas system achieves full efficiency if \( \sigma^2 = 0 \) and \( \sigma^2 \theta = 0 \).

*Proof:* See Appendix.

As I have shown before, conditional on the initial distribution of property rights, the presence of a market for water will increase efficiency. This means that the only way to overcome the inefficiencies created by the liquidity shocks is by reducing inequality in the distribution of property rights. Of course, this will only be efficient if the idiosyncratic shocks are negligible. If idiosyncratic shocks are important, thus the gains from trading are big, it might still be more efficient to have a non-perfect market than a non-market institution.

I do not need to show that a Quotas system will achieve full efficiency under any parameter set. For the argument to go through I only need to show that, under some parameters, the Quotas system is more efficient than the Auction system. However, in order to explain why the quota system has been present in most towns in the region until 1960s, and it is present in all of them until now, here I show that, indeed, the quotas system can achieve full efficiency under some parameter set.

4 Institutional Change

The previous section was intended to build the tools needed to understand why each of two institutions could achieve efficiency under different environments. This is the approach taken by most economists. This section is concerned with the problems that societies face when they try to change institutions in response to a change in technology and/or environment. When the allocation of property rights affects the total production of the economy, i.e. welfare, a given initial allocation of property rights may cause inefficiencies if the market for property rights is not perfect. In this section, I will show that this is the case if the farmer cannot fully commit to payback in the future.

Through this section I assume that \( \sigma^2 = 0 \). Hence, from Proposition 5, a sufficient condition to achieve full efficiency is \( \sigma^2 \theta = 0 \). In the case with one farmer with no water ownership and one Waterlord this condition is equivalent to the farmer owning all the water rights. I also drop the subscripts \( i \) for simplicity.

When \( \sigma^2 > 0 \) the transition to the quotas mechanism might not be efficient. The results presented in this section will still apply, but one will have to rewrite the incentive compatible restrictions of the farmer.

Let us now consider the case in which the Waterlord owns the land. The problem that the Waterlord will be facing will be identical for each farmer. Thus, we can focus on solving the problem of the Waterlord with just one farmer. The Waterlord will act as the principal and will offer a contract \( \Gamma \) to the farmer. The contract should be based on observables.\(^{10}\)

\(^{10}\)Through the paper I refer to observable or contractible as the same concept. I will not consider here situations in which some variables are observable but not contractible. Hence, we are in a complete contracts setting.
If the effort was also observable the analysis would be simpler. The Waterlord will ask the farmer to exert \( e = e^{FB} \) and pays him \( e^{FB} \). This situation, however, is unlikely to happen in the real world; hence, I assume that the effort is only observable by the farmer.

In the real world, financial markets may not work so well. Moreover, financial institutions may have not access to relevant information about the output generated. One can go even further and ask whether the Waterlord could act as a financial institution. After all, the Waterlord is also interested in selling the water rights to the farmer because the farmer has a greater valuation of the water rights than the Waterlord.

In this case, the farmer is suffering from a lack of ability to commit. The Waterlord could offer a contract \( \Gamma \) such that the farmer has to pay a fix amount of output after production has taken place. This contract is a debt contract and it is optimal in the present setting: it maximizes the set of parameters under which the sale will occur. I normalize the value of the land to zero and assume that the farmer has some wealth \( C \) that she can use as collateral. Let \( I \) be the value that the Waterlord assigns to the ownership of water rights which is equal to the market value of the water under the auction system. I consider the 2-stage game here. For details about the algebra as well as for the infinite-period game see the Appendix.

I am not considering here the possibility that the Waterlord sells only a fraction of the water to the farmer. The Waterlord will ask the farmer for a payment \( B \) after the (observable) output has occur. Since the Waterlord is incurring a risk because the farmer may not be able to pay the full amount \( B \), in equilibrium we have \( B \geq I \). I am concerned with the biggest set of parameters under which the sale will occur. Thus I assume that the Waterlord will sell the water rights as soon as he gets a profit from doing so. This means that the expected value for the Waterlord equals the market price of the water.

The game is sequential. In the first stage, the Waterlord decides whether to sell the water rights to the farmer and the amount to be paid \( B \). In the second stage, the farmer decides on the transfer. Since this is a world with perfect observability of the output and perfect contracting, the Waterlord could force the farmer to pay up to \( B \), provided that the farmer has any wealth. The farmer decides the level of (unobservable) effort to exert as a function of \( B, \tilde{e}(B) \). The amount that the Waterlord will get is a direct (increasing) function of the level of effort exerted by the farmer. Hence, the farmer is implicitly choosing the transfer. The rest of this section solves for the equilibrium of this game. I consider first the case in which the farmer has no wealth to use as collateral and then the more general case in which the farmer has some wealth to use as collateral \( C \geq 0 \). The details are in the Appendix.

If the farmer has some wealth that the Waterlord can appropriate in case of low rain, then the problem is less severe. If \( C \geq I \) the problem is trivial, because the farmer will always be able to pay back.

The Waterlord sells the farmer the water rights \( \theta \) and will ask for a fix amount \( B \) to be re-paid after production occurs. The problem of the farmer is then:

\[
\tilde{V}(B) \equiv \max_{\tilde{e}} \{ q \max \{ f(\tilde{\theta} + r_H, \tilde{e}) + C - B, 0 \} \} + (1 - q) \max \{ f(\tilde{\theta} + r_L, \tilde{e}) + C - B, 0 \} - \tilde{e}
\]

In a given state, the farmer will have to pay \( B \) to the Waterlord and keep the rest. If the farmer cannot pay \( B \), then the Waterlord will take the output and the collateral and the farmer will get nothing. The farmer should choose a level of effort as a function of \( B, \tilde{e}(B) \). We have to check that the Waterlord is indifferent between selling his water rights or not. Hence:

\[\text{\footnotesize\textsuperscript{11}}\text{The proof in the appendix. This is a general result in the Corporate Finance literature as well as in the Mechanism Design literature. For a detailed discussion on optimal contract, when the asset is the land, and the effect of wealth as collateral see Hoffman (1996), Chapter 3.}\]
\[ W(e, B) = \{q \min \{f(\theta + r_H, e) + C, B\}] + (1 - q) \min \{f(\theta + r_L, e) + C, B]\} = I \]

The left hand side of the equation \( W(e, B) \) is what the Waterlord will get if he sells the water rights to the farmer. The right hand side is just the expected price of the water, which is the value of the Waterlord under the auction system.

The structure of the problem requires that we compute the equilibrium in three regions:

- If \( B - C \leq f(\theta + r_L, \bar{e}(B)) \) the problem is simple. In this case, the farmer can always pay the loan, hence there is no moral hazard problem. There will always be change.

Since \( B \) does not affect the effort decision, the problem is identical as in the case in which the farmer owns the water, hence the effort level is efficient, \( \bar{e}(B) = e^{PB} \). Since the farmer will always be able to repay there will be no risk premium. Hence, the debt will be equal to the value of the water, \( B = I \).

- If \( f(\theta + r_H, \bar{e}(B)) \geq B - C > f(\theta + r_L, \bar{e}(B)) \), the farmer can only repay the output when the state is high. If the state of the world is high, the Waterlord will get \( B \), the farmer will get the remaining output. If the state of the world is low the farmer can not paid \( B \) and the Waterlord will take over the remaining output and collateral. If there is change, it will not achieve full efficiency. There will be change if the farmer is better off with the debt contract than with the auction mechanism. In this case neither contract (auctions or debt) achieves full efficiency. The option chosen will depend on the relative decrease in efficiency that each contract produces.

We have to check whether the farmer will be better off after the transition. Even if the Waterlord is willing to sell at \( B \) and the farmer will be able to repay the full amount in the high state and a sufficient amount in the low state, it could still be the case that the farmer prefers the old institution. In this case, we are considering the case of a farmer with no water rights, i.e. \( \theta_i = 0 \). Farmers with high property rights, \( \theta_i > \hat{\theta}(\pi) \), will be willing to sell in the same conditions as the Waterlord. We have to check whether:

\[ \hat{V}(B) > \hat{V}(\pi) + C \equiv (1 - \pi) \hat{V}(\pi) + \pi \max\{q[f(r_H, e)] + (1 - q)[f(r_L, e)] - e\} + C \]

where \( \hat{V}(\pi) \) is the value of a farmer with no water rights, before knowing whether she is liquidity constrained or not. This expression is hard to interpret. However, we can look at the extreme cases.

When \( \pi = 0 \), we have \( \hat{V}(\pi) = V \), hence the auction system achieves full efficiency, while the transition does not. In this case the transition will not happen.

