Playing Checkers in Chinatown*

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[VERY PRELIMINARY, PLEASE DO NOT CITE]

Abstract

In 1905-1935 the city of Los Angeles bought the water and land rights of the Owens Valley farmers and built and aqueduct to transfer the water to the city. The dark story is that the city bullied and isolated reluctant farmers to get cheap water. A map of the farmers plots sold in any given point in time, however, would look like a checkerboard either because the city is intentionally targeting specific farmers, or because the farmers were heterogeneous. We analyze the bargaining between the city and the farmers and the effects that farmers' actions had on one another, and use that evidence to assess the checkerboarding claim. We estimate a dynamic structural model of the farmers' decision on selling to the city. We found that there are large externalities when farmers sold. The externalities were larger for neighboring farmers, and when the selling farmer was closer to the river.

JEL Codes: N52, Q25, C73, L1

Keywords: Water Rights, War of Attrition

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"The only reason they were 'checkerboarding' was because this fellow wanted to sell out and the next one didn't."

A. A. Brierly (Owens Valley farmer), cited in Delameter (1977)

"Their efforts were focused on the key properties which controlled the points of access to the river, so that the less favorably situated ranchers inland could be cut off from their water supply if they refused to negotiate."

William Kahrl, *Water and Power* (1982)

1 Introduction

While urbanization is viewed as a critical engine of development, urban population growth can give rise to opportunities and challenges. As urbanization processes unfold, developing countries will have to deal with an unprecedented increase in the number of people moving into their cities. The United Nations predicts that the number of city dwellers will rise by 3.5 billion over the next 40 years (WHO, 2015). The movement of urban population from rural to urban environments will also entail a reallocation of natural resources, like water, to redeploy towards urban use. How can we ensure that the benefits these transfers generate are distributed evenly among urban and rural dwellers is a first-order concern for economists and policymakers.

To study this question, we revisit probably the most famous episode of water transfer in the history of the US. In 1905-1935 the city of Los Angeles (LA) purchased the water and land rights of the Owens Valley farmers, built an aqueduct to transfer the water, and changed the history of the Valley and that of water transfers forever. The city grew from 100,000 people in 1900 to 1.2 million in 1930, becoming the largest city in California and the second largest in the U.S., which would have been impossible without the water from the Owens River. Despite this achievement, the transfer has been immersed in controversy, exaggerated in the movie Chinatown, since its inception. The most serious accusations made against the city was that they were checker-boarding their land purchases, *i.e.*, that they were intentionally buying land surrounding reluctant sellers, to drive down their demanded price. In this paper, we first address the historical question of whether the city was checker-boarding and explore to what extent it might have behaved strategically in its purchases of land and water rights. We then study the bargaining that took place between the city and the farmers to assess how externalities might have affected the distributions of rents among the city and farmers.

This is a challenging question. First of all, there are data limitations as the current historical literature did not have geocoded data of each transaction nor specific dates of when the plots were sold. Secondly, water is a good that is very peculiar. When analyzing water transfers, we need to account for the presence of externalities among farmers. Therefore, we cannot study transactions between farmers and the city in isolation but look at these from a collective decision perspective, where the city of LA could strategically buy out different farmers and thus affect the trade-off of the remaining farmers. Ultimately, when looking at the decision to sell and prices, our reduced form analysis will not be able to capture the rich endogenous interactions taking place between farmers, which would require a model that can flesh out the dynamic incentives that farmers faced in a bargaining game.

We build a novel and very detailed dataset, containing the exact date of each sale, the precise geo-location of each plot, as well as other characteristics: acreage, water rights, sale price, crops under cultivation. We use this new dataset first to assess whether the city did indeed checkerboard their purchases. To do so, we first show that there is a spatial correlation on the date of sale within the whole valley, which highlights the importance of having geo-coded data. We then show reduced form regressions to explain whether a farmer sold or not and at what price, in a dynamic setting. Our results suggest that there is a significant interaction taking place at the ditch level, between farmers that have sold their land and farmers that have not and that externalities imposed by selling neighbors drive these patterns.

We model the purchased made by the city as a War of Attrition (WoA) with externalities, which in practice resembles a Monopsonist strategy in the Coase conjecture (Coase, 1972). If the city could commit not to offer a larger price in the future, the city could extract all the surplus from the farmers. However, if the farmers could bargain as one, they might be able to extract most of the surplus from the transfer. The situation is complicated by the heterogeneity of the farmers and the negative externalities they exert on others, *e.g.*, farmers whose plots are closer to the river where the ditch meets the river would produce a larger negative effect on the other farmers on the same ditch, than those farmers down the ditch. We exploit the detailed selling times to show that the shape of the hazard rate is not constant, which requires a model with valuations that change over time. Our focus is not on the interaction of the city vis-à-vis the farmers as a whole, but rather, the interaction among farmers, given the behavior of the city. We estimate the model on two steps. In the first step, we get a vector of the pseudo parameters that we recover using only exit times. In the second step, we use the estimated pseudo parameters and the probabilities they imply to estimate hedonic regressions to get a set of parameters for each fundamental farmer characteristic.

Unlike the previous literature on the topic, we have the location of each plot sold to the city. Therefore, there are questions we can answer that could not be explained without the location data. First, we can assess the externalities created by each farmer on the remaining farmers, *i.e.*, on their probability of selling and the price they would get. We find evidence that externalities depend on fundamental farmers' characteristics; for example, farmers with more water rights created substantial externalities. The same is true for farmers located closer to the river. Second, given the externalities, we could test the checker-boarding behavior of the city, *i.e.*, whether the city would offer more money to farmers that would create higher externalities, to drive down the prices for the remaining farmers. We do not find conclusive evidence that the city was checker-boarding. This is not surprising given that the offers were made by a committee intended to give each farmer a fair price for their land, not to minimize the time spent on negotiations.

Estimating a WoA with externalities and time changing valuations is challenging. In the presence of externalities, the payoff of each player is affected not only by their decisions but also by the decisions of other players. If a farmer sold at a given point, it could be because his value of waiting was low, given the "high" price offered by the city, or because the farmer expects one of his neighbors to sell soon, which would lower his continuation value. If we also consider that continuation values and the probability of selling are changing over time, separately identifying the parameters of such a model can be very demanding on the available data. We adapt the WoA game in Catepillan and Espín-Sánchez (2019) to our empirical setting and show that under general assumptions the parameters can be identified. Moreover, in equilibrium, the WoA with externalities and continuation values changing over time resemble a Proportional Hazard Rate Model, where the "shape" of the continuation value over time is a function of the selling probability. Moreover, the externalities and the direct effects of each variable can be estimated using simple linear regressions in a second stage. Finally, we use the estimated model to compute counterfactuals on what the prices paid would have been if the farmers had been able to bargain as one, or bargain as one in each ditch.

This paper relates to a rich literature in political economy studying the coordination problems associated with the overuse and depletion of natural resources, like water (Ostrom, 1962). The fact that water is a good that is both subtractable and challenging to exclude motivated a long tradition analyzing common-pool resources (Ostrom, 2010), and how to institutionally deal with the coordination problems that externalities entail. In our setting, we study how the city of Los Angeles strategically exploited this feature of waters markets, to maximize the amount of rents it could extract from the farmers.

In the presence of externalities, private decisions by farmers can be seen as a form of collective decision. Literature in vote buying (Dal Bo, 2007) has shown that a principal can influence collective decisions of agents to induce inefficient outcomes at almost no cost, as long as the principal can reward decisive players differently, and agents face high coordination costs. We show evidence consistent with the prediction that the city should target key players strategically, and that by doing so many farmers were bought at a price very close to their marginal costs.

There is extensive academic work on the Owens Valley controversy. The historical literature focuses on the characters of the story, and how their personal beliefs and personality traits affected the outcome (Hoffman, 1981; Kahrl, 1982; Davis, 1990). However, they differ on whether they portray LA as a villain, or just as a rational business-minded agent. Whereas Kahrl (1982) and Reisner (1987) portray the citizens of the valley as innocent victims, Hoffman (1981) takes a more neutral view of the situation as inevitable given the population growth of LA in the early 20^{th} century. Moreover, the few accounts that we have from Owens Valley farmers, such as Delameter (1977) and Pearce (2013), tell a different story. Their story is one of farmers willing to sell their ruinous farms, while the townspeople, with the help of the Watterson brothers and the local newspaper, bullied both the farmers and the city agents until they got compensation for their urban properties, which eventually happened in 1925. There has been some recent work in economics, most prominently by Libecap (2005, 2007, 2009). He focuses on the prices that farmers received for their lands. He showed that although all farmers were paid more than their lands were worth, the surplus generated by the transfer was enormous and the city got most of it. He also shows, confirming Kahrl (1982) claims, that on average, farmers that sold later received a higher price. Our model can account for this feature of the data. Our focus is not on the interaction of the city *vis-à-vis* the farmers as a whole, but rather, the interaction among farmers, *given* the behavior of the city.

Our paper contributes to literature studying the privatization of public services and public procurement. There are at least two accounts of government privatization decisions. One view, which focuses on transaction costs (Williamson, 1985; Oliver Hart, 1997) and an alternative view (Maxim Boycko, 1996) emphasizing the private benefits to politicians of keeping service provision inside the government. We study a unique case, where a public actor, a city, centralizes the provision of a public good, because of strategic considerations (water provision security). We contribute to literature studying the impact of water infrastructure in urban areas. As urban environments grow, low levels of piped water usage might threaten the welfare of unconnected households posing negative externalities on neighbors (Nava Ashraf, 2017). Indeed, there is plenty of evidence that large investments in water systems led to significant welfare gains in the US (Cutler and Miller, 2005) achieving near miraculous results, drastically improving life expectancy (Ferrie and Troesken, 2008) and declines in infant mortality (Alsan and Goldin, forthcoming). These results also hold for the city of Paris (Kesztenbaum and Rosenthal, 2017). This literature directly measures the impacts of having access to water in urban environments. We analyze the arguably most important water infrastructure project in the history of modern America, focusing on how the water was acquired to secure water access to urban dwellers.

