Title
The Impact of Innovation, Regulation, and Market Power on Economic Development: Evidence from the American West

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The Impact of Innovation, Regulation, and Market Power on Economic Development: Evidence from the American West

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Doctor of Philosophy in Economics

by

Jingyi Huang

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ABSTRACT OF THE DISSERTATION

The Impact of Innovation, Regulation, and Market Power on Economic Development:
Evidence from the American West

by

Jingyi Huang
Doctor of Philosophy in Economics
University of California, Los Angeles, 2021
Professor Dora L. Costa, Co-Chair
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This dissertation analyzes how technological and institutional changes influence economic development. Chapter 1 quantifies the long-term effect of refrigeration on agricultural production. Mechanical refrigeration greatly reduced transportation cost for perishable products but not non-perishable products. I leverage this differential effect to identify the effect of technological change on production with an event-study design. Results show that a one percentile increase in relative suitability of fodder versus wheat production leads to more land area being developed as farmland, higher values of total farm output, as well as higher land values. The effects were driven primarily by the top two quartiles of counties in terms of fodder versus wheat suitability, and most effects persisted until 1960.

Chapter 2 focuses on how the innovation influenced market power in the meatpacking industry. Refrigeration created a highly concentrated meatpacking industry due to the capital-intensive production process. Documents show that the five dominant firms formed a cartel to openly collude and manipulate the market by exploiting the time gap between

sellers' shipment decisions and final sales. I leverage an exogenous regulatory change and novel high-frequency data to quantify the welfare effects of the manipulation. Compared to the standard monopsony model, I find that cartel manipulation harmed cattle sellers attracting more cattle to the market and purchases them at a lower average price. The manipulation strategy also harmed downstream consumers by increasing beef prices and thus total household food expenditures.

Chapter 3 uses the historical evolution of fence laws to examine the impact of liability rules on economic development. Fence laws assigned the liability for livestock trespassing to either farmers or ranchers. I use newly compiled data on the evolution of county-level fence laws to analyze the causal relationship between liability rules and land allocation, production decisions, and agricultural productivity. Results show that, by making livestock owners liable for trespassing, the fence-in rule increased farmland development, corn cultivation acreage and yield, and the total value of farm output. I conclude that, with substantial transaction costs, legal institutions that govern liability rules and property rights can have large and persistent effects on economic development.

The dissertation of Jingyi Huang is approved.

Nico Voigtlaender

Michela Giorcelli

John W. Asker, Committee Co-Chair

Dora L. Costa, Committee Co-Chair

University of California, Los Angeles

2021

To my family

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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CHAPTER 1

Introduction

This dissertation employs both new historical data and modeling methods to explain how the interaction between innovation, market power, and regulation reshaped the American West before 1920. In particular, I focus on the long-term effect of mechanical refrigeration on agriculture productivity, how this innovation influenced market power in the meatpacking industry, and finally, the influence of liability rules on agricultural land use and livestock production. The evolution of technology, market structure, and legal frameworks in the past century provides a useful angle to understand current policy challenges.

I first analyze the long-term effect of mechanical refrigeration, which differentially influenced perishable goods production such as livestock. The analysis exploits the variation in relative natural suitability for livestock versus grain production across counties to capture the impact of refrigeration on agricultural productivity. The baseline event-study shows that after 1880, when refrigeration was commercially adopted in the meatpacking industry, counties relatively more suitable for ranching than farming witnessed more farmland development and higher value of output. For every percentile increase in the relative suitability ranking, counties experienced a 0.1 percentage point increase in the share of land areas being developed as farmland, and a 0.5 percent increase in output value and land value. The effects also differ for counties across the range of relative suitability but persist over time. The results were driven primarily by the top two quartiles, but the effects on output and land value persisted until 1960.

In addition to shifting the upstream agriculture production, how does the new technology affect market power and competition structure in the manufacturing sector? In Chapter 2, I answer this question by analyzing the American meatpacking industry in the early twentieth century. Because of the high fixed cost, mechanical refrigeration left a few firms with unprecedented market power to dominate the meatpacking industry. By the early twentieth century, five firms dominated the meatpacking industry. Under weak antitrust enforcement, they formed a monopsonistic cartel to manipulate the cattle wholesale market. Standard monopsony models evaluate the welfare loss while assuming a static response from the market. However, like many contemporary industries with time-to-build or time-to-ship, sellers in the livestock market had to commit to the market before they observe the market conditions at the point of sales. This delayed response allowed the monopsony cartel to manipulate the market with a dynamic strategy that took into account the future supply responses to current collusive price: cartel members manipulated market prices to attract large cattle shipments, then exploited the inelastic spot-market supply to obtain the input materials at lower prices.

The main analyses leverage exogenous regulatory changes that forced the cartel to switch from a dynamic to a static strategy. This allows me to directly observe the market outcomes absent of cartel manipulation. I first construct and estimate a structural model of the cattle wholesale spot-market using data from the static period. I then calculate the counterfactuals for the dynamic strategy period using the estimated static model. The difference between the model counterfactual and the observed market outcome is thus the effect of the dynamic monopsonistic cartel. Results show that, compared to the static benchmark, the dynamic strategy reduced the number of cattle the cartel purchased by 13.8 percent and reduced cattle wholesale prices by 14.1 percent.

Chapter 3 uses the historical evolution of fence laws in the American West to demonstrate that, in addition to the dramatic antitrust laws against cartels, even seemingly innocuous regulation can have profound economic implications. Counties throughout the U.S. had different fence laws that assign the liability for livestock trespassing to different parties.

Farmers under "fence-out" rule can claim damage from animal trespassing only if the land is enclosed by a legal fence, while those under "fence-in" rule can claim damage regardless of fence conditions. While Coase (1960) emphasizes that, absent of transaction cost, liability rules do not affect resource distribution, prolonged public debates and occasional violent conflicts between farmers and cattlemen suggest that the liability rules had significant economic implications.

For the analysis, I construct a new data set of county-level laws from 1850 to 1920 from state session laws. This data provides a comprehensive legislative history on liability rules for the western states. The analysis exploits the variation in fence laws at the county level over time to quantify the effects of liability rules on agricultural productivity. Consistent with historical accounts, the baseline difference-in-differences results show that fence-in rules incentived agricultural development. Compared to fence-out counties that required farmers to construct fences, fence-in rule increased the density of farmland by 13.4 percent and the share of improved farmland by 18.3 percent. Fence-in rule also increased the cultivation area and the average yield for corn, which is vulnerable to trespassing without fences. This eventually translates to a higher total value of farm output for fence-in counties, although the higher productivity was not reflected in land values.

This dissertation contributes to the literature in three aspects. First, this dissertation contributes to the literature on the American economic development in the early twentieth century. It quantifies the long-term economic impact of some of the most important technological and regulatory changes in American history. While historical work provides detailed documentation on the invention of refrigeration (Anderson, 1953), the evolution of meatpacking cartel (Yeager, 1981; Libecap, 1992), and the conflicts over fence laws (Hayter, 1963), few empirical works provide quantitative analysis on their economic implications. With newly constructed historical data and clear identification strategies, I fill the gap in the literature by providing new causal evidence on the persistent impact of innovation and regulation.

More broadly, the historical cases provide unique settings to study economic questions that are hard to answer with contemporary data. For example, there is growing evidence on the adverse effects of monopsony power, ranging from labor market (Dube et al., 2020) to input trade (Morlacco, 2019). However, economists have limited knowledge of monopsony cartel strategies beyond the standard static case. One of the obstacles is that collusive behaviors are usually illegal under the current legal framework, and the few cases uncovered through antitrust enforcement are likely to be unrepresentative. The historical case of the meatpacking cartel provides a rare opportunity to look into the strategies of a large cartel that operated successful for more than two decades with little legal concerns. Similarly, property rights are believed to be important pillars for economic growth (Besley and Ghatak, 2010). Past research focuses on the effect of allocation rules and enforcement (Banerjee et al., 2002; de Meza and Gould, 1992). However, there is limited causal evidence on the long-term impact of liability rules, which is an important but hard-to-measure aspect of contemporary property rights laws. The history of fence laws in the American West provides well-documented policy changes with a clear measure of who bears the cost under different liability rules. The results can thus help shed light on the economic implications of complex policies today.

Finally, this dissertation expands our understanding of the interaction between innovation and regulation, and how they can influence the market structure and economic development. Previous research has analyzed the effect of innovation on market power and competition (Nicholas, 2003; Cohen and Levin, 1989), or how regulatory framework affects productivity (Moser, 2005; Allen, 1991; Edwards et al., 2020). However, few empirical works study how firms adjust their collusive strategies under different legal regimes or the market response to the gradual evolution of local regulations. This dissertation tests the differences in cartel strategies under different regulatory frameworks and quantifies the welfare implication for both upstream and downstream markets. It also documents and identifies the causal effect of local fence laws on aggregate productivity. The historical setting also allows for the long-range testing of market responses.

CHAPTER 2

Long Term Effect of Mechanical Refrigeration on U.S. Agricultural Production

2.1 Introduction

Despite the historical importance of refrigeration, few studies have empirically analyzed its long-term impact on American agriculture. This chapter quantifies how the introduction of mechanical refrigeration in the meatpacking industry changed upstream agricultural production in the U.S. since the 1880s. Prior to refrigerated rail cars, livestock (such as cattle and hogs) needed to be transported alive from farms to urban markets to be slaughtered and sold. The transportation process was costly, with 30% of the transported weight being non-edible parts, and the risk of animals losing weight or dying on the trip. In 1880, meat packers in the midwest acquired the patent to build the first refrigerated rail car. The invention drastically reduced shipping cost by allowing meatpackers to ship only the carcasses, rather than the live cattle, from the west to the eastern urban market. Within ten years, from 1880 to 1890, the number of cattle slaughtered in Chicago more than quadrupled, and the meatpacking industry became the second largest manufacturing sector in terms of the value of output.

The research design exploits the variation in relative natural suitability for livestock versus grain production across counties to capture the impact of refrigeration. Perishable goods, such as beef, experienced a drastic reduction in transportation costs after 1880. Meanwhile, other non-perishable products, such as wheat, were not influenced by this change.

In other words, counties more suitable for livestock production were more influenced by the new technology, thus allowing an event-study analysis that compares changes in counties more or less suitable for livestock production before and after 1880.

I use detailed micro-level data from the Global Agro-Ecological Zones (GAEZ) project to construct the relative suitability measure. The relative suitability is defined as the percentile rank of yield ratio between fodder and wheat for each census year. The yield ratio measures the variation of comparative advantage between ranching and farming across counties. More importantly, by calculating the percentile rank of the yield ratio for each census year, this measure accommodates how the expanding frontier changed the comparative advantage across counties over time. I then combine the suitability measure with the decennial Census of Agriculture from 1860 to 1960 to identify the effect of refrigeration technology on aggregate agricultural production over time.

The baseline event-study results show that consistent with the hypothesis, after the introduction of refrigeration, places more suitable for fodder growth saw more land being developed for agriculture. On the extensive margin, for every percentile increase in the relative suitability ranking, counties experienced a 0.1 percentage point increase in the share of land areas being developed as farmland. On the intensive margin, counties relatively more suitable for fodder also saw a larger share of improved farmland, where every one percentile increase in the suitability ranking increased the share of improved farmland by 0.1 to 0.2 percentage point. In addition, refrigeration also changed the distribution of farm sizes. Higher marginal returns motivated farmers to shift from larger farms to smaller ones. After 1880, for every one percentile increase in relative suitability ranking, the number of small farms (50 to 100 acres) increased by 0.6 percent, while the number of large farms (above 1000 acres) decreased by 0.5 to 1.5 percent.

In addition to the land use pattern, refrigeration also changed agricultural productivity. On average, every one percentile increase in the suitability ranking led to a 0.5 to 0.7 percent increase in total farm output values, or a 0.5 percent increase in the value of farms. Both effects persist until 1960. Because refrigeration differentially benefited livestock production, it naturally leads to more livestock production after 1880. The baseline estimations show that a one percentile increase in the suitability ranking led to a 0.3 to 0.7 percent increase in the value of livestock per acre. The influence, however, is not different across different types of livestock, as the composition of livestock (cattle, swine, and sheep) did not change differently across counties with varying relative suitability.

I then extend the baseline event-study of average treatment effect to allow for heterogeneous treatment effects by quartiles of the relative suitability ranking. The yield ratios, and thus the percentile relative suitability ranking, measure land substitutability for different outputs. Thus, the treatment effects may not be linear across the relative suitability ranking as one moves along the production frontier. By estimating the treatment effects separately for each quartile, I find that the top two quartiles drove the average effects on land use and productivity. The bottom quartile did not experience measurable changes in land use patterns or the total value of output. However, counties in the bottom quartile saw a reduction in both the land value and the number of livestock. Intuitively, this is consistent with the gradual westward shift of livestock production, and thus demand for land, created by the adoption of refrigeration.

This chapter first contributes to the literature on agricultural innovation by quantifying the effect of refrigeration over a century. Past research has studied the prolonged effects of barbed wire fences (Hornbeck, 2010), the adoption and diffusion of tractors (Gross, 2018; Clarke, 1991), and more broadly, the general returns to agricultural research and development (Moser, 2020; Alston, Andersen, James and Pardey, 2011). This chapter expands the discussion from innovations directly affecting agricultural production to a downstream, general-purpose technology, refrigeration, that indirectly influenced farm productivity by re-allocate land and other input materials.

Other research in trade, such as Costinot and Donaldson (2016), also evaluates the influence of new modes of transportation on agriculture production. Instead of focusing on the aggregate effects of developing a transportation network, this chapter shows that marginal improvement on existing transportation methods can also have a large-scale effect on output.

In addition, this chapter contributes to the discussion of the impact of refrigeration, one of the most important innovations in the 19th century. Historical analysis on the development of refrigeration in the U.S. provides detailed qualitative evidence on the evolution of corporate governance, technology adoption, and labor relations (Yeager, 1981; Libecap, 1992; Skaggs, 1986). This complements the narrative evidence by documenting how the impact of refrigeration rippled through the supply chain to create long-lasting influence across the country.

The rest of the chapter is structured as follows. Section 2.2 describes the introduction of mechanical refrigeration and the changes in the meatpacking industry. Section 2.3 describes the data. Section 2.4 discusses the identification strategy and presents the estimation on the average effects of refrigeration on agricultural land use and production. Section 2.5 presents the heterogeneous effects by quartiles of the relative suitability ranking. Section 2.6 concludes.

2.2 Historical Background

The meatpacking industry adopted mechanical refrigeration in the 1880s. Prior to mechanical refrigeration, live cattle were shipped by rail in small lots from the Great Plains to the east and butchered locally near urban markets. The thousand-mile journey would cause ten to fifteen percent of weight loss, as well as other injuries and deaths. In addition, more than a third of the live weight of cattle were unmarketable wastes. The inefficient process motivated many entrepreneurs to develop a cheaper way to ship beef and other perishable products.

Since the 1860s, many entrepreneurs attempted to ship meat and other perishable produce from the west with refrigeration.[1] The first American patent for a refrigerated rail car was issued in 1867, followed by a string of new patents and experimental prototypes. However, the early models suffered from major design flaws: when the meat came into direct contact with the moist air or the ice, the product could quickly spoil or turn black (Rees, 2013). The inefficient design prevented the wide commercial adoption of refrigerated rail cars in the early years.

The breakthrough in refrigerated rail cars came in 1880. Livestock dealer Gustavus Swift acquired a new patent for ice-refrigerated rail cars in 1879. The new design put ice bunkers at each end of the rail car. This created the necessary air circulation of dry air through the compartment without dampening the meat; it also allowed ice to be replenished every day or two during the week-long journey east to keep the meat cold even in the summer. Swift built his own refrigerated warehouses, rail cars and ice plants along major railroads, and shipped his first load of refrigerated beef to Boston in 1880. By 1881, Swift was sending 3,000 carcasses per week to Boston (Anderson, 1953). Other packers acquired similar designs and quickly followed suit. Refrigeration technology became mature by the mid-1880s[2], with most of the new patents focusing on fuel efficiency, insulation, valve-safety, and other marginal improvements, while the fundamental design of the rail cars and other complementary facilities remained the same.

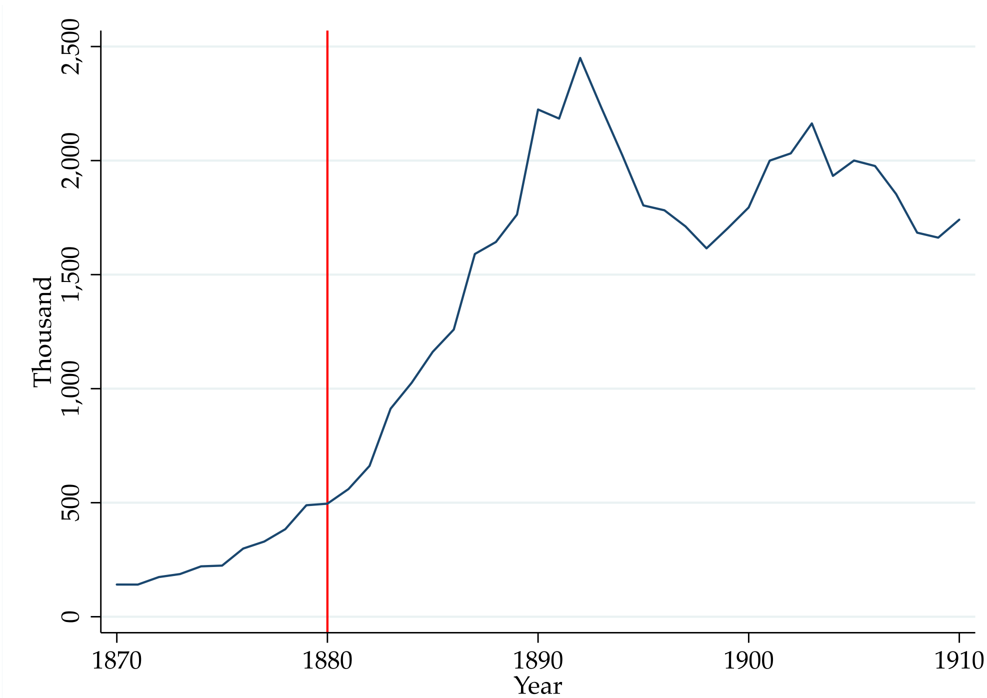
Refrigerated rail cars created the westward movement of the meatpacking industry. Refrigeration drastically reduced the production cost of meatpackers: beef carcasses could be shipped for one-third the cost of shipping live cattle (Bureau of Animal Industry, 1884; Skaggs, 1986). This incentivized packers to build processing plants in the west to be closer to

[1]In 1869, meatpacker George Henry Hammond experimented with shipping dressed beef to the east in winter months. It kept operating for long, though on a very small scale.