When \( \pi = 1 \), we have \( \hat{V}(1) = \max\{q[f(r_H, e)] + (1 - q)[f(r_L, e)] - e\} \). Whether this expression is greater than \( \hat{V}(B) - C \) will depend on the probability of high rain \( q \) and the productivity of water with more or less rain \( f_w(\cdot, e) \). If \( q = 1 \), \( \hat{V}(B) - C > \hat{V}(\pi) \) if and only if, \( \max\{q[f(\theta + r_H, e)] - e\} - \max\{q[f(r_H, e)] - e\} > B \). In this case, the collateral plays no role. The transition will happen only if the increase of productivity due to irrigation in the high state is greater than the debt required by the Waterlord, which is greater than the average price of water \( I \). By continuity, this result also holds for value of \( q \) close to 1, i.e. \( q \approx 1 \). If \( q = 0 \), then \( \hat{V}(B) = 0 \) and the transition will never happen. In this case, the collateral plays no role. By continuity, this result also holds for value of \( q \) close to 0, i.e. \( q \approx 0 \).

For intermediate values of \( q \) the collateral does play a role, since greater collateral requires a lower level of debt. Even if locally the collateral does not affect the level of effort exerted by the farmer it affects the value function of the farmer under the new institution.

\[ ^{12}\text{For a fix level of effort } e \text{ this is a zero-sum game: the Waterlord get what the farmer does not.} \]
• If $B > f (\theta + r_H, \tilde{e} (B)) + C$, the farmer will always default, and will get nothing. In this case, the farmer will not exert any effort and the profits for both (the farmer and the Waterlord) will be zero. Hence, there will be no change.

4.1 Institutional Inertia

I have just shown that, even in a world with perfect contracting and perfect observability, a mutually beneficial arrangement will not be attained if there are commitment issues. These issues could be generated by limited liability. In other words, the punishment that the Waterlord can use against the farmer in case of default is limited, because the farmer is penniless and the law, moral or monitoring technology prevents the Waterlord to impose a greater punishment than confiscating the entire farmer’s wealth. I have also show that this problem is not relevant if the farmer has some wealth that he can use as collateral.

Institutional Inertia is then a situation in which a new (more efficient) distribution of property rights cannot emerge due to lack of commitment from the potential winners (in this case the farmers). It is call inertia because the reason why the more new definition of property rights does not emerge is precisely because of the structure of the old institution. Efficiency requires the distribution of property rights to be egalitarian. If the new distribution cannot be attained due to contractual problems, it will not emerge. Moreover, since auctions can be run under any distribution of property rights, the inverse transition (from quotas to auctions) could always been achieved, without inertia. The Institutional Inertia is asymmetric.

Imagine a situation with several towns. Initially, in each town both the allocations of property rights ($G (\theta)$) and the original institution (quotas or auctions) is established arbitrarily. Notice that quotas requires $\sigma^2 = 0$ so the initial allocation of property rights is egalitarian. Farmers start with no wealth but they can save some money over time. If auctions are more efficient than quotas in all towns, i.e. $\pi = 0$ and $\sigma^2 > 0$, then the towns in which the original institution was quotas will immediately change to auctions. In this case there is no Institutional Inertia because as soon as the new is more efficient (in this case, auctions) the more efficient institution is implemented.

However, if quotas are more efficient than auctions, i.e. $\pi > 0$ and $\sigma^2 = 0$, then the situation is different. Towns where the original institution is quotas will not change. This was indeed the case for most towns in Murcia. Towns where the original institution is an auction will not change to either. Farmers can save some money over time. Thus each town will change to quotas when the wealth of their peasants, relative to the initial allocation of property rights in this town, is sufficiently high. Hence, this is supportive with the evidence that some small towns settled mainly by farmers and thus had a more equal distribution of property rights will change to quotas soon. This was the case of small towns like Totana and Librilla that did change to quotas by the 16th century. However, big cities like Lorca and Mula, where the original institution was auctions and had an unequal distribution of property rights, will take it longer to change to a new institution.

4.2 Empirical Predictions

There are several factors affecting the likelihood of a transition to a new institution:

• A more equal distribution of property rights (lower $\sigma^2$) implies a lower equilibrium price of water and, hence, the transition is more likely to happen.

• A change in $f (x)$ can be interpreted as a change in output prices. Moreover, when we re-scale up the production function, i.e. the new production function is $f' (x) = \alpha f (x)$ with $\alpha > 1$, the right hand side of the equation grows faster than the left hand side, because the collateral is not affected
by the increase in output price. Hence, an increase in the output prices means that the transition is less likely.

- The effect of a change in climate conditions \( q, r_H, r_L \) is ambiguous.

- The Savings/Collateral of farmers is greater. In the analysis presented above, there is an implicit assumption that bankruptcy costs are zero and banks earn zero profits in expectation. A more developed the financial system and a cheaper access to credit will also favor institutional change.

## 5 Data

The data in this paper comes from all water-auctions in Mula from March 1803 through August 1966, when the last auction was run. Figure 2 shows the oldest sheet in our sample. On August 1st, 1966 the allocation system was modified from being an auction allocation system to quota system in which each farmer will get a fix proportion of the water available in the dam every year.

Although the process of allocating water in Murcia has varied slightly over the years, its basic structure has remained, essentially, unchanged since the 13th century. Land in Murcia is divided into regadio (irrigated land) and secano (dry land). Irrigation is only permitted in the former. A channel system allows water from the river to reach all regadio lands. The fundamental reason for this division is that regadio are fertile lands that are close to rivers and, hence, allow a more efficient use of scarce water in the region. Since it is forbidden to irrigate lands categorized as secano, only the farmers that own a piece of regadio land in Murcia are allowed to buy water.

### 5.1 Agricultural Census and Economic data

I use data from different sources for the analysis. Most of the economic data comes from INE (Instituto Nacional de Estadística). The data includes prices of agricultural products, production and area cultivated of each product at a national and at regional level. I also collect financial data about deposits in public savings banks (Cajas de Ahorros) and rural loans provided by the government.

I use the price index computed by Ballesteros and Rehex (1993) because it covers the whole period considered here (1803-1991). It follows closely the Sarda (1998) for the 19th century, but the former is more volatile.

I augment the data with individual characteristics of the farmers’ land, which I obtain from the 1954/55 agricultural census. This census was conducted by the Spanish government to enumerate all cultivating soil, producing crops and agricultural assets available in the country. Individual characteristics for the farmers’ land (potential bidders which are matched with the names in the auctions data) include the type of land and location, area, number of trees, production and the price at which this production was sold in the census year. Figure 2 shows a sample card for one farmer from the census data. It can be seen in Table 3 that Land Extension, Number of Trees and Kg sold vary considerably across farmers. For the period 1954-1966, each farmer wins on average 22 units per year (an average of 792 thousand liters per
year). This is consistent with the census data collected, where mean land extension is 5.5 ha with an average of 33 trees per ha.  

5.2 Auction Data

Auction data, the primary source of data for this study, is obtained from the historical archive of Mula. Based on bidding behavior and water availability, auction data can be divided into three categories: (i) Regular periods, where for each transaction the name of the winner, price paid, date and time of the auction, etc.

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Table 3: Summary Statistics of Selected Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
<th>Obs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rain</td>
<td>8.53</td>
<td>46.33</td>
<td>.00</td>
<td>980.00</td>
<td>3,834</td>
</tr>
<tr>
<td>Price</td>
<td>271.61</td>
<td>374</td>
<td>.05</td>
<td>4,830</td>
<td>13,872</td>
</tr>
<tr>
<td>Land Extension</td>
<td>5.54</td>
<td>32.24</td>
<td>.25</td>
<td>900</td>
<td>819</td>
</tr>
<tr>
<td>Selling Price</td>
<td>15.07</td>
<td>222.52</td>
<td>.02</td>
<td>5,700</td>
<td>964</td>
</tr>
<tr>
<td>Kg sold</td>
<td>5,569.70</td>
<td>10,003.76</td>
<td>0</td>
<td>110,000</td>
<td>1,000</td>
</tr>
<tr>
<td>Number of Trees</td>
<td>161.49</td>
<td>493.45</td>
<td>1</td>
<td>12,300</td>
<td>946</td>
</tr>
</tbody>
</table>

Source: Own elaboration from the data from the Municipal Archive in Mula, “Heredamiento de Aguas”.

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18 Average annual rainfall during the period is 320 mm. Recent irrigation studies on young citrus plantings have shown a water use of 2-5 megalitres per hectare annually. Water savings are possible if the irrigation can be allocated to similar units of production such as young trees or reworked sections of a property. In arid regions like Murcia, water requirements could be around 20% less and, naturally, they are lower for grown up trees. Note that, as mentioned above, some farmers that are part of water-owner holding use their own water instead of selling it through auctions. Although water stress during droughts affects considerably the quality of production, trees would hardly die as a result. During a normal year without droughts trees could survive the whole year from rainfall. Finally, note that although the average number of trees per farmer is 161 (see Table 3), the average number of trees per hectare in our sample is 33 (this number is relatively lower than the conventional spacing for citrus trees of 100 trees per hectare).

19 From the section Heredamiento de Aguas, boxes No.: HA 167, HA 168, HA 169 and HA 170.
irrigation for each auction is registered, (ii) No-supply periods, where due to water shortage in the river or dam/channels damages (usually because of intense rain), no auction is carried out, and finally (iii) No-demand periods refer to auctions where no one bids and the registration auction sheet is blank. As we mentioned above, the sample for this study includes more than 150 years of auction data spanning from 1803 until 1966. Every week, 40 units (corresponding to 40 cuartas) are sold, with the exception being when no auction is run (no-supply) or no bids are observed (no-demand).