There is also a rich literature in development economics studying the health impact of access to water in rural environments (Nava Ashraf, 2017; Michael Kremer, 2011; Gamper-Rabindran Shanti, 2010; Florencia Devoto, 2012). Merrick (1985) and Sebastian Galiani (2005) find that the access to piped water infrastructure reduces the presence of diseases.

In terms of modeling and methodology, our paper contributes to the literature in industrial organization. Takahashi (2015) studies a WoA with symmetric players and without externalities. The classical article on offshore oil drilling by Hendricks and Porter (1996) consider a simpler WoA with information externalities. More recently, Hodgson (2018) studies oil drilling in the North Sea implicitly assuming a framework like ours but solves for an equilibrium restricting the behavior of firms. Our results extend to information externalities in R&D as in Bolton and Harris (1999).

2 Background and Data

2.1 Historical Background

By 1900 the officials of the city of LA realized that the water provided by the Los Angeles river would not be enough to meet the city's future water demand, given the projected population growth. Local leaders and business owners were interested in finding an external water supply to guarantee the city growth, and to compete with San Francisco for the main economic hub on California. The solution they devised was to bring the water from the Owens River, 300 miles north of LA, to the city. For this purpose, they would need to build a large aqueduct, many dams and reservoirs and, more importantly, buy the water rights from their owners, the farmers at Owen's Valley. The value of the water would be worth much more once it arrived at the city than at the valley. To keep these rents, the city officials devised a plan to get "enough" water rights from the farmers, before the project was made public. Because the water rights were tied to the land, the city had to buy the land to get the water rights. In 1904-1905, former mayor of LA Fred Eaton traveled through the valley buying options on the purchases of the land. At this stage, the intentions of the city were not public, and farmers sold their land at "normal" prices, that is, the value of the land plus the value of water, if the water was use for irrigation in the valley.

At the time, the Federal Reclamation Service (FRS) was considering a reclamation project for the Owens Valley. The chief of the FRS in California was J.B. Lippincott, resident of Los Angeles and friend of Fred Eaton. The controversy begun here. Eaton was later accused of using his association with Lippincott to imply that the options would go to the reclamation project, not to the city. Although both men denied the accusations, many farmers claim that they would have ask for a higher price, had they known the land was not going to the FRS.Fred Eaton returned to the city with all the options needed, and the plan was announced in the local newspapers. A $1.5 million bond issue is approved by the voters for a wide margin, to finance a feasibility study and to purchase the land from Eaton's options. William Mulholland is then appointed Chief Engineer of the project and in 1907 another bond is put to the voters, for $23 million, to finance the construction of the aqueduct. The aqueduct was completed in 1913. The policy in the city at the time prohibited to sell water for uses outside its limits. This meant that the nearby towns, which were also growing fast, had no option if the wanted to continue grow, but to apply for annexation to LA. The area of Los Angeles grew from 115 to 442 square miles in the following two decades.

The options bought by Eaton in 1905 were just the beginning. The city's actual growth surpassed all projections and soon the city had to buy more land and water rights from the Owens Valley. After the project was announced, and the aqueduct built, the farmers in the valley knew that the water would be used in LA, and demanded a higher price for their plots. In the beginning, residual rights on water were enough to satisfy the City's demand. Due to the increase in population, a new bond was passed on 1922 for $5 million. The drought of 1923 made the city to want to buy more water rights and in 1924 two more bonds passed for $8 million each. Due to the controversy of the massive land purchase, the city is forced to buy the land and buildings on the towns within the valley, at pre-Great Depression prices. "In May [1925], the legislature passed a bill specifically allowing the payment of reparations from damages caused by the loss of water but not for those arising from the construction or operation of the aqueduct." (Kahrl, 1982, p. 296). In 1930, a new bond is issued for $38.8 million, to acquire the town properties and to buy some land in the Mono Basin.[1] Notice that, these purchases made the bulk of the total

[1] According to (Kahrl, 1982), the city paid a total of $5,798,780 for the town properties: Bishop $2,975,833; big Pine $722,635; Independence $730,306; Laws $102,446; and Lone Pine $1,217,560.

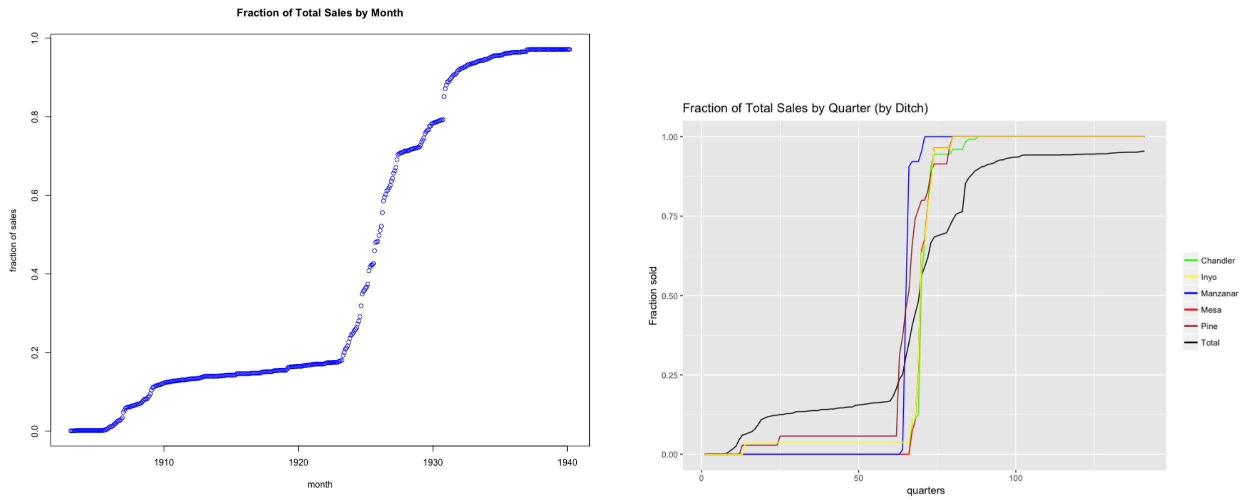
expenses although they contained no water rights. Subsequent bonds votes to buy more water rights happened in the following decades, and by 1934 the city own virtually all water rights in the valley, and over 95% of the farmland, and 85% of the town properties.

Within each bond, the same situation would arise. The city would have a fix amount of money to buy land. The city would announce a committee that would evaluate the potential lands to be bought, and will make offers to each of the farmers individually. The farmers would then engage in a "war of attrition" among themselves. They knew that if they hold up, the city would offer them more money for their lands. However, when one a farmer sold their land this would create an externality on the other farmers. After a purchase, the city would have less funds to continue buying up lands and will have less need for water. Moreover, for neighboring farmers, this externality would be larger. Farmers could get "isolated" from the river if the city bought all their neighbors' lands. If the city buys most (usually two thirds) of the farms in each ditch, it could then dissolve the ditch association and the remaining farmer would get no access to water. In this article, we focus on this game between the farmers. These externalities were important and were recognized by all parties involved. Therefore, the farmers tried initially to negotiate as one, so that they would internalize the externalities and would get a better price. They formed the Owens Valley Irrigation District (OVID) in 1923. The city then bought out the main members of the OVID. They begun by buying the lands "of the oldest canal on the river [McNally Ditch] before its property owners joined the irrigation district" (Hoffman, 1981, p. 179). "Farmers illegally diverted McNally Ditch water into their own ditches, leaving the city in the position of owning a ditch without water. In retaliation, Los Angeles adopted a policy of indiscriminate land and water purchases in the Bishop area, infuriating valley people, who accused the city of 'checkerboarding."' (Hoffman, 1981, p. 179). The city then began to buy "[...] into the Owens River, Bishop Creek, and Big Pine canal companies. As with the McNally Ditch, their efforts were focused on the *key properties which controlled the points of access to the river*, so that the less favorably situated ranchers inland could be cut off from their water supply if they refused to negotiate." (Kahrl, 1982, p. 279, emphasis added)(Kahrl, 1982, p. 279, emphasis added). The city, by not buying the whole valley, presumably engaged in "a strategy of *division and attrition*---[which] was especially cruel, [...] because it placed an even larger burden of responsibility on the *farmers and ranchers who held out*" (Reisner, 1987, p. 93, emphasis added). The remaining farmers then created three smaller cartels. Each pool was a subset of the farmers owning water rights in the three major ditches. In 1927, following the collapse of the Watterson Brother's Bank, the Cashbought and the Watterson pool collapsed.

Although the city ended up buying all the land in the valley, when they were negoti-

Figure 1: Sales over time.

A. Fraction of Total Sales by Month. B. Fraction of Total Sales by Ditch.



Notes: Panel A: Fraction of total sales in the data with monthly frequency. Panel B: Fraction of total sales in each ditch with quarterly frequency.

ating with the farmers, the farmers were unsure about how far they could sustain a hold up. The city "made indiscriminate property purchases, leaving farmers uncertain of their neighbors' intentions." (Hoffman, 1981, p. 180). This motivates our modeling as a game of perfect information because farmers knew each other very closely and each other plot valuations, and the uncertainty was due to what the farmers would do given the city's offer. Until the 1930s, there was uncertainty as to how much land and water the city of LA was going to buy and need. This uncertainty was driven by the recurrence of eventual droughts and by the increase in population in the city of LA. The ability of buying land was subject to availability of funds that came through sub sequential bonds. When the city run out of money, it was unclear whether they were going to be able to issue a new bond.

2.2 Water Law in the West

We now briefly discuss water rights in the Owens Valley. As mentioned in Libecap (2007) in Owens Valley, farmers held both appropriative and riparian surface water rights. Whereas appropriative rights can be separated from the land and be sold, riparian rights are inherent to the land and cannot be separated and sold apart. Appropriative rights are based on first appropriation, they typically are denominated in miner's inches, or as a percentage of all the water in each ditch.[2] In the data, when the farmer owns appropriative rights, we do observe whether the rights are senior or junior, and we have a measure in miner's inches or in a percentage of the flow in the ditch, which can be transformed into a measure of capacity. We compute the amount of water acre for each plot. When rights are riparian, they are attached to the land, and city typically buys the whole land surrounding the ditch, *e.g.*, "all rights in Sanger Ditch" or "all rights in Baker Creek." In those cases, we do not have a measure of water rights, because there is no explicit mention of the water capacity.