[2]Modern mechanical refrigeration based on ammonia-absorption was invented in the 1860s and patented both in Europe and in the US. Mechanical ice-making and refrigeration had been developed since the Civil War and adopted in other industries such as beer breweries that do not require mobile refrigeration (Anderson, 1953). Therefore, users can quickly combine this relatively mature ice-manufacturing technology with the new ice-refrigerated rail-car designs.

the supply of livestock. The dressed beef industry in the western railroad hubs expanded quickly after 1880: the number of cattle slaughtered in Chicago more than quadrupled in ten years, increasing from less than 0.5 million in 1880 to 2.2 million in 1890 (see Figure 2.1). Other stockyards saw similar growth in the cattle trade. Between 1880 and 1890, the number slaughtered increased from 50 thousand to 550 thousand in Kansas City, from 196 thousand to 277 thousand in St. Louis, and 5 thousand to 322 thousand in Omaha. By the early twentieth century, the meatpacking industry became the second largest manufacturing sector in terms of the value of product (Census of Manufacturer, 1900).

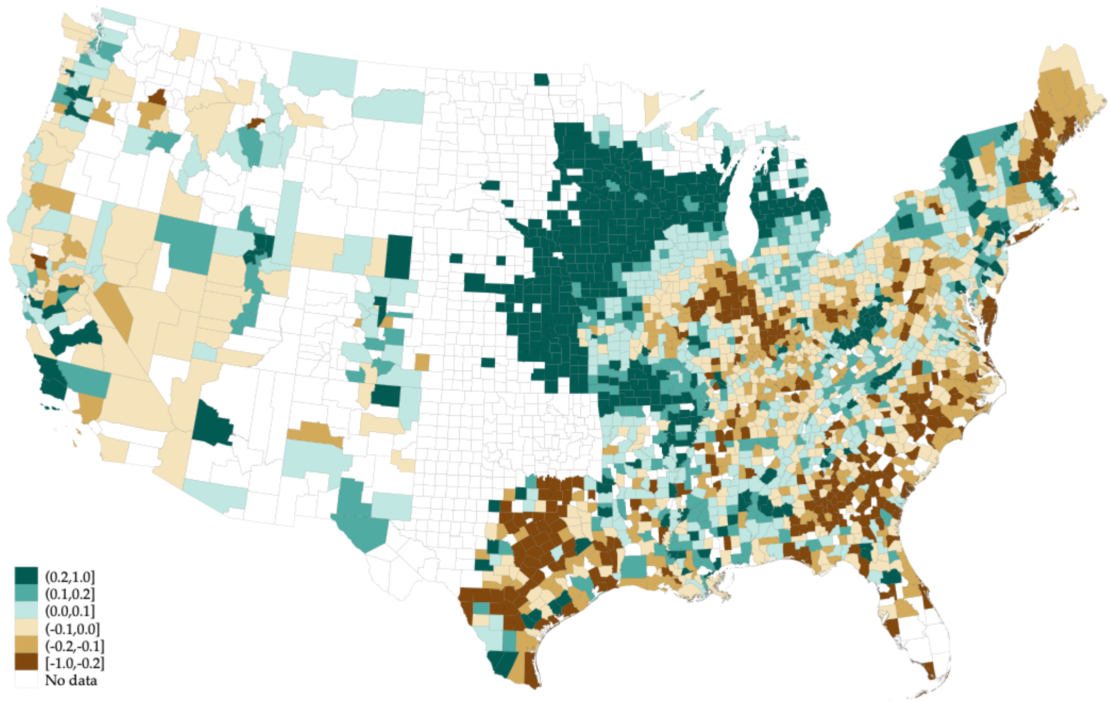
Figure 2.1: Number of Cattle Slaughtered in Chicago



Note: Annual data for cattle receipt and shipment collected from *Annual Report of the Board of Trade of the City of Chicago* (Chicago Board of Trade, various years).

The fast expansion of the meatpacking industry in the Midwest also influenced the upstream agricultural production. In particular, western counties more suitable for raising livestock than cultivating grain responded to the easier access to a larger market by shifting from grain to livestock production. Figure 2.2 shows the westward movement of cattle production.

Figure 2.2: Change in Percentile Rank of Cattle Density, 1870-1910



Note: County level data on number of cattle land area are from *Census of Agriculture* in 1870 and 1910 (Haines et al., 2018). The map is plotted with 1910 county borders.

The figure plots the change of each county's percentile rank of cattle density from 1870 to 1910 (Δ_i), which is calculated using the following formula:

$$\Delta_i = R_{i,1910} - R_{i,1870}$$

where R_{it} is the percentile rank of county i's cattle density (number of cattle per acre) at census year t. The percentile rank normalizes the density measures by each census year. This captures the general influence of the frontier expansion during this period: as more western frontier counties became settled and started to produce for the market, the changes in county composition shifts the spatial distribution of productivity, which is measured by cattle density here. In addition, the percentile rank also incorporates any potential long-term trend in agricultural technology (i.e., new feeding or breeding methods) that may increase the overall productivity across all counties. Thus, the Δ measure can be interpreted as how each county's cattle productivity changes relative to the national average: counties with positive values (plotted in green) experienced a faster increase in cattle density than the average. As shown in Figure 2.2, increases in cattle production were concentrated in the west, while eastern counties are more likely to see a decline in relative cattle density (plotted in brown).

2.3 Data

I collect the main outcome measures, including livestock and grain output quantity, output value, land value, from the county level decennial *Census of Agriculture* from 1850 to 1960 (Haines et al., 2018). These data provide a consistent measure of agricultural production and general economic conditions at the county level over the long run.[3] Table 2.1 provides summary statistics for the main agricultural outcome variables by each census year.

I use the exogenous measure of "naturally attainable yield" from Food and Agriculture Organization's Global Agro-Ecological Zones (GAEZ) data to measure each county's "suitability" for different types of agricultural products. Compared to other observed measures, such as per acre output quantity of value, the suitability measure has two main advantages. First, this measure depends purely on the natural endowment and underlying agronomic model that predicts the attainable output for each crop. Thus, it is not influenced by the endogenous choice of crop types and input levels. In addition, because the suitability measure does not depend on observed output, this provides the ideal counterfactuals for products that were not grown on a given land.

Specifically, the FAO calculates the attainable yield based on natural conditions, such

[3] County boundaries changed over this period. For the analysis, I only use the counties with the same name across the sample period. This does not account for the creation of new counties and, correspondingly, the adjustment of land sizes of the old county.

as soil type, rainfall, temperature, as well as input intensity and irrigation conditions, for each type of crop in every 0.5 degrees by 0.5 degrees field.[4] I aggregate the data at the county level and calculated the average yield level for each county. I approximate grain productivity using the yield of wheat. The GAEZ data does not have a direct measure of livestock productivity. Instead, I use the maximum yield of fodder crops (alfalfa and cold grass) as a proxy for livestock productivity. Finally, the GAEZ data reports yield levels for different input scenarios. For the analysis, I use "intermediate" input intensity with "irrigated" water supplies for all the crops. Figure 2.14 presents the county level GAEZ data of the attainable yield for maize and fodder.

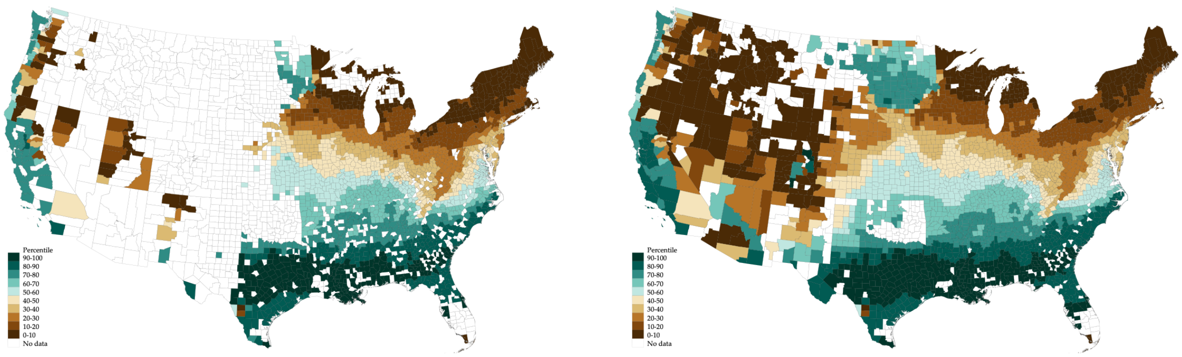
I calculate the percentile rank of fodder-to-wheat yield ratios by year as a measure of comparative advantage. While the attainable yield measure provides detailed absolute productivity measures at the county level, this does not reflect the variation in comparative advantage across counties over time. The comparative advantage across crops for each county is determined by both the natural conditions, which are assumed to be unchanged throughout the period, and how it performs compared to other counties. As more western counties became settled, new lands with varying suitability levels for different crops joined the market. This changed the comparative advantage of each county over time.

I use the relative productivity between fodder and wheat to measure the relative suitability between ranching and farming. One obvious alternative grain crop is corn. However, the fast-expanding refrigerated meat industry also spurred the development of feedlot agriculture, where farmers use corn to fatten livestock for the market. Thus, corn is also indirectly "treated" by the new technology and is a less desirable control group than wheat.

Figure 2.3 presents examples of the changes in relative rankings for fodder to wheat yield ratios between 1860 and 1900. Though the natural endowment for agricultural production remained the same, each county's rank in yield ratios changes as new places join the market.

[4]Each cell is roughly 56km by 56km. Nunn and Qian (2011) discuss details and validity of the data.

Figure 2.3: Fodder/Wheat Yield Ratio Ranks



(a) 1860 (b) 1900

2.4 Empirical Strategy and Baseline Results

To examine the long-term effects of refrigeration on U.S. agricultural production, I exploit the spatial variation in the relative suitability for ranching versus farming across counties. The event-study approach allows me to estimate the effects for each census year separately and flexibly control for the other long-term trend. For the baseline analysis, I focus on the average effects of refrigeration.

2.4.1 Identification Strategy

The identification strategy relies on the exogenous timing of the adoption of refrigeration and its differential effect on counties with varying relative suitability for ranching versus farming. Because refrigerated rail cars were adopted after a series of failed attempts, the timing is plausibly exogenous to other general economic trends or policy changes. All counties were exposed to the new technology at the same time. However, only perishable goods production (i.e., cattle) were exposed to this new technology after 1880, while the transportation conditions for non-perishable goods (i.e., wheat) remained the same. Therefore, counties relatively more suitable for cattle production than for farming were more influenced by this technology shock.

I estimate the effect of refrigeration on agricultural productivity with the following event-study specification:

$$y_{it} = \sum_{t=1860}^{1960} \beta_t (S_{it} \times \text{Year}_t) + \sigma_i + \delta_{st} + \epsilon_{it} \tag{2.1}$$

where y_{it} is the outcome of interest, which includes measures of land use and other productivity metrics, such as the value of total output, the value of farms, value of livestock, and the number of livestock. S_{it} is the percentile rank of fodder to wheat yield ratio for county i in year t. Year_t is the set of indicator variables for each census year between 1860 and 1960, with 1880 being the omitted group.

The coefficients of interest, β_t, trace out changes in the relationship between suitability ranking and the outcome measures across years relative to the omitted group (Year=1880). For the log outcome measures, this means that the coefficient of interest, β_t, can therefore be interpreted as "on average, for every one percentile increase in fodder-to-wheat yield ratios, the outcome measure y at year t change by 100β %."

County fixed effects σ_i control for time-invariant county-specific characteristics, such as distance to central market places or ease of transportation. I also flexibly controlled for time-varying state-level shocks with the state-by-year fixed effects δ_{st}, which includes bad weather for the census year or any state-level policy changes that may influence the outcome measure. Implicitly this also controls for other long-term trends in agricultural technologies that may improve productivity over time.

One caveat for this identification strategy is that I assume other technological improvements do not affect fodder and grain production areas differently. This assumption cannot account for the invention and adoption of refrigerated trucks and other portable cooling units in the 1940s.[5] Similar to the ice-based refrigeration, this technology benefits perishable goods producers more than grain producers. However, because the coefficients of interest, β_t, are estimated separately for each census year, the effect of the portable refrigeration would only affect the estimation for the last two decades, β_{1950} and β_{1960}. Since the adoption timing is colinear with the state-by-year fixed effects, I cannot explicitly control for the effect of refrigerated trucks. Assuming that the new technology would positively influence agricultural productivity for places more suitable for fodder growth, this means that the point estimates for β_{1950} and β_{1960} would be upper bounds for the actual long-term effects.

In addition, the GAEZ project calculates the baseline yield values calculated with the 1961-1990 climatic conditions. One concern is that the modern attainable yield data may not reflect the historical environment, either in production technology or climatic conditions, that corresponds to the outcome data. Past research, such as Olmstead and Rhode (2002) and Cochrane (1979), find that biological innovations and mechanization created significant growth in American agricultural productivity. However, this analysis focuses on the influence of the *comparative* advantage of each county relative to the rest of the country. Variation in the percentile rank of the relative suitability is driven by changes in the number of counties (i.e., potential competitors). Thus, a new technology that can influence productivity across all counties does not change S_{it}.

For the main analysis, I exclude the top one percent of counties in terms of population density by each census year to avoid the influence of urban centers such as San Francisco and New York county. Texas is also excluded from all the analyses because the ownership structure is different from other places. For results on livestock output, I also exclude counties with main stockyards or transit hubs, where the outcome measures are not associated with agricultural production.

[5] Frederick McKinley Jones received the patent for a portable air-cooling unit that can be used on trucks in 1940.

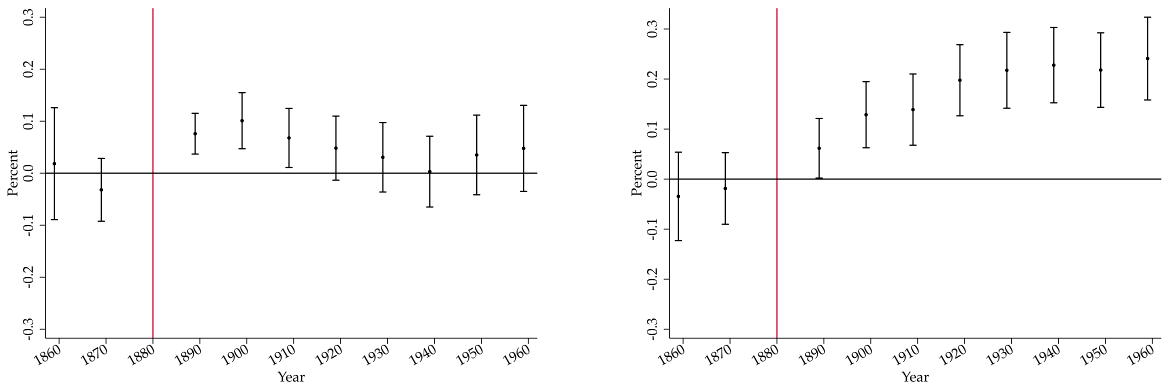
2.4.2 Effects on Farmland

The adoption of refrigeration increased the development of agricultural land. On the extensive margin, counties relatively more suitable for fodder than wheat saw a larger share of the county land area being developed as farmland. I first quantify the effect by estimating the event-study specification (2.1) using the share of the county land area that were reported as farmland, both improved and unimproved, as the outcome variable. Counties more suitable for fodder saw a larger share of the land areas became farmland in the three decades after the adoption of refrigeration. Panel (a) in Figure 2.4 shows the estimated coefficients β_t for each census year. Between 1890 and 1910, for every percentile increase in the relative suitability ranking, the share of county areas that are farmland increased by 0.1 percentage point. As a reference, 65 percent of the county land areas were farmland during this period. This effect disappeared after 1910, after which counties with different suitability rankings show similar concentrations of farmland.

Refrigeration influenced not only the aggregate level of agricultural land use but also the composition of farmland. Refrigeration increased the marginal returns to places more suitable for ranching and thus inspired more investment on those land. Census surveys divide farmlands into "improved" and "unimproved" land. Improved lands include all land regularly tilled or mowed, land pastured and cropped in rotation, land lying fallow, etc.[6] In other words, the share of improved lands provide one measure of how much investment the occupiers made to the land. Panel (b) in Figure 2.4 shows the coefficient by year. After 1880, every percentile increase in the relative suitability ranking corresponds to a 0.1 to 0.2 percentage point increase in the share of improved farmland. Compare to the effect on the share of farmland, which disappeared after thirty years, this effect persists until the 1960s.