5.3 Water Ownership data

I collected a series of ownership books, from the historical archive of Mula, for the years that were available. Each book contains the name of each owner and the amount of shares (cuartas) she owns. The total amount of shares is 832. This information is useful because I can use these names to match the names that appear in the auction data and see which of the buyers is also an owner; and whether he is a big owner or a small one. I can also use this match to see how many of the owners never buy water in the auction. These owners might have not buy water because they could irrigate their land with the water they own or because they have no land and, thus, are no farmer but investors that collect the money from the auction. Since we have the census for 1954/55 I can use this third data base to match again the names and (for 1954/55) see which of the owners that never buy water are also landless.

5.4 Rainfall data

The auctions data is complemented with daily rainfall data for Mula (1933-1992) from the Agencia Estatal de Meteorología, AEMET (Spanish National Meteorological Agency). Mediterranean climate rainfall occurs mainly in spring and autumn. Peak water requirements for the products cultivated in the region are reached in spring and summer, between April and August. During this period more frequent irrigation is advisable because it is in this period where citrus trees are more sensitive (in terms of quality of production) to water deficits. Although annual average rainfall is 320 mm, rainfall frequency distribution is skewed, making the majority of years dryer than this yearly average. Aridity during the summer is especially acute. Autumn is the only relatively humid season. The number of days when torrential rain occurs is not particularly high, but when such rain occurs it is substantial. Potential evaporation is four or five times higher than rainfall and the number of arid months vary from 7 to 11 a year in our sample. These arid conditions found in southeast Spain are related to the circular air movement in the occidental Mediterranean area and to the Atlantic-origin storms.

6 Empirical Evidence

In this section I address each of the empirical predictions made by the model. I will show that the institutional change cannot be attributed to changes in technology or payoffs. I will do so by looking at the data from the auction as well as other micro indicators: the distribution of water ownership, price of the water and prices of the output. I will show that, with the data available, we cannot predict a structural change in 1966 and that the improvements in production were temporary and happened one or several decades before.

The structure of power or ownership within the organization shows no particular trend during the years preceding the change. If what produced the change was a increase in the inefficiency gap we would observe

\[^{20}\text{For more details about the auction see Donna and Espín-Sánchez (2011).}\]

\[^{21}\text{We thanks the AEMET for support for this project.}\]

\[^{22}\text{As an example, on October 10th 1943, 681 mm. of rain water were measured in Mula, more than twice the yearly average for our sample.}\]
“In the city of Mula the 8th of May of 1803, Mr. Pedro Martinez Fernandez, Mayor of the city, […], Mr. Diego Maria de Blaya, Commissioner of the Heredamiento de Aguas, Mr. Diego Melgarejo Leones, Treasurer, the sale of one day and one night of water began, with the following result:”
Figure 4: Real Prices of water (1803-1966), Pesetas (1930=100)

Source: Own elaboration from the data from the Municipal Archive in Mula, “Heredamiento de Aguas”. Some years are missing.

A decrease in the concentration of water ownership as individuals farmers might have incentives to buy water rights. The evidence suggest some collective action solution, which is consistent with the idea that the risk of selling the water rights is lower if it is mutualized across farmers.

A financial revolution occurred in Spain in the late 1950s and the early 1960s. The Bank of Spain was nationalized very late, in 1962, unlike the Bank of England (1946) or the Bank of France (1945). An efficient financial market is not a necessary condition for an institutional change but it expands the set of parameters under which the change can occur. The increase in savings during the previous decade (especially since 1957) has no precedent in the history of Spain. A sufficiently high amount of savings to use as collateral is a necessary condition for a change in institution to occur according to the model.

6.1 Changes in Technology or Payoffs

In the absence of commitment problem, but where transaction costs are present, NIE (as in North (1973) and Libecap (1978)) would predict that a new institution, with more precise definition of property rights, will emerge when the price of the underlying asset is sufficiently high. As I have argued above, in the present case the transition goes from an institution with better defined property rights (auction) to an institution with more diffuse property rights (quota). The quota institution implies a reduction in property rights in at least two dimensions. Trading water rights is forbidden, hence ownership is not transferable. Selling the water is also forbidden; hence usage of water is restricted.

Moreover, in this case, there is clear relation between the relative level of efficiency under each institution and the price of water. If the technology improves or the demand for the output increases, the total surplus will increase under both institutions, i.e. the value of the water for the farmers, under the quota.

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23 Or when the inefficiency gap grows big enough. The inefficiency gap is the difference in total surplus under the new (more efficient) institution minus the total surplus under the old (less efficient) institution.
and the value of the water for the Waterlords, under the auction. Hence, the sign of the change of the inefficiency gap after an increase in the demand of the output is ambiguous, it will depend on the shape of the production function. If the production function is just “scaled up”, that is preserving its shape, the inefficiency gap will remain unchanged. This will be the case, for example, after an increase in output prices.

As we can see in Figure 5, there was a decline in real output prices starting in 1961. Prices increased in the early 1950s, peaked in 1961 and then deceased. The pattern observed is that prices first increased, due to the increase in international demand, and then slowly decreased. The shock to demand was transitory, not permanent. This implies that in the long run the value of the water does not change, but the profits that the farmers made in the short run are enough to provide the collateral needed to change the institution.

Figure 4 also shows that the real prices of water, that is the marginal productivity of water did not change much during the period considered here. It did not change at all during the 19th century, maybe with the exception of the 1898 crisis. There might be a slow upward trend at the beginning of the 20th century. In 1923 the construction of the new dam was announced. The dam was finished by 1930. This explains the high peak of the prices in 1930 and the drop in 1931. The farmers, anticipating the increase in supply, increased their demand for water since 1923 to grow more trees and increase their production capacity. The closer to the shift in supply (1930), the greater are the incentives to increase capacity, thus the peak. When the dam is opened in 1931 the supply increases and, hence, the price plummeted. The volatility during the 1930s and 1940s is due to the Spanish civil war (1936-1939) and WWII and their post-war period together with the autarky of the dictatorship (1939-1950s). Starting in 1952 with the new foreign policy of openness and boost of exports the prices rise dramatically. However, what happens with output prices is also true with the input prices: this rise is temporary, until the supply increase to adapt to the new (international) demand. By 1962 the price is already similar to historical standards and fell during the 1960s and 1970s. Although temporary, the farmers in Mula took advantage of this demand shock and used it to accumulate savings and capital (water ownership being the most remarkable) for the first time in History.
6.2 Ownership Distribution $G(\theta)$

One puzzling issue arises here. Why did each farmer not just buy water rights and solve his own problem? According to the intuition and the model buyers should have not wait until everyone have enough collateral. Richer farmers could afford to buy some water rights earlier than poorer farmers. Hence, the transition should have been gradual and not sudden. However, as Figure 6 shows that this is not what happened. The proportion of owners with just one share of the water, which is not sufficient to irrigate an average plot (there are 832 shares and about 500 farmers), is constant across time at about 30%. Of course, there are also some farmers that owned no water at all that are not in this sample. The other categories also remained unchanged over time. Several facts could help explain this puzzle.

First, the richer farmers might as well keep some cash and eliminate their liquidity issues without having to buy water rights. Moreover, as Lemma 2 shows, the more severe the liquidity problem among farmers is, the lower will be the equilibrium price. Since farmers are competing for water with each other in the auction, farmers with deep pocket need not buy water rights to have security: they already have.

Second, some of the gains with the quotas system actually come from internalizing externalities. Since the farmers and the water owners are now the same people conflicts about improving channels and rules of rationing during extreme drought will be easier to solve. Moreover, and related to the third point, a transition is easier when it is sudden because the lender (whether it is a Waterlord or a financial institution) can use the law of large numbers and eliminate the idiosyncratic risk associated with each farmer. By pooling all the claims into a single claim the lender still have to bear the aggregate risk, but not the idiosyncratic risk. This means that the risk premium that the lender is asking will be lower.

Third, and more important, since the farmers are asking collectively for the loan through the “Sindicato de Regantes”, this organization has better monitoring technology than a single Waterlord or a financial institution. The farmers are member of this organization and are jointly responsible for the loan. With better monitoring technology it can encourage each farmer to pay their share but also to prevent some farmers from “cheating”.

One of the odd results in this analysis is that both mechanisms achieve second-best, but not first-best, in general. Moreover, they farmers could do better by having a combination of both mechanisms: having an egalitarian distribution of property rights without trading but allowing for small sales of water among them. This is actually what happens in practice. Although trading is strictly forbidden, when a farmer does not need all the water he is using, another farmer in the same channel can use the remaining water.
In practice, farmers use this loophole to have bilateral (not multilateral) exchange of water, without money and without a centralize market (auction). The reason for having this non-centralized market instead of the more efficient centralized auction is unclear. Maybe the farmers think that having the centralized auction would incentivize speculators from accumulating land-and-water rights, sell the water in the auction and not cultivate the land. Which can create some problems in the long run like concentration of power, externalities due to the misuse of land or opportunistic behavior.