2.3 Sales Data

We created our main dataset from the transaction cards (deeds) stored at the Los Angeles Department of Water and Power (LADWP) archive in Bishop, Inyo county. In Figure 2.A we can see a sample in that transaction card. Each transaction card makes a reference to a particular Section, in a particular Township and a particular Range, all of them in Mount Diablo Meridian (M.D.M.). Typically, one section corresponds to a square of one mile times one mile, or 640 acres. Thus, a quarter of a section correspond to 160 acres; a quarter of a quarter corresponds to 40 acres; and half of a quarter of a quarter corresponds to 20 acres, as in Figure 2.A. This particular example is an easy one, but in some cases the same farmer owned several plots, sometimes non-contiguous. In many cases, the plots were not rectangular, and the geo-codification is more cumbersome. However, we were able to geo-code all the plots. This is important not just to be able to create the maps, but also to create variables that are relevant to our analysis, as we explain below in subsection 2.4. For our baseline analysis, we merge all continuous plots owned by the same farmer, and treated the merged plot as a single plot.

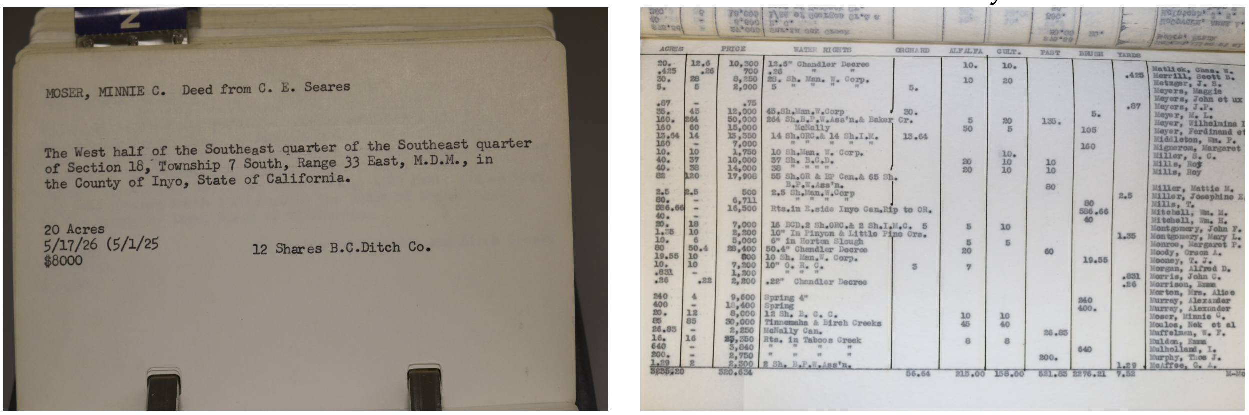
Table 1 shows summary statistics for the variables used in the analysis. As shown in Figure 2.A, we have not only the year of purchase but the exact date of purchase.[3] In the main analysis, we only consider transactions between 1905 and 1935. The reason is that, as explained above in subsection 2.1, before 1905 farmers were unaware of the intentions of the city, and they sold their land to Fred Eaton. By 1935, the city owned all the water rights and virtually all the non-federal lands in the Owens Valley. There are some sporadic transactions in the 1970s and 1980s, but they are very different in nature to the land purchases of the beginning of the 20^{th} century.

[2]They could be senior or junior rights. During a dry season, all the senior rights have to be fulfilled, before any junior rights claimant get any water.

[3]For many of the cards, we do see two dates. We know that the later date, or the only date when there is only one, was the date when the land was sold. We believe that the first date is the date when the offer was made.

Figure 2: Sample Pictures from data collection.

A. Transaction Card. B. Survey.



Notes: Panel A: Caption of a transaction between Minnie C. Moser and the city of Los Angeles. Panel B: Caption of the survey conducted by the city of Los Angeles, where the plot owned by Minnie C. Moser is seventh from the bottom.

In addition to the date of purchase, we have information regarding the size of the land and the amount paid for it, which we obtain directly from the cards. The cards do contain information regarding water rights, but in a format that is not directly comparable across farmers. In some cards, the information is regarding the number of shares, sometimes it says a percentage of all rights in a particular creek, and sometimes it mentions first or second rights using miner's inches. All those measures are homogeneous and comparable within a ditch, but not across ditches. To get a comparable measure of water rights across all farmers, we merged our dataset with the data collected by Gary Libecap. Gary Libecap's work cited above is based on the data available at the LADWP archive in Los Angeles. We merge our data with his data to obtain uniform measure of water rights.[4]

In addition to the transaction cards, we complemented the data with the surveys conducted by the surveyors hired by LADWP. Figure 2.B shows a sample picture of the surveys summary. We merge the dataset created using the transaction cards with the survey data using the names of the farmers. In the survey, we can also see how not only the name but also the acreage and the water rights data also match with the information in the cards.

[4]In Libecap's dataset there is a measure of annual water acres for each farmer. Hence, for the farmers in his dataset we have an exact measure of water acres. For reasons that are not clear to us, his dataset contain fewer farmers than ours. Whereas we were able to find merge all farmers in his dataset in our dataset, there are about 600 farmers in our dataset that do not appear in his dataset. However, most of those farmers have water rights in the same ditch as another farmer that appears in Libecap's dataset. We make the assumption that all shares and all miner inches in a given ditch convey the same number of water acres, and we use Libecap's data to extrapolate the water acres for those farmers.

Table 1: Summary Statistics.

Variable	Mean	SD	Min	Max	Obs
Year	1,927	13.4	1,903	1,997	1,390
Acres	209.6	741.9	1	11,918	1,390
Price	26169	104594	1	2,000,000	1,250
Water Acres	257.3	882.45	0	17,850	1,381
Distance to the river	5,128	9,987.184	0	250,957	1,390
Distance to Mono lake	111,920	44,454.43	0	434,895	1,390
Distance to Owens lake	69,446	41,558.31	0	246,874	1,390

Notes: Summary statistics for selected variables. *Year* is a numeric variable that measures the year where the plot was sold. *Acres* is the number of acres of the property sold. *Price* is the final price that the farmer received for her plot. The lower number of observations with prices is due to some farmers exchanging their land for another piece of land owned by the city. *Water Acres* ...

The survey, however, have an extra piece of information not present in the transaction cards, but that is an important determinant of the price paid: land use. In the survey, the land for each farmer is decomposed on how many acres are used for each of the following six categories: Orchard, Alfalfa, Cultivated, Pasture, Brush and Yards.

Based on the data used, we can distinguish three generations of work on the topic, and the same categorization applies to other setting. The first generation include historians such as Hoffman (1981) and Kahrl (1982), who used summary data to draw their conclusions. The sources that they cite most commonly are the summaries written by Thomas H. Means for the city of LA. Given the lack of detailed or individual data they could draw conclusions regarding the total amount that the city spent, but not detailed conclusions regarding the evolution of prices, the size of the surplus or the distribution of such surplus. The second generation includes the work by Gary Libecap (Libecap, 2005, 2007, 2009). He used individual data, but does not have the geographical location of the plots. He documented the upward trajectory of prices paid to the farmers and have robust measures of the surplus and concluded that the city got most of the surplus, and the farmers that sold later got a better price on average. The lack of geographical information also limits the analysis because there are some omitted variables that affect the value of the plot. This paper is a third generation on the topic and, in addition to detailed individual data, it uses geo-coded variables that help explain the heterogeneity of the plots. The crucial innovation, however, is that the geographical information allows us to test and compute spatial externalities. This allows us to address whether the city was in effect "checkerboarding" farmers and whether it was efficient or not.

2.4 Geo-location data

As mentioned above, the transaction cards provide a detailed description of the exact location of each plot. We geo-coded 2,750 plots. Figure 3.A shows the land holdings from the main sellers, *i.e.*, those who received over $1 million for their land.[5] Notice that the State of California was by far the largest seller. Fred Eaton appears as the second largest seller, despite not being a farmer or a landowner in the valley before 1905. He acted as an intermediary who bought land from the farmers and sold it to the city. Most of the land is in the lower part of the valley, close to Owens lake. However, it is worth noticing the large plot of land sold by Eaton in Mono county. This plot of land correspond to the Rickey ranch, covering 11,190 acres and purchased for $425,000 after "a week of Italian work" by Eaton (cited by Reisner, 1987).[6] The ranch had the best natural spot for a reservoir (Long Valley) and its contentious sale to the city by Eaton destroyed the friendship between him and Mulholland.

In addition to creating the maps, which are very useful to have a better understanding of the data, the goal of the geo-location is to create more variables. For each polygon geo-coded, we can merge it with data available in GIS (Geographical Information Systems). After the merge, we have important variables such as: altitude, roughness, slope, suitability and distance to the Owens river. All of which are important determinants of the quality of the land and thus the price received. We are specially interested on the distance to the river because, based on the historical literature, we conjecture that farmers, in a given ditch, whose plots are closer to the Owens river, would create a larger externality in the other farmers, than farmers that farmers that are further away. Finally, geo-coding the plots for all farmers allow us to compute distances between farmers, and to perform a rigorous spatial analysis. The distance between the farmers' plots would also affect the size of the externality created by other farmers' sales.