[6] Census of Agriculture 1910, Chapter 9.

Figure 2.4: Effects on Farmland



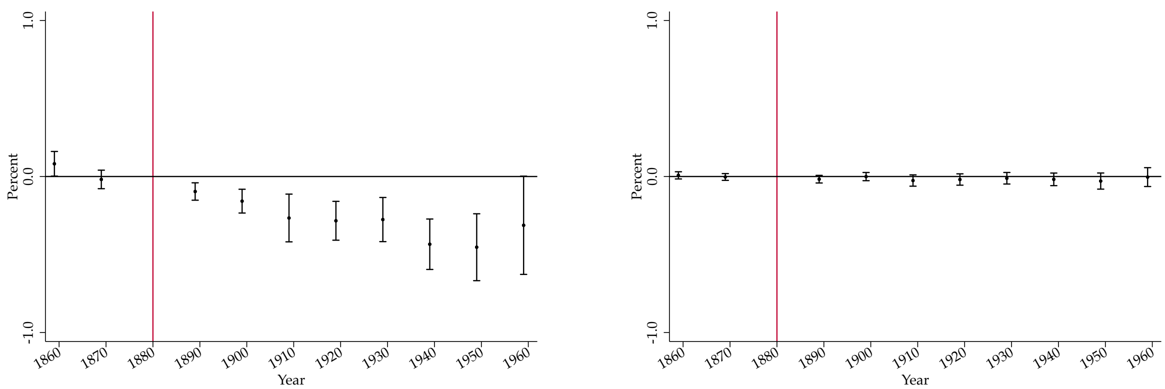
(a) Farmland as a share of total land area (b) Share of improved farmland

Note: Coefficients are normalized relative to 1880. Standard errors clustered at the county level. The sample excludes the top one percent of counties in terms of population density and Texas. Coefficients are scaled by 100 to be presented in terms of percent. See detailed results in Table 2.2, columns (1) and (2).

It is worth emphasizing that any general development in agriculture technology or productivity does not confound this result. The event study includes the state-by-year fixed effects, which flexibly controlled for other common shocks for each state-by-year pair. The main assumption here is that the adoption of other general-purpose agricultural technologies, such as tractors or other mechanics, does not correlate with the relative suitability between fodder and wheat. Under this assumption, though other technologies may influence the share or composition of farmland, those changes would be fully controlled by state-by-year fixed effects. The coefficient here is thus the differential effect that came only from the adoption of refrigeration.

Refrigeration also influenced the population that the farmlands can support. As the number of smaller farms increased, the acreage of farmland per capita decreased. Specifically, for every one percentile increase in the suitability ranking, on average, every person had 0.15 to 0.45 acres less farmland (panel (a) in Figure 2.5). This result can be interpreted in two ways. First, with few acreages per capita, it suggests that the farms may become more productive and thus can support more people with fewer land input. Alternatively, this can also be interpreted as growing labor input in agricultural production. Refrigeration increased the marginal returns for places more suitable for fodder, which in turn incentivized higher marginal input and thus smaller farmland areas per capita. However, there is no differential effect between improve versus unimproved farmland (see panel (b) in Figure 2.5).

Figure 2.5: Effects on Farm Land Per Capita



(a) Farm land per capita

(b) Improved farm land per capita

Note: Coefficients are normalized relative to 1880. Standard errors clustered at the county level. The sample excludes the top one percent of counties in terms of population density and Texas. Coefficients are scaled by 100 to be presented in terms of percent. See detailed results in Table 2.2, columns (3) and (4).

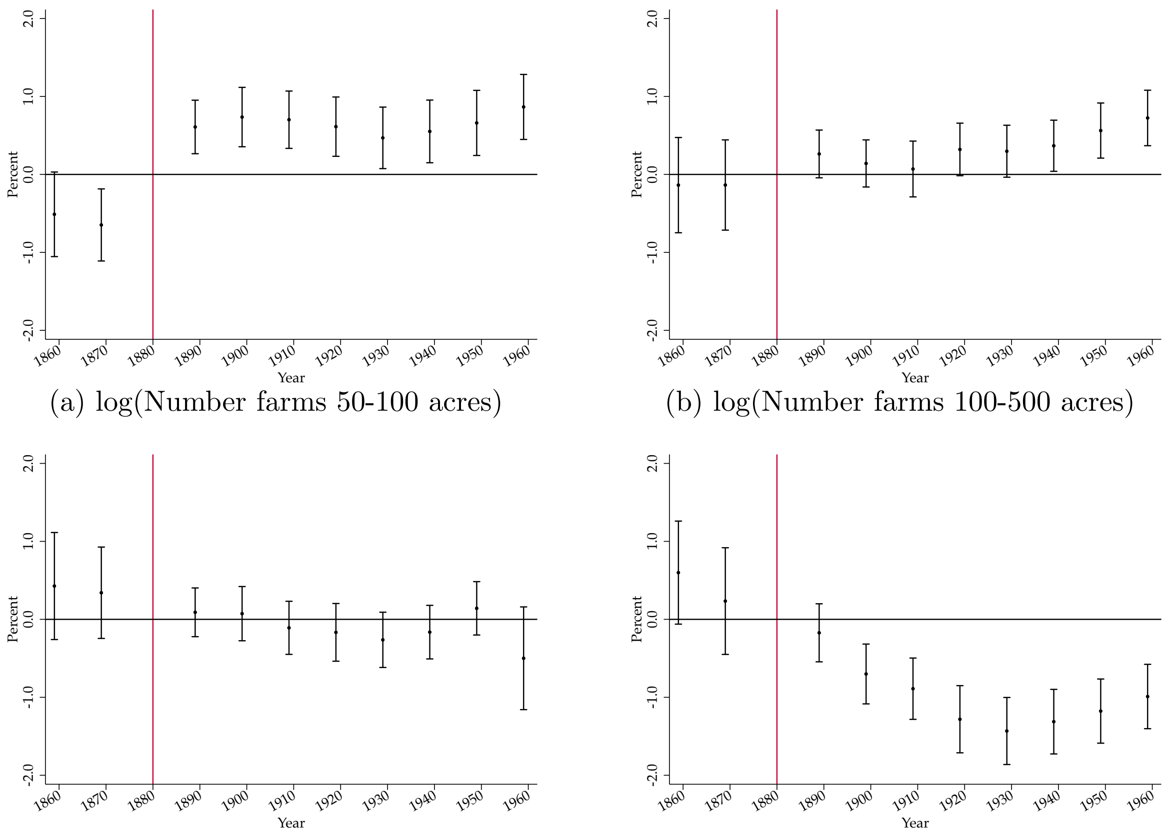
2.4.3 Effects on Farm Size Distribution

Refrigeration also the distribution of farm sizes. Most importantly, the modern meatpacking industry made small feedlot farms economically feasible. In other words, after the introduction of refrigeration, the higher marginal return for small farms specialized in feedlot livestock production is likely to lead to an increase in the number of small farms.

I use the same event-study specification, (2.1) , where the outcome y_{it} is the (logged) number of farms for each of the following size bracket: 50 to 100 acres, 100 to 500 acres, 500 to 1000 acres, and above 1000 acres. Figure 2.6 presents the estimated values for β_t over time. As expected, the effect is most pronounced on the smaller farms: after 1880, for every one percentile increase in relative suitability ranking, the number of farms between 50 and

100 acres increased by 0.6 percent (see panel (a)). Meanwhile, the effect on medium-size farms (between 100 and 1000 acres) is smaller and mostly statistically insignificant (see panel (b) and panel (c) in Figure 2.6).

Figure 2.6: Effects on Farm Size Distribution



(a) log(Number farms 50-100 acres) (b) log(Number farms 100-500 acres)

(c) log(Number farms 500-1000 acres) (d) log(Number farms above 1000 acres)

Note: Coefficients are normalized relative to 1880. Standard errors clustered at the county level. The sample excludes the top one percent of counties in terms of population density and Texas. Coefficients are scaled by 100 to be presented in terms of percent. Estimation results are also presented in Table 2.3.

On the other extreme, as small feedlot farms replaced the traditional large ranch-style livestock production, refrigeration reduced the number of extremely large farms, which primarily were used for ranching before. Since 1900, for every percentile increase in relative suitability ranking, the number of farms more than 1000 acres decreased by 0.5 to 1.5 percent (panel (d) of Figure 2.6). This effect also persisted until 1960, though the trend of reduction has slowed down in the last three decades.

2.4.4 Effects on Agricultural Productivity

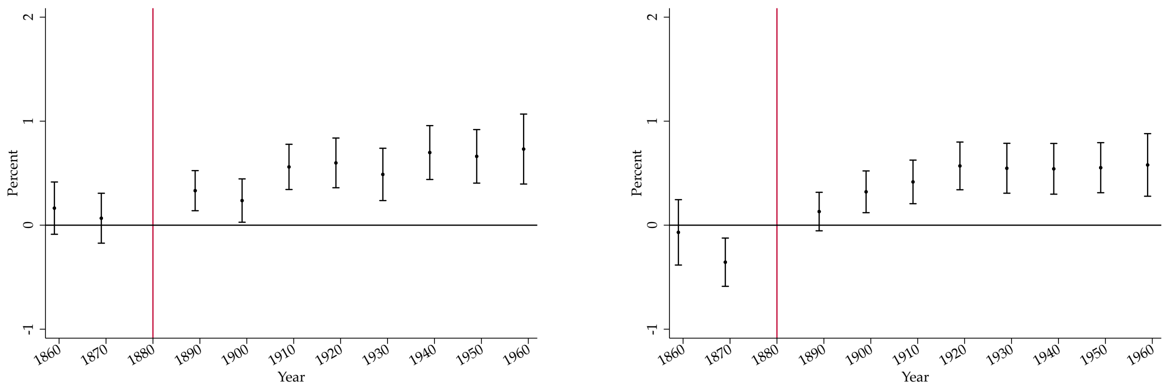
Places more suitable for fodder also saw higher farm output values. The event-study results show that, after 1880, counties ranked one percentile higher in terms of relative suitability have 0.5 to 0.7 percent higher values of total farm output. To benchmark this coefficient, I translate this percentage change into dollar values. For example, the average value of farm output per acre is $28.4 in 1910, while the average effect is 0.56, which suggests that the output value would increase by $0.19 per acre for every one percentile increase in the suitability ranking. If I scale it with the average farm size in 1910, which is 174.3 acres, this means that an average farm will receive $27.7 more in terms of output.[7]

Panel (a) in Figure 2.7 also shows that the difference across counties with different suitability rankings is increasing over the years. This is consistent with previous research, which has found slow and gradual adjustment to market shocks (Bleakley and Ferrie, 2014; Hornbeck, 2012) in agricultural production.

Higher output values also lead to a permanent increase in the value of land. As shown in panel (b) of Figure 2.7, between 1900 and 1960, a one percentile increase in the relative suitability ranking led to a 0.5 percent increase in the value of farms. The trend stabilized after 1920, though the price gap persisted until 1960.

[7] All cash values are in 1920 dollars.

Figure 2.7: Effects on Total Output and Farm Values



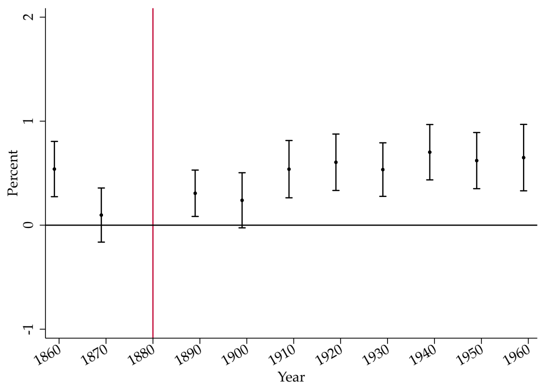
(a) log(Value of total farm output per acre) (b) log(Value of farm per acre)

Note: Coefficients are normalized relative to 1880. Standard errors clustered at the county level. The sample excludes the top one percent of counties in terms of population density and Texas, as well as counties where the cattle density is above 10 heads per acre (i.e. stockyard hubs). Value of farm is defined as the cash value of the land and buildings on the farm. Estimation results are also presented in Table 2.4, columns (1) and (2).

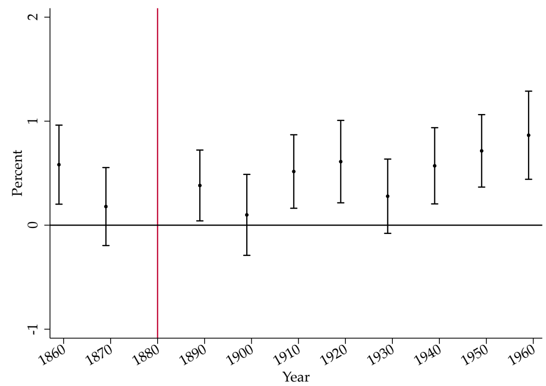
2.4.5 Effects on Livestock Production

Because the direct effect of refrigeration is on livestock production, I also quantify the impact on the value and quantity of livestock. Figure 2.8 shows that, after 1880, places with higher fodder-to-wheat relative suitability rankings also saw higher values of livestock per acre. Specifically, a one percentile increase in the suitability ranking leads to a 0.3 to 0.7 percent increase in the average value of livestock per acre. This is associated with the shift towards livestock production. Panel (b) of Figure 2.8 shows that places with higher relative suitability rankings also tend to have more livestock on the farm.

Figure 2.8: Effects of Refrigeration on Livestock Production



(a) log(Value of livestock per acre)

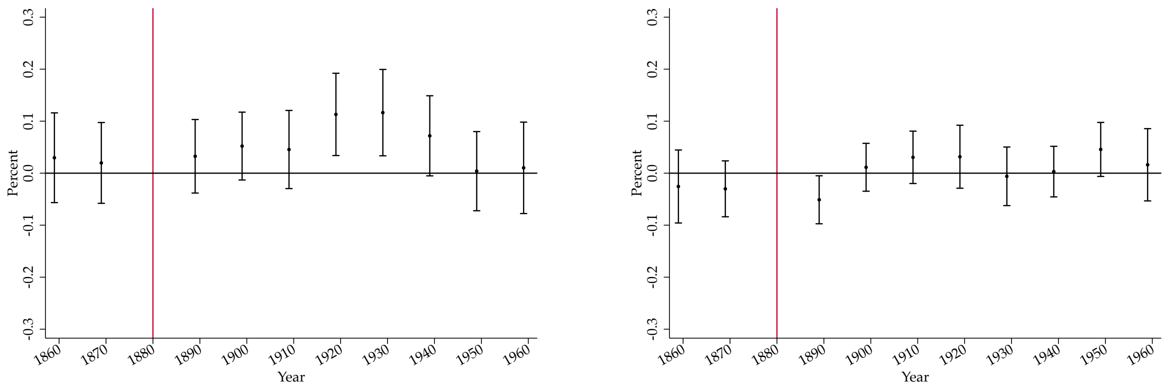


(b) log(Number of livestock per acre)

Note: Coefficients are normalized relative to 1880. Standard errors clustered at county level. The sample excludes the top one percent of counties in terms of population density and Texas. Estimation results are also presented in Table 2.4. Estimation results are also presented in Table 2.4, columns (3) and (4).

There are no differential effects across types of livestock. As shown in Figure 2.9, the number of cattle or swine as a share of the total number of livestock, which is defined as the sum of cattle, swine, and sheep, do not appear to behave differently before and after 1880 across counties with different relative suitability rankings. Though beef is the dominant product of the U.S. meatpacking industry, all large livestock were affected by the innovation in the same way. Thus, there are limited composition shifts between the types of animals that a farmer may raise over time.

Figure 2.9: Effect on Livestock Composition



(a) Share of cattle (b) Share of swine

Note: The outcome variable is the number of cattle or swine as the share of the total number of livestock, which is calculated as the sum of cattle, swine, and sheep. Coefficients are normalized relative to 1880. Standard errors clustered at the county level. The sample excludes the top one percent of counties in terms of population density and Texas and counties where the cattle density is above ten heads per acre (i.e., stockyard hubs). Estimation results are also presented in Table 2.4, columns (5) and (6).

2.5 Heterogeneous Effects

This section estimates the treatment effects separately for each quartile of the suitability rank. The baseline results present the average effect of refrigeration on agricultural land use and production across counties with different relative suitability. However, such effects are likely to be non-linear in relative suitability rankings, suggesting that the estimated average effects may mask the heterogeneous effects across different segments of the relative suitability rankings.

I expand the baseline event-study specification (2.1) by

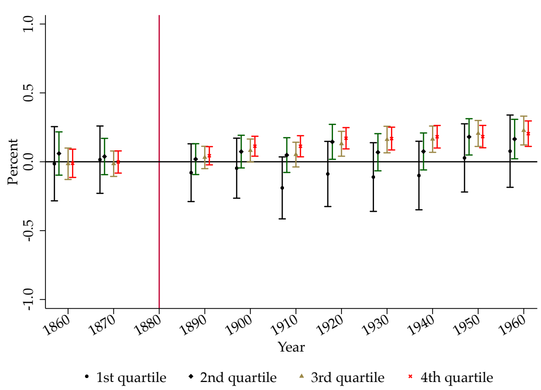
$$y_{it} = \sum_{j=1}^{4} \sum_{t=1860}^{1960} \beta_{tj}(S_{it} \times \text{Year}_t \times \mathbb{I}(S_{it} \in q_j)) + \sigma_i + \delta_{st} + \epsilon_{it} \tag{2.2}$$

where $\mathbb{I}(S_{it} \in q_j)$ is an indicator variable for each of the four quartiles brackets. For example, a county whose relative suitability ranking is in the 15th percentile would have the indicator equal to 1 for the first quartile ($j = 1$) and 0 for the other three quartile indicators.