6.3 Savings and Living Conditions

In Figure 7 we can see that the evolution of real deposits follow an erratic path during the 19th century. Slowly growing until it peaks during the crisis of 1898 and then declining until the inter-wars period. During Primo de Rivera’s dictatorship (1927-1930) they seem to recover until the civil war (1936-1939). The deposits did not grow during the post-war and autarky period and it is not until the 1950s that we see the deposits growing again, this time more sharply and steadily.

The graph makes clear that, however erratic and dependent of the macro-environment the deposits were, the tendency that began in the fifties of uniform growth is unprecedented. Living conditions and the savings of the lower and middle class (the target audience of the public savings banks) increase during the 1950s and by 1960 they were greater that they have ever been. This tendency is important for Murcia, which began at a lower level than the average, but by 1937 is already ahead and continue this way.

This tendency and the fact that real deposits in 1966 were higher than they have ever been are consistent with the model. In order to solve the commitment problems the farmers had to be able to put collateral sufficiently big as to show a credible commitment to pay back.

In 1931, when the new Dam was completed, the government made an offer to the Waterlords. The government would buy all the shares of the water, hence becoming the sole owner, for a price of 4.2 Million of pesetas. The goal of the government was to give the water for free to the owner of the land and let them establish a system of quotas, the same that they did in 1966. The offer was discussed among the owners and, according to the report they gave and the records of the general meetings, the opinion of

\[ \text{Source: Own elaboration with data from INE (Fondo documental del Instituto Nacional de Estadística). Average value of deposits in pesetas (Base 1930).} \]
owners were divided in three groups. The first group, made of small owners (1 or 2 shares each), mostly farmers, was in favor of accepting the offer. Not surprisingly, since they were mostly farmers they were actually gaining more water than they have after the re-distribution promised by the government. The second group, made of middle-size owners (4 to 8 shares each) was in favor of the offer, if the quantity offered was big enough. A third group, made of the big owners, were in favor of the offer, only if the payment was made in cash. The owners get together in the general meetings and decided that 4.2M was a good offer, if paid in cash. They were worried that once they give away the ownership of the water the government will not be willing or able to pay the promised amount. The government in question was the 2nd Republic in Spain, established just 6 months away and very unstable. It was so unstable that a few years later a civil war ended with a long-live dictatorship.

What this story tells us is that the Waterlords were rational agents, and willing to sell their water rights for the good price. They were not so much concerned with power and controlling the peasants as with making profit out of their own property. They were also aware that a promised payment is different than a bird-in-the-hand, and they will only sell if they have confidence on being paid at the end. This is precisely what happened in 1966: the farmers have enough collateral as to convince the Waterlords that they will be eventually paid.

In Figure 1 we can see that the total amount offered was 4.2 Million pesetas in 1931. If we knew how many farmers were there to divide the water we could know how much each farmer had to pay. In the census data we see that there were 452 cultivating in 1954. This is a lower bound because there might be small farmers that did not appear in the census. In auction data we see that between 1954 and 1966 there were 537 farmers buying water in the auction. This is an upper bound because in 12 years some farmers could have sold his plot to another farmer or to his own son; hence we will be observing two different names/farmers that are using the same plot. In Figure 3 we can see what percentage of the water could have the farmer afford each year. The percentage goes from less than 5% to about 15% in 1966 and more beyond. Although 15% seems a small amount it is much greater than 3-4%. Also, the deposit is a lower bound measure for the collateral. Surely the farmers wanting to buy the water had been saving at a greater-than-average rate. Hence, their deposits would have been greater than the average deposit.

6.4 Liquidity and Solvency

It is important to make a distinction between liquidity and solvency and their relation with the model. Insolvency will produce inefficient institutions to persist. Illiquidity will make auctions be inefficient. A farmer can be illiquid but solvent.

Solvency is a structural and permanent inability to make a payment. Insolvent farmers will make the transition unlikely because they do not have the money to pay for the water rights, and a debt contract does not provide enough incentives for them to repay the loan. If I try to buy a Ferrari, I would not be able to pay for it, hence, I am insolvent in this transaction.

Liquidity is a temporary inability to make a payment, typically in cash. Illiquid farmers make the

\[\text{The water has different valuation depending on the season.}\]

\[\text{The farmers could have also asked for loans from their relatives and friends. Asking money from their relatives or neighbors is something that was not very likely. Before the increase in living conditions that began in the 1950s the living conditions in the town were not far from subsistence, which makes an informal lending market unlikely. Moreover, their potential lenders would be in the same situation as they were, needing cash right before the harvest months. Even if they were not short of cash, the neighbors might be reluctant to lend money to another farmer that would then try to outbid them during the next auction. Lastly, the most obvious source of credit would have been the Waterlords. By allowing the farmers to delay the payment of water until after the harvest. However, the evidence points into another direction. Not only did the Waterlords not like to delay the payments, but they also have a special book with the names of debtors to the Heredamiento, and debtors were not allowed to bid in the auction. The historical evidence is full with cases in which the Waterlords have troubles trying to get their money from small farmers (mostly from fines) and it is no wonder that they wanted to be tough in this aspect. This evidence also suggest that land could not be used as collateral as it would be hard to take it over in case of unpaid debts.}\]
market to be inefficient because sometimes the farmer with the higher valuation for the water has no cash to pay for it at the moment of the auction. If I try to buy a coffee, but I have forgotten my wallet at home, I am illiquid, but not insolvent. I could pay for the coffee and my valuation for the coffee is greater than the posted price, however I could not buy the coffee.

I could try to go to the Ferrari dealer and tell him that I want to buy a Ferrari, that I value it more than the price posted, but I have forgotten my wallet at home. I do not think that he would sell the car to me.

6.5 The Financial Revolution 1957-1962

The last empirical prediction of the static model is that more efficient financial markets will help to solve the commitment problem that the Waterlords and the farmers are facing. The work by Francisco Comin (Comin (2005) and (2007)) shows the role that the government and government agencies played in the 1950s and 1960s to promote economic development. The goals of the government were to increase the industrial sector, to modernize the agriculture and to provide cheap credit to small businesses and households. The main instrument used was the “Cajas de Ahorros” (Public Savings Banks). “[...] things begin to change for [the Savings Banks] in 1957 when they exchanged the oversight of the Ministry of Labor for that of the Ministry of Finance. Thereafter, they were treated more as financial institutions than as charitable organizations.”

The economic growth that followed the openness of Spain to international trade, mostly in western Europe and the US, together with the ease access to credit and an efficient financial sector reinforced each other in a virtue circle. Economic growth in the 1960 enabled Savings Banks to expand their operations thanks to growing deposits, and to diversify them through the new regulations established in the “Development Plans” set in motion starting in 1964.

The role of the Savings Banks in fostering economic growth was especially important among the middle and lower classes. “Indeed, the savings banks carried out an essential function in fostering and attracting savings, in a specialized manner, among the middle and lower classes by means of strategies normally associated with what came to be known as ‘retail banking’.”

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During the Franco’s dictatorship (1939-1975) Saving Banks were forced by law to invest most of their resources in public debt issues and bonds of private companies selected by the National Institute of Industry (INI). Before 1951 the amount required by law was 30% of their resources. In 1951 the requirement changed to 60% and then to 80% in 1964.

In 1962 the Bank of Spain was nationalized and new legislation concerning banking regulation was passed in Spain. The new legislation changed dramatically the banking system. It changed the role that the Savings Banks were to play in the financial sector and increase the importance of the ICCA, a national agency whose main role was to coordinate the macro-decisions of the local Saving Banks. The new law also fostered banking specialization and long and medium term stability.

Figure 9 shows how both the number and the total amount of rural loans began to increase in 1951 at an exponential rate. However, the change in the institution did not occur in 1951, nor during the 1950s. In Figure 10 we can see that the average real value of the loans did not change much during this period.

**Figure 9: Evolution of Rural Loans and Deferred Rural Loans in Spain**

![Graph showing the evolution of rural loans and deferred rural loans in Spain](image)

*Source: Own elaboration with data from INE (Fondo documental del Instituto Nacional de Estadística). Data for Deferred Rural Loans for the years 1952-1956 is missing. The left graph shows the nominal volume of loans in 1,000 pesetas for Spain.*

**Figure 10: Average Rural Loans and Deferred Rural Loans in real terms (Base 1930)**

![Graph showing the average rural and deferred rural loans in real terms](image)

*Source: Own elaboration with data from INE (Fondo documental del Instituto Nacional de Estadística). Data for Deferred Rural Loans for the years 1952-1956 is missing. Average value of loans in 1,000 pesetas (Base 1930) for Spain.*
7 Conclusions

The main contribution of this paper is to explain a puzzling transition that happened in agricultural communities in Southern Spain in the 1960s where some towns that have been using auctions to allocate the water of the river decided to change and allocate the water through a system of fixed quotas. This transition is puzzling for two reasons. First, the transition happened in the absence of political instability or important technological changes. Second, unlike most of the institutional changes that have happened in the world in the last two centuries, the allocation mechanism went from a market institution (auctions) to a non-market institution (quotas).

