Playing Checkers in Chinatown*

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[VERY PRELIMINARY, PLEASE DO NOT CITE]

Abstract

From 1905 to 1935, the city of Los Angeles bought rights to water and land from Owens Valley farmers and built an aqueduct to transfer the water to its residents. The dark version of the story is that Los Angeles bullied and isolated reluctant farmers in order to get cheap water. A map of the plots farmers sold at any given point in time, however, could look like a checkerboard either because the city intentionally targeted specific farmers, whose land sales would create negative externalities for the remaining farmers, or because farmers were heterogeneous and sold at different times. To assess the checkerboarding claim, we analyze sales between the city and farmers and evaluate the effects that farmers' actions had on one another. We estimate a dynamic structural preemption model of farmers' decisions to sell to the city. Although, we find large spatial and size externalities, we do not find evidence that the city targeted particular farmers.

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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 creates both opportunities and challenges. As developing countries urbanize over the next forty years, the United Nations predicts an unprecedented increase in the number of people–3.5 billion–moving into cities: "Urban areas are expected to absorb virtually all the future growth of the world's population," This presents a challenge to make new cities sustainable, including guaranteeing a safe supply of water (United Nations, 2019). The movement of people from rural to urban environments presents a challenge that will require the reallocation of natural resources like water. Evenly distributing transfer benefits among urban and rural dwellers is an important concern for economists and policymakers.

To study this distributional question, we revisit the most famous episode of water transfer in American history. Between 1905 and 1935, the city of Los Angeles (L.A.) purchased water and land rights from Owens Valley farmers, built an aqueduct to divert water to city dwellers, and changed the Valley's history forever. Hydrated by Owens River water, the city grew from a population of 100,000 in 1900 to 1.2 million in 1930, becoming the largest city in California and the second largest in the U.S. Despite this achievement, the water transfer was controversial, dramatized in popular culture by the movie Chinatown and investigated by journalists and scholars ever since. The most serious accusation leveled against the city was that officials *checkerboarded* their land purchases, i.e., that they intentionally bought land surrounding reluctant sellers to drive down prices. In this paper, we first address the historical question of whether the city was checkerboarding and explore to what extent it might have behaved strategically in its purchases of land and water rights.

We then study sales from the farmers to the city to assess how externalities might have affected the distribution of rents between the two parties. Two externalities are mentioned in the historical literature. The first externality relates to the amount of water and land rights sold to the city, i.e., when a large farmer sold his plot to the city, it increased the cost of maintaining the ditch for the remaining farmers. The second externality relates to the location of the selling farmer. A farmer who sold his plot would stop maintaining his own ditch, therefore affecting farmers downstream, but not upstream. This means that farmers located at "the points of access to the river" would produce the largest externalities.

Due to the limitations of historical data, and the nature of water as an economic good, it is challenging to assess the checkerboarding claim. First of all, the current literature does not use geo-coded transaction or dated plot sale data. Secondly, water is a very peculiar good that imposes externalities on private owners and public users alike. Therefore, we cannot study transactions between farmers and the city in isolation but must use a collective decision perspective, in which L.A. could strategically buy out different farmers to influence the selling value for the remaining farmers. Ultimately, a reduced-form analysis cannot capture the rich endogenous interactions between farmers deciding to sell, and at what price, which would require a model that can flesh out the dynamic incentives farmers faced in a preemption game.

We built a novel and very detailed dataset containing the exact date of each sale, the precise geo-location of each plot, and other property characteristics including acreage, water rights, sale price, and crops under cultivation. We use this new dataset to assess whether the city purchased land in a checkerboard pattern. To do so, we first show that there is a spatial correlation on the date of sale within the whole valley. We then estimate reduced form regressions to explain in a dynamic setting whether a farmer sold or not and at what price. Our results suggest that there is a significant interaction taking place at the irrigation ditch level, driven by externalities from neighbors who were sellers, between farmers who sold their land and farmers who did not.

We model the purchases made by the city as a dynamic game with externalities, which in practice resembles a Monopsonist strategy in the Coase conjecture (Coase, 1972). If the city could commit not to offer a higher price in the future, the city could extract all of the farmers' surplus from the transfer. However, if farmers could bargain as one group, they might have been able to obtain a large share of the surplus. The situation is complicated by farmers' heterogeneity and the negative externalities they exert on others, e.g., farmers whose plots were closer to the river at its juncture with an irrigation ditch would produce a larger negative effect on other farmers on the same ditch than those farmers located further along the ditch. In a model without externalities, each farmers bargains with the city and cannot be made worse off than she was before the city began its purchases, i.e., a given farmer can continue farming on his own if she does not sell to the city. In a model with externalities, however, this is no longer true. The city purchases would produce large negative externalities which would make a given farmer worse off. Indeed, it could make her farming operations unprofitable, and force the farmer to sell at distress prices.

Unlike the previous literature on the topic, we locate each plot sold to the city and can thus answer broader questions. First, we can assess externalities each farmer imposes on other farmers, i.e., their probability of selling and the price they take. We find evidence that externalities depend on fundamental farmer characteristics including total water rights and proximity to the Owens River. Second, given the externalities, we can test the city's checkerboarding, i.e., whether the city offered more money to farmers who created higher externalities in order to drive down prices for the remaining farmers. We do not find conclusive evidence that the city was checkerboarding. This is not surprising given that the offers were made by a committee intended to give each farmer a fair price for their land rather than to minimize overall negotiation time. In summary, although the city did not target key farmers with higher prices, when these farmers sold their land to the city, they created large negative externalities which made the remaining farmers sell sooner and at lower prices.

Since Schelling (1971), economists have been studying how extreme forms of segregation can arise from social interactions, giving rise to different types of tipping point equilibria (Card et al., 2008). This nonlinear behavior in human clustering can be observed both in the negative sense (racial segregation) and in the positive sense (clustering of talent). For instance, the geographic concentration of high-tech sectors even in high costs cities can be in part explained by social externalities (Moretti, 2021). As Robert E. Lucas (1988) pointed out, "there are group interactions that are central to individual productivity. We know this kind of external effect is common to all the arts and sciences.". Furthermore, it's not just that social externalities are crucial for explaining clustering and segregation, it is also the case that who clusters also happen to matter. Indeed, Azoulay et al. (2019) show that the premature death of eminent life scientists alters the flow of articles by close collaborators. Therefore agglomeration externalities might crucially depend on the identity of who clusters and their pair-wise relations.

Estimating a dynamic game with externalities and time variable valuations is challenging on multiple dimensions. In the presence of externalities, each farmer's payoff is affected by their own decisions and by those of other farmers. If a farmer sold land at a given price, it could mean his value of waiting was *low* given the *high* price offered by the city. With negative externalities, this behavior is also consistent with the price offered by the city being *low,* but the farmer expected one of his neighbors to sell soon, which would lower his continuation value, and the price the city would offer him in the future. Moreover, because farmers' continuation values and probabilities of selling change over time, separately identifying all parameters places high demands on the data. Our preemption game model is similar to the War of Attrition (WoA) game in Catepillan and Espín-Sánchez (2019). In our dynamic game, farmers' equilibrium behavior resembles a Proportional Hazard Rate Model (PHRM), in which the "shape" of the continuation value over time is a function of sale probability. Finally, we use the estimated model to compute counterfactual sale times and prices.

This paper relates to a rich political economy literature on coordination problems associated with the overuse and depletion of natural resources like water (Ostrom, 1962). Within this literature, there is a long tradition of analyzing common-pool resources (Ostrom, 2010) and institutional management of negative externalities for goods like water that are both subtractable and difficult to exclude. In Los Angeles, we study how the city strategically exploited these features of water markets to maximize the rents it could extract from farmers. In the presence of externalities, private decisions by farmers can take the form of collective decisions. Literature on vote buying (Dal Bo, 2007) has shown that a principal can influence agents' collective decisions to induce inefficient outcomes at almost no cost, as long as the principal can reward decisive players differently and agents face high coordination costs.

Historians and economists have extensively researched the Owens Valley controversy. The historical literature tells a story focused on how characters' beliefs and personalities affected land sales and water transfers (Hoffman, 1981; Kahrl, 1982; Davis, 1990). However, historians differ on whether L.A. behaved as a villain, or just as a rational business-minded agent. Whereas Kahrl (1982) and Reisner (1987) portray valley citizens as innocent victims, Hoffman (1981) takes a more neutral view of the inevitability of conflict given LA's early 20^{th} century population growth.[1] Owens Valley farmers, cited in Delameter (1977) and Pearce (2013), instead tell a story of farmers willing to sell their failing farms while townspeople, with the help of the Watterson brothers and the local newspaper, bullied both farmers and city agents until they received compensation for their urban properties. In economics, the most prominent work is Libecap (2005a, 2007, 2009), who concludes that, although all farmers were paid more than their land was worth, the transfer of property rights generated an enormous surplus, most of which the city got. Confirming claims by Kahrl (1982), Gary Libecap found that on average, farmers who sold later received a

[1] The interested reader can also consult Nadeau (1950), Ostrom (1953), Sauder (1994), Haddad (2000), Erie (2006) and Fleck (2016).

higher price. Our model accounts for this time feature of the data. However, our focus is not on the interaction of the city *vis-à-vis* the farmers as a group, but rather, interaction among farmers, *given* the behavior of the city.

Our paper contributes to the literature on the procurement and privatization of public services. There are at least two accounts of government privatization decisions. One view, focuses on transaction costs (Williamson, 1985; Hart et al., 1997) and an alternative view emphasizes politicians' private benefits (Boycko et al., 1996). We study a unique case, in which a public actor strategically centralizes the provision of a public good to secure its availability. We also contribute to the literature on the impact of access to water infrastructure like mains and pipes in urban areas. If urban environments expand, without building out this infrastructure, unconnected households may suffer negative welfare effects and impose negative externalities on their neighbors (Ashraf et al., 2017). By contrast, there is plenty of evidence that large investments in water systems led to significant welfare gains in the U.S. (Cutler and Miller, 2005) as life expectancy drastically improved (Ferrie and Troesken, 2008) and infant mortality declined (Alsan and Goldin, forthcoming). These near miraculous results also hold for the city of Paris (Kesztenbaum and Rosenthal, 2017). We analyze arguably the most important water infrastructure project in the history of modern America, focusing on how a city acquired water from farmers to guarantee access for urban dwellers. Given the developmental state of California at the beginning of the 20^{th} century, our results also relate to the rich development economics literature about the health impacts of water access in rural environments (Ashraf et al., 2017; Kremer et al., 2011; Shanti et al., 2010; Devoto et al., 2012). Merrick (1985) and Galiani et al. (2005) find that the access to piped water infrastructure reduces the incidence of disease.