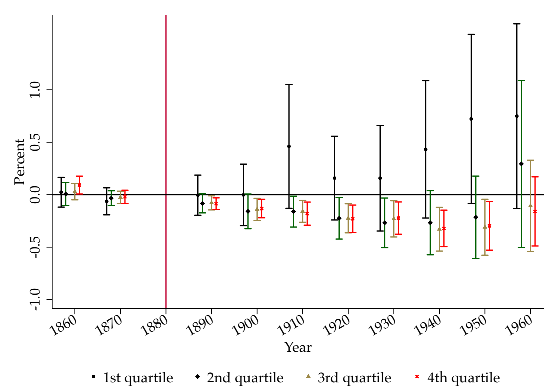
The coefficients of interests, β_{tj} in (2.2), are the average yearly effects of refrigeration on the outcomes for each quartile. This allows for different average effects of refrigeration by each quartile of the relative suitability ranking. Because S_{it} is the percentile rank of fodder-to-wheat yield ratio, this means that the first quartile includes counties with the lowest fodder-to-wheat yield ratios. In other words, counties that were more suitable for growing wheat. Similarly, the fourth quartile includes counties with the highest fodder-to-wheat yield ratio, or counties more suitable for growing fodder crops.

The decomposition shows that the effects on farmland are driven primarily by the third and fourth quartiles, or places most suitable for fodder growth. As shown in panel (a) of Figure 2.10, for counties ranked in the third and fourth quartile, the share of improved farmland increased after 1880. Meanwhile, the bottom half of the counties did not exhibit such positive trends. Similarly, only the top two quartiles experienced a reduction in farmland per capita. Intuitively, the top two quartiles were the places least suitable for grain production, and thus much less likely to be settled and developed before refrigeration made livestock production economically viable.

Figure 2.10: Effects on Farmland by Suitability Rank Quartiles



(a) Share of improved farmland

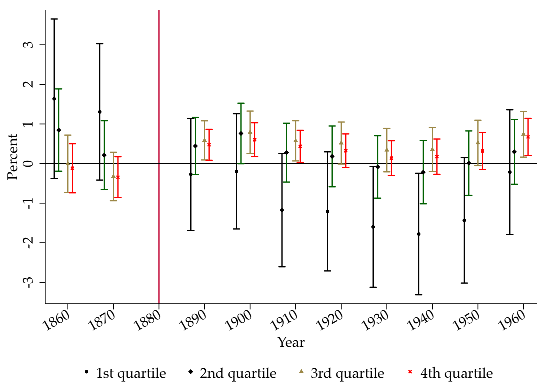


(b) Farmland per capita

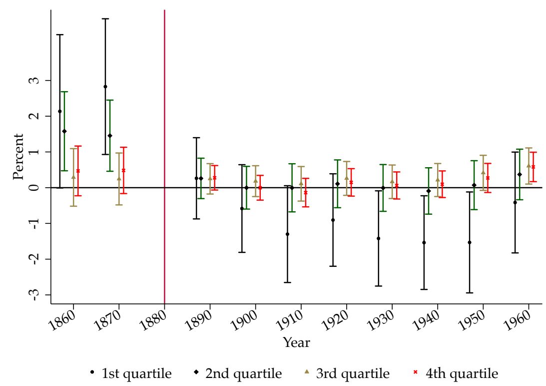
Note: Coefficients are normalized relative to 1880. Standard errors clustered at the county level. The sample excludes the top one percent of counties in terms of population density and Texas. Coefficients are scaled by 100 to be presented in terms of percent.

Consistent with the land use pattern results, the top two quartiles also drove the changes in farm sizes. While Figure 2.6 shows that, on average, places more suitable for fodder saw the number of small farms increased and the number of extremely large farms decreased after 1880, Figure 2.11 show that only the top two quartiles saw measurable changes.

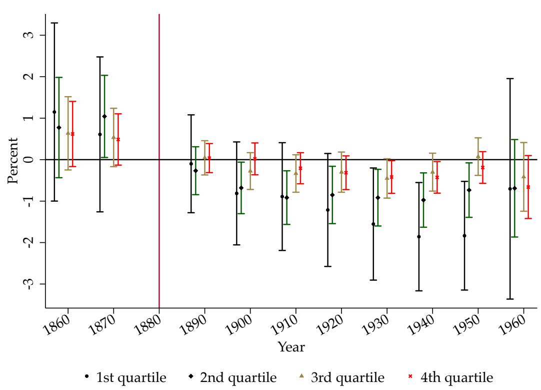
Figure 2.11: Effect on Farm Size Distribution by Suitability Rank Quartiles



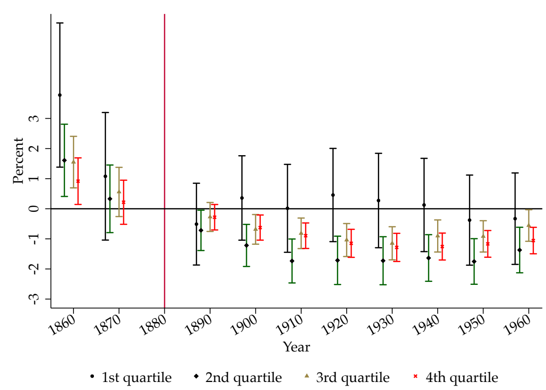
(a) log(Number farms 50-100 acres)



(b) log(Number farms 100-500 acres)



(c) log(Number farms 500-1000 acres)



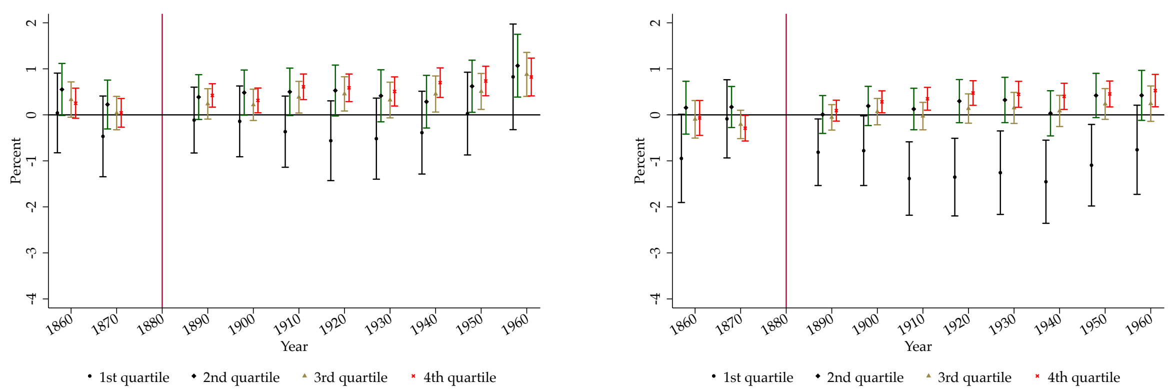
(d) log(Number farms above 1000 acres)

Note: Coefficients are normalized relative to 1880. Standard errors clustered at the county level. The sample excludes the top one percent of counties in terms of population density and Texas. Coefficients are scaled by 100 to be presented in terms of percent.

Specifically, for every one percentile increase in the relative suitability ranking for the third and fourth quartile group, the number of small farms (50-100 acres) increased by 0.5 percent (see panel (a) of Figure 2.12). Changes in the suitability ranking for the first and second quartile groups generally did not lead to any change in the number of farms. On the other extreme, the bottom quartile also did not see any changes in the number of extremely large farms (above 1000 acres), while on average, a one percentile increase in the suitability ranking for the top three quartiles leads to more than one percent decrease in the number of large farms.

The top two quartiles also dominated the changes in total farm output values. As shown in panel (a) of Figure 2.12, for every percentile increase in the relative suitability ranking, the top two quartiles experience a 0.5 percent increase in the average value of total farm output per acre, while the bottom two quartiles did not exhibit similar trend.

Figure 2.12: Effects on Farm Output by Suitability Rank Quartiles



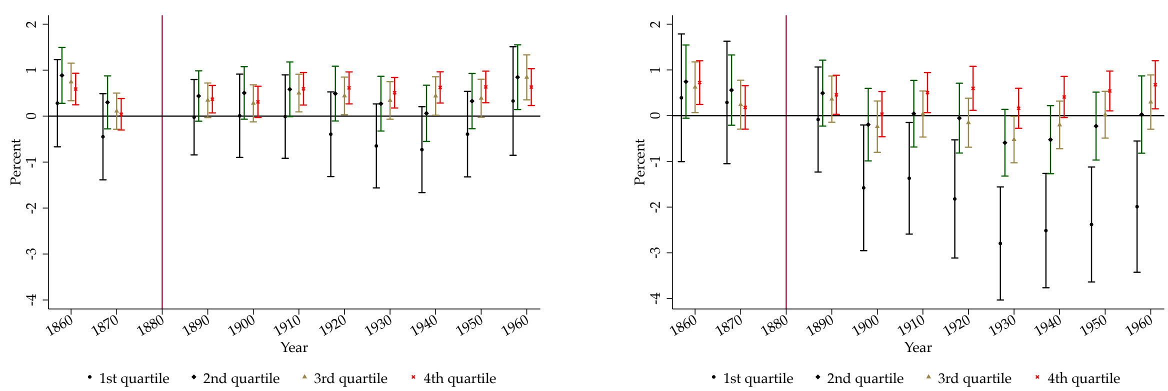
(a) log(Value of total farm output per acre) (b) log(Value of farm per acre)

Note: Coefficients are normalized relative to 1880. Standard errors clustered at the county level. The sample excludes the top one percent of counties in terms of population density and Texas. Coefficients are scaled by 100 to be presented in terms of percent.

The land value presents dichotomous trends for the top and bottom quartiles. While Figure 2.7 suggests that, on average, land value increased by 0.5 percent for every percentile increase in suitability ranking, panel (b) in Figure 2.12 suggests that the positive effects concentrated on the top quartile. In the meantime, counties at the bottom quartile, which are relatively the most suitable for wheat growth, experienced a decline in land prices. On average, for the bottom quartile, for every percentile increase in relative suitability, the land value decreased by 1 percent after 1880. Though the reduced form results cannot perfectly identify the specific mechanism, the divergent trend for ranching versus farming land suggests potential shifts in demand. As more frontier areas more suitable for fodder production became economically more attractive after the introduction of refrigeration, demand for land more suitable for grain production may decrease. This shifting demand for different types of agricultural land can explain the divergent trend in land values for the top and bottom quartiles.

In addition to changes in total farm output values, the top two quartiles also dominated the changes in the value of livestock. Panel (a) of Figure 2.13 shows that, for every percentile increase in the suitability ranking, counties in the top two quartiles experienced a 0.5 percent increase in the average value of livestock per acre, while counties in the bottom two quartiles did not see such changes.

Figure 2.13: Effects on Livestock Production by Suitability Rank Quartiles



(a) log(Value of livestock per acre)   (b) log(Number of livestock per acre)

Note: Coefficients are normalized relative to 1880. Standard errors clustered at the county level. The sample excludes the top one percent of counties in terms of population density and Texas. Coefficients are scaled by 100 to be presented in terms of percent.

The top and bottom quartile also had divergent trends in livestock production decisions. While counties in the top quartile experienced an increase in the number of livestock, counties in the bottom quartile that are relatively most suitable for grain production saw a large decrease in the number of livestock. As shown in panel (b) of Figure 2.13, on average, the bottom quartile experienced a 2 percent reduction in the average number of livestock. This is consistent with the descriptive evidence in Section 2.2 that the center of livestock production gradually shifted west, towards the dryer counties that were less suitable for grain production and better for raising livestock.

2.6 Conclusion

Mechanical refrigeration is one of the major innovations in the late 19th century that changed the production process and market relationships throughout the supply chain. This chapter uses the spatial variation in the influence of refrigerated rail cars to investigate the long-term effects of refrigeration on U.S. agriculture. Comparing changes in land use pattern and agricultural output across counties more or less suitable for livestock versus grain production, I show that the adoption of refrigeration increased agricultural land, the total value of output, and land value, for places relatively more suitable for fodder than wheat growth.

In addition to quantifying the average effects of refrigeration, this chapter also analyzes how the changes in land use and productivity differed across suitability quartiles. I find that most of the positive effects were driven by counties in the top two quartiles in terms of relative suitability, i.e., those most suitable for fodder growth. Counties relatively more suitable for wheat production did not see big differences in terms of land use and value of output, though they experienced a reduction in land value and livestock production.

2.A Appendix Tables

Table 2.1: Summary Statistics of Agricultural Productivity Measures by Census Year

	Number of livestock (per acre) (1)	Output value ($ per acre) (2)	Farm value ($ per acre) (3)	Livestock value ($ per acre) (4)	Number of observations (5)
1850	0.12	6.01	10.50	2.12	1,524
	(0.12)	(4.15)	(10.61)	(2.32)	
1860	0.09	6.96	16.04	2.81	1,865
	(0.15)	(3.90)	(14.62)	(1.72)	
1870	0.13	10.31	19.18	4.38	2,266
	(0.34)	(12.73)	(20.52)	(10.47)	
1880	0.26	7.28	17.11	3.27	2,580
	(0.88)	(6.12)	(17.99)	(4.62)	
1890	0.24	7.67	20.44	3.75	2,748
	(0.47)	(4.90)	(17.90)	(3.47)	
1900	0.29	9.41	21.32	4.33	2,799
	(0.71)	(8.78)	(18.97)	(6.88)	
1910	0.24	13.22	42.49	6.15	2,935
	(0.40)	(6.91)	(39.17)	(4.23)	
1920	0.16	27.59	76.94	9.46	3,049
	(0.17)	(15.80)	(69.33)	(5.50)	
1930	0.18	17.62	60.58	7.22	3,079
	(0.17)	(12.10)	(74.70)	(4.46)	
1940	0.15	12.26	40.31	5.05	3,062
	(0.10)	(8.09)	(36.84)	(2.85)	
1950	0.17	29.77	84.71	12.31	3,063
	(0.12)	(19.54)	(73.83)	(7.83)	
1960	0.22	36.13	157.98	15.27	2,768
	(0.16)	(32.07)	(253.80)	(16.19)	

Note: County level data on number of cattle land area are from *Census of Agriculture* in 1870 and 1910 (Haines et al., 2018). All dollar values are adjusted to $1920. The sample excludes the top one percent of counties in terms of population density and Texas.

Table 2.2: Effect on Farmland

	(1) Farmland per acre	(2) Improved farmland % of total farmland	(3) Farmland per capita	(4) mproved farmland per capita
Suitability Percentile Rank (S_{it})	0.035	-0.062*	0.053**	0.007
	(0.035)	(0.033)	(0.022)	(0.012)
$\text{Year}_{1860} \times S_{i1860}$	0.018	-0.035	0.082**	0.007
	(0.055)	(0.045)	(0.040)	(0.012)
$\text{Year}_{1870} \times S_{i1870}$	-0.032	-0.019	-0.019	-0.003
	(0.031)	(0.036)	(0.030)	(0.011)
$\text{Year}_{1890} \times S_{i1890}$	0.076***	0.062**	-0.096***	-0.017
	(0.020)	(0.030)	(0.028)	(0.012)
$\text{Year}_{1900} \times S_{i1900}$	0.101***	0.129***	-0.158***	-0.000
	(0.027)	(0.034)	(0.039)	(0.013)
$\text{Year}_{1910} \times S_{i1910}$	0.068**	0.139***	-0.266***	-0.026
	(0.029)	(0.036)	(0.078)	(0.018)
$\text{Year}_{1920} \times S_{i1920}$	0.048	0.198***	-0.284***	-0.019
	(0.031)	(0.036)	(0.063)	(0.019)
$\text{Year}_{1930} \times S_{i1930}$	0.031	0.217***	-0.276***	-0.011
	(0.034)	(0.039)	(0.072)	(0.019)
$\text{Year}_{1940} \times S_{i1940}$	0.003	0.228***	-0.434***	-0.018
	(0.035)	(0.038)	(0.082)	(0.021)
$\text{Year}_{1950} \times S_{i1950}$	0.035	0.218***	-0.453***	-0.029
	(0.039)	(0.038)	(0.109)	(0.026)
$\text{Year}_{1960} \times S_{i1960}$	0.048	0.241***	-0.313*	-0.004
	(0.042)	(0.042)	(0.161)	(0.031)
County Fixed Effects	Yes	Yes	Yes	Yes
State-by-year Fixed Effects	Yes	Yes	Yes	Yes
N	27,367	27,298	27,347	27,347
R^2	0.54	0.54	0.35	0.50

Note: Coefficients are normalized relative to 1880. Standard errors clustered at county level. The sample excludes the top one percent of counties in terms of population density and Texas.