In order to explain the first puzzle, I suggest that what really changed and made the transition happen was not a change in the decision power over the water rights or a change in the payoffs. What changed was the commitment ability of the farmers to credibly pay the value of the water rights to its owners. Following a transitory boom in agricultural exports in the region the farmer were able to accumulate savings for the first time in centuries. They used the savings as upfront payment (collateral) to buy the water rights from the Waterlords. The transition was delayed for centuries because the farmers were not solvent.

The second puzzle is even more surprising. For economists markets, and auctions even more so, are efficient by default, so I have to show why this particular market might not have been efficient. The reason is that farming is a seasonal activity. In a world with imperfect financial markets the farmers might be short of cash during the months before the harvest, which are the months in which they really need to buy water. Hence, some farmers will not be able to buy water. This will create both inefficiencies in allocation and loss of revenue: the water is not allocated to the farmer with the highest valuation. Moreover, this can create underinvestment. The most profitable crop in this region are fruit trees. However, trees are a risky investment if you do not have a secure supply of water. If water has to be bought in a market in cash, and you are not sure whether you will have enough cash, you might chose to plant safer (less profitable) crops, like tomatoes or vegetables. Markets are inefficient in this situation because farmers faced liquidity constrains.

The inertia produced by the lack of commitment here is asymmetric: you can go from quotas to auctions at any time by you need a specific distribution of property rights to go from auctions to quotas. This feature the model is not related to markets intrinsically, but rather to the fact that one of the institutions requires a specific distribution of property/decision rights.

Water ownership is not an important issue in some places. However, it is very similar to episodes of land redistribution all over the world, specially in Latin America (20th century Mexico) and Eastern Europe (19th century Russia). The general consensus that the land would be more productive in the hands of the farmers but the Landlords are not willing to give them the land for free. The typical solution to this problem has been a government intervention whether with guaranteed loans, expropriation without compensation or anything in between.

References


A Mathematical Appendix

A.1 Model

Let there be an economy in which there is one Waterlord and a continuum of farmers of mass equal 1. All players are risk neutral. Time is discrete and there is an infinite horizon. All players discount the future with a common discount rate $\beta$. Only farmers can produce goods. There is only one output good in this economy, food, with price normalized to 1. Individual output is perfectly observable by all players. The production function of food depends on two factors: water $w_{it}$ and effort $e_{it} \in \mathbb{R}^+$, and in some random technology parameter $A_{it}$ which probability distribution is common knowledge. Effort $e_{it}$ is chosen by farmer $i$ and is only observable by him. Each farmer is entitled with some irrigation rights $\theta_i$. For simplicity, I assume that the amount of water available for irrigation is the same every period, hence, $\int_0^1 \theta_i \, di = \theta$.

Water comes from two sources: rain and irrigation, i.e. $w_{it} = r_{it} + \gamma_{it}$. Rain $r_{it}$ is a random variable and has a finite mean every period $\int_0^1 r_{it} \, di = R_t$, while the total amount of irrigating water is $\theta$. The production function of food is then $f(w, e)$, with $f(0, e) = f(w, 0) = 0$. This function is increasing and concave in each argument, i.e. $f_w, f_e \geq 0$ and $f_{ww}, f_{ee} \leq 0$. A farmer working on a plot will receive a (dis)utility from effort equal to $-e$. Inada conditions (marginal productivity is infinite at zero and is zero at infinite, for each factor) are sufficient to guarantee an interior solution if there is a market for water.

It is important to distinguish between aggregate uncertainty and idiosyncratic uncertainty. Aggregate uncertainty measures the differences in the total rain that farmers receive every period $r_t$. Idiosyncratic uncertainty measures the differences in individual rain among farmers for a given period. The rain that every farmer receives in every period can then be decomposed into two components: the aggregate component $r_t$ and the idiosyncratic component $\epsilon_{it}$ such that $r_{it} = r_t + \epsilon_{it}$. I assume that the upper bound of $r_{it}$ is such that there is never too much rain in any plot, i.e. $r_{it} < r_t + \theta$. This assumption implies that there is not a corner solution, so that one farmer has too much (rainfall) water, and he would like to sell some of this (rainfall) water.

The random variable $r_t$ can take only two values at every period:

$$r_t = \begin{cases} r_H & \text{with prob. } q \in [0, 1] \\ r_L & \text{with prob. } (1 - q) \in [0, 1] \end{cases}$$

The random variable $\epsilon_{it}$ comes from a distribution with density function $h(\epsilon) > 0$, $E_i(\epsilon_{it}) = 0, \forall it$ and $\text{Var}(\epsilon_{it}) = \sigma^2$. The distribution function $h(\epsilon)$ is the same every period (otherwise it will not represent pure idiosyncratic shocks) and is the same for all farmers.

At every period $t$ a farmer is hit with a “liquidity shock” with probability $\pi \in [0, 1]$. I assume that a liquidity shock is uncorrelated with the rainfall that a farmer receives. A liquidity shock can be thought as any unexpected situation (independent of the rain) that affects the ability of the farmer to make payments: a cow died, his son got ill or he lost the previous harvest for any reason. This assumption is very conservative. If I assume that it is only the rain that affects the ability to payback of the farmer, it would be like assuming perfect correlation between the liquidity shock and the idiosyncratic shock. In this situation, the financial exposure of the farmer would be much worse: in periods when rain is low he needs more water, but those would be precisely the periods in which he cannot buy water. In other words, the

The assumption of a liquidity shock is introduced to be consistent with the speech of 19th century historians about the negative consequences of the auction in the “illiquid” farmers as well as for simplicity, since we can summarize the inefficiency in a single parameter. The whole analysis as well as all the results will not change qualitatively if we assume that there are no liquidity shocks but the farmers are risk-averse.
inefficiency cause by the inability of the farmer to buy water would be worse in the case when the liquidity shock and the low rain periods are positively correlated, because the average unmet needs of water will be greater-than-average during the low rain periods. When both shocks are independent, the unmet needs of water will be equal to the average, given $\theta_i$. The average is taken across periods.

This probability $\pi$ is equal for all farmers. If a farmer is hit with a liquidity shock, she cannot buy any water during this period. She could still sell some water if she chooses to. This means that, for farmers that are financially constrained, the amount of water they can use is also limited, i.e. $w_{it} \leq r_{it} + \theta_i$. It should be noticed that, because there is a continuum of farmers with mass equal 1, the parameters $\theta_i$ should be noticed during this period. She could still sell some water if she chooses to. This means that, for farmers hence we have a mass of $\theta_i = \theta$, $\forall i$. In this case I say that the distribution of water rights is egalitarian.

Let $\pi > 0$ be the probability that a given farmer is facing a liquidity constraint. A constrained farmer cannot buy any amount of water in the market. This probability is independent of $\theta_i$. The equilibrium in this case is fully characterized by a price $p_i$ and an neutral farmer $\tilde{\theta} (\pi)$ such that:

- $p_i (\pi) = f_w \left( r_i + \tilde{\theta} (\pi), e^* \right)$

- All (constrained or not) farmers with $\theta_i > \tilde{\theta} (\pi)$ will sell water and all non-constrained farmers with $\theta_i < \tilde{\theta} (\pi)$ will buy water. The farmer with $\theta_i = \tilde{\theta} (\pi)$ will not buy nor sell water. Moreover, the final allocation of water is the same among all farmers that are not constrained and constrained farmers with $\theta_i > \tilde{\theta} (\pi)$. Constrained farmers with $\theta_i < \tilde{\theta} (\pi)$ will not buy nor sell water.

**Proposition 7.** The equilibrium in this case is fully characterized by $\tilde{\theta} (\pi) = G^{-1} \left( \frac{1}{\pi - \pi} \right)$.

Notice that without liquidity constraints ($\pi = 0$) we have $\tilde{\theta} (0) = G^{-1} \left( \frac{1}{2} \right)$: the indifferent farmer is the median farmer.

When $\pi > 0$ we know that farmers with $\theta_i > \tilde{\theta} (\pi)$ will sell water whether they are constrained or not, hence we have a mass of $1 - G \left( \tilde{\theta} \right)$ of sellers. We also know that farmers with $\theta_i < \tilde{\theta} (\pi)$ that are not constrained will buy water. Hence, we have a mass of $(1 - \pi) G \left( \tilde{\theta} \right)$ of buyers. Finally we have a mass of $\pi G \left( \tilde{\theta} \right)$ of constrained farmers that will not buy water, but would buy if they were not constrained.