In terms of modeling, our paper contributes to the literature in industrial organization. Fudenberg et al. (1983) is the classic model of preemption games, applied to patent races. Hendricks (1992) considers a similar duopoly model, with imperfect information and Hopenhayn and Squintani (2011) generalize their model for more than two players. In such games, firms profits are greater if they innovate than if another firm innovates. However, this does not imply that firm profits increase after the innovation. It could be the case that firms profits actually decrease after the innovation, but firms innovate anyway, due to the fear that their competitor would innovate first. Therefore, firms have an incentive to innovate, and preempt their rivals, even in cases where profits after innovations decline. Argenziano and Schmidt-Dengler (2014) consider a symmetric preemption game with more than two players and show how clustering can occur even in the absence of positive externalities. We generalize existing models by allowing players to be asymmetric and to be more than two players. Our results also extend to information externalities in R&D as in Bolton and Harris (1999).

On the empirical side, there is a recent literature estimating preemption effects (Schmidt-Dengler, 2006; Igami and Yang, 2016; Zheng, 2016). Our approach is different, as we assume continuous time and allow players to take action at any time, rather than at fixed periods. Moreover, we leverage that detailed information on the precise timing, measured in days, to estimate the shape of the distribution of exit times, which we use to identify the shape of the valuations over time. This could not be done in discrete time. Finally, our paper is related to WoA games, which are similar to preemption games. The classic article on offshore oil drilling by Hendricks and Porter (1996) consider a simpler WoA with information externalities. Takahashi (2015) studies a WoA with symmetric players and without externalities. More recently, Hodgson (2018) studies oil drilling in the North Sea using a framework and solving for an equilibrium by restricting the behavior of firms.

2 Background and Data

2.1 Historical Background

The territory known today as the Owens Valley was occupied by the Paiute Indians when the Spanish missionaries entered in contact with them in the early 19^{th} century (Lawton et al, 1976). The Paiute practice irrigation, even if they had not developed proper Agriculture (tilling, planting) (Steward, 1930). The Paiute trade some of their agricultural products with the Spaniards, but where not affected by them. This changed in the late 19^{th} century when Anglo Americans arrived to the valley, during the California gold rush. The hostilities culminated in 1863 when the 2nd Regiment California Volunteer Cavalry and local militias killed many of the Paiute and forced those who remained alive, nearly one thousand, to relocate to Fort Tejon (Bauer, 2012). The Anglo Americans were then free to settle and allocate land and water rights among themselves. The grandchildren of the members of these militias would later sell these land and water rights to L.A.

By 1900, L.A. city officials had realized that Los Angeles River water could not meet the growing city's future water demand. Political leaders and business owners wanted to find an external water supply to compete with San Francisco for economic primacy in the state. To transport water from the Owens River 300 miles to the north, these civic leaders needed to build a large aqueduct in addition to many dams and reservoirs and, most importantly, buy water rights from Owens Valley farmers. Since the value of the water would be higher in the city than the valley, city officials devised a plan to keep these rents: buy "enough" water rights from farmers before the project went public. Because water rights were tied to land ownership, the city first had to buy land. In 1904 and 1905, former L.A. mayor

Fred Eaton traveled through the valley buying options to purchase land. At this stage, the city's intentions were still private and farmers sold their land for "normal" prices, that is, the value of the land plus the value of water, used for irrigation in the valley.

At the same time, the Federal Reclamation Service (FRS) considered a reclamation project for the Owens Valley. The chief of the FRS in California, J.B. Lippincott, was a Los Angeles resident and friend of Fred Eaton. This relationship later proved controversial when Eaton was accused of using his association with Lippincott to imply that he was purchasing options for the reclamation project, not the city. Although both men denied the accusations, many farmers claimed that they would have asked for a higher price if they had known the land was not going to the FRS. Fred Eaton returned to the city with all the necessary options and announced the plan in local newspapers. Voters approved a $1.5 million bond issue by a wide margin, financing a feasibility study and raising funds to purchase the land on Eaton's options. After William Mulholland was appointed Chief Engineer of the project, voters approved a $23 million bond in 1907 to finance construction of the aqueduct. When the aqueduct was completed in 1913, city policy prohibited water sales outside municipal boundaries. This meant that fast-growing nearby towns needed to apply for annexation to L.A. Indeed, Los Angeles grew from 115 to 442 square miles in the following two decades.

This growth surpassed all projections, and soon the city had to buy more land and water rights from the Owens Valley. Now, valley farmers knew their water would be used in LA and demanded a higher price for their plots. In the beginning, residual water rights satisfied the City's demand but population increases soon put pressure on these supplies. In quick succession, voters passed a new $5 million bond in 1922, and after the drought of 1923, two $8 million bonds in 1924. Due to the controversy over the initial massive land purchase, the city was forced to buy land and buildings from the townspeople at pre-Great Depression prices. Still, when the California legislature permitted reparations for water loss in 1925, it limited the city's liability for damage from "construction or operation of the aqueduct" (Kahrl, 1982, p. 296). In 1930, Los Angeles issued a new bond for $38.8 million to acquire land without water rights:town properties and plots in the Mono Basin.[2] Over the following decades, Los Angeles voters approved additional bonds to purchase water rights. By 1934, the city owned virtually all of the valley's water rights, over 95% of its farmland and 85% of its towns. As part of the 1937 Land Exchange Act, L.A. traded 1,392 acres of land to create the Bishop, Big Pine and Lone Pine reservations. This allowed most of the remaining Paiute Indians to return to the Owens Valley. This fact is usually

[2]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.

overlooked in the literature when identifying stakeholders in this water exchange.

Each bond set in motion the same pattern of purchases. With its investment fund fixed, the city announced a committee to evaluate potential purchases, and made individual offers to farmers. The farmers then played a preemption game among themselves. Each farmer knew that if they held out, the city would offer more money for their land. However, when one farmer sold their land, this decision imposed an externality on other farmers since the city had less money to buy land and lower demand for water.

The closer the farmers, the bigger the externality. Farmers could be "isolated" or cut off from the river if the city bought all of their neighbors' lands. If the city bought most (usually two thirds) farms on each irrigation ditch, it could dissolve the ditch association and deprive remaining farmers of access to water. In this article, we focus on the strategic game between farmers. These externalities were important and acknowledged by all parties involved. Therefore, farmers initially tried to negotiate together in order to internalize externalities and raise prices. In 1923, farmers formed the Owens Valley Irrigation District (OVID). Then, the city bought out the OVID's leaders. Next, the city began buying land adjacent to "the oldest canal on the river [McNally Ditch] before its property owners joined the irrigation district" (Hoffman, 1981, p. 179). In a retaliatory cycle, farmers stole water from the McNally Ditch, and the city "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 canal companies operating on the Owen and Big Pine rivers and Bishop Creek, starting with *"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). One scholar judges this "strategy of *division and attrition*" as "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 who owned water rights on the two major ditches created three smaller associations (pools). The Keough (Karl Keough) pool located on the Owens River Canal and the Watterson (Watterson Brothers) and Cashbaugh (William Cashbaugh) pool on the Bishop Creek Ditch. Libecap (2005b)shows how farmers in the three selling pools were able to sold their lands and water rights at a later date, and extract higher prices from the city. The members of two of the pools (Cashbrought, Watterson), however, sold in 1926 and 1927 at prices only marginally greater than farmers in non-pool ditches. Only farmers in the Keough pool extracted a large premium over other farmers.[3] Libecap (2005a) argues

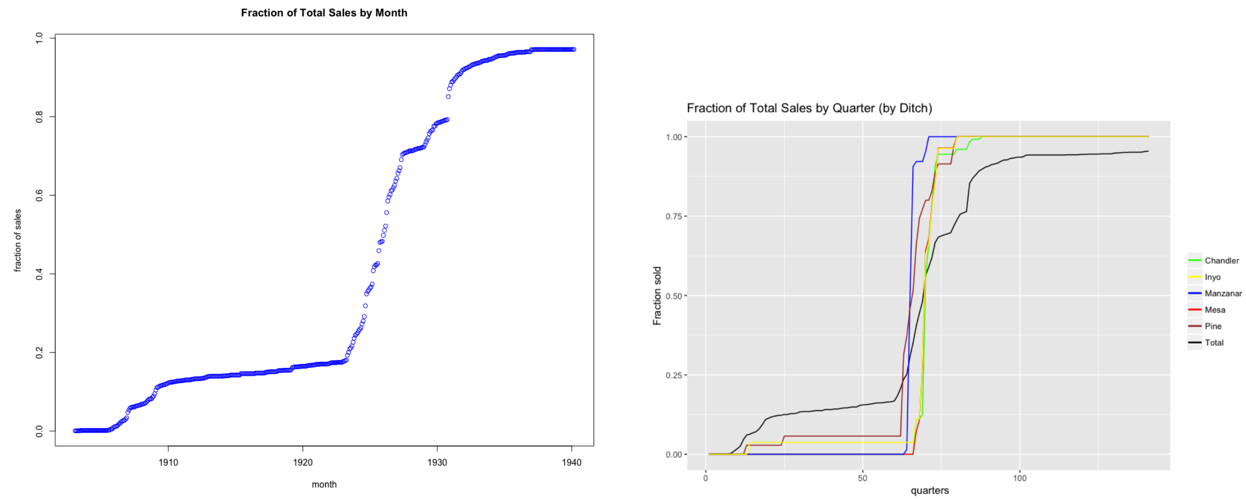
[3]"Those farmers who were in the Keough pool commanded the highest price per acre of land (receiving $443 per acre as compared to an average of $198 for all farms), they sold the latest (held out the longest),

that this was due to the large water rights owned by farmers in the Keough pool, and particularly its leader, Karl Keough. We complement his insights by looking at the location of the lands of the three pool leaders. The lands of William Cashbaugh and the Watterson Brothers were located far from the Owens river, at 250m and 800m respectively. The land of Karl Keough, however, was adjacent (0m) to the Owens river. This suggest that large water holdings were not enough to command a large surplus from the city, as evidenced by the small premia received by Cashbaugh and Watterson. On the other hand, the combination of large holdings (*size* externalities) and location at the ditch intake (*spatial* externalities) did command a large surplus. The intuition for this is both simple and new. When there are no spatial externalities, the formation of a pool/coalition is determined by the distribution of size among the farmers. Libecap (2005b) shows that the three pools have more concentrated land holdings, with much larger Herfindahl indexes, than the non-pool ditches. When spatial externalities are present, high land concentration is not enough. A pool/coalition with high land concentration would be unstable if there are a few key farmers with small land holding with lands at the intake of the river. These key farmer could be bought by the city easily, and they would greatly reduce the continuation value of the remaining farmers.