3 Preliminary Evidence

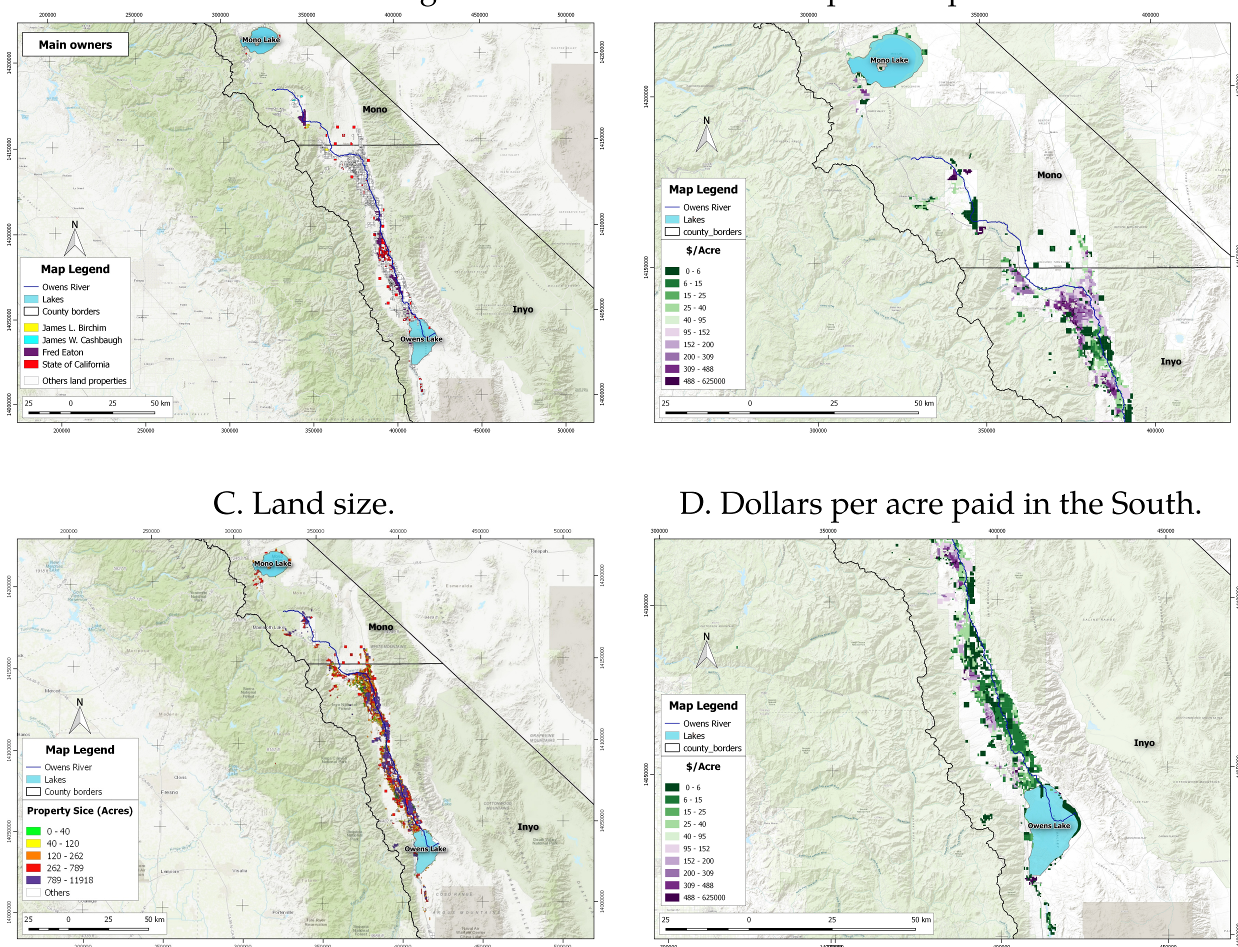
In this section, we present descriptive statistics and reduced-form analysis that, together with the historical evidence presented in Subsection 2.1 motivates the design of our theoretical modeling. We first show that there is spatial correlation on date of sale within

[5]James Birchim received $2 million in 1981 for 646.12 acres. James Cashbaugh received $1.4 million in 1985 for 636.66. Because these sales were so late, they are not included in our analysis.

[6](Reisner, 1987) also implies that Lippincott favored the application of the Nevada Power Mining and Milling Company, founded by Thomas B. Rickey, over that of the Owens River company, for the building of a power plant in the valley. Lippincott recommendation was then key to convince Rickey to sell the ranch.

Figure 3: Digitized maps in Owens Valley.

A. Main Owners of rights. B. Dollars per acre paid in the North. C. Land size. D. Dollars per acre paid in the South.



Notes: Panel A: Map with the main water rights owners, i.e., those who received over $1 million. Notice that Fred Eaton is listed although he was an intermediary. Panel B: Map of the dollars per acre paid for each plot in the north of the Owens Valley. Panel C: Map of the total area holding of each seller. Panel D: Map of the dollars per acre paid for each plot in the south of the Owens Valley.

Figure 4: Spatial Correlation.

Moran's I Test Results

Model	Observations	Moran I statistic	p-value
Sample P/A	1158	-1.21E-03	0.5139
Sample Timming	1158	0.333178241	2.20E-16
Timming (<1906)	38	0.38125082	0.0004194
Timming (1907-1912)	108	0.161978265	0.02568
Timming (1913-1921)	8	-0.12837051	0.4805
Timming (1922-1923)	90	0.265955734	0.000847
Timming (1924-1925)	135	0.278952641	4.11E-05
Timming (1926-1927)	154	0.504066624	1.42E-12
Timming (1927-1928)	188	0.062588665	0.1414
Timming (1928-1929)	178	0.367887174	2.16E-08
Timming (1930>)	259	0.503678295	2.20E-16

Notes: Results from a Moran Test of Spatial correlation on the year that each farmer sold their plot. *Sample P/A* corresponds to the spatial correlation of price per acre. *Sample Trimming* corresponds to the spatial correlation of year of sale, taking all the observations between 1906 and 1935. *Timing* (X) corresponds to the spatial correlation of year of sale, taking all the observations included in X.

the whole valley, to highlight the importance of the geo-coded data. Second, we show reduced form regressions to explain whether a farmer sold or not and at what price, in a dynamic setting. The results are consistent with the historical evidence. Third, we show robustness results that confirm that the patterns are due to the externalities imposed by the sale of a neighbor, and not other hypotheses. Finally, we show that the shape of the hazard rate of selling times is not constant over time. This means that we could not use the classical model of War of Attrition which predicts a constant hazard rate. This motivates our use of a model of War of Attrition with valuations that change over time.

3.1 Spatial Correlation

[TO COME]

3.2 Farmers sales

Table 2 shows the results for whether a sale will take place in a given month for each ditch (notice that as we calculated our variables at the ditch level, is as if we were adding a ditch fixed effect). The sale variable would be either zero if no sale took place that month or one if at least one sale happened that month. We build state-level variables, which reflect how conditions are changing in time in each ditch. Sales to date represent the percentage of farmers that have sold to LADWP up to that month. Shares to date, on the other hand, represents the fraction of total shares that have been sold to the city until that moment in time. Price per acre represents the average price of the sales that have taken place up to that moment in time, and acres to date is the percentage of total acres in a given ditch that has been sold to the city. We control for year-month to absorb any unobserved time-varying changes.

Our results suggest that there is a significant interaction taking place at the ditch level, between farmers that have sold their land and farmers that have not. For instance, the lower the fraction of shares that have been sold and the higher dispersion on the remaining ownership of the shares, the higher the likelihood that a deal might take place in the future, which points out towards the city trying to get control of the decision rights in each ditch (recall that the LADWP needed 2/3 of the shares of a ditch to get the decision power). We find that the higher the average price the city paid in a ditch, the higher the chance it will buy land in the future (this might just be reflecting the fact that a particular ditch might be more attractive to the city). Finally, the higher fraction of land the city already controls, the lower the chances of observing a sale in the future. All of these results are suggestive of important co-dependence of sales among members of a given ditch.

In Table 3 we change our unit of analysis to look into the probability that any farmer would sell to LADWP any given quarter. We do this analysis at the individual level to compute how the actions of the four spatially closer neighbors affect the probability of a farmer selling in the future. We control for ditch level, time-varying characteristics. From the table below we see that the higher the fraction of neighbors that have sold their land around a farmer, the lower the probability that the farmer will sell in the future. .

Table 3 is suggestive of the LADWP buying strategy. First, it could reflect the fact that LADWP was buying plots of lands around farmers that were either unwilling to sell or were aggressively bargaining (selection). It could also capture the fact that once the city bought the property around a given farmer, that farmers' land is less valuable to it, showing the presence of negative externalities (treatment). To separate selection from treatment effects, we will require a structural model.

Table 2: Logistic regression at the Ditch Level.

	Dependent variable:						
	sale						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Time	0.0005***	0.0005***	0.0004***	0.0003***	0.0003***	0.0003**	0.0001
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Sales to Date	−0.157	−0.483	−0.911	−0.680	−0.232	1.107	5.308***
	(0.437)	(1.207)	(1.267)	(1.223)	(1.439)	(1.559)	(1.876)
Shares to Date		0.307	−1.311	−1.437	−1.781	−2.101	−4.264***
		(1.061)	(1.229)	(1.165)	(1.302)	(1.315)	(1.542)
SD of Shares			2.148***	1.638***	1.759***	1.628***	1.234*
			(0.565)	(0.553)	(0.593)	(0.602)	(0.693)
Price per Acre				1.178***	1.380***	1.453***	2.234***
				(0.267)	(0.432)	(0.432)	(0.502)
SD of Price per Acre					−0.321	−0.222	−0.785
					(0.546)	(0.546)	(0.625)
Acres to Date						−1.049**	−2.502**
						(0.409)	(1.234)
Water to Date							0.739
							(0.996)
Constant	5.598***	5.601***	4.494**	2.727	2.314	1.717	−1.872
	(1.899)	(1.901)	(1.967)	(2.009)	(2.128)	(2.129)	(2.432)
Observations	1,094	1,094	1,094	1,090	1,090	1,090	1,007
Log Likelihood	−345.291	−345.249	−338.097	−323.786	−323.613	−320.396	−259.804
Akaike Inf. Crit.	696.581	698.498	686.194	659.572	661.226	656.792	537.608

*p<0.1; **p<0.05; ***p<0.01

Notes: Results from a Logistic regression computed at the ditch level. The dependent variable is whether any farmer in a given ditch sold in a given period. All independent variables measure a stock, unlike the dependent variable that is a flow. All independent variables are normalized so that they begin at 0 and end at 1. *Time* is the number of periods since the first sale. *Sales to Date* is the number of farmers that sold up to that period. *Shares to Date* is the number of shares in the same ditch that farmers that have sold up to that period. *SD of Shares* is the Standard Deviation of the shares in the same ditch that farmers that have sold up to that period. *Price per Acre* is the average price per acre paid to farmers in the same ditch. *SD of Price per Acre* is the Standard Deviation of the price per acre paid to farmers in the same ditch that have sold up to that period. *Acres to Date* is the total number of acres sold in that Ditch up to that period. *Water to Date* is the total number of water acres sold in that Ditch up to that period.