Table 2.3: Effect on Farmland

	(1)	(2)	(3)	(4)
	log(Number of farms)			
	50-100 acres	100-500 acres	500-1000 acres	1000+ acres
Suitability Percentile Rank (S_{it})	-0.002	-0.002	0.002	0.008***
	(0.002)	(0.002)	(0.002)	(0.002)
$\text{Year}_{1860} \times S_{i1860}$	-0.005*	-0.001	0.004	0.006*
	(0.003)	(0.003)	(0.004)	(0.003)
$\text{Year}_{1870} \times S_{i1870}$	-0.006***	-0.001	0.003	0.002
	(0.002)	(0.003)	(0.003)	(0.003)
$\text{Year}_{1890} \times S_{i1890}$	0.006***	0.003*	0.001	-0.002
	(0.002)	(0.002)	(0.002)	(0.002)
$\text{Year}_{1900} \times S_{i1900}$	0.007***	0.001	0.001	-0.007***
	(0.002)	(0.002)	(0.002)	(0.002)
$\text{Year}_{1910} \times S_{i1910}$	0.007***	0.001	-0.001	-0.009***
	(0.002)	(0.002)	(0.002)	(0.002)
$\text{Year}_{1920} \times S_{i1920}$	0.006***	0.003*	-0.002	-0.013***
	(0.002)	(0.002)	(0.002)	(0.002)
$\text{Year}_{1930} \times S_{i1930}$	0.005**	0.003*	-0.003	-0.014***
	(0.002)	(0.002)	(0.002)	(0.002)
$\text{Year}_{1940} \times S_{i1940}$	0.006***	0.004**	-0.002	-0.013***
	(0.002)	(0.002)	(0.002)	(0.002)
$\text{Year}_{1950} \times S_{i1950}$	0.007***	0.006***	0.001	-0.012***
	(0.002)	(0.002)	(0.002)	(0.002)
$\text{Year}_{1960} \times S_{i1960}$	0.009***	0.007***	-0.005	-0.010***
	(0.002)	(0.002)	(0.003)	(0.002)
County Fixed Effects	Yes	Yes	Yes	Yes
State-by-year Fixed Effects	Yes	Yes	Yes	Yes
N	27071	27175	23842	22097
R^2	0.58	0.52	0.53	0.57

Note: Coefficients are normalized relative to 1880. Standard errors clustered at county level. The sample excludes the top one percent of counties in terms of population density and Texas.

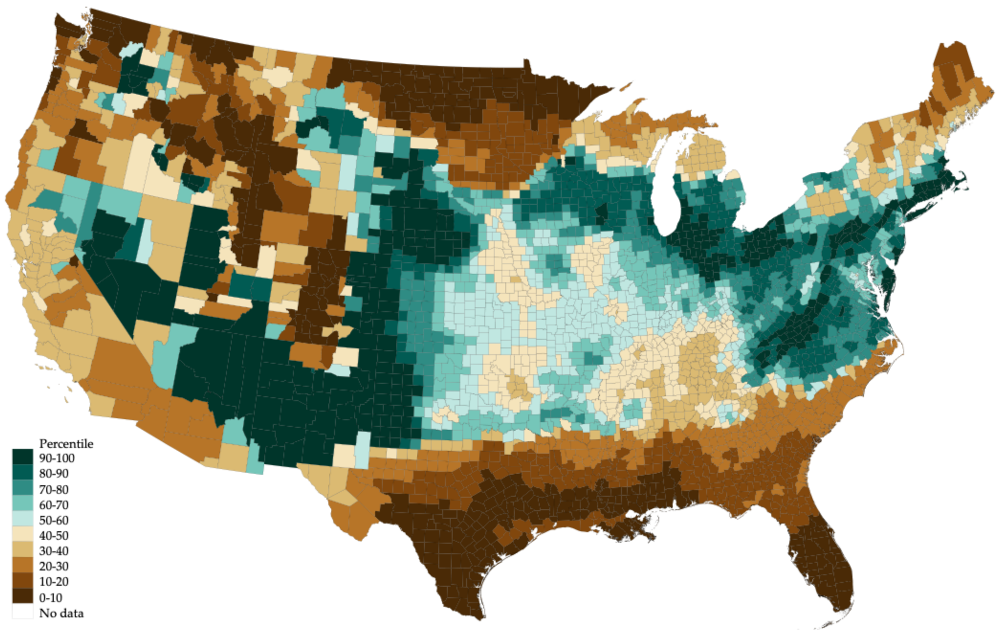
Table 2.4: Effect on Output, Farm Values, and Livestock Production

	(1)	(2)	(3)	(4)	(5)	(6)
		Log(values per acre)			%total livestock number	
	Farm output value	Farm value	Livestock value	Livestock number	Cattle	Swine
Suitability Percentile Rank (S_{it})	-0.003***	-0.002**	-0.005***	-0.005***	-0.100***	0.187***
	(0.001)	(0.001)	(0.001)	(0.002)	(0.036)	(0.025)
$\text{Year}_{1860} \times S_{i1860}$	0.002	-0.001	0.005***	0.006***	0.030	-0.026
	(0.001)	(0.002)	(0.001)	(0.002)	(0.044)	(0.036)
$\text{Year}_{1870} \times S_{i1870}$	0.001	-0.004***	0.001	0.002	0.020	-0.030
	(0.001)	(0.001)	(0.001)	(0.002)	(0.040)	(0.027)
$\text{Year}_{1890} \times S_{i1890}$	0.003***	0.001	0.003***	0.004**	0.033	-0.051**
	(0.001)	(0.001)	(0.001)	(0.002)	(0.036)	(0.024)
$\text{Year}_{1900} \times S_{i1900}$	0.002**	0.003***	0.002*	0.001	0.052	0.011
	(0.001)	(0.001)	(0.001)	(0.002)	(0.033)	(0.023)
$\text{Year}_{1910} \times S_{i1910}$	0.006***	0.004***	0.005***	0.005***	0.046	0.031
	(0.001)	(0.001)	(0.001)	(0.002)	(0.038)	(0.026)
$\text{Year}_{1920} \times S_{i1920}$	0.006***	0.006***	0.006***	0.006***	0.113***	0.032
	(0.001)	(0.001)	(0.001)	(0.002)	(0.040)	(0.031)
$\text{Year}_{1930} \times S_{i1930}$	0.005***	0.005***	0.005***	0.003	0.116***	-0.006
	(0.001)	(0.001)	(0.001)	(0.002)	(0.042)	(0.029)
$\text{Year}_{1940} \times S_{i1940}$	0.007***	0.005***	0.007***	0.006***	0.072*	0.003
	(0.001)	(0.001)	(0.001)	(0.002)	(0.039)	(0.025)
$\text{Year}_{1950} \times S_{i1950}$	0.007***	0.006***	0.006***	0.007***	0.004	0.046*
	(0.001)	(0.001)	(0.001)	(0.002)	(0.039)	(0.026)
$\text{Year}_{1960} \times S_{i1960}$	0.007***	0.006***	0.006***	0.009***	0.010	0.016
	(0.002)	(0.002)	(0.002)	(0.002)	(0.045)	(0.035)
	(0.002)	(0.002)	(0.002)	(0.002)	(0.000)	(0.000)
County Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
State-by-year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
N	27,288	27,289	27,284	27,254	27,259	27,259
R^2	0.67	0.73	0.71	0.55	0.62	0.69

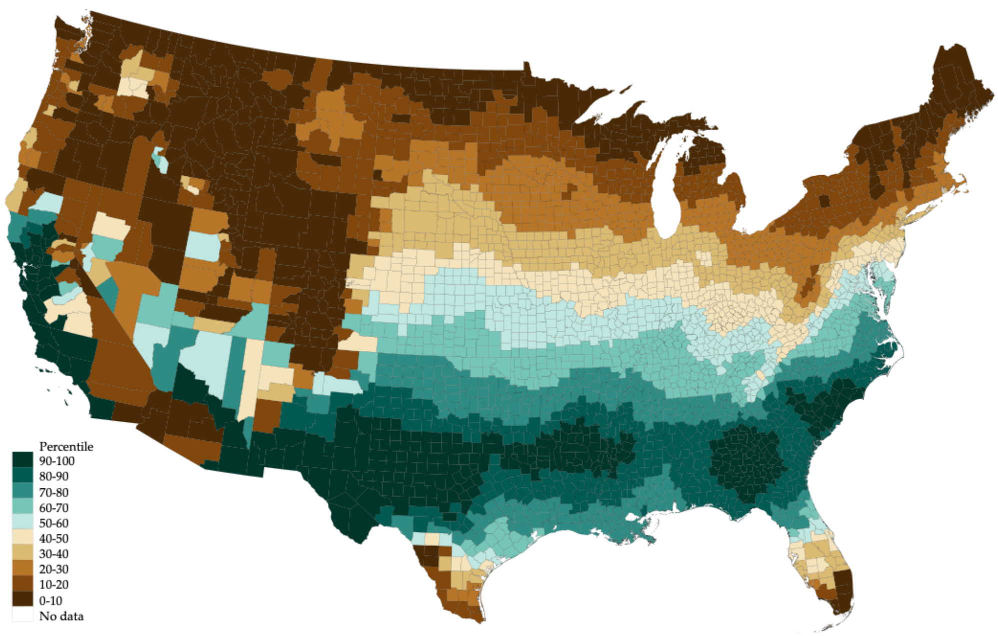
Note: Coefficients are normalized relative to 1880. Standard errors clustered at county level. The sample excludes the top one percent of counties in terms of population density and Texas, as well as counties where the cattle density is above 10 heads per acre (i.e. stockyard hubs).

2.B Appendix Figures

Figure 2.14: Agro-Ecological Attainable Yield



(a) Wheat



(b) Fodder

CHAPTER 3

Monopsony, Cartels, and Market Manipulation: Evidence from the U.S. Meatpacking Industry, 1903–1918

3.1 Introduction

Policymakers and academics are increasingly concerned about the anticompetitive effects of monopsony power. Several recent court rulings in the United States highlight the prevalence of collusion among dominant buyers in industries ranging from digital publishing to dairy manufacturing,[1] and empirical research has documented monopsonies' impact on a wide range of markets, including labor, retail distribution, input trade, and agricultural products.[2]

Though policymakers have tried to address monopsonies' adverse effects through regulatory guidelines or legislative actions,[3] economic theory provides limited understanding of monopsonistic cartel strategies and the resulting welfare losses. Standard monopsony models consider only static responses from the market. However, sales in many markets such

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[1] *United States v. Apple, 952 F. Supp. 2d 638.* The court found "Apple orchestrated a price-fixing conspiracy with five major e-book publishers." *Knevelbaard Dairies v. Kraft Foods, Inc., 232 F.3d 979.* The court charged the manufacturer for unlawful manipulation of the cheese market.

[2] See Dube, Jacobs, Naidu and Suri (2020) and Manning (2003) for analysis on the labor market, Inderst and Mazzarotto (2008) on retail distribution, Morlacco (2019) on input trade, and Blair and Harrison (2010) and Chatterjee (2019) on agricultural products.

[3] The Department of Justice and the Federal Trade Commission issued guidelines to human resource professionals in 2016 regarding no-poach and non-compete agreements. See also Senate Committee on the Judiciary (2004); Department of Justice (2012); Council of Economic Advisors (2016).

as agricultural products can lag far behind production or shipment. Because sellers need to make decisions about future production or shipments based on current market information alone, they must commit to the market before observing the realized spot-market price at the time of delivery.[4] Such markets can be vulnerable to a more complex form of dynamic manipulation: monopsonists can potentially manipulate current prices to influence future supply for higher collusive profits.

In this paper, I examine the U.S. meatpacking cartel to show that a monopsonistic cartel can obtain substantial markdowns by manipulating future supply responses. In the early 20th century, five meatpackers formed one of the largest manufacturing cartels in American history; collectively, they produced more than 80% of refrigerated beef. In an era of weak antitrust enforcement, they openly colluded to manipulate the wholesale cattle market from 1893 to 1920.[5]

Two factors make this historical case an ideal setting in which to analyze the effect of a dynamic monopsonistic cartel strategy. First, because the cartel was eventually challenged in court, the resulting litigation created detailed documentation on the cartel's manipulation strategies. The court found that the cartel members were guilty of "bidding up through their agents, the prices of livestock for a few days at a time, to induce large shipments, and then ceasing from bids, to obtain livestock thus shipped at prices much less than it would bring in the regular way."[6] In addition, exogenous changes in the regulatory environment later forced the cartel to switch from the aforementioned dynamic strategy to a static fixed-market-share agreement, while other features of the market remained unchanged. Thus, I observe the behaviors of the same cartel and sellers under both dynamic and static strategies. This allows me to compare the empirical outcomes under the dynamic strategy to counterfactuals suggested by the well-understood static monopsony model.

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[4] Jeon (2017), for example, describes the time-to-build feature in the container shipping industry.

[5] See Yeager (1981) for details on the evolution of the meatpacking cartel.

[6] *United States v. Swift et al (122 F 529).*

I collected weekly data from historical trade journals published between 1903 and 1918 for the four largest stockyards, which collectively produced more than 58% of U.S. refrigerated beef. These new data offer two advantages. First, given that the cartel set the dynamic strategies at weekly meetings, this high-frequency weekly data provides a good measure of the market under cartel manipulation. Second, the data cover both the dynamic and the static periods. I can thus quantify the impact of cartel manipulation by comparing the realized outcomes during the dynamic period to the benchmark measures suggested by a static monopsony model, which can be estimated using the data from the static period.

I start by providing descriptive evidence on how dynamic manipulation affects the cattle wholesale market. I first show that such manipulation led to different aggregate market outcomes: under manipulation, on average, 15.8% more cattle were shipped to the stockyards for sale, while the realized price was 35.5% lower. Then, I show that, consistent with narrative evidence, the cartel benefited from manipulating cattlemen's shipment decisions. Under cartel manipulation, higher shipment quantities did not correspond to higher realized prices. In other words, cattlemen were "tricked" to believe that the market would be good when they made large shipments; once the cattle arrived at the stockyards, however, cattlemen ended up facing lower-than-expected spot-market prices. Without manipulation, however, more cattle were shipped when the market price was higher. This result suggests that cattlemen could correctly predict market conditions once the cartel stopped their dynamic manipulation.

Though the reduced-form results are informative, they provide only limited information about the dynamic strategy. To measure the level of distortion created by the dynamic cartel manipulation, I need to construct the market outcomes absent cartel manipulation. For this, a model of standard static monopsony is required.

The regulatory change provides observations under both dynamic and static strategies. I leverage this unique historical setting and start by constructing and estimating a structural model of spot-market cattle sales under the static monopsony. I then calculate the counterfactuals for the dynamic monopsony period. The difference between the observed market outcome under the dynamic strategy and the counterfactuals under the static strategy is, therefore, the effect of the dynamic monopsonistic cartel.

On the supply side, I model the cattlemen's spot-market supply with a discrete choice model: sellers either choose to sell to the cartel at the spot-market price or to try the competitive outside market. To solve the standard price endogeneity problem, I use prices of downstream beef substitutes as instrumental variables. The estimated spot-market supply is more elastic under the static strategy. Intuitively, this is consistent with the cartel's manipulation strategy, which was designed to attract and exploit sellers more likely to accept the low spot-market price, that is, those with inelastic supplies. Markdown is 6.8 higher under dynamic manipulation strategy, meaning that cattlemen received 35.9% less of their marginal value of product.

On the demand side, I construct the cartel's profit function in terms of cattle supply and beef demand. The cartel chose the quantity of cattle to maximize profit, facing both an upward-sloping supply as a monopsony in the cattle market and downward-sloping demand as a monopoly in the refrigerated beef market. I use the standard Almost Ideal Demand System (Deaton and Muellbauer, 1980) to estimate the cartel's downstream demand. Combining the price elasticity of supply estimated before with the demand elasticity for the product, I then calculate the optimal cartel quantity and spot-market price under the static strategy.

I examine how cartel manipulation affected the input market by comparing the observed market outcomes under the dynamic strategy with the counterfactual outcome under the static cartel strategy. I first calculate the overall changes in wholesale cattle prices and quantities. Because antitrust regulators may care about the policy implications of disrupting cartel manipulation on downstream consumers, I also calculate the effect of the dynamic manipulation on downstream wholesale beef market. The results show that the dynamic cartel strategy hurt both small cattle sellers and urban beef consumers: compared to the static benchmark, the dynamic strategy reduced the number of cattle the cartel purchased by 13.8% and reduced cattle wholesale prices by 14.1%; meanwhile, it increased downstream wholesale prices by 10% and increased household food expenditure by 2%.

I exploit the unique data structure by taking the market outcomes under dynamic cartel strategy as given. This approach avoids specifying agent beliefs in the dynamic environment with complicated data generating processes while still effectively estimating the aggregate impact of dynamic cartel manipulation. In spirit, this approach is similar to a growing body of research that estimates market distortion in complicated economic and institutional environments. Instead of specifying intricate models to fit particular market settings, many empirical works focus on comparing the observed outcomes to some benchmark counterfactuals derived from classic theories.[7]

My research contributes to three strands of existing literature. First, it quantifies the effect of the monopsonistic cartel with dynamic seller responses on the input market. A growing literature on monopsony power (Chatterjee, 2019; Rubens, 2019) in the agricultural markets documents the negative effect of dominant buyers on prices. Similar works in labor markets (Ashenfelter, Farber and Ransom, 2010; Azar, Berry and Marinescu, 2019; Card, Cardoso, Heining and Kline, 2018; Goolsbee and Syverson, 2019; Manning, 2003) also find that monopsonistic employers exert a negative effect on wages. Recent research from legal and antitrust policy perspectives calls for more attention to monopsony's adverse effects on both sellers and overall market efficiency (Blair and Harrison, 2010; Hemphill and Rose, 2018; Werden, 2007). To my best knowledge, this paper is the first to consider the monopsony strategy under dynamic market responses. My results suggest that the static model understates the welfare loss from monopsonistic market power.

Second, this paper contributes to the literature on the inner workings of cartels. Past research dissects specific cartel strategies across different market and regulatory environments (Marshall and Marx, 2012; Röller and Steen, 2006). Some have emphasized the role of com-

[7]For examples of measuring market distortion by comparing empirical outcomes with theoretical counterfactuals, see Asker, Collard-Wexler and De Loecker (2019) on global oil production, Borenstein, Bushnell and Wolak (2002) on the California electricity market, and Rafey (2019) on the Australian water market.

munication in sustaining collusion (Genesove and Mullin, 2001; Harrington and Skrzypacz, 2011). I present new evidence that a monopsony cartel can use frequent communication to employ a more complicated dynamic strategy to manipulate the market. This paper provides a first-order estimate on the cartel damage and expands our understanding of the strategic toolkit available for cartels. The results also highlight the need for theoretical advances in monopsony collusion and coordinated market manipulation.