Although the city eventually bought all the land in the valley, during negotiations, farmers were unsure how long they could hold out. The city indiscriminately purchased property, "leaving farmers uncertain of their neighbors' intentions." (Hoffman, 1981, p. 180). This observation motivates our modeling a game of perfect information because since farmers knew each other, and each other's plot valuations, any uncertainty was due farmers' reactions to the city's offers. Until the 1930s, there was uncertainty as to how much land and water the city of LA needed and would buy. This uncertainty was driven by the recurrence of drought and by LA's population increase. Further, the city's ability to purchase land was subject to the availability of funds from sequential bonds. When the

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.

city ran out of money, it was unclear whether a new bond could be issued.

2.2 Water Law in the West

We now briefly discuss water rights in the Owens Valley. As mentioned in Libecap (2007), farmers held both appropriative and riparian surface water rights in the Owens Valley. Whereas appropriative rights can be separated from the land and sold, riparian rights are inseparable and unsellable. Appropriative rights are based on first appropriation and measured in miner's inches or as a percentage of all water in each irrigation ditch.[4] In our data, when a farmer owns appropriative rights, we observe whether the rights are senior or junior, and we transform either miner's inches or a percentage of flow

and had the most water per acre to offer Los Angeles" (Libecap 2005b, p. 2082).

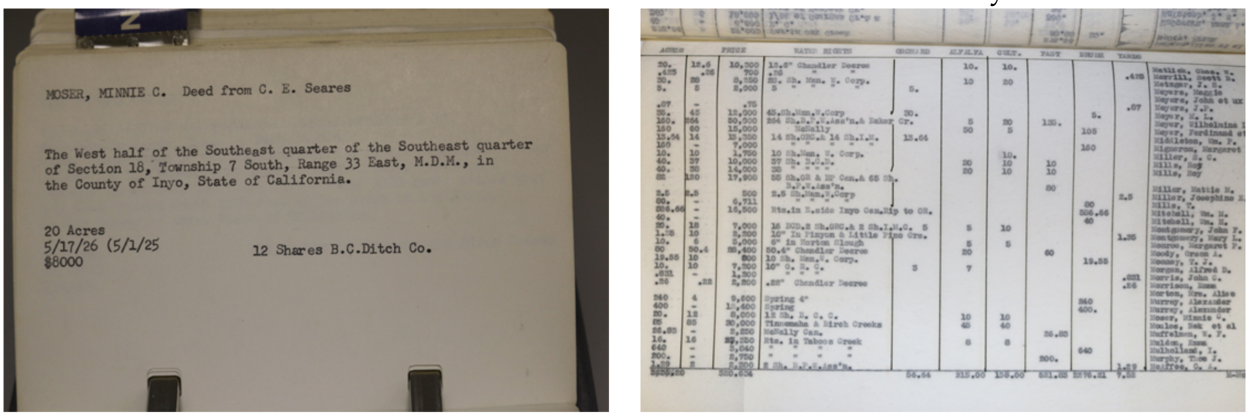
"The core of the pool, led by the largest land owner, Karl Keough with 4,482 acres (60 percent) of the 7,862 acres on the Owens River Canal and by far the most water of any other pool member, and five other farmers held out until 1931 for higher prices" (Libecap 2005a, p. 24).

"By contrast, the Cashbaugh and Watterson appear to have sold too early, earning less per acre. Within the Watterson pool, the leaders and largest land owners, Wilfred and Mark Watterson, agreed to sell to the Board in 1926 at a slight premium, as did all but three of the 20 pool members. The others sold in 1927. Although the Cashbaugh group began to face erosion of its bargaining stand in 1926, when 20 of the 43 members sold, most of the remaining farmers, including the leader, William Cashbaugh with 596 1927.50 acres and more than twice as much water as any other pool farmer, sold in 1927" (Libecap 2005a, p. 24).

[4] These rights could be senior or junior. During a dry season, all the senior rights have to be fulfilled before any junior rights claimants receive water.

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 the ditch into a measure of capacity. We compute the amount of water in acres for each plot. For the remaining plots were we cannot find proper measures, we use Gary Libecap's data on water acres.

2.3 Sales Data

We created our main dataset from the transaction cards of deeds stored at the Los Angeles Department of Water and Power (LADWP) archive in Bishop, Inyo County. In Figure 2.A we show a sample transaction card. Each transaction card refers 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 corresponds 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. Two features make the deed data cumbersome to process: in some cases the same farmer owned several, sometimes non-contiguous, plots and in many cases, the plots were not rectangular. We were nonetheless able to geo-code all plots, enabling us to create the maps and variables we need for the estimation2.4. 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 the exact date of purchase.[5] We only consider transactions between 1905 and 1935 for reasons explained above in subsection 2.1: before 1905, farmers were unaware of the city's intentions and their land to Fred Eaton but by 1935, the city owned all water rights and virtually all non-federal lands in Owens Valley. There are some sporadic transactions in the 1970s and 1980s, but they are very different in nature from early 20^{th} century land purchases.

In addition to the purchase date, we obtain plot size and sale price directly from the transaction cards. Water rights are recorded as number of shares, percentage of all rights in a particular creek, and first or second rights using miner's inches. These measures are homogeneous and comparable within a ditch, but not across ditches. To construct a uniform measure of water rights across all farmers, we merged our dataset with data collected by Gary Libecap from the LADWP archive in Los Angeles.[6]

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* represents the amount of water rights, measured in water acres per year, that each farmer owns.

We supplemented the dataset with surveys conducted by LADWP surveyors. Figure

[5] 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.

[6] In Libecap's data set, there is a measure of annual water acres per 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 contains fewer farmers than ours. Whereas we were able to match all farmers in his dataset to our dataset, there are about 600 farmers in our dataset who do not appear in Libecap's dataset. However, most of these missing farmers have water rights in the same ditch as another farmer who appears in Libecap's dataset. We assume 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.

2.B, shows a sample picture of the survey summary. We merge the transaction cards data with survey data on farmer names. In the survey data, we observe that acreage size and water rights also match the transaction card data. The survey contains an extra piece of information that is an essential determinant of sale price: land use categorized as Orchard, Alfalfa, Cultivated, Pasture, Brush and Yards.

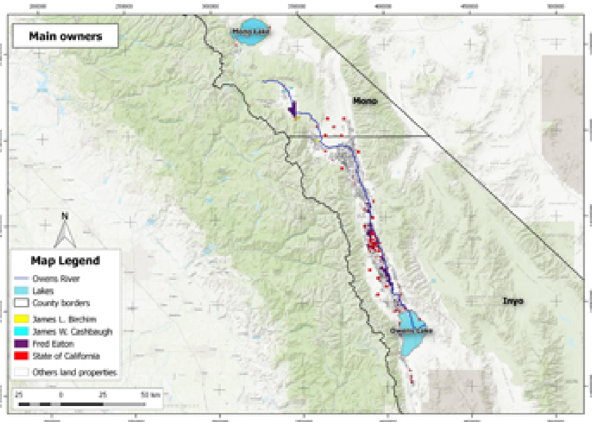
We distinguish three generations of academic work on LA water by data source. The first generation includes historians such as Hoffman (1981) and Kahrl (1982) who used summary data, most commonly compiled by Thomas H. Means,to draw their conclusions. Given the lack of detailed or individual data they determine the total amount that the city spent but reach no definite conclusions regarding the evolution of prices or the size and distribution of the surplus. The second generation includes Gary Libecap's conclusions that as prices increased, the city extracted most of the surplus and farmers who wold later received better prices on average (Libecap, 2005b,a, 2007, 2009). Gary Libecap, however, compiled individual but not geographical data and thus omitted variables that affected plot value. This paper is a third generation analysis using geo-coded variables that help explain plot heterogeneity. Our crucial innovation is using geographical information to test and compute spatial externalities, which allow us to evaluate the efficiency and *checkerboarding* of city purchases.

2.4 Geo-location data

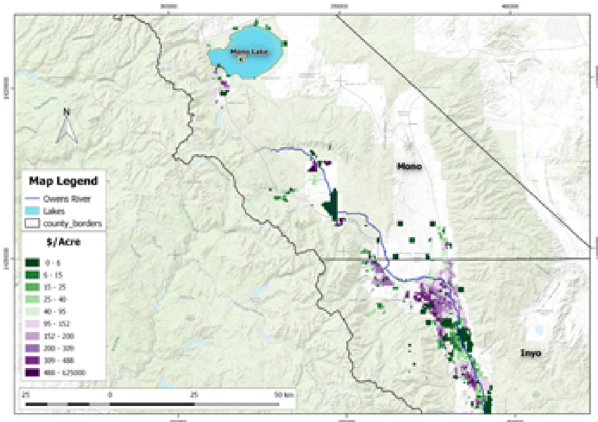
As mentioned above, the transaction cards describe each plot's exact location. We geocoded 2,750 plots. Figure 3.A shows land held by main sellers who received over $1 million for their land.[7] Notice that the State of California was by far the largest seller. Despite not being a farmer or landowner in the valley before 1905, Fred Eaton was the second largest seller because he acted as an intermediary who bought land from farmers and sold it to the city. Most land was located in the southern 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, corresponding to the 11,190 acre Rickey ranch, had the best natural spot for a reservoir (Long Valley). After "a week of Italian work," Eaton purchased the ranch for $425,000$ and sold it to the city, thereby destroying his friendship with Los Angeles engineer Mulholland

Figure 3: Digitized maps in Owens Valley.