Table 3: Logistic regression at the Individual Level.

	Dependent variable:								
	first_sale								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Time	0.001***	0.0002***	0.0001**	0.0001**	0.0001*	0.0001	0.0001*	0.0001*	−0.00001
	(0.00003)	(0.00005)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Sale by Neighbours	−1.340***	−1.274***	−0.936***	−0.936***	−0.850***	−0.841***	−0.843***	−0.833***	−0.797***
	(0.100)	(0.099)	(0.100)	(0.100)	(0.100)	(0.101)	(0.101)	(0.101)	(0.128)
Price per Acre by Neighbours	0.00003*	0.00002*	0.00002	0.00002	0.00001	0.00002*	0.00002*	0.00002*	0.00003
	(0.00001)	(0.00001)	(0.00001)	(0.00001)	(0.00001)	(0.00001)	(0.00001)	(0.00001)	(0.00002)
Water Acre by Neighbours	−0.0004	−0.0003	−0.0002	−0.0002	−0.0002	−0.0002	−0.0002	−0.0002	−0.0005
	(0.0004)	(0.0004)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.001)
Sales to Date		2.178***	−10.293***	−10.293***	−10.477***	−10.064***	−11.053***	−10.600***	−2.114
		(0.243)	(0.688)	(0.688)	(0.789)	(0.782)	(0.915)	(0.958)	(1.554)
Shares to Date			12.720***	12.720***	10.102***	8.849***	9.639***	9.659***	−1.718
			(0.706)	(0.706)	(0.926)	(0.974)	(1.046)	(1.041)	(1.539)
SD of Shares					2.797***	2.934***	2.673***	2.719***	6.342***
					(0.367)	(0.364)	(0.391)	(0.390)	(0.616)
Price per Acre						0.856***	0.297	0.048	0.839
						(0.229)	(0.376)	(0.417)	(0.521)
SD of Price per Acre							0.852**	0.973**	0.159
							(0.423)	(0.434)	(0.583)
Acres to Date								−0.531	0.415
								(0.330)	(0.778)
Water to Date									−0.807
									(0.751)
Constant	6.551***	−1.238	−4.089***	−4.089***	−4.776***	−5.084***	−4.656***	−4.433***	−6.726***
	(0.548)	(0.927)	(1.093)	(1.093)	(1.098)	(1.094)	(1.114)	(1.127)	(1.543)
Observations	43,928	43,928	43,928	43,928	43,928	43,928	43,928	43,928	26,656
Log Likelihood	−1,588.745	−1,541.913	−1,394.515	−1,394.515	−1,355.908	−1,348.143	−1,345.999	−1,344.724	−830.496
Akaike Inf. Crit.	3,187.490	3,095.826	2,803.030	2,803.030	2,727.815	2,714.285	2,711.998	2,711.449	1,684.992

*p<0.1; **p<0.05; ***p<0.01

Notes: Results from a Logistic regression computed at the individual level. The dependent variable is whether a farmer sold in a given period. All independent variables measure a stock, unlike the dependent variable that is a flow. All independent variables are normalized so that they begin at 0 and end at 1. *Time* is the number of periods since the first sale. *Sale by Neighbours* Dummy vairable that takes the value of 1 if a neighbour sold in the same period. *Water Acre by Neighbours* Number of water acres sold by neighbors. *Price per Acre by Neighbours* is the average price per acre paid to neighbouring farmers. *Sales to Date* is the number of farmers that sold up to that period. *Shares to Date* is the number of shares in the same ditch that farmers that have sold up to that period. *SD of Shares* is the Standard Deviation of the shares in the same ditch that farmers that have sold up to that period. *Price per Acre* is the average price per acre paid to farmers in the same ditch. *SD of Price per Acre* is the Standard Deviation of the price per acre paid to farmers in the same ditch that have sold up to that period. *Acres to Date* is the total number of acres sold in that Ditch up to that period. *Water to Date* is the total number of water acres sold in that Ditch up to that period.

3.3

3.4

3.5

4 Econometric Model

This section introduces the theoretical model. We model the game between the farmers as a game of perfect information, unlike (Takahashi, 2015), which estimates a model of imperfect information. Using the arguments in Harsanyi (1973), as we explain in more detail below in subsection 4.4, one can see that the two games are observationally equivalent. In other words, the data can be rationalize either by a game of perfect information, or by a game of imperfect information.[7] We choose to model the interaction as a game of perfect information because we think that it is realistic in the empirical setting studied here. The historical literature has pointed out how all farmers were informed both about the actions of other farmers selling their plots to the city, the amount they got offered and the characteristics of each plot.[8]

4.1 Theoretical Model

We model the interaction between the farmers as a War of Attrition (WoA) based on the results in Catepillan and Espín-Sánchez (2019), when they take as given the offer made by the city, and the contingent offers that the city would make over time. One can think of each game presented here as the game between farmers in the same ditch. There are N farmers with each farmer (he) indexed by $i = 1, ..., N$ and the city of LA (she) as $i = 0$. The game begins a $t = 0$ and time is continuous. There $t = 0$ the city makes an offer to each farmer. The offer consists on a price $V_{i\cdot}(0)$ that the farmer would receive for their plot if she sold at $t = 0$. There is perfect information and we assume that the city can commit to a stream of future offers to each farmer. Future offers are then common knowledge and may depend on the time since the game began, denoted by the scalar t; the number of farmers that have sold at a given point denoted by the scalar k; and in general in the identity of

[7] Typically the game of imperfect information has a unique equilibrium, while the game of perfect information have many. We focus on the equilibria of the perfect information game where all farmers use mixed strategies, as this is the one that rationalized the data and the one that is observationally equivalent to the game of imperfect information.

[8] Pearce (2013) documents how close the community was in the small towns in the valley and how everyone knew even when their neighbor took the train to LA to sign the sale.

each of the farmers that have sold at a given point, denoted by the set $\mathcal{K}$. At each instant in time, a farmer decides whether to stay in the market or to sell his farm to the city. While staying, each farmer pays a monetary unitary instantaneous cost. The interpretation of this instantaneous cost in continuous time is that of discounting.

It is important to make a distinction between the whole game, that involves all the farmers in a ditch and their selling times, and each stage game, that involves only the subset of farmers that have not sold up to that point. We can focus on each stage game, when farmers take the continuation value after another farmer sells as given. In a stage game with n remaining farmers, the value of a given farmer of selling is just the offer made by the city for that case $V_{i\mathcal{K}}(t)$. Notice that the offer depends on the time, the identity of the farmer and the set of farmers that have sold already. If a farmer does not sell, his continuation value, that is the value of being active in the next stage game, would depend on the identity of the farmer who sold. The continuation value of the farmer is then $W^j_{i\mathcal{K}}(t)$ when farmer j sold his plot at time t. Because the farmer is deciding whether to sell or not, the important element is the difference between selling at time t, which involves and immediate reward $V_{i\mathcal{K}}(t)$, and not selling at time t, which involves a continuation value $W^j_{i\mathcal{K}}(t)$. We denote this difference by $\Delta^j_{i\mathcal{K}}(t) \equiv W^j_{i\mathcal{K}}(t) - V_{i\mathcal{K}}(t)$. Finally, we define $\Delta_{i\mathcal{K}}(t)$ as the expected difference between selling or not at time t. In particular

$$\Delta_{i\mathcal{K}}(t) \equiv \sum_{j \neq i} f_{j\mathcal{K}}(t) W^j_{i\mathcal{K}}(t) - V_{i\mathcal{K}}(t) = W_{i\mathcal{K}}(t) - V_{i\mathcal{K}}(t) \tag{1}$$

where $f_{j\mathcal{K}}(t)$ is the instantaneous probability that farmer j sells at time t. Notice that the expected difference is not a fundamental element of the game, not even a fundamental element of the stage game, because it depends on the probability of selling of each of the other farmers $f_{j\mathcal{K}}(t)$, which are equilibrium objects.

In order to solve the equilibrium, we make one assumption regarding the evolution of $\Delta^j_{i\mathcal{K}}(t)$ over time.

Assumption A1: The difference in valuation between selling or not for each farmer is separable in time and all farmers have a common time component.

$$\Delta^j_{i\mathcal{K}}(t) = \Delta^j_{i\mathcal{K}} \cdot v(t)$$

Assumption A1 implies that the "shape" of $\Delta^j_{i\mathcal{K}}(t)$ over time is the same for all farmers. The intuition is that although the value is different for each farmer, and is changing over time, the "shape" of the change is common to all farmers. It is worth noticing that in the classical WoA models, the value of the "prizes" that the players get do not change over time, *i.e.*, in the classical WoA $v(t) = 1$. This means that both the values of selling and the continuation values are constant over time. A constant $\Delta^j_{i\mathcal{K}}(t)$, as we show below, implies a constant probability of selling over time, which means that the distribution of selling times will have a constant hazard rate. Therefore, the assumption of constant values is equivalent to assuming that the distribution of selling times is exponential. Below we show how there is a direct relation between the shape of the valuations over time and the shape of the distribution of selling times, *i.e.*, given a function of valuations over time $v(t)$, there is a unique distribution of selling times in equilibrium and given a distribution of selling times in the data, the is a unique function of valuations over time that rationalizes it. In Subsection 4.4 we show how our data allow us to non-parametrically identify the distribution of valuations. For simplicity and we chose a flexible parametric form for the estimation.