Finally, the analysis complements previous research on the meatpacking cartel by quantifying the effect of the manipulation strategy. The meatpacking cartel was one of the largest manufacturing cartels in U.S. history and was among the first to be challenged in court. Prior research has detailed the impact of regulatory changes (Aduddell and Cain, 1981; Libecap, 1992), the evolution of the cartel (Yeager, 1981), and innovation in management (Chandler Jr., 1993). I extend the past narrative and reduced-form results by highlighting the excess welfare loss created by the dynamic manipulation strategy.

The rest of the paper is structured as follows. Section 4.2 describes the meatpacking industry and the cattle wholesale market. Section 4.3 introduces the data. Section 3.4 presents descriptive evidence on the effectiveness of the dynamic strategy. Section 3.5 sets the analytical framework for the market under static strategy. Section 4.4 discusses identification of the spot-market supply and demand, and presents the estimation results. Section 3.7 presents the counterfactual analysis.

3.2 Historical Background of the Meatpacking Cartel

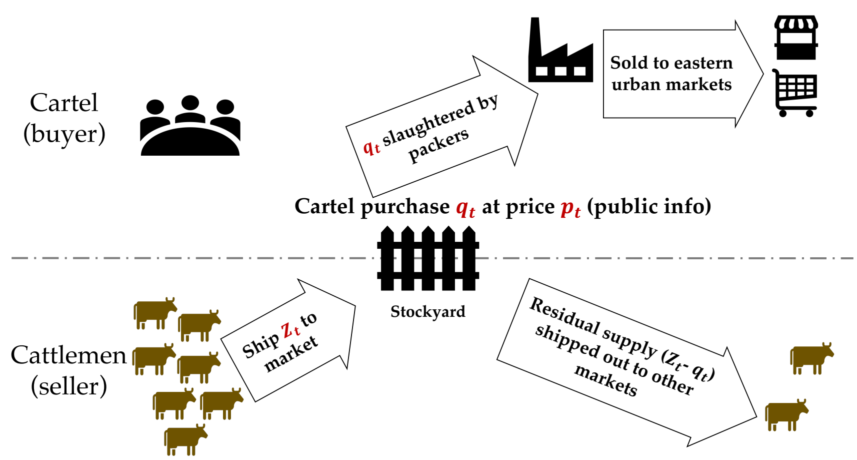
In this section, I offer some historical background on the meatpacking industry and the meatpacking cartel, and I describe the evolution of the regulatory environment between 1893 and 1918. The nature of the livestock market and the meatpacking industry provides the basis for the structural model I describe in Section 3.5. An exogenous regulatory change allows me to identify key parameters for the model I describe in Section 4.4.

3.2.1 History of the Meatpacking Industry

The introduction of mechanical refrigeration and the subsequent adoption of ice-refrigerated rail cars by Chicago meatpackers in the 1880s created the modern meatpacking industry (Anderson, 1953). Instead of shipping live cattle to eastern markets, packers could now ship just the carcasses in tightly-packed refrigerated rail cars. On the one hand, refrigerated rail cars greatly reduced the shipping cost of beef: carcasses could be shipped for one-third the cost of shipping live cattle (Bureau of Animal Industry, 1884; Skaggs, 1986). On the other hand, the fixed cost of constructing specialized rail cars, ice plants, and refrigerated warehouses along the transportation lines created high barriers to entry.By the early 20th century, five firms (the "Big Five") had come to dominate the meatpacking industry.

Figure 3.1 illustrates the production chain of the meatpacking industry. The cartel dominated both the live-cattle wholesale market in the Midwestern stockyards and the refrigerated beef wholesale market in the urban centers of the eastern United States.

Figure 3.1: Meatpacking Industry Value Chain



Note: Cattle wholesale market data reported the variables in red: number shipped into the stockyard, market price, and number of cattle purchased/slaughtered by packers at the stockyard.

The Big Five dominated both the live cattle market and the urban wholesale beef market.

On the cattle market, the Big Five were the dominant buyers. In 1916, they slaughtered 6.5 million head of cattle, generating 82.2% of all wholesale refrigerated beef sold in interstate commerce (Federal Trade Commission, 1919). They purchased most of the cattle shipped to the stockyards and accounted for almost all cattle slaughtered (see Table 3.1). On the downstream wholesale beef market, refrigerated beef constituted 75% of beef in New York City, 85% in Boston, 60% in Philadelphia, and 95% in Providence (Bureau of Corporations, 1905).

Table 3.1: Concentration of Refrigerated Beef Production, 1916

Stockyard	Head Slaughtered	"Big Five",%	Interstate Slaughter,%
Chicago	1,949,735	87.1	24.5
Kansas City	1,169,658	99.6	14.7
Omaha	806,863	100.0	10.2
St. Louis	694,715	89.2	8.7
NYC	409,917	97.7	5.2
St. Joseph	311,848	99.4	3.9
Fort Worth	364,014	100.0	4.6
St. Paul	230,452	100.0	2.9
Sioux City	203,482	100.0	2.6
Oklahoma City	174,541	100.0	2.2
Top 10 Stockyards	6,315,225	94.6	79.5
Total Interstate Slaughter	7,947,798		

Note: Data from the *FTC Report on the Meat Packing Industry*, Vol 1. The 10 largest packing centers are ordered in size.

3.2.2 Cattle Production and the Stockyard Spot-Market

Aggregate cattle supply at the stockyards responded to past prices. During this period, Cattle production was concentrated in the Midwest.[8] Small feedlot farmers shipped live cattle to stockyards, where they were sold on the spot-market. Proximity to stockyards

[8]Figure 3.10 displays the spatial distribution of cattle in 1910. Illinois, Wisconsin, Iowa, and Kansas had the highest cattle density. About 85 percent of beef steers shipped to Chicago stockyard were fattened by feedlot farmers in the "corn belt" (Clemen, 1923).

allowed these farmers to respond quickly to price fluctuations when making their shipment decisions. In a 1905 report, the Bureau of Corporations noted "there is always a large potential supply of cattle ready or nearly ready for market compared with the amount actually shipped [...] and a large number, therefore, can be rushed to market at a day's notice if the prices are sufficiently attractive." (Bureau of Corporations, 1905).

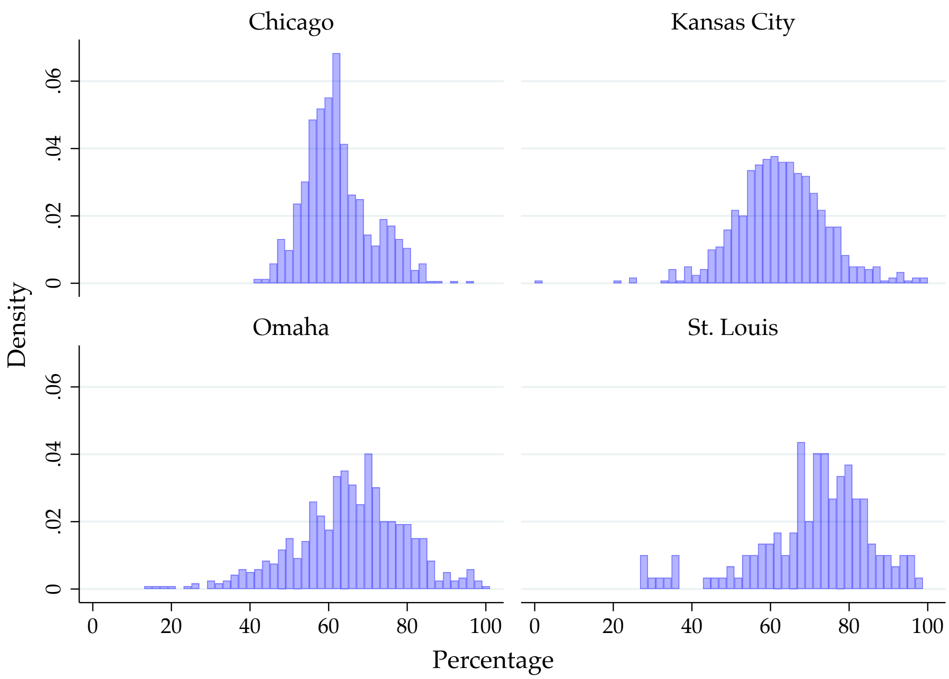
The stockyard markets were composed of inelastic, price-taking sellers and the monopsonistic meatpacking cartel. Chicago's Union Stock Yards, for example, received on average nearly 10,000 cattle per day. The total number of cattle available for sale on the market dwarfed the capacity of any individual seller. Further, the high cost to ship live cattle led to inelastic supply decisions on the spot-market. It cost between \$4.43 and \$8.03 to ship a steer from a feedlot in Kansas to Chicago, while average profit per head was \$12.70 over the same period (Skinner, 1912).[9] Therefore, cattlemen were reluctant to take their cattle off the market once they arrived at the stockyards.

The spot-market trading environment was conducive to collusion among the meatpackers. Livestock trading occurred in the open market, where packers could directly observe the realized quantity and prices of other buyers (see Figure 3.12).[10] In other words, cartel members could easily monitor compliance with their collusive agreements at little cost.

[9]This cost covers the freight (\$0.25-\$0.55 per 100 pounds), as well as feed along the route, driving the cattle from feedlot ,and loading them onto rail cars. Andrews (1908).

[10]In fact, the quantity purchased by each packer was published in livestock trade journals (see Figure 3.14). Also, the meatpackers built their slaughtering and packing plants adjacent to the stockyard to minimize the travel distance from market to production line. Figure 3.15 is a map of Chicago Union Stock Yards; it shows that all the major packing plants were located next to the stockyard.

Figure 3.2: Percentage of Cattle Purchased by the Big Five



Note: Data are from *The National Provisioner*.

There *was* a large alternative market for live cattle beyond the stockyards. Figure 3.2 plots the distribution of the share of cattle in the stockyards purchased by the cartel. On average, 15% of cattle shipped to the stockyards were not sold on the spot-market. Rather, cattlemen, unhappy with the spot-market conditions, would forward their livestock to be sold in the outside market. In 1909, slaughtering and meatpacking establishments processed 59.6% of all cattle slaughtered for food in the United States (1909 Census of Manufactures). The rest were processed in retail slaughterhouses near urban markets or on-farm. Cities closer to the Corn Belt, such as Cleveland, Cincinnati, and Indianapolis, relied more on local slaughter for fresh, unrefrigerated beef. In these cities, packers contributed less than a third of the fresh beef supply (Bureau of Corporations, 1905).

3.2.3 Refrigerated Beef Production

The main variable cost of refrigerated beef production was the cost of live cattle; labor and other variable costs were low. According to the 1909 Census of Manufactures, in the slaughtering and meatpacking sector, wages and salaries accounted for only 5.4% of total production cost, while nonfuel materials, primarily livestock, accounted for 90.7% of production cost. In addition, labor was a perfect complement to the material input (cattle). Workers never secured a contract with fixed hours of work. Instead, they received hourly wages to "work until the day's killing is done" (Commons, 1904).

3.2.4 The Meatpacking Cartel

Between 1893 and 1918, the Big Five formed a cartel that controlled both the live cattle market and wholesale beef market. In 1913, regulatory changes forced the cartel to switch from a dynamic manipulation strategy to a static non-manipulation strategy.

Phase 1: Cartel Used Dynamic Strategy to Manipulate the Livestock Market

Between May 1893 and July 1912, the cartel used dynamic strategies to manipulate the livestock market. Though the Sherman Act was passed in 1890, enforcement against anti-competitive practices was lax.[11]

In the livestock wholesale market, the cartel not only fixed the market share and charged the same price but also used its market power to manipulate cattle prices to gain more than a monopsony. The strategy is best summarized by Circuit Judge Peter Grosscup in a 1903

[11] In the 1894 case *United States v. E.C. Knight Co.*, the Supreme Court ruling exempted manufacturing from "interstate commerce" restrictions, effectively barring the federal government from pursuing antitrust action against manufacturing firms under the Sherman Act. In 1898, in *Hopkins v. United States*, the court held that livestock trade occurring at the Kansas City stockyards did not constitute interstate commerce; this ruling further restricted application of the Sherman Act to the livestock market (Walker, 1910).

case[12]:

> That the defendants are engaged in an unlawful combination and conspiracy under the Sherman Act in (a) directing and requiring their purchasing agents at the markets where the livestock was customarily purchased, to refrain from bidding against each other when making such purchases; (b) *bidding up through their agents, the prices of livestock for a few days at a time, to induce large shipments, and then ceasing from bids, to obtain livestock thus shipped at prices much less than it would bring in the regular way*; (c) in agreeing at meetings between them upon prices to be adopted by all, and restriction upon the quantities of meat shipped. [emphasis added]

In 1905, in a unanimous decision, the U.S. Supreme Court upheld the lower court's ruling (*Swift & Co. v. United States*, 196 U.S. 375)[13]. In the majority opinion, Justice Oliver Wendell Holmes wrote:

> For the same purposes [to restrain competition], *the defendants combine to bid up, through their agents, the prices of livestock for a few days at a time, so that the market reports will show prices much higher than the state of the trade will warrant, thereby inducing stock owners in other States to make large shipments to the stockyards, to their disadvantage.* [emphasis added]

The main intuition behind the cartel's strategy was that it could exploit the highly responsive aggregate shipment to stockyards and the inelastic spot-market supply to "hold up" sellers.[14]

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[12] *United States v. Swift & Co.* (122 F 529).

[13] Though the court never overruled the decision in *United States v. E.C. Knight*, here the court held that the federal government can regulate manufacturing when it affects interstate commerce.

[14] Figure 3.11 presents two numeric examples to show that manipulating the market created higher profits

Though courts issued injunctions against certain anticompetitive behaviors in the aforementioned cases, the injunctions were weakly enforced and they had no explicit restriction against potential price manipulation. The Big Five continued to meet every week until July 1912, when the Department of Justice brought new charges against them. Despite abundant evidence on their collusive behavior, the grand jury found the packers and their executives not guilty for restraining trade under the Sherman Act.[15]

Phase 2: Cartel was Forced to Adopt Static Strategy

In 1913, after halting their weekly collusive meetings, the cartel resorted to a fixed-market-share agreement. The packers, though found not guilty in the 1912 case, decided the weekly meetings were too risky to continue. Though they had previously been challenged in court by state and federal authorities, their perception of their legal risk did not change until a couple of landmark cases in the 1910s. In particular, rulings against Standard Oil and American Tobacco made the packers legally more vulnerable in the ensuing civil case (Federal Trade Commission, 1919). The Big Five maintained their market-share agreement until 1920, when they were eventually forced to divest the production chain under a consent decree.

3.3 Data

I collected weekly livestock market data from historical trade journals to quantify the effect of market manipulation facilitated by weekly cartel meetings. These data cover the four largest stockyards from 1903 to 1918. Figure 3.3 shows where the data lie on the overall

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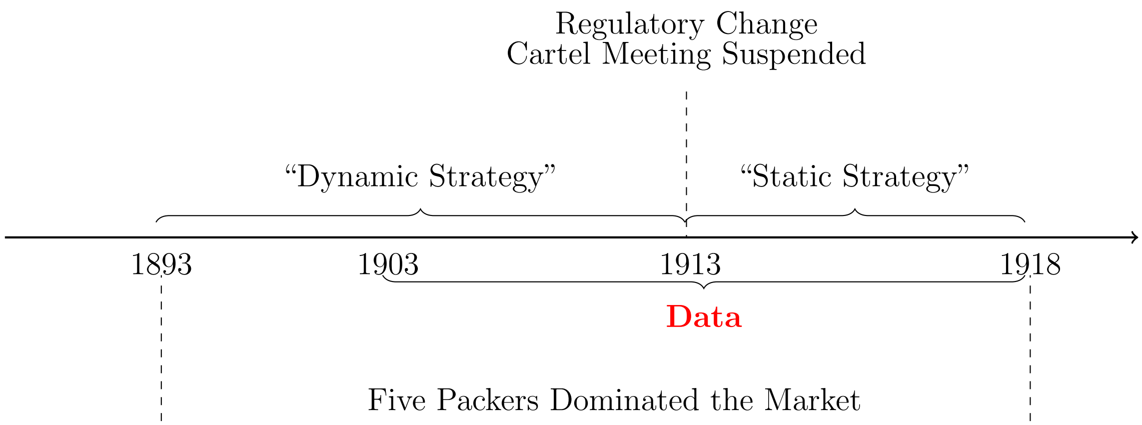
than the static monopsony strategy.

[15] Minutes of the weekly director meetings of the National Packing Company were admitted as evidence in court, showing the presence and participation of cartel executives. The court also admitted evidence of weekly telegraphs summarizing shipments and prices for every meeting. (*The National Provisioner*, March 9, 1912.) The consensus among contemporary newspapers and historians later was that jurors were reluctant to impose criminal penalties upon the socially prominent defendants, whereas only civil charges were brought in the previous antitrust cases against industry giants (Lamoreaux, 2019).

time frame. To analyze the decisions of both the cattlemen and the cartel, I combined this livestock market data with information on input cost and downstream sales.