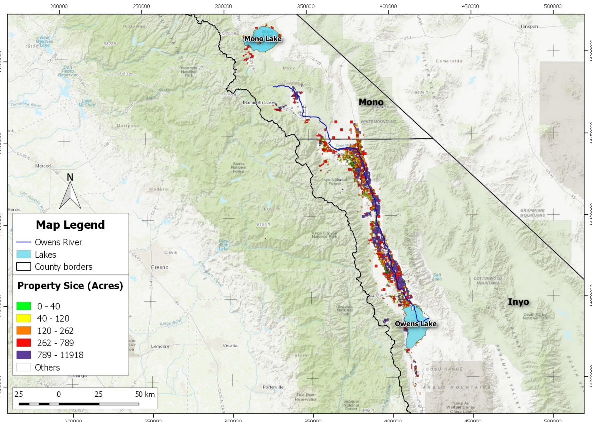
A. Main Owners of rights.



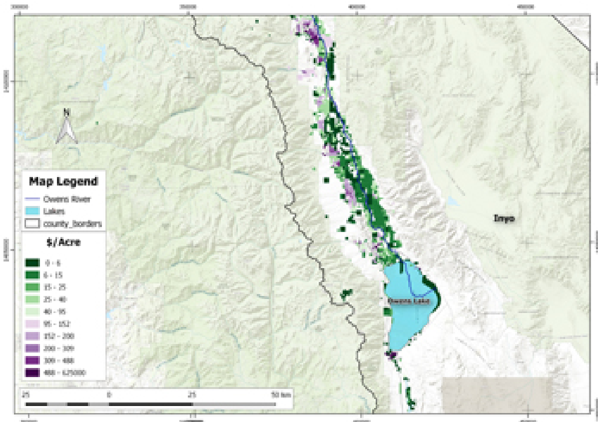
B. Dollars per acre paid in the North.



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 dollars paid per acre paid for each plot in northern Owens Valley. Panel C: Map of the total land area held by each seller. Panel D: Map of the dollars paid per acre for each plot in southern Owens Valley.

(cited by Reisner, 1987).[8]

Geo-located data is useful both for mapping and creating variables. We can merge each geo-coded polygon with data available in GIS (Geographical Information Systems) software. We construct important variables such as altitude, roughness, slope, suitability and distance to the Owens River,which are important determinants of land quality and thus sale price. We are especially interested in distance to the river based on our conjecture that within a ditch, farmers whose plots are closer to Owens River impose a larger externality than farmers further away. Finally, geo-coding all farmers' plots allows us to calculate distances between farmers, and thus the magnitude of externalities, and to perform a rigorous spatial analysis.

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 our design of the theoretical model and structural estimation. We first run a Moran test of spatial correlation. Table 2 shows that there is spatial correlation on the date of sale within the whole valley, suggesting the presence of spatial externalities and the importance of geo-coded data. We also compute the unconditional hazard rates of sale time by ditch. Figure 4 demonstrates that the shape of the hazard rate of sale time varies over time, which means that a standard linear regression cannot capture the variation in our data. Finally, we show several reduced-form regressions to explain in a dynamic setting whether or not a farmer sold land, and at what price.

3.1 Spatial Correlation

In Table 2, we present the results of a Moran's I test of spacial correlation. The Moran's I is a non-parametric test that measures the spacial correlation of a particular value. Consider an example where half of the farmers sell at one time while the other half sell at another time. If all those who sold first are clustered together on one side, and all those who sold later are clustered together on another side, then the Moran's I statistic would be equal to 1. Instead, if farmers who sold first do not neighbor any other farmer who sold first–a checkerboard pattern–then the Moran's I statistic would be equal to -1. Finally, if farmers sold their land at random times, the Moran's I statistic would be equal to 0.

[7] 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 happened so late, they are not included in our analysis.

[8] (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.

The first row in Table 2 shows the results of a Moran's I test for the variable of interest Price per Acre. The test shows no spacial correlation on Price per Acre for the whole sample. This finding seemingly contradicts the hypothesis proposed by Kahrl (1982) that farmers who "clustered" along the river received higher prices per acre for their plots. Notice, however, that this is a strong weak test because it considers linear relations and imposes the same relationship across the whole map. Kahrl hypothesizes a strong spacial relationship, presumably only for farmers on the main ditches, between location on the river or far away from the river, but a zero relation between any other pair of plots. Therefore, zero spatial correlation for the whole map does not necessarily contradict Kahrl (1982).

The second row in Table 2 shows the results of a Moran's I test for the variable of interest sale date. The test shows a strong and significant positive spacial correlation on sale dates consistent with our motivation of spacial externalities across neighboring farmers. In other words, when a farmer sold his plot, his neighbors were more likely to sell. Notice that this correlation could also be spurious. Given the nature of the city's land purchases, the began making offers to farmers in the southern Valley, and as water demands increased, moved north. In other to control for this change, we decompose the sample into several time windows and run the test within those windows. Before 1906, Fred Eaton purchased plots farmers did not know would be sold to the city. Sales from 1907 to 1912 correspond to sales after the city announced but had not finished the aqueduct construction, Here too we see a positive spacial correlation. After the aqueduct was built, but before the city passed a new bond to buy more water (1913-1921), eight reluctant farmers who sold at random times for idiosyncratic reasons drove the lack of spatial correlation. Since the city decided to raise funds to buy more water in 1922, this is our period of interest, which contains most water and land sales and most of the conflict Dividing the sample into two year windows, we see that the spacial correlation is very high and significant. This implies that the high spacial correlation in the second row is not an artifact of the city first buying the southern part of the valley, but rather results from strong spacial correlation across farmers whose lands were *within* the same part of the valley.

3.2 Hazard Rates

Figure 4 shows the unconditional hazard rates of farmers exiting by quarter. We compute hazard rates following a similar approach as Hendricks and Porter (1996). We restrict attention to farmers who belonged to a ditch with more than five farmers. We set the first period for each ditch to be the quarter when the first farmer in that ditch sold his land to

Table 2: Spacial 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's I 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.

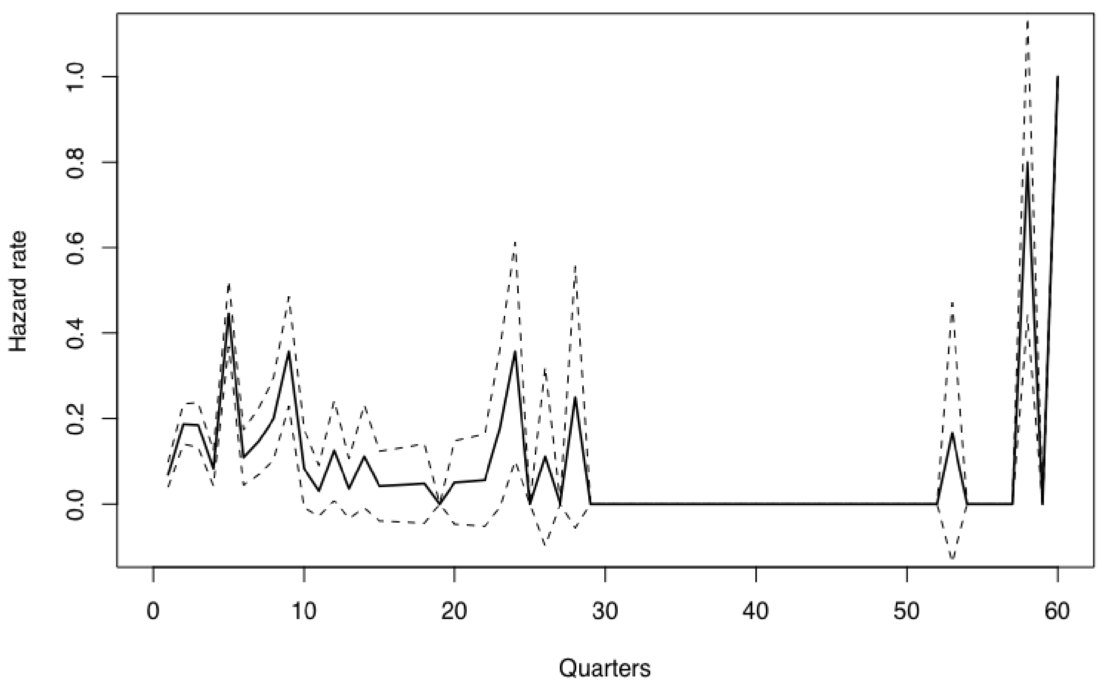
the city. During the first 30 quarters, the hazard rate is erratic but trends downward. As we show later in Section 4, a downward sloping hazard rate is consistent with an upward value of waiting. After 30 quarters, most of the farmers sold while a handful of outliers explain the positive hazard rate after 50 periods.

The hazard rate's variation from high to low suggests that the baseline rate is not constant and that our estimation should be dynamic. Moreover, not only does the hazard rate differ by period, it also changes slope sign from very high to very low values. This behavior is consistent with our interpretation of spacial externalities. After a key farmer sold, a negative externality on the remaining farmers rushed their sales. Transactions were quiet for a while until another key farmer, or a number of small farmers, triggered another run.

3.3 Reduced-Form Analysis

In Table 3 we regress several covariates on the price paid by LA. We include variables from archival records that affect price such as Acres and Water Acres. The results are unsurprising, and the sign and size of effects are reasonable. In addition to these variables, we linked each individual plot with climatic and geophysical information. The climatic and geophysical variables affect productivity and are usual inputs to compute land productivity. The additional climatic variables are annual precipitation, snow and humidity. The additional geophysical variables are mean elevation, slope and roughness. Below we

Figure 4: Unconditional Hazard Rates.



Notes: Unconditional hazard rate for farmers who belong to a ditch with five or more farmers.

use all of these variables as controls when estimating the effects of externalities.

We included climatic and geophysical variables to address concerns that plots of land were heterogeneously on productive and thus the results driven by unobserved differences. We do find differences in climate and physical characteristics across the valley. Moreover, as the results in Table 3 show, these differences affected the price that farmers received, i.e., farmers with more productive lands received a higher price per acre for their land.

Table 3: Price Determinants.