4.2 Equilibria

We now show how to solve for the unique equilibria where all farmers are using mixed strategies.[9] As defined above the value of staying until the next stage for farmer i when farmer j sells at time t in a stage game when the set $\mathcal{K}$ of farmers have already sold is $\Delta^j_{i\mathcal{K}}(t) = \Delta^j_{i\mathcal{K}} \cdot v(t)$. Since the cost of staying is unitary, the cost function over time is $C(t) = t$. We assume that $v(t)$ is differentiable. The utility for farmer i of staying until time t, given that farmer j is leaving at time s with probability $f_{j\mathcal{K}}(s)$ is:

$$U^j_{i\mathcal{K}}(t) \equiv \sum_{j \neq i} \int_0^t \left[\Delta^j_{i\mathcal{K}} \cdot v(s) - s\right] f_{j\mathcal{K}}(s) \prod_{k \neq i, k \neq j} \left[1 - F_k(s)\right] ds - t \left\{ \prod_{j \neq i} \left[1 - F_{j\mathcal{K}}(t)\right] \right\} \quad (2)$$

That is, farmer i gets $\left[\Delta^j_{i\mathcal{K}} \cdot v(s) - s\right]$ if farmer j is the first to sold, and does so at time $s < t$; and farmer i gets $-t$ if nobody sells before t. The derivative of the utility exists and we get the following expression

[9] See Catepillan and Espín-Sánchez (2019) for details and a broader discussion of equilibria.

$$
\begin{aligned}
\frac{dU^j_{i\mathcal{K}}(t)}{dt} &\equiv \sum_{j\neq i}\left[\Delta^j_{i\mathcal{K}}\cdot v\left(t\right)-t\right]f_{j\mathcal{K}}\left(t\right)\prod_{k\neq i,k\neq j}\left[1-F_{k\mathcal{K}}\left(t\right)\right]-\left\{\prod_{j\neq i}\left[1-F_{j\mathcal{K}}\left(t\right)\right]\right\}\\
&+ t\sum_{j\neq i}f_{j\mathcal{K}}\left(t\right)\prod_{k\neq i,k\neq j}\left[1-F_{k\mathcal{K}}\left(t\right)\right]\\
&= \left\{\prod_{j\neq i}\left[1-F_{j\mathcal{K}}\left(t\right)\right]\right\}\cdot\sum_{j\neq i}\left[\Delta^j_{i\mathcal{K}}\cdot v\left(t\right)\cdot f_{j\mathcal{K}}\left(t\right)-1\right]
\end{aligned}
\tag{3}
$$

In equilibrium the expected utility of not selling for any farmer that is using a mixed strategy need to be constant. Otherwise the farmer would just sell (if his expected utility is negative) of not sell (if his expected utility is positive). Thus, in equilibrium, $\frac{dU^j_{i\mathcal{K}}(t)}{dt}=0$ and the probability that farmer j sells at time t, $f_{j\mathcal{K}}\left(t\right)$, is the strategy followed by farmer j that makes all other farmers indifferent between selling or not, that is, $\lambda_{j\mathcal{K}}\left(t\right)$. This produces the following equilibrium condition for farmer i:

$$
\sum_{j\neq i}\left[\Delta^j_{i\mathcal{K}}\cdot v\left(t\right)\cdot\lambda_{j\mathcal{K}}\left(t\right)\right]=1,\,\forall i \tag{4}
$$

Notice that we have one equilibrium condition for each remaining farmer, n equations in total. The system of n equations will solve the strategies for each farmer $\lambda_{i\mathcal{K}}\left(t\right)$. We do so in two steps. The first step is to solve for $\phi_{i\mathcal{K}}$, such that

$$
\sum_{j\neq i}\Delta^j_{i\mathcal{K}}\cdot\phi_{j\mathcal{K}}=1,\,\forall i
$$

This is a linear system of equations and it is easy to solve. Appendix **??** solves the case for three farmers to show the intuition behind the role of the values and the externalities on the probabilities of selling. The intuition extends to more than three farmers but the algebra is cumbersome. Then, the strategy for farmer i, that is the probability distribution of selling over time, must follow a hazard rate that satisfy equilibrium condition 4:

$$
\lambda_{i\mathcal{K}}\left(t\right)=\frac{1}{\phi_{i\mathcal{K}}\cdot v\left(t\right)} \tag{5}
$$

Therefore, the distribution of selling times for farmer i in game $\mathcal{K}$ is

$$
F_{i\mathcal{K}}\left(t\right)=1-c\cdot exp\left[-\int_0^t\frac{\phi_{i\mathcal{K}}}{v\left(s\right)}ds\right] \tag{6}
$$

where c is the constant of integration that makes $F_{i\mathcal{K}}\left(t\right)$ a probability distribution. Notice that equation 5 is key to identify the shape of $v(t)$. In the model, using equation 6, for each $v(t)$ we can compute the exact shape of the distribution of selling times for each farmer in each game. When we look at the data, we can see the empirical distribution of selling times for each farmer for a given game, $\widehat{F_{i\mathcal{K}}(t)}$. With that distribution, we can compute the empirical hazard rate of selling times for each farmer for a given game, $\widehat{\lambda_{i\mathcal{K}}(t)}$. Then, using equation 5 we can compute the shape of $v(t)$ and estimate the externalities using the estimates on $\phi_{i\mathcal{K}}$.

4.3 Linear value function

The model presented above computes the equilibria for any value function $v(t)$. We now show the results when the value function is linear. Therefore the value function is now

$$v(t) = \alpha + \beta t \tag{7}$$

Following equation 5 and equation 7 we can write the hazard rate of selling times for farmer i as

$$\lambda_{i\mathcal{K}}(t) = \frac{1}{\phi_{i\mathcal{K}}(\alpha + \beta \cdot t)} = \frac{1}{\alpha_i + \beta_i \cdot t} \tag{8}$$

The hazard rate in equation 8 correspond to the hazard rate of a Generalized Pareto Distribution (GPD), with scale parameter α_i and shape parameter β_i. In other words, when $v(t)$ is linear, the equilibrium distribution of selling times of each farmer follows a GPD.[10] Notice that this example also includes as a particular case the Exponential distribution, *i.e.*, when $\beta = 0$ the value function is constant, the hazard rate is constant and the distribution of selling times is Exponential.

The GPD has the nice property that if a random variable t has a GPD, then the conditional distribution of $t - \tau$ given $t > \tau$ is also a GPD, with the same shape parameter β_i and a scale parameter equal to $\alpha_i^{'} = \alpha_i + \tau\beta_i$. This means that in every stage game, the distribution of selling times since last sale, for each farmer follows a GPD. The intuition is simple. When one farmer sells the game is similar than the original game. In the original game we have a set of $\phi_{i\mathcal{K}}$ that is characteristic of each game and have one element for each farmer. In that game, looking at the future each farmer is playing a game where there is an immediate value of selling of $\alpha_i = \phi_{i\mathcal{K}}\alpha$ and a slope of $\beta_i = \phi_{i\mathcal{K}}\beta$, where $\mathcal{K}$ is the original

[10] The Generalized Pareto Distribution has a cumulative distribution function $F(t) = 1 + (1 + \beta_i t/\alpha)^{1/\beta_i}$ and a probability density function $f(t) = \alpha^{-1}(1 + \beta_i t/\alpha)^{1/\beta_i - 1}$.

set of farmers. If another farmer sells at time $t = \tau$, then each farmer is playing a game with an immediate value of selling of $\alpha_i^{'} = \phi_{i\mathcal{K}'}(\alpha + \beta\tau)$ and a slope of $\beta_i = \phi_{i\mathcal{K}'}\beta$, where $\mathcal{K}^{'}$ is the original set of farmers minus the farmer that sold. In other words, the time at which a stage game ends would affect the scale but not the shape of the distribution of sell times of subsequent stage games, and it would affect the scale parameter linearly. Given this structure, we only need to estimate two parameters α and β that would determine the shape and the original scale in the value function that the city offered to the farmers. We could estimate one pair for each ditch.

4.4 Identification

For simplicity, we drop the sub-index reflecting that in a given game the remaining player belong to the set $\mathcal{K}$. From the previous section we know that in a game of WoA the distribution of selling times are determined by the value of selling. Equation 1 defined the object of interest $\Delta_i(t)$ as the difference between the continuation value when another farmer sells $W_i^j(t)$ and the value of selling $V_i(t)$. In the empirical application we only observe each farmer selling once, so we will not be able to estimate all ϕ_i. However, we can classify farmers depending on their observable characteristics, such that we will observe several selling times for a given configuration of the game. Therefore we can identify the function $v(t)$ non-parametrically. We will also observe all realizations of $V_i(t)$, which are the prices at which the farmers sold their plot. Therefore we are able to independently identify the functions $W_i(t)$ and $V_i(t)$. This means we could identify asymmetric values for each farmer, but not externalities. Finally, because we have information regarding the locations of the farmers' plots and their characteristics, we will be able to identify and estimate different functions $W_i(t)$, for different pairs of farmers i and j.

In other words, if we only have information on selling times, as is usually the case (see Takahashi, 2015), then we could only identify $v(t)$, that is the probability of selling for a farmer in a particular game, and we would have to restrict attention to symmetric games, estimating a single ϕ for a given number of farmers, identified up to a constant. In this case the function $\Delta(t)$ is just equal to the hazard rate of the distribution of selling times for each game with the same number of farmers. That is, we could estimate a function for games with two farmers, another function for games with three farmers and so on.

If we also have information on the size of land and the value of the land for each farmer, then we could estimate an asymmetric WoA game and estimate $\Delta_i(t)$, thus identifying $v(t)$ and ϕ_i, up to a constant. If in addition, we have information on the prices received by the farmers, we could also estimate $W_i(t)$ from $V_i(t)$, thus identifying $v(t)$ and ϕ_i exactly. This is not trivial, and it is key in this case for both the estimation of the game and the counterfactuals. Moreover, it is rare to have such detailed data in an empirical estimation. Finally, if we have information regarding the locations of the farmers' plots and their characteristics, as well as the prices, we will be able to identify and estimate different functions $W_i^j(t)$, for different pairs of farmers, thus identifying $v(t)$ and ϕ_i exactly. Notice that this is the main innovation of the paper. We are estimating the externalities that a farmer exert on another farmer when she sells her land. Depending on the variability of the data, and how we define a market (game) we could be more or less flexible on the structure of $W_i^j(t)$. Summarizing, we can identify

- **Symmetric Game** — Data on selling times: $\Delta(t)$.
- **Asymmetric Game** — Data on selling times and individual characteristics: $\Delta_i(t)$.
- **Asymmetric Game** — Data on selling times, individual characteristics and sale prices: $W_i(t)$ and $V_i(t)$.
- **Asymmetric Game with Externalities** — Data on selling times, individual characteristics, sale prices and pair-specific information: $W_i^j(t)$ and $V_i(t)$.