We have then $1 - G \left( \tilde{\theta} \right) + (1 - \pi) G \left( \tilde{\theta} \right) + \pi G \left( \tilde{\theta} \right) = 1$. A necessary condition for equilibrium is that the amount of water bought and sold is the same. Since farmers are distributed continuously in the interval $[0,1]$ and the average water right is $\theta$, this condition is equivalent as having the same number of buyers and sellers. Hence, $(1 - \pi) G \left( \tilde{\theta} \right) = 1 - G \left( \tilde{\theta} \right)$. Solving this equation gives us: $(2 - \pi) G \left( \tilde{\theta} \right) = 1$ or $G \left( \tilde{\theta} \right) = \frac{1}{2 - \pi}$. Since $g \left( \theta_i \right) > 0$ in the support of $\theta_i$, the cumulative distribution $G \left( \theta_i \right)$ is strictly increasing and, hence, invertible. Thus, we can write $\tilde{\theta} (\pi) = G^{-1} \left( \frac{1}{2 - \pi} \right)$ and $G^{-1} (\cdot)$ is also strictly increasing.

**Lemma 8.** The equilibrium price is decreasing in $\pi$. 

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Since $\tilde{\theta}(\pi)$ is increasing in $\pi$, the price that clears the market is decreasing in $\pi$. A greater value of $\pi$ means that there are more people that cannot buy water and, hence, the indifferent farmer has a greater endowment of water rights. The price is determined by the indifferent farmer. Decreasing returns of water implies that the equilibrium price is decreasing in $\pi$. Notice also that inefficiency is increasing in $\pi$. The case with $\pi = 1$ coincides also with the case in which trading water is forbidden, hence, the inefficiency is maximal.

**Definition.** The distribution $H(\cdot)$ is second-order stochastic dominant (SOSD) over $G(\cdot)$ if and only if $S_h(\theta_i) < S_g(\theta_i)$ for all $\theta_i \in (0, 1)$ and $S_g(1) = S_h(1)$, where $S_g(\theta_i) = \frac{\theta_i}{0}^{\theta_i} G(t) \, dt$ and $S_h(\theta_i) = \frac{\theta_i}{0}^{\theta_i} H(t) \, dt$

**Lemma 9.** Let $\pi > 0$, and let $H(\cdot)$ SOSD $G(\cdot)$ or let $G(\cdot)$ be a mean-preserving spread of $H(\cdot)$. Efficiency will be greater under $H(\cdot)$ than under $G(\cdot)$.

We will need to integrate by parts twice. Let $u(\theta_i) \equiv f(r_i + \theta_i)$ and let $S_g(\theta_i) = \frac{\theta_i}{0}^{\theta_i} G(t) \, dt$ and $S_h(\theta_i) = \frac{\theta_i}{0}^{\theta_i} H(t) \, dt$ be the supercumulative distributions of $G(\cdot)$ and $H(\cdot)$ respectively. The expression for the efficiency is then:

\[
\frac{1}{0} \int u(\theta_i) g(\theta_i) \, d\theta_i = \left[ u(\theta_i) G(\theta_i) \right] \frac{1}{0}^{1} - \int \frac{1}{0}^{1} u'(\theta_i) G(\theta_i) \, d\theta_i \quad \text{integrating by parts}
\]

\[
= u(1) * 1 + u(0) * 0 - \int \frac{1}{0}^{1} u'(\theta_i) G(\theta_i) \, d\theta_i
\]

\[
= u(1) - \frac{1}{0}^{1} u'(\theta_i) G(\theta_i) \, d\theta_i
\]

\[
= u(1) - \frac{1}{0}^{1} u'(\theta_i) S_g(\theta_i) \, d\theta_i + \frac{1}{0}^{1} u''(\theta_i) S_g(\theta_i) \, d\theta_i \quad \text{integrating by parts again}
\]

Therefore

\[
\frac{1}{0} \int u(\theta_i) h(\theta_i) \, d\theta_i - \frac{1}{0} \int u(\theta_i) g(\theta_i) \, d\theta_i = u'(1) \left[ S_g(1) - S_h(1) \right] + \int \frac{1}{0}^{1} u''(\theta_i) [S_h(\theta_i) - S_g(\theta_i)] \, d\theta_i
\]

Notice that $u'(\cdot) > 0$ and $u''(\cdot) < 0$. We also need to show that $S_g(1) = S_h(1)$. We can write:

\[
S_g(1) = \frac{1}{0} \int G(t) \, dt
\]

\[
= \left[ \theta_i G(\theta_i) \right] \frac{1}{0}^{1} - \int \frac{1}{0}^{1} \theta_i g(\theta_i) \, d\theta_i \quad \text{integrating by parts}
\]

\[
= 1 * G(1) - 0 * G(0) - \int \frac{1}{0}^{1} \theta_i g(\theta_i) \, d\theta_i
\]

\[
= 1 - E[\theta_i]
\]

Since both $G(\cdot)$ and $H(\cdot)$ have the same expectation, $S_g(1) = S_h(1)$. We are left with:

\[
\int \frac{1}{0}^{1} u(\theta_i) h(\theta_i) \, d\theta_i - \int \frac{1}{0}^{1} u(\theta_i) g(\theta_i) \, d\theta_i = \int \frac{1}{0}^{1} u''(\theta_i) [S_h(\theta_i) - S_g(\theta_i)] \, d\theta_i
\]
Since $u''(\cdot) > 0$, the right hand side is positive if, and only if, $S_h(\theta_i) < S_g(\theta_i)$. Hence, efficiency is greater under $H(\cdot)$ if and only if $H(\cdot)$ SOSD $G(\cdot)$.

**Lemma 10.** When there are idiosyncratic shocks to farmers, i.e. $\sigma^2 \neq 0$ and farmers face financial constraints, i.e. $\pi > 0$, allowing for water markets will increase efficiency.

The proof is trivial. The problem that the farmers are facing is identical in both scenarios, except that in one of them we have an extra constraint: no trading. Hence markets weakly increase efficiency. Market will strictly increase efficiency whenever the constraint is binding, that is, whenever some farmer wants to trade, which will happen with positive probability.

**Proposition 11.** The Auctions system is inefficient if $\pi > 0$.

We have two types of inefficiencies here. On one hand, there is mass of farmers ($\frac{\pi}{2-\pi}$) that cannot buy water but would be willing to buy water at the current price. On the other hand, we have a mass of farmers ($\frac{\pi}{2-\pi}$) that are using “too much” water. This “too much” refers to a situation in which markets are efficient ($\pi = 0$). The inefficiency will then be the difference in output when $\pi = 0$ and when $\pi > 0$:

$$
\int_0^1 f\left(r_t + \tilde{\theta}(0)\right) g(\theta_i) \, d\theta_i - \left[\int_0^1 f\left(r_t + \theta_i\right) g(\theta_i) \, d\theta_i + \left[1 - \pi G\left(\tilde{\theta}(\pi)\right)\right] f\left(r_t + \tilde{\theta}(\pi)\right)\right]
$$

This inefficiency can also be decomposed in:

$$
\int_0^1 \left[f\left(r_t + \tilde{\theta}(0)\right) - f\left(r_t + \theta_i\right)\right] g(\theta_i) \, d\theta_i + \left[1 - \pi G\left(\tilde{\theta}(\pi)\right)\right] \left[f\left(r_t + \tilde{\theta}(0)\right) - f\left(r_t + \tilde{\theta}(\pi)\right)\right]
$$

The sign of the first term is ambiguous. Since $\tilde{\theta}(\pi) > \tilde{\theta}(0)$, the second term is negative. We know that this amount is positive, because the liquidity constraints introduce inefficiencies, thus the first term must be positive. The second term being negative is a consequence that the farmers with a greater endowment are producing using an inefficiently high amount of water. Even though the production is inefficient, their production is greater than it would be with the (smaller) efficient amount of water. The first term is positive and big (at least bigger than the second term in absolute value) and it accounts for the lack of production suffered by the low-endowed farmers that cannot “afford” to pay for the water.

**A.3 Non-Market Mechanism: Quotas**

In this section I present some results that I have already sketch in the previous section. I show under which circumstances it will be more efficient to have a Quotas system than an auction system and under which circumstances a quotas system will achieve full efficiency.

A Quotas system is just a mechanism in which there is a ban on trading both water and water property rights. Hence, in every period, each farmer can only use the water that comes from rain and from her property rights, $w_{it} = r_{it} + \theta_i$. The ban on trading water property rights is needed to ensure that in every period the “initial” distribution of property rights is always egalitarian. The following result is useful to understand the specific role of each element in the present analysis.

**Proposition 12.** The Quotas system achieves full efficiency if $\sigma^2 = 0$ and $\sigma_{\theta}^2 = 0$.

When $\sigma^2 = 0$ the marginal productivity of every farmer is the same. Hence, a necessary and sufficient condition for efficiency is that each farmer receives the same amount of water for irrigation $\theta_i = \theta$. When $\sigma_{\theta}^2 = 0$ each farmer has the same water rights $\theta_i = \theta$. Hence, full efficiency is achieved.
B Institutional Change

The previous section was intended to build the tools needed to understand why each of two institutions could achieve efficiency under different environments. This is the approach taken by most economists. This section is concerned with the problems that societies face when they try to change institutions in response to a change in technology and/or environment. When the allocation of property rights affects the total production of the economy, i.e. welfare, a given initial allocation of property rights may cause inefficiencies if the market for property rights is not perfect. In this section, I will show that this is the case if the farmer cannot fully commit to paying back in the future.