	Dependent variable:							
	Price per acre							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Acres	−0.56***	−0.83***	−1.18***	−1.08***	−0.56***	−0.83***	−1.19***	−1.08***
	(0.14)	(0.18)	(0.35)	(0.38)	(0.14)	(0.18)	(0.35)	(0.38)
Water acres		0.01**	0.01**	0.01		0.01**	0.01**	0.01
		(0.003)	(0.004)	(0.01)		(0.003)	(0.004)	(0.01)
Annual precip.			−9.39	−8.50			−10.45	−9.58
			(7.00)	(11.19)			(7.06)	(11.23)
Annual snow			1.16	0.45			1.39	0.70
			(1.29)	(2.62)			(1.31)	(2.63)
Annual humidity			2.01	2.76			2.10	2.87
			(1.80)	(4.12)			(1.80)	(4.13)
Mean elev.				0.04				0.03
				(0.15)				(0.15)
Mean slope				39.98				39.91
				(32.36)				(32.35)
Mean rough				−102.56				−100.35
				(78.91)				(78.92)
Pool Member					−62.49	−65.03	−152.51	−145.61
					(108.80)	(108.45)	(130.76)	(131.49)
Constant	494.10***	520.59***	563.84***	570.89***	502.63***	529.53***	585.63***	594.17***
	(41.28)	(42.68)	(72.49)	(78.41)	(43.88)	(45.23)	(74.83)	(81.16)
Observations	675	675	530	530	675	675	530	530
R^2	0.02	0.03	0.04	0.04	0.02	0.03	0.04	0.04
Adjusted R^2	0.02	0.03	0.03	0.03	0.02	0.03	0.03	0.03
Note:								*p<0.1; **p<0.05; ***p<0.01

Table 4 uses the same variables as Table 3 above but the explanatory variable is Sale Date, i.e., days since January 1, 1900. The negative coefficient on the variable Acres means that farmers who owned larger plots, typically big landowners or ranchers, sold sooner than smaller farmers. The large negative and significant coefficient on Mean roughness means that farmers with poor quality land also sold earlier. Notice that in both Tables 3 and 4, belonging to a pool does not significantly affect the price per acre or the date of sale.

The others coefficients in the tables change somewhat, specially in Table 4. This is because the characteristics of the plots for farmers that formed a pool are different from those of farmers that did not form a pool.

Table 4: Time of Sale Determinants.

	Dependent variable:							
	Days between 01/01/1900 and sale							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Acres	33.67***	28.61***	−0.63	−4.43***	33.52***	28.48***	−0.65	−4.46***
	(2.86)	(2.64)	(0.76)	(0.64)	(2.86)	(2.64)	(0.76)	(0.64)
Water acres		0.42***	0.15***	0.18***		0.42***	0.15***	0.18***
		(0.03)	(0.01)	(0.01)		(0.03)	(0.01)	(0.01)
Annual precip.			53.86	−172.21***			51.80	−175.12***
			(40.18)	(33.27)			(40.25)	(33.30)
Annual snow			13.31*	44.78***			13.67*	45.30***
			(7.10)	(6.86)			(7.11)	(6.87)
Annual humidity			145.61***	116.85***			145.89***	117.24***
			(7.36)	(10.48)			(7.37)	(10.47)
Mean elev.				1.08***				1.08***
				(0.23)				(0.23)
Mean slope				1,641.74***				1,642.92***
				(173.24)				(173.14)
Mean rough				−2,855.45***				−2,855.11**
				(411.34)				(411.08)
Pool Member					−7,604.72	−7,150.69	−1,458.40	−1,933.48
					(6,773.56)	(6,179.28)	(1,659.94)	(1,307.13)
Constant	17,648.74***	17,404.17***	1,637.58***	4,092.69***	18,255.58***	17,974.89***	1,752.54***	4,247.62***
	(1,876.85)	(1,712.31)	(493.79)	(401.86)	(1,952.89)	(1,781.64)	(510.89)	(415.05)
Observations	675	675	530	530	675	675	530	530
R^2	0.12	0.27	0.95	0.97	0.13	0.27	0.95	0.97
Adjusted R^2	0.12	0.27	0.95	0.97	0.12	0.27	0.95	0.97

Note: *p<0.1; **p<0.05; ***p<0.0

The econometric specification in Table 4 implicitly assumes that the probability of selling is constant over time. Based on the estimated hazard rate in Figure 4, the hazard rate is not constant. Hence, we in the next section we allow for the hazard rate of the distribution of exit times to vary over time.

4 Econometric Model

This section introduces the theoretical model. We model interaction between farmers as a game of perfect information following the historical literature.[9] The historical literature notes that all farmers were informed about sales, prices, and characteristics of other farmers' plots.[10]

4.1 Theoretical Model

We model the interaction between farmers as a preemption game similar to the War of Attrition game in Catepillan and Espín-Sánchez (2019). We take as given the city's offers. One can think of each game as one played 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. When $t = 0$ the city makes an offer to each farmer. The offer consists of a price $V_{i\cdot}(0)$ that the farmer would receive for their plot if he 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 time since the game began, indicated by the scalar t; the number of farmers that have sold at a given point denoted by the scalar k; and in general on the identity of each of the farmers who sold at a given point, denoted by the set $\mathcal{K}$. At each moment in time, a farmer decides whether to stay in the market or to sell his farm to the city. If staying, each farmer receives an instantaneous profit $\pi'_{i\mathcal{K}}(t)$. Where $\pi_{i\mathcal{K}}(t)$ is the total payoff that farmer received i up to time t in stage game $\mathcal{K}$. Because we think that farmers revenues do not change systematically over time, we assume that $\pi'_{i\mathcal{K}}(t) = \pi_{i\mathcal{K}}$.

It is important to distinguish between the whole game played by all farmers in a ditch and each stage game between the subset of farmers who have not sold up to that point. In each stage game, farmers take the continuation value–that is, the value of being active in the next stage game–after another farmer sells as given. In a stage game with n remaining farmers, the value of selling for a given farmer is the city's offer $V_{i\mathcal{K}}(t)$. Notice that the offer depends on time, the farmer's identity, and the set of farmers who have already sold. If a farmer does not sell, his continuation value may depend on the identity of the farmer who did sell, i.e., there may be spacial externalities. The continuation value of the farmer is $W^j_{i\mathcal{K}}(t)$ if farmer j sold his plot at time t. As the farmer decides whether to sell or not, he considers the difference between selling at time t, which involves an 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

[9] Using the arguments in Harsanyi (1973), as we explain below in subsection 4.5, the two games are observationally equivalent. In other words, the data can be rationalized either by a game of perfect or imperfect information. Typically, whereas a game of imperfect information has a unique equilibrium, a game of perfect information has multiple. The perfect information game equilibrium in which all farmers used mixed strategies rationalizes the data and is observationally equivalent to the game of imperfect information.

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

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

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

where $f_{j\mathcal{K}}(t)$ is the instantaneous probability that farmer j sells at time t. We can also define the expected continuation value if another farmer exits as $W_{i\mathcal{K}}(t) \equiv \sum_{j\neq i} f_{j\mathcal{K}}(t)\cdot W^j_{i\mathcal{K}}(t)$. Notice that the expected difference is not a fundamental element of the whole game or the stage game because it depends on other farmers' probabilities of selling $f_{j\mathcal{K}}(t)$, which are equilibrium objects.

In summary, at any point in time there are three elements in the stage game: i) the instantaneous payoffs that a farmer is making every instant that he keeps the farm and not sells, $\pi_{i\mathcal{K}}$; ii) the (certain) value that the farmer can get if he sells the farm, $V_{i\mathcal{K}}(t)$; and iii) the expected continuation value if another farmer exits, $W_{i\mathcal{K}}(t)$. The first element is an instantaneous payoffs, whereas the other two are stock values. The intuition of the model is a trade-off between the (positive) payoff flow $\pi_{i\mathcal{K}} > 0$ and a potential negative (stock) shock $\Delta_{i\mathcal{K}}(t) \equiv W_{i\mathcal{K}}(t) - V_{i\mathcal{K}}(t) < 0$. This is what characterize this game as a preemption game (similarly to the centipede game). Each player receives a positive flow payoff while no one exits, but when someone exits, all the remaining players will receive a negative shock in their continuation value. In a preemption game, actions are strategic complements, i.e., if other players are staying forever, I want to stay forever. If other players plan on exiting now, I want to exit now, or ideally, before they exit.[11]

Given the trade-off between $\pi_{i\mathcal{K}}$ and $\Delta_{i\mathcal{K}}(t)$ we now define the normalized difference in continuation value $\overline{\Delta}_{i\mathcal{K}}(t)$. Given the structure of the model, we can normalize the difference in continuation value, i.e., the size of the negative externality upon other players exiting, by dividing the actual difference by the instantaneous payoff flow. As we show later, this normalized difference is enough to characterize the equilibrium.

$$\overline{\Delta}_{i\mathcal{K}}(t) \equiv \frac{\Delta_{i\mathcal{K}}(t)}{\pi_{i\mathcal{K}}} \tag{2}$$

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

[11]Notice that a preemption game is the mirror image of War of Attrition (WoA) game. In a WoA, the flow payoff is negative but the exit shock creates a positive externality. In a WoA, actions are strategic substitutes, i.e., if other players exit, I want to stay and viceversa.

$$\Delta_{i\mathcal{K}}^{j}\left(t\right)=\Delta_{i\mathcal{K}}^{j}\cdot v\left(t\right)$$

where $\Delta_{i\mathcal{K}}^{j}$ is a scalar and $v\left(t\right)$ is differentiable. Assumption A1 implies that the "shape" of $\Delta_{i\mathcal{K}}^{j}\left(t\right)$ over time is the same for all farmers. The intuition is that although the value differs for each farmer and changes over time, the "shape" of the change is common to all farmers. In time-independent games we have $v\left(t\right)=1$. In that case, both sale values and continuation values are constant over time. A constant $\Delta_{i\mathcal{K}}^{j}\left(t\right)$implies a constant probability of selling over time, which means that the distribution of sale times will have a constant hazard rate. Therefore, assuming constant values is equivalent to assuming that the distribution of selling times is exponential. Below, we show how there is a direct relationship between the shape of valuations over time and the shape of sale time distributions, i.e., given a function of valuations over time $v\left(t\right)$, there is a unique distribution of sale times in equilibrium and given a distribution of sale times in the data, there is a unique function of valuations over time that rationalizes it. In Subsection 4.5, we show how our data allow us to non-parametrically identify the distribution of valuations. For simplicity, we choose a flexible parametric form for the estimation.