5 Estimation Strategy

In the data, there are events that would affect all farmers, not only farmers in the same ditch. The implicit assumption here is that we assume that sales by farmers outside the ditch affect all farmers in a given ditch in the same way. In particular, we will use the cumulative sales as a state variable in each game. In contrast, we believe that sales by farmers in the same ditch, will affect more farmers within the same ditch. Moreover, we think they could affect each farmer differently. Each stage game, as explained in Section 4, provides a selling time, which is the key variable. Each stage game also provides us with information regarding the farmer that sold, the farmers that were active but were not the first to sold, and the set of farmers that belonged to the same ditch, but have sold already.

The estimation consists on two steps. In the first step (Inner Loop), we get one pseudo parameter, θ^n from each game with a given number of farmers. In the second step (Outer Loop), we use *hedonic* regressions to get a set of parameters β from the pseudo-parameters in the first step. This allows us to estimate directly the first step, without having to use simulations.

5.1 Proportional Hazard Rate Models

In Section 4 we used assumption A1 to solve the model. Assumption A1 implies that when looking at the empirical distribution of selling times for each farmer, their hazard rates $\lambda_{i\mathcal{K}}(t)$ are proportional to each other. Thus, we need to estimate a Proportional Hazard Rate Model (PHRM). The CDF of a PHRM is defined by

$$1 - F(t;\Omega;\theta) = [1 - G(t;\Omega)]^{\theta}, \theta > 0, \tag{9}$$

and we write the PDF as

$$f(t;\Omega;\theta) = \theta g(t;\Omega)[1 - G(t;\Omega)]^{\theta-1}, \theta > 0, \tag{10}$$

where $G(t;\Omega)$ is a CDF, θ is a positive shape parameter and Ω is a parameter vector that characterizes the source distribution. The hazard rate of a PHRM distribution is $\frac{f}{1-F} = \frac{\theta g[1-G]^{\theta-1}}{[1-G]^{\theta}} = \theta\frac{g}{1-G}$ which implies that the hazard rate of F is proportional to that of G, and the scalar of proportionality is the shape parameter θ. In both cases, we call $G(x;\Omega)$ the source CDF, due to the generation process. This class of models is interesting because, as shown above, a WoA with changing values will generate this statistical process. The equilibrium strategies for each farmer will be to choose a selling time. The probability distribution of selling times for a given farmer in a given stage game will then follow a PHRM distribution. All farmers will have the same source distribution, which is determined by $v(t)$ but a different shape parameter $1/\phi_{i\mathcal{K}}$.

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There is, however, one issue when linking the model to the data. Even when the equilibrium strategy for each farmer consists on choosing a selling time for each stage game, we would only observe the selling time for the farmer who sells, *i.e.*, the farmer whose selling time is the lowest. In other words, we have a censored problem. For the other farmers we can only infer that their selling times were larger. This is similar to the issue of estimating the distribution of valuations in a second price auction (SPA) when the econometrician only observes the winning bid. In a SPA, the observed behavior (winning bid) is the second order statistic of the underlying distribution of valuations. In the WoA, the observed behavior (selling time) is the minimum of the underlying distribution of selling times. Moreover, in our case, it is the minimum of asymmetric random variables, because the farmers have different valuations for staying or selling in a given stage game. The properties of the PHRM are useful when dealing with this issue.

Following Espín-Sánchez and Wu (2019) we have also developed the distribution of order statistics for an asymmetric sample. Let $T_1, ..., T_n$ be a random sample of size n where each realization comes from a PHRM with different parameters $\Theta \equiv (\theta_1, ..., \theta_n)$. In particular, $T_i \sim G(\theta_i)$ for $i = 1, 2, ..., n$, that is $T_1 \sim PHRM(\theta_1)$, $T_2 \sim PHRM(\theta_n)$,..., $T_n \sim PHRM(\theta_n)$. In this case, we can compute the order statistics of the asymmetric random sample. In particular, here we are interested in the first asymmetric order statistic (minimum) which has the form

$$f_1(t) = f\left(t; \Omega; \bar{\theta}\right), \tag{11}$$

where $f\left(t; \Omega; \theta\right)$ is the density function of a PHRM and $\bar{\theta} = \sum_{k=1}^{n} \theta_k$. Notice that in the symmetric case there $\theta_i = \theta$, equation 11 becomes simpler. In particular, the distribution of the minimum for the symmetric case is just that of a PHRM with parameter $n\theta$.

In our baseline case, as shown above in subsection 4.3, we assume that the value function is linear over time and, thus, the distribution of selling times follows a Generalized Pareto Distribution (GPD), where $\Omega \equiv (\alpha, \beta)$. A PHRM with GPD is characterized by

$$f\left(t; \alpha, \beta; \theta\right) = \frac{\theta}{\alpha}\left(1 + \beta t/\alpha\right)^{(\theta-\beta)/\beta} \tag{12}$$

and a cumulative distribution function

$$1 - F\left(t; \alpha, \beta; \theta\right) = \left(1 + \beta t/\alpha\right)^{\theta/\beta} \tag{13}$$

The hazard function is then

$$h\left(t; \alpha, \beta; \theta\right) = \frac{f\left(t; \alpha, \beta; \theta\right)}{1 - F\left(t; \alpha, \beta; \theta\right)} = \frac{\frac{\theta}{\alpha}\left(1 + \beta t/\alpha\right)^{(\theta-\beta)/\beta}}{\left(1 + \beta t/\alpha\right)^{\theta/\beta}} = \theta \frac{1}{\alpha + \beta \cdot t} \tag{14}$$

We can then characterize equation 11 for the case where the source distribution follows a GPD as

$$f_1\left(t; \alpha, \beta; \theta\right) = \frac{\bar{\theta}}{\alpha}\left(1 + \beta t/\alpha\right)^{(\bar{\theta}-\beta)/\beta} \tag{15}$$

A PHRM is characterized empirically by a separability assumption, *i.e.*, we can decompose the hazard rate into two independent components: a baseline hazard rate that depends on time but is common across individuals and an idiosyncratic component that does not change over time. Therefore, we can write the empirical hazard function as

$$h\left(t,x\right) = h_0\left(t\right) \cdot \theta\left(X_i,\beta\right) \tag{16}$$

where $h_0\left(t\right)$ is the baseline hazard rate and $\theta\left(X_i,\beta\right)$ is the idiosyncratic component. The vector X_i should not change over time. However, in our case each observation is a particular stage-game that begins when one farmer sells and ends when the next farmer sells. Therefore we can include variables in X_i that change over time, as long as they do not change during the stage game, *i.e.*, we can include state variables that change over time such as the percentage of farmers in a ditch that have already sold, or the fraction of water rights remaining in a given ditch.

5.2 First Step

In the first step of the estimation, we recover a θ for each farmer. We allow farmers to be heterogeneous concerning their "shape" parameter. To do so, we consider that each ditch is an independent game and thus estimate a vector of shape parameters for each game independently. We have thirteen ditches that feature at least six sales from farmers in that ditch. For each ditch, we order farmers as a function of their selling time, and we calculate the number of days between farmers' sales.

Using only selling times, we calculate the probability that a given farmers sell in x days when there are n remaining farmers in a game. In such game, the strategy for each farmer is to sell at each point in time using an instantaneous probability $\eta^n(t)$. However, we do not observe all the realizations of sell times. We only observe the lowest among all realizations, that is the minimum or the first order statistic.[11] Therefore, the distribution of sell times would follow the distribution of the sell times of the first order statistic. We can also define $\Psi^n(x;\theta^n)$, with density $\psi^n(x;\theta^n)$, as the distribution of the first order statistic (minimum) or n draws from of $\Psi^n(t;\theta^n)$. In other words, each farmer will draw a time of selling t_i from an $EG(\theta^n)$ but we will only observe the sell of the farmer with the lowest realization.

To estimate an asymmetric game with n farmers, we use the following likelihood function

$$l\left(T_i^n,\theta^n\right) = \prod_{i=1}\psi^n(x_i^n;\theta^n) = \prod_{i=1}\left\{f_{1:n}(x_i^n;\theta^n)\right\} \tag{17}$$

where x_i is the realization of number of days until the sale, since the beginning of the

[11] Remember that a War of Attrition can be modeled as a particular all pay auction, where all n farmers pay the lowest bid, and the $n-1$ farmers with the highest bids get the prize, that is, they get to stay in the game. In that analogy, the waiting time is the War of Attrition game is equivalent to the bid in the all pay auction.

game, in a game with n remaining farmers, and $f_{1:n}(x_i^n;\theta^n)$ is the density of the minimum as defined in equation (8). We estimate our vector of parameters running a Maximum Likelihood Estimator (MLE) for each game.

giving us an estimate for θ^n that allows us to calculate the probability that any farmer sells and also the continuation value for each farmer $\Delta^n(t^n)$.

Given the functional forms derived from the theory, we can build continuation values using our estimated hazard rates.

In particular, the theoretical results imply that $h\left(x^n,\theta^n\right)=\eta^n(x^n)=\frac{1}{(n-1)\Delta^n(x^n)}$, for all games. Therefore, since $\Delta^n(x^n)=\frac{1}{(n-1)h(x^n,\theta^n)}$ with the estimated value $\hat{\theta}^n$ we can compute the estimated hazard function $h\left(x,\hat{\theta}^n\right)$. and thus recover the distribution of valuations for each game $\Delta^n(x)$, which is equal to

$$\Delta^n(x)=\frac{1}{(n-1)h\left(x,\hat{\theta}^n\right)}$$

The advantage of using a Proportional Hazard Rate Model is that we can compute what would be the probability of the minimum for each game making the likelihood estimation computationally feasible.]