Figure 3.3: Event Timeline and Data Coverage



3.3.1 Livestock Market Data

I collected weekly cattle trade data from *The National Provisioner* for 1903 to 1918 on the four largest stockyards: Chicago, Kansas City, St. Louis, and Omaha. This trade journal published weekly data on the number of cattle shipped into the stockyards, the number of cattle slaughtered (i.e., purchased by the cartel), the number of cattle that left the stockyards, and wholesale cattle prices,[16] as well as wholesale refrigerated beef prices in New York City. These data allow me to directly measure cattlemen's aggregate shipment decision as well as the cartel's input quantity and price. The weekly publication also noted cases in which transactions were affected by exogenous events such as disease quarantine or extreme weather. I exclude all such cases from my analysis. Appendix 3.A.1 provides details on variable construction and validation.

Table 3.2 provides the summary statistics of the cattle market. On average, more than 9,000 head of cattle a day were shipped to the Chicago's Union Stock Yards, 60% of which

[16]Figure 3.14 shows examples of the weekly publication.

were purchased in transactions valued at $1 million. The other three stockyards operated on a smaller scale, but they were all dominated by the same packers.

Table 3.2: Summary Statistics

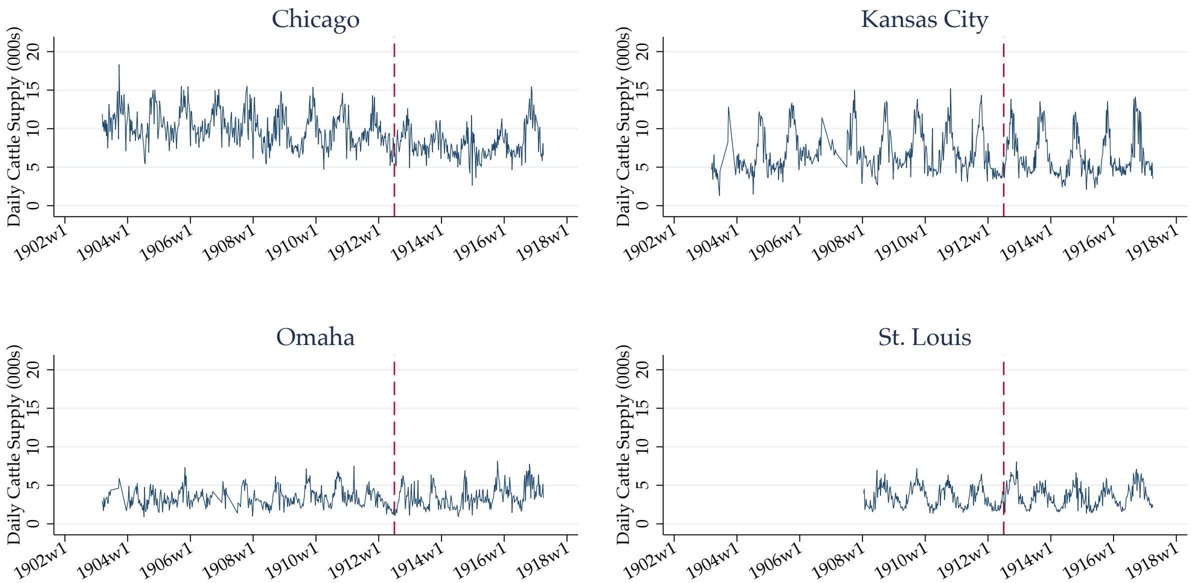
	Chicago (1)	Kansas City (2)	Omaha (3)	St. Louis (4)	All Four Stockyards (5)
Cattle Price (per cwt, $1920)	17.49	16.52	16.38	18.64	16.99
	(3.03)	(2.65)	(2.49)	(1.78)	(2.78)
Average Daily Shipment (000s)	9.44	6.76	3.47	3.47	6.63
	(2.35)	(2.71)	(1.28)	(1.44)	(3.31)
Share of Total Shipment Slaughtered (%)	62.53	64.50	72.41	73.56	66.50
	(8.80)	(13.25)	(23.06)	(18.24)	(16.21)

Note: Price and quantity data are from *The National Provisioner*.

Cattle supply exhibits large variations from week to week. Figure 3.4 displays the average daily shipment for each stockyard. The cattle supply exhibits obvious seasonality, driven by the natural production cycle of cattle. The supply also varied widely from week to week.[17] In other words, the aggregate supply at the stockyard spot-market can be drastically different from one week to the next, even for cattle fattened over the same period with similar feed costs.

[17]The coefficient of deviation for the average shipment is 0.49.

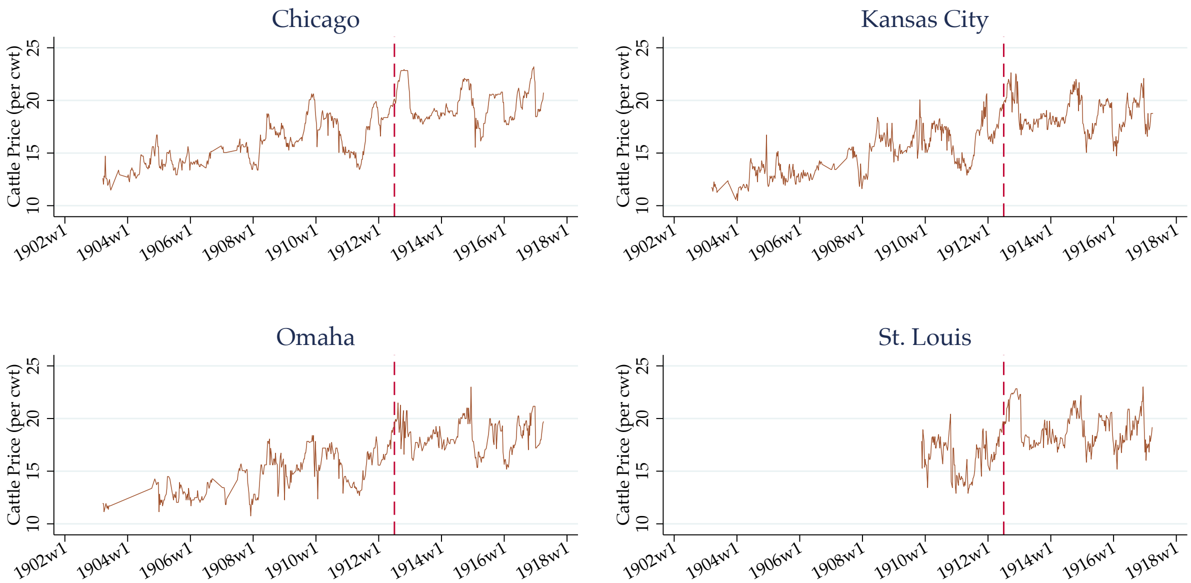
Figure 3.4: Average Daily Shipment Into the Stockyards



Note: Data are from *The National Provisioner*. The early reporting for Omaha and St. Louis, and occasionally for Kansas City, was irregular (e.g., not all days of the week were reported). For the analysis, I include only the weeks with more than two days of reported shipments. The plots only include data before the United States joined WWI on April 6, 1917.

Spot-market prices for cattle also varied dramatically from week to week (see Figure 3.5). As a benchmark, the average profit margin per head of cattle is $12.80 in 1909 (University of Illinois at Urbana-Champaign Agricultural Experiment Station, 1912). Thus, a $0.25 drop in the wholesale price would wipe out 30% of a cattleman's net profit.

Figure 3.5: Cattle Price by Stockyards



Note: Data are from *The National Provisioner*. Cattle price is the weekly high top value for "Good to Prime" steers.

3.3.2 Auxiliary Data

I collected weekly wholesale prices in New York City for other animal products, such as eggs and lard, from the *Wholesale Price Bulletin*[18] and prices for live hogs from the *The National Provisioner*. I consider these animal proteins as substitutes for refrigerated beef. Their wholesale prices in the downstream urban market capture week-to-week consumer demand fluctuations faced by the cartel. Such prices would influence the cartel's demand on the cattle market; therefore, I use them as instrumental variables to estimate the supply parameters.

To control for cost factors of cattle production, I collected monthly wholesale corn and hay prices from the *Chicago Board of Trade Annual Report*.[19] To measure weather shocks, I

[18]Bureau of Labor Statistics (various years), access through https://fraser.stlouisfed.org/

[19]Specifically, I use the No.2 Corn and No.1 Baled Timothy Hay prices. (Chicago Board of Trade, various years)

constructed the area-weighted average of monthly temperature and precipitation using the county-level historical data from Bleakley and Hong (2017).

I used the 1917–1919 *Consumer Expenditure Survey*[20] to estimate the retail demand for beef and other food items. This is the earliest household consumption and expenditure survey available. It provides detailed household expenditure data on 12,817 families of wage earners or salaried workers in 99 U.S. cities, coinciding with the type of urban markets served by the cartel. In Section 3.6.2, I discuss how I constructed the data for demand estimation.

3.4 Descriptive Evidence of the Dynamic Cartel Strategy

Using high-frequency data covering the market with and without frequent cartel communication, I can empirically document the market outcomes under different cartel strategies. In this section, I first quantify the aggregate market effect of the manipulation coordinated through the weekly meetings. I then show that the main difference between the two periods is whether cattlemen could correctly predict market prices. This difference provides the basis for identification in Section 4.4.

3.4.1 Dynamic Manipulation Is Effective

I first use an event-study design to examine how cartel manipulation influences aggregate market outcomes. Because the external legal environment forced the cartel to suspend market manipulation, without changing any other aspects of the market, it is plausible to attribute the changes in aggregate outcomes to frequent cartel communication.

Specifically, I estimate the event-study regression

$$y_{kt} = \alpha_1 \mathbb{I}(\text{Dynamic Period}_{1903-1912}) + X_{kt} + \eta_{kw} + T + \epsilon_{kt} \tag{3.1}$$

[20] Bureau of Labor Statistics (1992). The data is digitized by the Inter-university Consortium for Political and Social Research (ICPSR) and available as ICPSR study 8299.

where y_{kt} is the outcome variable for stockyard k at time t; η_{kw} is the stockyard-by-week-of-the-year fixed effect, which captures the seasonality of the cattle market at each stockyard; T is the time trend; X_{kt} includes lagged weather shocks, lagged input prices, as well as the monthly temperature and precipitation of the counties where the stockyards were located. α_1, the event-study coefficient, represents the average difference of the outcome y_{kt} between the dynamic manipulation and static non-manipulation period.

Table 3.3 shows that market manipulation was effective. During the dynamic manipulation period (1903–1912), 18% more cattle were shipped to the stockyards, and the cartel purchased a smaller share (11.5 % lower) at a lower average price (5.6% lower). Cattlemen's margin, defined as the difference between the wholesale cattle and corn prices, was 34% lower.

Table 3.3: Prices and Quantities During and After Manipulation

	Total Shipments (1)	% of Shipments Purchased (2)	Price (3)	Cattlemen's Margin (4)
Dynamic Period Dummy	1.080***	-7.392***	-1.064***	-1.529***
(03/1903–06/1912)	(0.123)	(2.266)	(0.144)	(0.134)
Time Controls	Yes	Yes	Yes	Yes
Weather Controls	Yes	Yes	Yes	Yes
Cost Controls	Yes	Yes	Yes	No
Observations	2469	2469	2110	2110
Adjusted R-squared	0.97	0.90	0.99	0.85
Mean	5.88	64.50	18.95	4.44
% wrt Mean	18.36	11.46	5.61	34.44

Note: "% of Shipment Purchased" is the share of total shipments into the stockyards purchased at the spot-market. "Cattlemen's Margin" is defined as the difference between cattle price and input cost, which is approximated by the three-month lagged corn price. "% wrt Mean" shows the the estimated coefficient of the manipulation period dummy (first row) as a percentage of the variable's sample mean during the non-manipulation period. The manipulation period covers March 1903 to June 1912. Time controls include stockyard-by-week fixed effects and year trend. Weather controls include quarterly lagged weighted average temperature and rainfall, as well as the current temperature and rainfall in the counties where the stockyards were located. The cost controls include quarterly lagged No.4 Corn and Hay prices at the Chicago Commodity Exchange. The data exclude period when the stockyards were closed due to quarantine or extreme weather. Standard errors are in parentheses.
* $p < 0.10$ **, $p < 0.05$, *** $p < 0.01$

One concern for this event study is the effect of World War I. To avoid this influence, I use only the data from before April 1917, when the United States joined the war, for my main analyses. Though WWI may have spurred agricultural production even before then,[21] the competitive structure at the wholesale livestock market remained unchanged. Therefore, I assume the market behaved the same during this period.[22] Finally, column (4) of Table 3.3 directly addresses the concern about rising price levels caused by the war. Though this is an event study, column (4) can also be seen as a difference-in-differences result, which compares the price of cattle with the price of corn before and after the cartel meetings stopped. The result suggests that under cartel manipulation, cattle prices were lower compared to the price of corn, which was traded in a competitive market throughout the whole period.

3.4.2 Cattlemen Behave Differently Under Static and Dynamic Strategies

As the narrative evidence in Section 4.2 suggests, the cartel benefited from manipulating the total supply of cattle at the stockyard from week to week. Because the weekly data contain both the total number of cattle shipped to the stockyards and the realized market price after their arrival, I can empirically document the cattlemen's behavioral responses under different cartel strategies.

I estimate the relationship between the realized market price and total shipments into the stockyards, controlling for seasonality, production shocks, and general time trend. Specifically,

$$p_{kt} = \alpha_z Z_{kt} + X_{kt} + \eta_{kw} + \tau_y + \epsilon_{kt} \tag{3.2}$$

where p_{kt} is the realized cattle price for the week t in stockyard k; Z_{kt} is the number of cattle shipped to the stockyard; η_{kw} is the stockyard-by-week-of-the-year fixed effect, and τ_y

[21]Agricultural production increased steadily during the second half of the 1910s to satisfy robust export demand (Henderson et al., 2011).

[22]I explicitly control for the production cost of cattle. I use the price of corn and hay to approximate the input cost in cattle production. One can view this as an approximation for the actual cost of feed, or as the opportunity cost of raising cattle instead of growing grains.

is the year fixed effect.[23] X_{kt} include the same set of weather and cost controls as in (3.1). Note that cattlemen made the shipment decisions *before* they observed the market price for the week. Therefore, α_z captures whether cattlemen's shipment decisions are "correct": if they correctly predicted the market condition and shipped more cattle when the market price turned out to be high, one would expect α_z to be positive.

Table 3.4 shows the estimation for α_z under different cartel strategies. The first two columns cover the dynamic manipulation period; the estimated coefficient suggests that the total number of cattle arriving at the stockyards during the dynamic manipulation period did not correlate with the realized market price. When the cartel stopped manipulating the price, however, more cattle were shipped to the stockyards when the realized price was high, as suggested by the positive and significant coefficient in columns (3) and (4).

[23] In the event-study regression, I include only the year trend because of the dummy variable for the dynamic manipulation period. In (3.2), because I estimate the results for dynamic manipulation and static non-manipulation periods separately, I can include year fixed effects to control for potential nonlinear changes in the trend.

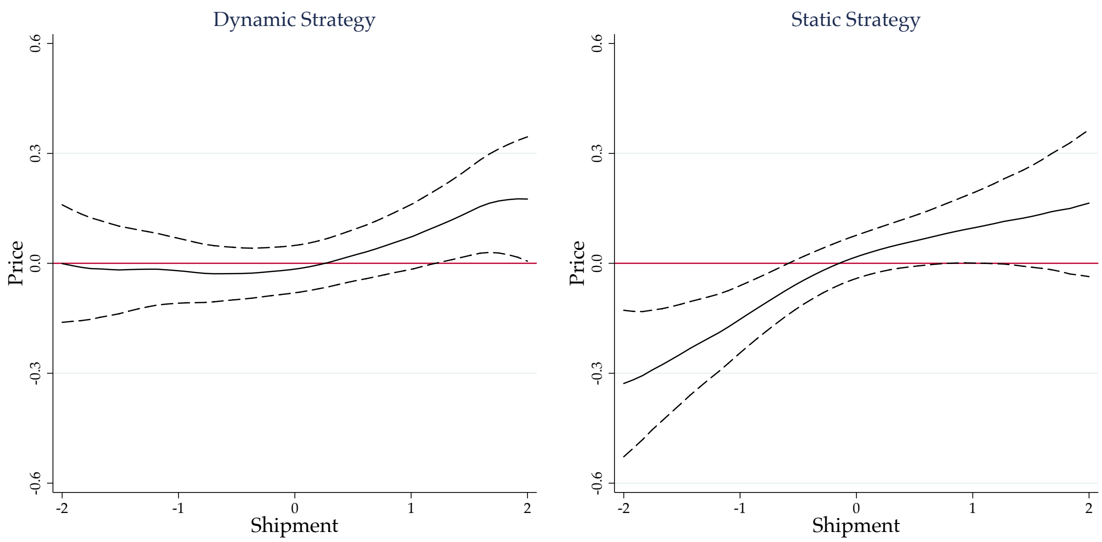
Table 3.4: Prices vs. Shipments

Dependent variable: Cattle Price	Manipulation		Non-Manipulation	
	(1)	(2)	(3)	(4)
Daily Average Shipment	-0.010	0.040	0.102***	0.115***
	(0.030)	(0.029)	(0.037)	(0.035)
Time Controls	Yes	Yes	Yes	Yes
Lagged Corn Price	No	Yes	No	Yes
Weather Controls	No	Yes	No	Yes
Observations	1317	1309	798	798
R-squared	0.79	0.81	0.65	0.70

Note: The table shows the regression coefficients α_z of price on average daily shipment, $p_{kt} = \alpha_z Z_{kt} + X_{kt} + \eta_{kw} + \tau_y + \epsilon_{kt}$. Weather controls include quarterly lagged weighted average temperature and rainfall, as well as the current temperature and rainfall in the counties where the stockyards were located. The cost controls include quarterly lagged No.4 Corn and Hay prices at the Chicago Commodity Exchange. The data exclude period when the stockyards were closed due to quarantine or extreme weather. Columns (1) and (2) cover the whole manipulation period. The point estimates for the manipulation period are either negative or statistically zero, suggesting that total shipments are not positively related to the actual realized market price. Columns (3) and (4) show the results for the non-manipulation period, where shipments are positively correlated with realized price. In other words, cattlemen correctly predicted the market during the non-manipulation period, where larger shipments to the stockyard coincided with higher prices. Standard errors are in parentheses.
$p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Figure 3.6 depicts the estimation for (3.2), plotting the flexible local linear regression with the full set of controls (columns (2) and (4) in Table 3.4). During the dynamic manipulation period (left panel), no obvious relationship exists between total shipment and realized price. In other words, when cattlemen shipped a large number of cattle to the market, they may not have received favorable prices. When the cartel stopped manipulating the market price, however, the relationship between price and total shipment resembles a typical supply curve, where larger total shipments into the stockyard correspond to higher prices.