4.2 Equilibrium

We now show how to solve for the unique equilibrium where all farmers use mixed strategies. As defined above, farmer i's value of waiting until the next stage when farmer j sells at time t in a stage game when the set $\mathcal{K}$ of farmers have already sold is $\Delta_{i\mathcal{K}}^{j}\left(t\right)=\Delta_{i\mathcal{K}}^{j}\cdot v\left(t\right)$. Farmer i's utility of waiting until time t, given that farmer j leaves at time s with probability $f_{j\mathcal{K}}\left(s\right)$ is

$$U_{i\mathcal{K}}^{j}\left(t\right)\equiv\sum_{j\neq i}\int_{0}^{t}\left[\Delta_{i\mathcal{K}}^{j}\left(s\right)-s\right]f_{j\mathcal{K}}\left(s\right)\prod_{k\neq i,k\neq j}\left[1-F_{k}\left(s\right)\right]ds+t\left\{\prod_{j\neq i}\left[1-F_{j\mathcal{K}}\left(t\right)\right]\right\}\tag{3}$$

That is, farmer i gets $\left[\Delta_{i\mathcal{K}}^{j}\left(s\right)-s\right]$ if farmer j is the first to sell, and she sells at time $s<t$; and farmer i gets t if no one sells before t. The derivative of the utility exists and we obtain the following expression

$$
\begin{aligned}
\frac{dU_{i\mathcal{K}}^{j}(t)}{dt} \equiv & \sum_{j\neq i}\left[\Delta_{i\mathcal{K}}^{j}(t)-t\right] f_{j\mathcal{K}}(t) \prod_{k\neq i,k\neq j}\left[1-F_{k\mathcal{K}}(t)\right]+\left\{\prod_{j\neq i}\left[1-F_{j\mathcal{K}}(t)\right]\right\} \\
- & \quad t\sum_{j\neq i} f_{j\mathcal{K}}(t) \prod_{k\neq i,k\neq j}\left[1-F_{k\mathcal{K}}(t)\right] \\
= & \left\{\prod_{j\neq i}\left[1-F_{j\mathcal{K}}(t)\right]\right\}\cdot\sum_{j\neq i}\left[f_{j\mathcal{K}}(t)\cdot\Delta_{i\mathcal{K}}^{j}(t)+1\right]
\end{aligned} \tag{4}
$$

In equilibrium, the expected utility of not selling for any farmer using a mixed strategy needs to be constant. Otherwise, the farmer would sell (if his expected utility is negative) or not sell (if his expected utility is positive). Thus, in equilibrium, $\frac{dU_{i\mathcal{K}}^{j}(t)}{dt}=0$ and the probability that farmer j sells at time t, $f_{j\mathcal{K}}(t)$. In equilibrium we get:

$$
-\sum_{j\neq i}\left[f_{j\mathcal{K}}(t)\cdot\Delta_{i\mathcal{K}}^{j}(t)\right]=1, \forall i
$$

$$
-\sum_{j\neq i}\left[f_{j\mathcal{K}}(t)\cdot\Delta_{i\mathcal{K}}^{j}(t)\right]=1, \forall i \tag{5}
$$

The equilibrium is characterize by the set of farmers strategies $\lambda_{j\mathcal{K}}(t)$ that makes equation (5) hold for $f_{j\mathcal{K}}(t)=\lambda_{j\mathcal{K}}(t), \forall i$. $\lambda_{j\mathcal{K}}(t)$ is farmer j's strategy that makes all other farmers indifferent between selling or not. Using assumption A1 we get the following equilibrium condition for farmer i

$$
\sum_{j\neq i}\left[\Delta_{i\mathcal{K}}^{j}\cdot v(t)\cdot\lambda_{j\mathcal{K}}(t)\right]=1, \forall i \tag{6}
$$

Notice that we have one equilibrium equation for each remaining farmer. The system of n equations solves strategies for each farmer $\lambda_{i\mathcal{K}}(t)$ in two steps. The first step is to solve for $\theta_{i\mathcal{K}}$, such that

$$
\sum_{j\neq i}\Delta_{i\mathcal{K}}^{j}\cdot\lambda_{j\mathcal{K}}=1, \forall i
$$

This system of equations is linear and easy to solve. The intuition extends to more than three farmers but the algebra is cumbersome in games with externalities. Then, the strategy for farmer i, i.e., the probability distribution of selling over time, must follow a hazard rate that satisfies equilibrium condition (6)

$$
\lambda_{i\mathcal{K}}(t)=\frac{1}{\lambda_{i\mathcal{K}}\cdot v(t)} \tag{7}
$$

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

$$F_{i\mathcal{K}}(t) = 1 - c \cdot exp\left[-\int_0^t \frac{\lambda_{i\mathcal{K}}}{v(s)} ds\right] \tag{8}$$

where c is the constant of integration that makes $F_{i\mathcal{K}}(t)$ a probability distribution. Notice that equation (7) is key to identify the shape of $v(t)$. In the model, using equation (8), for each $v(t)$ we can compute the exact shape of the distribution of each farmer's sale time in each game. When we look at the data, we see the empirical distribution of each farmer's sale time for a given game, $\widehat{F}_{i\mathcal{K}}(t)$. With that distribution, we can compute the empirical hazard rate of sale times for each farmer for a given game, $\widehat{\lambda}_{i\mathcal{K}}(t)$. Then, using equation (7) we can compute the shape of $v(t)$ and estimate the externalities using the estimates on $\lambda_{i\mathcal{K}}$.

4.3 Linear value function

The model presented above computes the equilibrium for any value function $v(t)$. We next show results from a linear value function:[12]

$$v(t) = a + b \cdot t \tag{9}$$

For easy of exposition we now remove the subscript $\mathcal{K}$, e.g., we write $\lambda_{i\mathcal{K}} = \lambda_i$. Following equation 7 and equation 9 we can write the hazard rate of sale times for farmer i as

$$\lambda_i(t) = \frac{\lambda_i}{a + b \cdot t}$$

Since there are three parameters in this hazard rate, we can normalize this equation by dividing by b the numerator and the denominator

$$\lambda_i(t) = \frac{\lambda_i/b}{a/b + b/b \cdot t} = \frac{\lambda_i/b}{\sigma + t} \tag{10}$$

The hazard rate in equation (10) corresponds to the hazard rate of a Generalized Pareto Distribution (GPD) with location parameter equal zero, *scale* parameter σ, *shape* parameter λ_i and *location* parameter $\mu = 0$. This distribution is also called the Lomax distribution. In other words, when $v(t)$ is linear, the equilibrium distribution of each farmer's sale times follows a GPD. a and b are policy parameters, i.e., are determined by the city. λ_i are

[12]Notice that this example also includes the Exponential distribution as a particular case, i.e., when $\xi = 0$ the value function is constant, the hazard rate is constant and the distribution of sale times is Exponential.

pseudo-parameters, determined by the structural parameters as explain below. Given the functional form, however, we cannot identify the scale of λ_i independently from b. In the remaining of the paper we will just take $\sigma = a/b$ as the main policy parameter, or equivalently, assume $b = 1$. This is not a problem for our counterfactuals. If we are interested in a counter factual were the policy parameter b is α times bigger, we just need to divide the value of λ_i and σ by α.

The Lomax distribution has a cumulative distribution function (CDF) $F(t) = 1 - \left(1+\frac{t}{\sigma}\right)^{-\lambda_i}$ and a probability density function (PDF) $f(t) = \frac{\lambda_i}{\sigma}\left(1+\frac{t}{\sigma}\right)^{-(\lambda_i+1)}$.

The Lomax has the nice property that if a random variable t has a Lomax, then the conditional distribution of $t-\tau$ given $t>\tau$ is also a Lomax with the same *shape* parameter λ_i and a *scale* parameter equal to $\sigma_i^{'} = \sigma_i + \tau$. For each farmer in every stage game, the distribution of sale times since the last sale follows a Lomax 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 λ_i characteristic of each game with one element for each farmer. When a stage game ends, the continuation value of farmers drop. This affects the shape parameterλ_i but not the scale parameter σ of the distribution of subsequent stage games' sale times, i.e., all games have the same scale parameter σ but a different shape parameter λ_i Given this structure, we only need to estimate one parameter σ that determines the value function's scale for the city's offer to farmers.

4.4 Proportional Hazard Rate Models

In Section 4 we solved the model with Assumption A1, which implies that for the empirical distribution of each farmer's sale times, 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

$$1 - F(t;\sigma;\lambda) = [1 - G(t;\sigma)]^{\lambda}, \lambda > 0, \tag{11}$$

and we write the PDF as

$$f(t;\sigma;\lambda) = \lambda g(t;\sigma)[1 - G(t;\sigma)]^{\lambda-1}, \lambda > 0, \tag{12}$$

where $G(t;\sigma)$ is the source CDF, λ is a positive shape parameter and σ is a parameter that characterizes the source distribution. The hazard rate of a PHRM distribution is

$\frac{f}{1-F} = \frac{\lambda g[1-G]^{\theta-1}}{[1-G]^{\theta}} = \lambda \frac{g}{1-G}$ which implies that the hazard rate of F is proportional to that of G and the scalar of proportionality is the shape parameter λ. This class of models is interesting because, as shown above, a preemption game with changing values will generate this statistical process. Each farmer's equilibrium strategy will be to choose a sale time. In a given stage game, the probability distribution of sale times for a given farmer follows a PHRM distribution. All farmers will have the same source distribution, which is also determined by $v(t)$ but has a different shape parameter λ_i. Notice that, in the original Lomax, the shape parameter λ_i appears in the exponent. This means that a PHRM with a Lomax as source CDF, also follows a Lomax.

There is, however, one issue in linking the model to the data. Even when each farmer's equilibrium strategy is to choose a sale time in each stage game, we only observe sale time for the farmer who sells, i.e., the farmer whose with the quickest sale time. In other words, we have a censored problem. We can only infer that other farmers' sale times were later. This issue is similar to estimating the distribution of valuations in a second price auction (SPA) when the econometrician only observes the winning bid. In a SPA, observed behavior (winning bid) is the second order statistic of the underlying distribution of valuations. In the preemption game, observed behavior (sale time) is the minimum of the underlying distribution of sale times. Moreover, in our case, it is the minimum of asymmetric random variables because farmers have different valuations for holding or selling in a given stage game. Properties of the PHRM are useful when dealing with this issue.