5.3 Second Step

From the previous section we know that in a game of WoA the distribution of selling times are determined by the value of selling. Moreover, in equilibrium, the hazard function of the selling distribution for a particular game with a set of n farmers is identical to the difference in continuation values $\Delta_i(t)$, where

$$\Delta_i(t)\equiv\sum_{j\neq i}p_j(t)W_i^j(t)-V_i(t)=W_i(t)-V_i(t) \tag{18}$$

where $p_j(t)$ is the instantaneous probability that farmer j sells at time t, $W_i^j(t)$ is the continuation value of a game where farmer j has just sold and $V_i(t)$ is the value that farmer i gets by selling. Notice that while $W_i^j(t)$ and $V_i(t)$ are fundamentals of the model, p_j is an equilibrium outcome that will be determine with similar equations for the other farmers, that is using $\Delta_j(t)$. Notice that as we observe several selling times for a given configuration of the game, we have already identify the function $\Delta_i(t)$ non-parametrically. We will also observe several realizations of $V_i(t)$ which are the price at which the farmers sold their plot. Therefore we are able to independently identify the functions $W_i(t)$ and $V_i(t)$. Finally, since we have information regarding the locations of the farmers' plots and their characteristics, we will be able to identify and estimate different functions $W_i^j(t)$, for different pairs of farmers. We can thus re-write the equation as:

$$V_i(t) = \sum_{j \neq i} p_j(t) W_i^j(t) - \Delta_i(t) \tag{19}$$

Here we can observe prices, and we already have an estimate for the probability of any farmer selling, and their continuation values. We will need to make one further assumption to be able to identify the potential externalities.

Given that the number of parameters we need to estimate is very big, and the fact that we only observe certain sales as each game is played only once, then we will need to assume a parametric function for the counterfactual estimation values. We will assume that we can decompose such value as the linear combination of relative observable characteristics between i and j.

$$W_j^i = \beta_1 X_{ij}^1(x_i) + \beta_2 X_{ij}^2(x_i) + .. + \beta_K X_{ij}^K(x_i) = \beta_{1\times K} X_{K\times 1}^{ij}$$

Where we have K hedonic characteristics we will use, and $< X_{ij}^1 = g(X_i^1, X_j^1, x_i)..$ $X_{ij}^K = g(X_i^K, X_j^K, x_i) >$ is some function of time-varying attributes J (or the attribute in time x_i) for i and j (this could be the difference, yet we could also use a more flexible specification).

We are interested in recovering $\beta_{1\times K} \equiv < \beta_1 ... \beta_K >$. We can write the system of equations that we need as:

$$\begin{gathered}
\sum_{j<2} \hat{p}_j^2(x_2 : \hat{\theta}) W_j^2(x_2) - \Delta_i^2(t) = V^2(x_2) \\
\sum_{j<3} \hat{p}_j^3(x_3 : \hat{\theta}) W_j^3(x_3) - \Delta_i^3(t) = V^3(x_3) \\
.... \\
\sum_{j<N} \hat{p}_j^N(x_N : \hat{\theta}) W_j^N(x_N) - \Delta_i^N(t) = V^N(x_N)
\end{gathered}$$

Where N is the maximum number of farmers in a given ditch (or as many as we need to use).

Note that this system can be r-written as:

$$\begin{gathered}
\sum_{j<2} \hat{p}_j^2(x_2 : \hat{\theta}) \beta_{1\times K} X_{K\times 1}^{2j} - \Delta_i^2(t) = V^2(x_2) \\
\sum_{j<3} \hat{p}_j^3(x_3 : \hat{\theta}) \beta_{1\times K} X_{K\times 1}^{3j} - \Delta_i^3(t) = V^3(x_3) \\
.... \\
\sum_{j<N} \hat{p}_j^n(x_N : \hat{\theta}) \beta_{1\times K} X_{K\times 1}^{nj} - \Delta_i^N(t) = V^N(x_N)
\end{gathered}$$

Notice that we can re arrange terms here. Rearranging we get:

$$\sum_{j<2} \hat{p}^2_j(x_2 : \hat{\theta})\beta_{1\times K} X^{2j}_{K\times 1} = \hat{p}^2_1(x_2 : \hat{\theta}) \left[\beta_1 X^1_{2j}(x_2) + \beta_2 X^2_{2j}(x_2) + .. + \beta_K X^K_{2j}(x_2)\right]$$

$$= \beta_{1\times K} \cdot \left[\hat{p}^2_1(x_2 : \hat{\theta}) X^1_{2j}(x_2), .., \hat{p}^2_1(x_2 : \hat{\theta}) X^K_{2j}(x_2)\right]_{K\times 1}$$

$$\sum_{j<3} \hat{p}^3_j(x_3 : \hat{\theta})\beta_{1\times K} X^{3j}_{K\times 1} =$$

$$\hat{p}^3_1(x_3 : \hat{\theta})[\beta_1 X^1_{3j}(x_3) + \beta_2 X^2_{3j}(x_3) + .. + \beta_K X^K_{3j}(x_3)] + \hat{p}^3_2(x_3 : \hat{\theta}) \left[\beta_1 X^1_{3j}(x_3) + \beta_2 X^2_{3j}(x_3) + .. + \beta_K X^K_{3j}(x_3)\right]$$

$$= \beta_{1\times K} \cdot \left[\sum_{j<3} \hat{p}^3_j X^1_{3j}(x_3), .., \sum_{j<3} \hat{p}^3_j X^K_{3j}(x_3)\right]_{K\times 1}$$

In general we will have that

$$\sum_{j<N} \hat{p}^N_j(x_N : \hat{\theta})\beta_{1\times K} X^{Nj}_{K\times 1} = \beta_{1\times K} \cdot \left[\sum_{j<N} \hat{p}^N_j X^1_{Nj}(x_N), .., \sum_{j<N} \hat{p}^N_j X^K_{Nj}(x_N)\right]_{K\times 1}$$

Therefore we can re-write the system as:

$$\beta_{1\times K} \cdot \begin{matrix} \left[\hat{p}^2_1(x_2 : \hat{\theta}) X^1_{2j}(x_2), .., \hat{p}^2_1(x_2 : \hat{\theta}) X^K_{2j}(x_2)\right]_{K\times 1} \\ [...] \\ \beta_{1\times K} \cdot \left[\sum_{j<N} \hat{p}^N_j(x_N : \hat{\theta}) X^1_{Nj}(x_N), .., \sum_{j<N} \hat{p}^N_j(x_N : \hat{\theta}) X^K_{Nj}(x_N)\right]_{K\times 1} \end{matrix} - \Delta_{Nx1} = V_{N\times 1}$$

Lets denote

$$\hat{M}_{K\times N} = \begin{matrix} \left[\hat{p}^2_1(x_2 : \hat{\theta}) X^1_{2j}(x_2), .., \hat{p}^2_1(x_2 : \hat{\theta}) X^K_{2j}(x_2)\right]_{K\times 1} \\ [...] \\ \beta_{1\times K} \cdot \left[\sum_{j<N} \hat{p}^N_j(x_N : \hat{\theta}) X^1_{Nj}(x_N), .., \sum_{j<N} \hat{p}^N_j(x_N : \hat{\theta}) X^K_{Nj}(x_N)\right] K\times 1 \end{matrix}$$

$M_{K\times N}$ is a matrix that has as many columns as hedonic characteristics, and as many rows as farmers in a ditch. This matrix represents the weighted average (weighting by probability) of relative hedonic characteristics. What is crucial, is that we can compute this matrix, since we can compute the probabilities, and we observe relative characteristics. Then we have the following linear system:

$$V_{N\times 1} = \beta_{1\times K}\hat{M}_{K\times N} - \Delta_{Nx1}$$

Hence from this expression, we get that we can recover the fundamental structural parameters of the game $\hat{\beta}$, running a simple linear regression of the form:

$$V_{N\times 1} = \beta_{1\times K}\hat{M}_{K\times N} - \Delta_{Nx1} + \varepsilon$$

Notice that the above expression is very flexible. We can estimate the same regression with a random coefficients model, allowing for the hedonic parameters to be ditch dependent. Also, and more generally, this model allows to include as many characteristics as farmers in the game, in order to be properly estimated.

Table 4: Structural Results.

	Dependent variable:				
	Distance	Days	Area	Shares	Crops+Water
Manzanar	−3.223584e-04	−9.381279e-02	1.055789e+03	5.339839e+02	1.121949e+02
	(1.244922e-03)	(3.913213e-02)	(1.599250e+03)	(2.474765e+03)	(3.378295e+03)
Chandler	−2.724007e-01	−8.838188e-01	5.579362e+03	1.047035e+05	1.412057e+06
	(2.323421)	(3.983956)	(6.801470e+04)	(4.567618e+05)	(5.942558e+06)
Baker	−9.955914e-02	−2.007032e-01	1.708856e+03	2.565922e+03	1.097686e+03
	(0.3331052)	(0.9408778)	(9432.15)	(4329.12)	(2936.54)
Inyo	−7.596677e-03	−1.008741e-01	4.856670e+02	1.992594e+03	5.338233e+02
	(0.01346477)	(0.08179139)	(723.83)	(827.86)	(559.74)
Pine	−1.677243e-03	−1.756256e-02	6.734066e+03	1.982493e+04	8.913564e+03
	(5.126984e-02)	(1.305122e-01)	(5.085023e+03)	(2.139731e+04)	(1.385493e+04)
Mcnally	−4.172011e-02	−1.946022e-01	8.000062e+03	4.319828e+03	1.629090e+04
	(1.324503e-01)	(4.713139e-01)	(1.597603e+04)	(7.317147e+03)	(3.938971e+04)
Rawson	−9.991557e-03	−2.897122e-01	4.142184e+02	1.085068e+03	1.203814e+03
	(4.793053e-04)	(1.478321e-02)	(1.562292e+01)	(4.743587e+01)	(5.316033e+01)
Farmers	−1.339126e-02	−1.379332e-02	1.412972e+04	1.056362e+04	7.988343e+02
	(0.1065179)	(0.0987675)	(5184.468)	(5291.69)	(5.428533e+02)
Collins	−3.343431e-02	−1.338889	1.666359e+03	1.122440e+02	
	(1.675754e-01)	(3.602116)	(1.771236e+03)	(2.716665e+03)	
Fish	−1.357456e-02	−1.620848	1.197909e+03		
	(2.040101e-02)	(1.118644)	(1.438405e+03)		

Notes: Results from the structural estimation

Table **??** reports the estimated value, as the matrix we invert using the last six farmers in a given ditch. In order to have a sense of the sensibility of our point estimates, we perform a bootstrapping method where we calculate our parameters, changing one farmer randomly 1000 times.

First we observe that there is a general consistency of the estimates across ditches. We find that the closer you are in space and in time, the higher the externality it would generate on a sell. On the other hand, big sales, tend to be more important than small sales, yet this varies by ditch.

6 Counterfactuals

[TO COME]

7 Conclusions

[TO COME]

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