Through this section I assume that \( \sigma^2 = 0 \). Hence, from Proposition 5, a sufficient condition to achieve full efficiency is \( \sigma^2 \theta = 0 \). In the case with one farmer with no water ownership and one Waterlord this condition is equivalent to the farmer owning all the water rights. I also drop the subscripts \( i \) for simplicity.

If each farmer owns the plot he is working on and has water rights equal to \( \theta \). The problem of the farmer is then:

\[
V = \max_e [E_w [f(w,e)] - e]
\]

Notice that this problem corresponds to the first best because there are no distortions in the decision of the farmer. The first order condition of this problem implies: \( \frac{\delta E_w[f(w,e)]}{\delta e} \big|_{e=e^FB} = 1 \). I will use this result as a benchmark. In the example this is equivalent to: \( q \left((\theta + r_H) e^{FB}\right)^\lambda + (1-q) \left((\theta + r_L) e^{FB}\right)^\lambda = e^{FB} \).

Let us now consider the case in which the Waterlord owns the land. The problem that the Waterlord will be facing will be identical for each farmer. Thus, we can focus on solving the problem of the Waterlord with just one farmer. The Waterlord will act as the principal and will offer a contract \( \Gamma \) to the farmer. The contract should be based on observables.\(^{29}\)

If the effort was also observable the analysis will be simpler. The Waterlord will ask the farmer to exert \( e = e^{FB} \) and pays him \( e^{FB} \). This situation, however, is unlikely to happen in the real world; hence, I assume that the effort is only observable by the farmer.

In the real world, financial markets may not work so well. Moreover, financial institutions may have not access to relevant information about the output generated. One can go even further and ask whether the Waterlord could act as a financial institution. After all, the Waterlord is also interested in selling the water rights to the farmer because the farmer has a greater valuation of the water rights than the Waterlord.

In this case, the farmer is suffering lack of commitment. The Waterlord could offer a contract \( \Gamma \) such that the farmer has to pay a fixed amount of output after production has taken place. This contract is a debt contract and it is optimal in the present setting: it maximizes the set of parameters under which the sale will occur.\(^{30}\) I normalize the value of the land to zero and assume that the farmer has some wealth \( C \) that she can use as collateral. Let \( I \) be the value that the Waterlord assigns to the ownership of water rights which is equal to the market value of the water under the auction system. I consider the 2-stage game here. For details about the algebra as well as for the infinite-period game see the Appendix.

I am not considering here the possibility that the Waterlord sells only a fraction of the water to the farmer. The Waterlord will ask the farmer for a payment \( B \) after the (observable) output has occurred. Since the Waterlord is incurring a risk because the farmer may not be able to pay the full amount \( B \), in

\(^{29}\)Through the paper I refer to observable or contractible as the same concept. I will not consider here situations in which some variables are observable but not contractible. Hence, we are in a complete contracts setting.

\(^{30}\)The proof in the appendix. This is a general result in the Corporate Finance literature as well as in the Mechanism Design literature. For a detailed discussion on optimal contract, when the asset is the land, and the effect of wealth as collateral see Hoffman (1996), Chapter 3.
equilibrium we have $B \geq I$. I am concerned with the biggest set of parameters under which the sale will occur. Thus I assume that the Waterlord will sell the water rights as soon as he gets a profit from doing so. This means that the expected value for the Waterlord equals the market price of the water.

The game is sequential. In the first stage, the Waterlord decides whether to sell the water rights and the amount to be paid $B$. In the second stage, the farmer decides the transfer. Since this is a world with perfect observability of the output and perfect contracting, the Waterlord could force the farmer to pay up to $B$, provided that the farmer has any wealth. The farmer decides the level of effort to exert as a function of $B$, $\hat{e}(B)$. The amount that the Waterlord will get is a direct (increasing) function of the level of effort exerted by the farmer. Hence, the farmer is implicitly choosing the transfer. The rest of this section solves for the equilibrium of this game. I consider first the case in which the farmer has no wealth to use as collateral and then the more general case in which the farmer has some wealth to use as collateral $C \geq 0$.

With a debt contract the problem of the farmer is:

$$\hat{V}(B) \equiv \max_e \{ q \left[ \max \{ f(\theta + r_H, e) + C - B, 0 \} \right] + (1 - q) \left[ \max \{ f(\theta + r_L, e) + C - B, 0 \} \right] - e \}$$

and her optimal level of effort:

$$\hat{e}(B) \equiv \arg \max_e \{ q \left[ \max \{ f(\theta + r_H, e) + C - B, 0 \} \right] + (1 - q) \left[ \max \{ f(\theta + r_L, e) + C - B, 0 \} \right] - e \}$$

Notice that the function $\hat{e}(B)$ is weakly decreasing and it is strictly decreasing when $C + f(\theta + r_L, \hat{e}) \geq B$.

With a debt contract the problem of the Waterlord is:

$$W(e, B) \equiv \{ q \left[ \min \{ f(\theta + r_H, e) + C, B \} \right] + (1 - q) \left[ \min \{ f(\theta + r_L, e) + C, B \} \right] - e \}$$

B.1 Benchmark: No collateral

The Waterlord sells the farmer the water rights $\theta$ and will ask for a fix amount $B$ to be re-paid after production occurs. The problem of the farmer is then:

$$\hat{V}(B) \equiv \max_e \{ q \left[ \max \{ f(\theta + r_H, e) - B, 0 \} \right] + (1 - q) \left[ \max \{ f(\theta + r_L, e) - B, 0 \} \right] - e \}$$

The farmer should choose a level of effort as a function of $B$, $\hat{e}(B)$. Because of the structure of the problem we need to define the equilibrium in three regions:

- If $B \leq f(\theta + r_L, \hat{e}(B))$, the problem is simple. In this case, the farmer can always pay the loan, hence there is no moral hazard problem. There will always be sale.

In this case, the problem becomes:

$$\hat{V}(B) \equiv \max_e \{ q \left[ f(\theta + r_H, e) \right] + (1 - q) \left[ f(\theta + r_L, e) \right] - e \} - B = V - B$$

Since $B$ does not affect the effort decision, the problem is identical as in the case in which the farmer owns the water, hence the effort level is efficient, $\hat{e}(B) = e^{FB}$. Since the farmer will always be able to repay there will be no risk premium. Hence, the debt will be equal to the value of the water, $B = I$. 

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In this case, the Waterlord is willing to sell and will not incur any risk. Moreover, the farmer will own all the inputs and will exert the First-Best level of effort, hence, there is no need to check whether the farmer is better of after the transition.

- If \( f(\theta + r_H, \hat{\theta}(B)) \geq B > f(\theta + r_L, \hat{\theta}(B)) \), the farmer can only repay the output when the state is high. If the state of the world is high, the Waterlord will get \( B \) and the farmer will get the remaining output. If the state of the world is low the farmer can not paid \( B \) and the Waterlord will take over the remaining output.

In this case, the problem becomes:

\[
\tilde{V}(B) \equiv \max \{ q \left[ f(\theta + r_H, \hat{\theta}) - B \right] + (1 - q) \left[ 0 - e \right] \}
\]

The first order condition in this case is \( q f_e(\theta + r_H, \hat{\theta}) = 1 \). In the example, this condition is:

\[
q \left( (\theta + r_H) \hat{\theta} \right)^\lambda = \frac{\xi}{\xi - \lambda}. \text{Since } q < 1 \text{ we have } \hat{\theta} < e^{FB}. \text{Notice that even if the Waterlord sells the water rights to the farmer, the effort level is still sub-optimal. The effort level is independent of } B \text{ when } f(\theta + r_H, \hat{\theta}(B)) \geq B > f(\theta + r_L, \hat{\theta}(B)), \text{but it will be suboptimal.}
\]

The market clearing condition is in this case:

\[
qB + (1 - q)f(\theta + r_L, \hat{\theta}(B)) = I
\]

The farmer will default with probability \( (1 - q) \), hence \( B \geq I \). Notice that there is no guarantee that this equation will have a solution for \( B \), because \( \hat{\theta}(B) \) is decreasing in \( B \). If the risk is too high the Waterlord will ask for a high \( B \). This high \( B \) may make the farmer not willing to participate in the trade, i.e. \( B > f(\theta + r_H, \hat{\theta}(B)) \).

In particular, when \( r_H \) is very high and \( r_L \) is very low, or when \( q \) is low, the Waterlord will find it optimal not to sell the water rights to the farmer but to write a sharecropping contract or to stay with the auctions system. Hence, when the aggregate rainfall is very volatile, the Waterlord will not sell the water rights to a penniless (\( C = 0 \)) farmer and, thus, efficiency cannot be achieved.