Following Espín-Sánchez and Wu (2021) 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 $\Lambda \equiv (\lambda_1, ..., \lambda_n)$. In particular, $T_i \sim G(\lambda_i)$ for $i = 1, 2, ..., n$, that is $T_1 \sim PHRM(\lambda_1)$, $T_2 \sim PHRM(\lambda_n)$,..., $T_n \sim PHRM(\lambda_n)$. In this case, we compute order statistics for the asymmetric random sample. In particular, we are interested in the first asymmetric order statistic (minimum) which has the form

$$f_1(t) = f\left(t; \sigma; \bar{\lambda}\right), \tag{13}$$

where $f\left(t; \Omega; \lambda\right)$ is the density function of a PHRM and $\bar{\lambda} = \sum_{k=1}^{n} \lambda_k$. Notice that in the symmetric case when $\lambda_i = \lambda$, equation 13 becomes simpler. For the symmetric case, the distribution of the minimum is the same as that of a PHRM with parameter $n\lambda$.

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 sale times follows a Lomax . A PHRM with Lomax is characterized by

$$f\left(t;\sigma;\lambda\right)=\frac{\lambda}{\sigma}\left(1+\frac{t}{\sigma}\right)^{-(\lambda+1)} \tag{14}$$

and a cumulative distribution function

$$F\left(t;\sigma;\lambda\right)=1-\left(1+\frac{t}{\sigma}\right)^{-\lambda} \tag{15}$$

The hazard function is then

$$h\left(t;\sigma;\lambda\right)=\frac{f\left(t;\sigma;\lambda\right)}{1-F\left(t;\sigma;\lambda\right)}=\frac{\frac{\lambda}{\sigma}\left(1+\frac{t}{\sigma}\right)^{-(\lambda+1)}}{\left(1+\frac{t}{\sigma}\right)^{-\lambda}}=\lambda\frac{1}{\sigma+t} \tag{16}$$

We can then characterize equation 13 in the case where the source distribution follows a Lomax as

$$f_1\left(t;\sigma;\bar{\lambda}\right)=\frac{\bar{\lambda}}{\sigma}\left(1+\frac{t}{\sigma}\right)^{-\left(\bar{\lambda}+1\right)} \tag{17}$$

A PHRM is empirically characterized 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 shared across individuals and an idiosyncratic component that does not change over time. Therefore, we write the empirical hazard function as

$$h\left(t,x\right)=h_0\left(t\right)\cdot\lambda\left(X,Z;\mathit{\Omega}\right) \tag{18}$$

where $h_0\left(t\right)$ is the baseline hazard rate, $\lambda\left(X,Z;\mathit{\Omega}\right)$ is the idiosyncratic component, and $\mathit{\Omega}\equiv\left(\beta,\gamma\right)$ is the vector of structural parameters to estimate. The vector of data (X,Z) 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,Z) that change over time as long as they do not change during the stage game, i.e., we can include time variable state variables such as percentage of farmers in a ditch that have already sold, or the fraction of water rights remaining in by ditch.

4.5 Identification

For simplicity, we drop the sub-index denoting that in a given game, the remaining player belongs to the set $\mathcal{K}$. From the previous section, we know that in a preemption game the distribution of sale times is 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 cannot estimate all λ_i. However, we can classify farmers depending on their observable characteristics such that we observe several sale times for a given configuration of the game. Therefore we can identify the function $v(t)$ non-parametrically. We also observe all realizations of $V_i(t)$, which are the prices farmers sold their plots for. Therefore, we independently identify the functions $W_i(t)$ and $V_i(t)$. This means we could identify asymmetric values but not externalities for each farmer. Finally, because we have information regarding the location of farmers' plots and their characteristics, we 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 sale times, as in Takahashi, 2015, then we could only identify a farmer's probability of selling in a particular game $v(t)$. Thus, we would restrict our attention to symmetric games, estimating a single θ for a given number of farmers identified up to a constant. In this case, the function $\Delta(t)$ equals the hazard rate of the distribution of sale 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.

The object that we observe from the data is $\overline{\Delta}_{i\mathcal{K}}(t)$, which is a function of three objects of interest: the exit value $V_{i\mathcal{K}}(t)$; the continuation value if someone exits $W_{i\mathcal{K}}(t)$; and the continuation value if nobody exits $\pi_{i\mathcal{K}}(t)$. The model does not have a solution without assumptions on $\overline{\Delta}_i(t)$. Assumption A1 guarantees that the model has en equilibrium and we can compute that equilibrium. For estimation, we assume that, $W_{i\mathcal{K}}(t) = W_{i\mathcal{K}} \cdot v(t)$ from $V_{i\mathcal{K}}(t) = V_{i\mathcal{K}} \cdot v(t)$ and , $\pi_{i\mathcal{K}}(t) = \pi_{i\mathcal{K}} \cdot t$. It is easy to see that these assumptions would make Assumption A1 holds. The intuition is that the exit value is separable in time. From that, it follows that the continuation value when another farmer exits is also separable in time. Finally, we assume that the instantaneous profits when nobody exits are constant over time. This is reasonable because farmers profits come from agricultural production and that should not be affected if no other farmer exits.

With information on individual characteristics for each farmer, we could model an asymmetric preemption game and estimate $\Delta_{i\mathcal{K}}(t)$, thus identifying $v(t)$ and λ_i, up to a constant. If in addition, we have information on the prices farmers received, we could also estimate $W_{i\mathcal{K}}(t)$ from $V_{i\mathcal{K}}(t)$, thus identifying $v(t)$ and λ_i exactly. It is rare to have such detailed data in an empirical estimation, and its availability crucially allows us to estimate both the game and the counterfactuals. Finally, if we have information regarding the locations, characteristics, and prices of farmers' plots, we will be able to identify and estimate different functions $W_{i\mathcal{K}}^j(t)$ for different pairs of farmers, thus identifying $v(t)$ and λ_i exactly. Notice that this is the main innovation of the paper: we estimate the externalities a farmer exerts on another farmer when he sells land. Depending on data variability and market definition, we could be more or less flexible with the structure of $W^j_{i\mathcal{K}}(t)$. Summarizing, we can identify

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

Notice that, if we do not have information on V_i we cannot recover the "scale" of the parameters. In other words, if we have a game where the vector of valuations of all farmers is represented by V and game $V^{'}$, where the elements in it are just the elements in V multiplied by a scalar α, i.e., $V^{'}_i = \alpha V_i$. Then the predictions for both games would be the same. In particular, the distribution of exit times for each player in each game would be the same, and the vector of parameters λ would be the same. In our case, we do have information on V_i, therefore, we are able to identify the "scale" of the game. In other words, we can recover the implicit discount factor of the farmers by using the information on the prices they actually paid.

5 Estimation Strategy

We model farmers' sales as affecting other farmers within their same ditch differently, depending on observable characteristics.[13] Each stage game, as explained in Section 4, contains the key variable of sale time and information on farmers who sold, who were active but not the first to sell, and who belonged to the same ditch but already sold. The key econometric innovation concerning previous work relates to spatial externalities and time-varying values. As mentioned above, we have information regarding the location of each

[13] In the data, some events affect all farmers, regardless of their irrigation ditch. We model sales by farmers outside their ditch affect all farmers in their given ditch the same way by including time-ditch fixed effects.

farmer's plot and the exact date they sold land. This information is essential to estimate the spacial externalities and, therefore, test the checkerboarding claim. Moreover, preliminary evidence shows two relevant empirical facts: the hazard rate of sale time varied over time and sales by farmers on the same ditch influenced remaining farmers' behavior. The former means that we need to model the dynamics of the farmer's behavior. The latter means that we need to model the externalities among farmers. Our econometric model can account for both facts.

In subsection 4.4, we used the equilibrium conditions developed in the previous section to show that farmer behavior can be predicted using a generalization of the proportional hazard rate models (PHRM). Our model is more general than the usual application of PHRM as we allow the baseline hazard, i.e., the component of the hazard rate that depends on time only, to vary by game. In other words, we allow the baseline hazard rate to reset each time a farmer in the same ditch sells their land. Therefore, our model encompasses the Cox model in terms of the generality of the data generating process, being the Cox model a particular case of our model when the hazard rate does not reset. The Cox model does not impose restriction on the probability distribution of the baseline hazard. In the main estimation, we assume value functions to be linear over time. Thus, given the equilibrium conditions, exit times follow a Generalized Pareto distribution.

The identification proceeds in two steps. In the first step, we get the pseudo-parameters $\bar{\lambda}$, as defined above for each game, i.e., we use the timing of exit in each game to obtain a measure of the probability of exiting by each player in each game. In the second step,we use *hedonic* regressions to obtain a set of structural parameters β using the pseudo-parameters $\bar{\lambda}$ we estimated in the first step, i.e., we use the intensity of exiting for each player in each game λ_k, and relate them to the individual characteristics X of each player to obtain the structural parameters β. This allows us to separate both parts and estimate hedonic parameters without having to use simulations.

We now explain how to estimate the model structurally. The estimator works in one step, but below we decompose how we created the estimator into several parts. First, we explain how to relate the exit times t to the *probability pseudo-parameters* λ of each game. Second, we explain the relation between the *value pseudo-parameters* of the game Δ and the structural parameters of the estimation β and γ. Third, we show for each case—symmetric, asymmetric and externalities—how to solve explicitly for the *probability pseudo-parameters* λ as a function of the *value pseudo-parameters* of the game Δ.

5.1 Distribution of exit times as a function of pseudo-parameters

We now show how to estimate the structural parameters using a one-step structural estimator. The unit of observation is a game, or an exit time. The dependent variable being the time it took a particular stage game, with n farmers, to end. From the model, we know that in each stage game, each farmer is playing a mixed strategy where they exit with instantaneous probability $\lambda_i(t)$. Therefore, the exit time of any particular farmer in a given game, is a random variable t_i that follows a distribution $F_i(t)$. Assuming separability and linearity in the baseline value function we get that

$$\lambda_i(t) = \frac{\theta_i}{v(t)} = \frac{\lambda_i}{\sigma + t}$$

The exit time for farmer i follows a Lomax with location parameter equal zero, *scale* parameter σ_i and *shape* parameter λ_i. In practice, we do not observe all strategies being played, because after one farmer exits, the game ends, and a different game begins. That means that what we observe is the minimum exit time among all farmers. The distribution of that minimum is then $G(t) = F\left(t; \sigma; \bar{\lambda}\right)$, where $\bar{\lambda} \equiv \sum_i \lambda_i$. In other words, the distribution of the minimum of exit times in a given game belongs to the same family.

5.2 Relation between structural parameters and pseudo-parameters

The next step now is to relate the observable characteristics in the data and the structural parameter vectors β and γ to the pseudo-parameters σ and ξ_i. We do this in two steps. First, we use the equilibrium conditions to solve explicitly for $\lambda_i(t)$ as a function of $\overline{\Delta}^j_{i\mathcal{K}}(t)$. Notice that this solution is different depending on whether the game is symmetric, asymmetric or with externalities. Second, we substitute using the hedonic model to make $\overline{\Delta}^j_{i\mathcal{K}}(t)$ a function of the data and the structural parameters only.

Using the assumptions discussed above, we define

$$\Delta^j_{i\mathcal{K}}(t) \equiv W^j_{i\mathcal{K}}(t) - V_{i\mathcal{K}}(t) = \left(W^j_{i\mathcal{K}} - V_{i\mathcal{K}}\right) v(t) = \Delta^j_{i\mathcal{K}} \cdot v(t) \tag{19}$$

Normalizing the common value we get

$$\overline{\Delta}^j_{i\mathcal{K}}(t) = \frac{W^j_{i\mathcal{K}} - V_{i\mathcal{K}}}{\pi_{i\mathcal{K}}} \cdot v(t) \tag{20}$$

Given that we need to estimate a vast number of parameters but can only observe some sales since each game is only played once,we need to assume a parametric function for the counterfactual estimation values. We assume that we can decompose this value as the log-linear combination of relative observable characteristics between i and j. In the econometric specification in the next section, we can identify $\pi_{i\mathcal{K}}$ independently from W_i for two reasons. $\pi_{i\mathcal{K}}$ should only depend on elements that affect the agricultural value of the land, i.e., $\pi_{i\mathcal{K}} = e^{\frac{X_i'\gamma}{K}}$. $\Delta_{i\mathcal{K}}^j$ reflects the value of the externalities and can depend on pair-specific variables, i.e., $\Delta_{i\mathcal{K}}^j = e^{\frac{Z_{ij}'\beta}{K}}$.

Assumption A2: (Hedonic) The relationship between the externality $\overline{\Delta}_{i\mathcal{K}}^j$, the structural parameters $\Omega \equiv (\beta, \gamma, \sigma)$ and the data, in a given game, is

$$\overline{\Delta}_i^j = e^{\frac{Z_{ij}'\beta - X_i'\gamma}{K}}$$

Where we have hedonic characteristics from individual information on farmer i X_i, and their effect on $\overline{\Delta}_i^j$ is measured by the vector of structural parameters γ; hedonic characteristics from pair-specific information on farmer i from farmer j, Z_{ij}, and their effect on $\overline{\Delta}_i^j$ is measured by the vector of structural parameters β; and σ is a structural parameter that measures the slope of $v(t)$. We are interested in recovering the vector of structural parameters $\Omega \equiv (\beta, \gamma, \sigma)$. Notice that the above expression is very flexible. We can add ditch fixed effects or we could estimate the same regression with a random coefficients model, which allows the hedonic parameters to be ditch-dependent.

We can write $\overline{\Delta}_i^j(t)$ as a function of data (X, Z) and structural parameter vectors $\Omega \equiv (\beta, \gamma, \sigma)$.

5.3 Solving $\lambda_i(t)$ as a function of $\overline{\Delta}_i^j(t)$

We now solve explicitly each $\lambda_i(t)$ as a function of $\overline{\Delta}_i^j(t)$. The formulas are more complicated the more general we allow the game to be. Assumption A1 is helpful here. We can write $\lambda_i(t) = \frac{\lambda_i}{v(t)}$ and $\overline{\Delta}_i^j(t) = \frac{W_i^j - V_i}{\pi_i} v(t) = \overline{\Delta}_i^j v(t)$, where λ_i is a scalar that measures the *idiosyncratic* intensity of exiting by player i in equilibrium and $\overline{\Delta}_i^j$ represents the *idiosyncratic* component of the change in continuation value for player i when player j exits. Hence, This steps then only involves solving a system of linear equations. We can write the system for a game with n players as $\overline{\boldsymbol{\Delta}}_{\boldsymbol{n}}\boldsymbol{\lambda}_{\boldsymbol{n}} = \boldsymbol{\pi}_{\boldsymbol{n}}$ where $\overline{\boldsymbol{\Delta}}_{\boldsymbol{n}}$ is a $n \times n$ matrix, $\boldsymbol{\lambda}_{\boldsymbol{n}}$ is a $1 \times n$ vector and $\boldsymbol{\pi}_{\boldsymbol{n}}$ is a $1 \times n$ vector. We have

$$\overline{\boldsymbol{\Delta}}_{\boldsymbol{n}} \equiv \begin{bmatrix} 0 & \overline{\Delta}_1^2 & \cdots & \overline{\Delta}_1^i & \cdots & \overline{\Delta}_1^{n-1} & \overline{\Delta}_1^n \\ \overline{\Delta}_2^1 & 0 & \cdots & \overline{\Delta}_2^i & \cdots & \overline{\Delta}_1^{n-2} & \overline{\Delta}_2^n \\ \vdots & \vdots & \ddots & \vdots & \iddots & \vdots & \vdots \\ \overline{\Delta}_i^1 & \overline{\Delta}_i^2 & \cdots & 0 & \cdots & \overline{\Delta}_i^{n-1} & \overline{\Delta}_i^n \\ \vdots & \vdots & \iddots & \vdots & \ddots & \vdots & \vdots \\ \overline{\Delta}_{n-1}^1 & \overline{\Delta}_{n-1}^2 & \cdots & \overline{\Delta}_{n-1}^i & \cdots & 0 & \overline{\Delta}_{n-1}^n \\ \overline{\Delta}_n^1 & \overline{\Delta}_n^2 & \cdots & \overline{\Delta}_n^i & \cdots & \overline{\Delta}_n^{n-1} & 0 \end{bmatrix} ; \boldsymbol{\lambda_n} \equiv \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \vdots \\ \lambda_i \\ \vdots \\ \lambda_{n-1} \\ \lambda_n \end{bmatrix} ; \boldsymbol{\pi_n} \equiv \begin{bmatrix} 1 \\ 1 \\ \vdots \\ 1 \\ \vdots \\ 1 \\ 1 \end{bmatrix}$$

To find the solution to this system we multiply both sides by the inverse of $\overline{\boldsymbol{\Delta}}_{\boldsymbol{n}}$ and get $\boldsymbol{\lambda_n}$. Thus, for each farmer i we get a scalar λ_i that is a function of the structural parameters and the data. We then take λ_i into the likelihood function, and we can estimate the structural parameters Ω using Maximum Likelihood Estimation.

6 Counterfactuals [TO COME]

7 Conclusions

In this article, we explore the most famous and controversial water transfer in US history, from the Owens Valley to Los Angeles. Ever since, the city has been accused of *checkerboarding*, i.e., targeting particular farmers to increase other farmers' willingness to sell, and to decrease their price. In economic terms, the accusation implies the existence of spatial externalities among farmers whose plots were contiguous or on the same irrigation ditch. Checkerboarding requires both that there were spatial externalities and that the city acted upon them by strategically targeting key farmers.We find large externalities of two types. *Size* externalities mean that the sales by large landowners produce large drops (increases) in the continuation value (probability of selling) by remaining farmers in the same ditch. *Spatial* externalities mean that the sales by farmers with lands close to the river will produce larger effects than sales by farmers inland. Finally, somewhat contrary to the historical literature, we did not find systematic targeting of key farmers. Nonetheless, the city targeted particular farmers in 1922, which did create significant externalities and effectively broke the coordination problem by disrupting the farmers' sale association. Therefore, it is possible that the city did not systematically checkerboard farmers because, after buying out key farmers on central irrigation ditches, the threat of farmers coordinating threat was effectively over.

These conclusions were only possible due to the collection of new data including the price, date, and location of each land sale. Our key contribution to the historical literature is to precisely locate each farmer's plot and determine its exact date of sale. This information is essential to estimate spatial externalities and, therefore, test the checkerboarding accusation. Moreover, preliminary evidence reveals two relevant empirical facts: the hazard rate of sale time varied over time and farmers' sales the selling behavior of other farmers with land on the same irrigation ditch. The former means that we need to model farmer's behavioral dynamics, and the latter means that we need to model externalities among farmers. We present a new econometric model of a preemption game that accounts for both facts and produces a unique equilibrium consistent with the data. The model predicts that the distributions of farmers' exit times fall within the class of proportional hazard rate models (PHRM). We leverage this property, together with a new result in probability theory, to present an original estimation method. Despite the complexity of the game and the presence of unobserved ditch heterogeneity, we are able to estimate our model using Maximum Likelihood Estimation. In summary, we obtain important insights from the combination of detailed historical research—by identifying historians' claims about the past and looking closely at historical data—and rigorous analytical economic analysis—by collecting comprehensive data and developing new models and estimation techniques. We think these dual research strategies would be useful in many other historical settings.

Our findings speak directly to the Owens Valley Syndrome. By assessing the checkerboarding claim, we validate some of the complaints made in the press and the historical literature, i.e., the presence of spatial externalities could make farmers sell for a low price, even a price below what their land was worth before the city became interested in the valley. On the other hand, contrary to the dark legend of the Owens valley transfer, we do not find evidence that the city strategically acted upon these externalities. We believe the results here would help us understand other historical water transfers, as well as future ones. By focusing on spatial externalities in addition to size externalities we will be better able to predict the stability of potential coalitions, as well as to better predict the timing in resolution of the sales. The same intuition applies to other settings where a monopsonist, typically a public utility company or a government body, needs to acquire land (or other assets) from a group of heterogeneous sellers. For example, the case where a developer needs to buy the land or houses of several owners to build a new large complex. The setting developed here could also be applied to cases with positive externalities (war of attrition). For example, when a railroad need to buy tracks of land along a path. In this case, as the railroad company buys more land, it increases the price that the remaining owners could get for their land, because tracks of land are complements in this case.Finally, our framework (theory and estimation) could be applied to other settings with preemption games or games with spatial externalities. We believe our framework is both flexible and tractable and could be easily adapted to other contexts.

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