We still have to check whether the farmer will be better off after the transition. Even if the Waterlord is willing to sell at \( B \) and the farmer will be able to repay the full amount in the high state and a sufficient amount in the low state, it could still be the case that the farmer prefers the old institution. In this case, we are considering the case of a farmer with no water rights, i.e. \( \theta_i = 0 \). Farmers with high property rights, \( \theta_i > \hat{\theta}(\pi) \), will be willing to sell in the same conditions as the Waterlord. We have to check whether:

\[
\tilde{V}(B) > \tilde{V}(\pi) \equiv (1 - \pi)V(\pi) + \pi \max_e \{ q \left[ f(r_H, e) \right] + (1 - q) \left[ f(r_L, e) \right] - e \}
\]

where \( \tilde{V}(\pi) \) is the value of a farmer with no water rights, before knowing whether she is liquidity constrained or not. This expression is hard to interpret. However, we can look at the extreme cases.

When \( \pi = 0 \), we have \( \tilde{V}(\pi) = V \), hence the auction system achieves full efficiency, while the transition does not. In this case the transition will not happen.

When \( \pi = 1 \), we have \( \tilde{V}(1) = \max_e \{ q \left[ f(r_H, e) \right] + (1 - q) \left[ f(r_L, e) \right] - e \} \). Whether this expression is greater than \( \tilde{V}(B) \) will depend on the probability of high rain \( q \) and the productivity of water with more or less rain \( f_w(\cdot, e) \). If \( q = 1 \), \( \tilde{V}(B) > \tilde{V}(\pi) \) if and only if, \( \max_e \{ q \left[ f(\theta + r_H, e) \right] - e \} - \max_e \{ q \left[ f(r_H, e) \right] - e \} > B \). The transition will happen only if the increase of productivity due to irrigation in the high state is greater than the debt required by the Waterlord, which is greater than the average price of water \( I \). By continuity, this result also holds for value of \( q \) close to 1, i.e. \( q \approx 1 \). If \( q = 0 \), then \( \tilde{V}(B) = 0 \) and the transition will never happen. By continuity, this result also holds for value of \( q \) close to 0, i.e. \( q \approx 0 \).
• If $B > f(\theta + r_H, \tilde{e}(B))$, the farmer will always default, and will get nothing. In this case, the farmer will not exert any effort and the profits for both (the farmer and the Waterlord) will be zero. Hence, there will be no sale.

In this case, the problem becomes:

$$\tilde{V}(B) \equiv Max \{ q \{ 0 \} + (1 - q) \{ 0 \} - e \}$$

The solution is trivial, $\tilde{e}(B) = 0$ and the output will always be 0.

### B.2 Collateral

If the farmer has some wealth that the Waterlord can appropriate in case of low rain, then the problem is less severe than before. If $C \geq I$, then the problem is trivial, because the farmer will always be able to payback. Moreover, $C \geq f(\theta + r_L, \tilde{e})$ is sufficient to ensure that the farmer will payback. In this case the Waterlord knows that he will always be repaid, hence $B = I$.

The Waterlord sells the farmer the water rights $\theta$ and will ask for a fix amount $B$ to be re-paid after production occurs. The problem of the farmer is then:

$$\tilde{V}(B) \equiv Max \{ q \{ max \{ f(\theta + r_H, e) + C - B, 0 \} \} + (1 - q) \{ max \{ f(\theta + r_L, e) + C - B, 0 \} \} - e \}$$

The farmer should choose a level of effort as a function of $B$, $\tilde{e}(B)$. Because of the structure of the problem we need to define the equilibrium in three regions:

• If $B - C \leq f(\theta + r_L, \tilde{e}(B))$ the problem is simple. In this case, the farmer can always pay the loan, hence there is no moral hazard problem. There will always be sale.

In this case, the problem becomes:

$$\tilde{V}(B) \equiv Max \{ q \{ f(\theta + r_H, e) \} + (1 - q) \{ f(\theta + r_L, e) \} - e \} + C - B = V + C - B$$

Since $B$ does not affect the effort decision, the problem is identical as in the case in which the farmer owns the water, hence the effort level is efficient, $\tilde{e}(B) = e^{FB}$. Since the farmer will always be able to repay there will be no risk premium. Hence, the debt will be equal to the value of the water, $B = I$.

• If $f(\theta + r_H, \tilde{e}(B)) \geq B - C > f(\theta + r_L, \tilde{e}(B))$, the farmer can only repay the output when the state is high. If the state of the world is high, the Waterlord will get $B$ and the farmer will get the remaining output. If the state of the world is low the farmer can not paid $B$ and the Waterlord will take over the remaining output.

In this case, the problem becomes:

$$\tilde{V}(B) \equiv Max \{ q \{ f(\theta + r_H, e) + C - B \} + (1 - q) \{ 0 \} - e \}$$

The first order condition in this case is $[q f_e (\theta + r_H, \tilde{e})] = 1$. In the example, this condition is:

$q (l (\theta + r_H) \tilde{e})^\lambda = \frac{\tilde{e}}{\lambda}$. Since $q < 1$ we have $\tilde{e} < e^{FB}$. Notice that even if the Waterlord sells the water rights to the farmer, the effort level is still sub-optimal. The effort level is independent of $B$ and $C$ when $f(\theta + r_H, \tilde{e}(B)) \geq B - C > f(\theta + r_L, \tilde{e}(B))$, but it will be suboptimal.

The market clearing condition is in this case:
\[qB + (1-q)[f(\theta + rL, \tilde{e}(B)) + C] = I\]

The farmer will default with probability \((1 - q)\), hence \(B \geq I\). Notice that there is no guarantee that this equation will have a solution for \(B\), because \(\tilde{e}(B)\) is decreasing in \(B\). If the risk is too high the Waterlord will ask for a high \(B\). This high \(B\) may make the farmer not willing to participate in the trade, i.e. \(B > f(\theta + rH, \tilde{e}(B))\).

In particular, when \(r_H\) is very high and \(r_L\) is very low, or when \(q\) is low, the Waterlord will find it optimal not to sell the water rights to the farmer but to write a sharecropping contract or to stay with the auctions system. Hence, when the aggregate rainfall is very volatile, the Waterlord will not sell the water rights to a penniless \((C_i = 0)\) farmer and, thus, efficiency cannot be achieved.

However, notice that the greater is \(C\) the closer we are to be in the previous case. Also, the greater is \(C\), the more likely it is that this equation will have a solution. This is due to the fact that the greater is \(C\) the lower is the \(B\) that solves this equation.

We still have to check whether the farmer will be better off after the transition. Even if the Waterlord is willing to sell at \(B\) and the farmer will be able to repay the full amount in the high state and a sufficient amount in the low state, it could still be the case that the farmer prefers the old institution. In this case, we are considering the case of a farmer with no water rights, i.e. \(\theta_i = 0\). Farmers with high property rights, \(\theta_i > \hat{\theta}(\pi)\), will be willing to sell in the same conditions as the Waterlord. We have to check whether:

\[\tilde{V}(B) > \tilde{V}(\pi) + C \equiv (1-\pi)\tilde{V}(\pi) + \pi \max_{\tilde{e}} \{q\tilde{f}(r_H, e) + (1-q)\tilde{f}(r_L, e)\} - \tilde{e} + C\]

where \(\tilde{V}(\pi)\) is the value of a farmer with no water rights, before knowing whether she is liquidity constrained or not. This expression is hard to interpret. However, we can look at the extreme cases.

When \(\pi = 0\), we have \(\tilde{V}(\pi) = V\), hence the auction system achieves full efficiency, while the transition does not. In this case the transition will not happen.

When \(\pi = 1\), we have \(\tilde{V}(1) = \max_{\tilde{e}} \{q\tilde{f}(r_H, e) + (1-q)\tilde{f}(r_L, e)\} - \tilde{e}\). Whether this expression is greater than \(\tilde{V}(B) - C\) will depend on the probability of high rain \(q\) and the productivity of water with more or less rain \(\tilde{f}_w(\cdot, e)\). If \(q = 1\), \(\tilde{V}(B) - C > \tilde{V}(\pi)\) if and only if, \(\max_{\tilde{e}} \{q\tilde{f}(\theta + rH, e)\} - \tilde{e}\) - \(\max_{\tilde{e}} \{q\tilde{f}(r_H, e)\} - \tilde{e}\) > \(B\). In this case, the collateral plays no role. The transition will happen only if the increase of productivity due to irrigation in the high state is greater than the debt required by the Waterlord, which is greater than the average price of water \(I\). By continuity, this result also holds for value of \(q\) close to 1, i.e. \(q \simeq 1\). If \(q = 0\), then \(\tilde{V}(B) = 0\) and the transition will never happen. In this case, the collateral plays no role. By continuity, this result also holds for value of \(q\) close to 0, i.e. \(q \simeq 0\).

For intermediate values of \(q\) the collateral does play a role, since greater collateral requires a lower level of debt. Even if locally the collateral does not affect the level of effort exerted by the farmer it affects the value function of the farmer under the new institution.

- If \(B > f(\theta + rH, \tilde{e}(B)) + C\), the farmer will always default, and will get nothing. In this case, the farmer will not exert any effort and the profits for both (the farmer and the Waterlord) will be zero. Hence, there will be no sale.

In this case, the problem becomes:

\[\tilde{V}(B) \equiv \max_{\tilde{e}} \{q[0] + (1-q)[0] - \tilde{e}\}\]