Figure 3.6: Prices vs. Shipments



Note: The solid line is a local linear regression of cattle price on daily average shipment, where both values are residualized using week fixed effects, year trend, one-quarter lagged average temperature and precipitation, and up to one-year quarterly lagged corn price. The dash lines are 95% confidence intervals.

I conduct two main robustness checks to show that the results are not driven by learning or by changes in the available market outlet. One concern is that cattlemen may have learned more about the market over time, implying that the estimation using the whole dynamic manipulation period may be biased. The second concern is that, because marginal cattlemen could have shipped to either one of the stockyards, they may have behaved differently when multiple stockyards were closed (due to animal quarantine or extreme weather). Table 3.13 presents the estimations for the two robustness checks. Results in columns (1) and (2) show that cattlemen behaved the same in both the early and late halves of the dynamic manipulation period.[24] Columns (3) to (6) show that results from the main specification in Table 3.4 still hold after restricting the sample to only the periods with data from at least

[24]Given that the data cover the second half (1903–1912) of a two-decade-long manipulation scheme (1893–1912), this result is consistent with the assumption that the market should have arrived at an empirical equilibrium state after ten years.

three stockyards.

3.4.3 Cartel Members Did Not Deviate

The observed cartel outcome during the static period coincides with the optimal cartel strategy only if cartel members did not cheat. Past research shows that cartels may have used frequent meetings also to resolve other disagreements among the members (Genesove and Mullin, 2001). Therefore, suspending the weekly meetings may cause potential deviation from the collusive agreement and thus sub-optimal cartel outcomes.

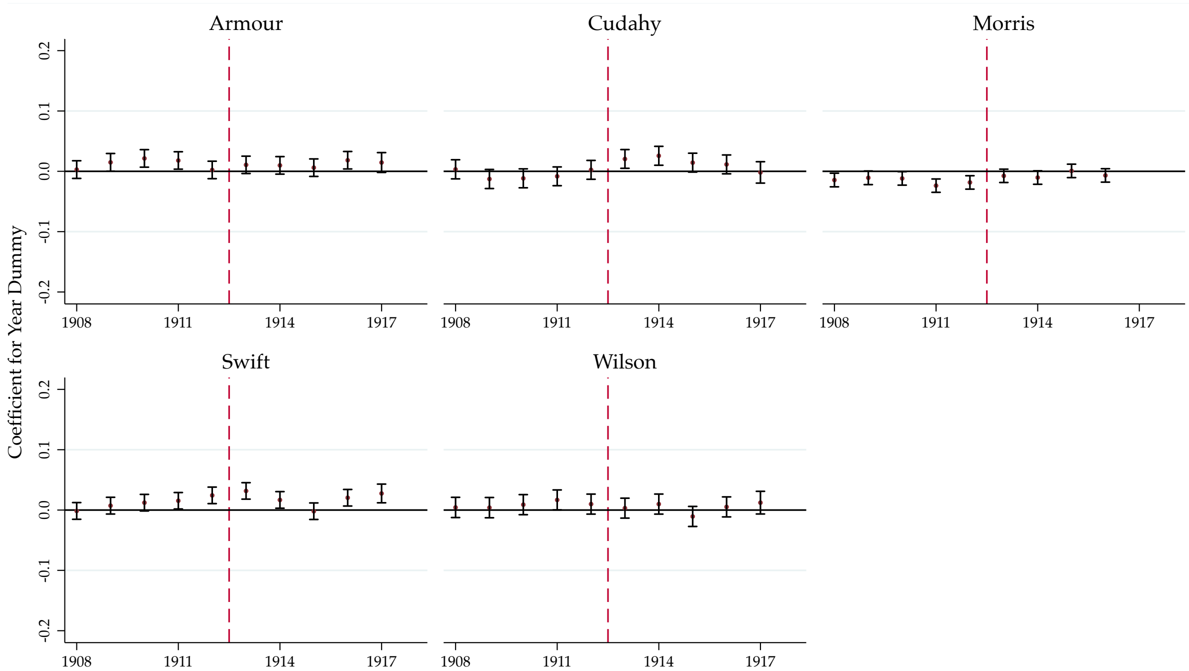
To show that cartel members did not deviate under the static strategy, I test whether the observed market share among the packers remained unchanged during the non-manipulation period . Specifically, I estimate the coefficients for the year dummies α_y in

$$s_{ft} = \sum_{y=1905}^{1917} \alpha_y \mathbb{I}(Year = y) + \epsilon_{ft}$$

where s_{ft} is the market share of firm f.

Figure 3.7 plots the estimated coefficient. Despite large week-to-week fluctuations in aggregate market supply, relative market share among the Big Five remained constant throughout the whole period. This suggests that cartel members did not deviate from their collusive market-share agreement after they suspended the weekly meetings. This is consistent with the narrative evidence described in Section 3.2.2: the stockyard environment made it hard for cartel members to cheat even without frequent meetings. Cartel members could directly observe the quantity purchased by other packers and the price they paid.

Figure 3.7: Cartel Members Did Not Deviate



Note: The graph plots the coefficient for year dummies in the regression $s_{ft} = \Sigma \alpha_y \mathbb{I}(Year = y)$, where s_{ft} is the market share of firm f. This analysis uses data of cattle purchases by each cartel in the Kansas City Stockyard, which has the longest data series of firm purchases and covers both the manipulation and the non-manipulation periods.

3.5 Analytical Framework of the Cattle Spot-Market

In this section, I present a structural model of spot-market cattle supply and cartel demand. Though results from the event study provide an arguably causal estimate on the effect of the dynamic cartel strategy on input market price and quantity, it provides only limited information on the underlying mechanism. In particular, it does not capture the counterfactual market outcome with both price and quantity changes, nor does it provide any information on the corresponding influence on the markdown. Therefore, I developed the structural model to estimate what would happen during the dynamic period if the cartel were to adopt a static strategy. The main goal is to quantify the effect of dynamic cartel manipulation by comparing the empirical outcomes with the counterfactuals under static cartel strategy.

On the supply side, cattlemen make spot-market supply decisions following a discrete choice model: cattlemen choose between selling to the cartel and selling to the competitive market outside the stockyard. I use the standard logit choice model to capture cattlemen's sales decisions. On the demand side, I specify the static cartel problem: the cartel chooses the quantity of cattle, facing both upward-sloping input supply and downward-sloping demand, as it was also the monopoly seller of refrigerated beef.

I estimate downstream demand faced by the cartel separately, with the Almost Ideal Demand System. I then combine the spot-market supply and downstream retail demand to characterize the cartel's equilibrium static strategy for counterfactuals.

This modeling choice is driven primarily by the historical market setting. Regulatory changes forced packers to adopt the static strategy, without changing any other aspects of the market. This allows me to directly estimate the static equilibrium with observed market outcomes under the static strategy. One intuitive alternative would be to specify the model under the dynamic strategy. However, the equilibrium solution under the dynamic strategy requires strong assumptions on how cattlemen and the cartel formed their expectations on the future market. Instead, leveraging the historical setting, I focus on solving the model under static conditions and use the estimated static model to derive the counterfactuals. This approach is effective for estimating the scope and severity of cartel damages, though it is less informative about the specific mechanism of the cartel manipulation.

3.5.1 Cattlemen's Spot-Market Supply

Following Berry (1994), I use a logit discrete choice model to capture cattlemen's spot-market supply decisions. For cattleman i, he can sell to buyer j: $\mathcal{J} = \{\text{cartel, outside}\}$. As in Section 3.2.2, because of the high shipping cost, I assume that sellers cannot take the cattle off the market and have to either sell to the cartel at the stockyard or forward the cattle farther east to an outside market.

The utility for cattleman i depends on price p_{jt}, time-invariant characteristics of the buyer γ_j, and the error term ξ_{ijt}. Specifically, γ_j is an indicator variable for the cartel. This includes features such as auxiliary services like cattle loan company managed by the packers at the stockyards. I also control for other factors that may influence cattle supply, such as seasonality, with X_t. Therefore,

$$U_{ijt} = \gamma_p p_{jt} + \gamma_x X_t + \gamma_j + \sigma_{jt} + \epsilon_{ijt} \tag{3.3}$$

where the idiosyncratic preference ϵ_{ijt} follows the type-I extreme value distribution; σ_{jt} is the unobserved time-varying characteristics of the buyer that may enter cattlemen's utility (e.g., railroad accidents or strikes). I further normalize the utility of selling to non-cartel buyers to be zero, or $U_{i,outside,t} = 0$.

Following the standard logit form, (3.3) leads to the market-share expression

$$\ln(S_{cartel,t}) - \ln(S_{outside,t}) = \gamma_p p_{cartel,t} + \gamma_x X_t + \gamma_j + \sigma_{jt} \tag{3.4}$$

where $S_{cartel,t}$ is the share of cattle purchased by the meatpacking cartel, and $S_{outside,t}$ is the share transported out of the stockyard to an outside market.

Given the market-share expression, the spot-market price elasticity of cattle supply can be expressed as

$$e_s = \gamma_p p_{jt}(1 - S_{jt}) \tag{3.5}$$

In a market with Z_t cattle arrived at the stockyard, the cartel can expect to purchase q_t^* head at a given price p_t, where

$$q_t^* = \frac{\exp(\gamma_p p_t^* + \gamma_x X_t + \gamma_j)}{1 + \exp(\gamma_p p_t^* + \gamma_x X_t + \gamma_j)} Z_t \tag{3.6}$$

3.5.2 Cartel's Demand

Based on the production process described in Section 3.2.3, I assume that (1) there is no substitution between cattle and other variable inputs and (2) all inputs can be adjusted without cost. The two assumptions lead to a Leontief production function for the cartel:

$$m_t = \min\{\theta_1 q_t, \theta_2 v_t\}$$

A packer uses q_t head of cattle and v_t units of other variable inputs to produce m_t units of refrigerated beef. For reference, a 1,200-pound steer yields a 750-pound carcass, or 63% of the input weight. Because the cost of cattle constitutes more than 90% of variable cost, I consider only the cost of cattle in the cartel's cost function:[25]

$$c(m_t) = c(\theta_1 q_t) = p(q_t) \times q_t$$

where $p(.)$ is the spot-market supply function determined by cattlemen's choices.

Because the cartel is also a monopolist seller of refrigerated beef, it faces a downward-sloping demand curve $D(m_t) = D(\theta_1 q_t)$. Therefore, under the static strategy, the cartel chooses optimal quantity q_t^* to maximize per-period profit:

$$\begin{aligned} q_t^* &= \arg\max_{q_t} \Pi(q_t) \\ &= \arg\max_{q_t} D(m_t)m_t - p(q_t)q_t \\ \text{s.t. } m_t &\leq \min\{\theta_1 q_t, \theta_2 v_t\} \end{aligned} \tag{3.7}$$

[25] According to the 1909 Census of Manufactures, for the whole slaughtering and meatpacking sector, non-fuel material (cattle) accounted for 90.8% of production expenses; wages (excluding officials and clerks) accounted for 3.9%.

With the cattlemen's supply decision and the cartel's profit function, I can specify the market equilibrium:

Definition 1. Spot-market equilibrium is the set of price and cartel quantities $\{p_t^*, q_t^*\}$ such that the quantity corresponds to the expected spot-market supply given by (3.6), and the quantity also solves the cartel's profit-maximization problem in (3.7).

In particular, the cartel's first-order condition implies

$$(\frac{1}{e_D(m_t^*)} + 1)\theta_1 D(m_t^*) = (\frac{1}{e_s(q_t^*)} + 1)p_t^* \tag{3.8}$$

where $e_D(.)$ is the beef demand elasticity and $e_s(.)$ is the spot-market cattle supply elasticity.

3.5.3 Alternative Dynamic Model

The analysis focuses primarily on the spot-market, where cattlemen interacted with the cartel, and abstracts from discussing cattlemen's shipment decisions. The primary goal is to quantify the distortion created by the dynamic cartel strategy, while taking the empirical aggregate market supply and spot-market elasticity as given. One obvious alternative is to extend the supply side to incorporate cattlemen's shipment decisions with a dynamic discrete choice model and explicitly solve for the cartel's dynamic strategy given cattlemen's responses.

Appendix 3.A.3 presents the dynamic discrete choice model of cattle shipment. Every period, cattlemen decide whether to ship their cattle to the stockyards, given expected spot-market prices formed after observing the state of the market (the previous week's price). This is analogous to the dynamic choice in job-search literature in which a worker chooses between accepting an offer or waiting for the next period. Appendix 3.A.4 discusses the dynamic cartel strategy when the cartel incorporates future supply responses in its decisions. This provides the intuition behind the manipulation: with elastic shipment decision and inelastic spot-market supply, the monopsonistic cartel can create a temporary glut and take advantage of the inelastic suppliers after they arrive at the spot-market.

However, two factors make this approach less desirable. First, estimating the dynamic discrete choice of shipment decisions requires data on the relative market share of *shipment* to the stockyards and the outside competitive market, which is not available at the weekly level. Second, solving for the equilibrium under the dynamic cartel strategy requires an explicit belief structure. Section 3.4 suggests that cattlemen's behavior was not consistent with rational expectations. Meanwhile, scant evidence exists to support any specific belief forms.

The historical setting allows me to analyze the effect of cartel manipulation without estimating the dynamic decisions on either the cattlemen or the cartel. The drawback of this approach is that the counterfactual results are of a partial equilibrium nature: they do not account for the changes in total supply to stockyards or aggregate cattle production under the static strategy. However, because the wholesale market price of cattle would be higher under the static cartel strategy, supply to the stockyards and aggregate production would both be higher than the observed value during the dynamic manipulation period. Therefore, the counterfactual results that take the empirical supply and production levels as given correspond to a lower bound of the effect of the cartel strategy on the input market.

3.6 Identification and Estimation

I start by estimating the supply function and calculating the input-price markdowns of the spot-market cattle supply under different cartel strategies. I then estimate the demand for refrigerated beef and construct the cartel's quantity decision given the cattle supply and beef demand. I use these results in the next section to simulate counterfactuals.

3.6.1 Spot-Market Supply

As discussed in Section 3.5.1, estimating spot-market elasticity with observed market share and price data faces the typical simultaneity problem in industrial organization: the unobserved market shock σ_{jt} may influence both market price p_{jt} and cartel demand.[26] A demand shifter can be used as an instrument for price to identify the spot-market supply function. Because the volume of cattle purchased by the cartel is influenced by the downstream demand for refrigerated beef, I use the retail price of beef substitutes to instrument for the cattle price. Specifically, I use the lagged downstream price of eggs, lard, and live hogs as instruments for cattle prices at the stockyards.

I estimate (3.4) separately for the dynamic and static periods. As discussed in Section 3.4.2, the marginal cattlemen on the market are different in the dynamic and static periods, and therefore need to be estimated separately to account for their potentially different sales decisions. Table 3.5 presents the estimated coefficient for γ_p. Different price instruments generate similar point estimates for the coefficient.

[26]One example of such shocks is railroad accidents, which influence both shipment of live cattle to outside markets and the cartel's productivity.

Table 3.5: Spot-Market Supply

	Dynamic Manipulation			Static Non-manipulation		
	(1)	(2)	(3)	(4)	(5)	(6)
Cattle Price (1920$)	-0.114	0.023	-0.049	0.118**	0.136**	0.096*
	(0.069)	(0.027)	(0.035)	(0.054)	(0.061)	(0.050)
Instrument Price	Egg	Lard	Live Hog	Egg	Lard	Live Hog
Average Elasticity	-0.65	0.13	-0.28	0.80	0.93	0.65
Observations	876	876	578	507	507	443
R-squared	0.46	0.52	0.57	0.58	0.58	0.65
First-stage F-statistic	4.33	28.46	19.33	19.74	14.89	24.63

Note: The table shows the regression coefficient γ_p in equation (3.4). The dependent variable is $\ln(S_{cartel,kt}) - \ln(S_{outside,kt})$. All estimations control for stockyard-by-week fixed effects, year fixed effects, one-quarter lagged average temperature and precipitation, and one-quarter lagged corn price. The sample excludes the top and bottom 5% of observations. Average elasticity is calculated as the average of estimated elasticity $e_s = \hat{\gamma_p} p(1 - \hat{S})$, where $\hat{\gamma_p}$ is the estimated coefficient for price and $\hat{\gamma_p}$ is the estimated cartel market share. Instrument prices are from the *BLS Wholesale Price Bulletin*. Standard errors are in parenthesis.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

To interpret the result, I calculate the corresponding elasticity following (3.5). The spot-market supply was inelastic when the cartel adopted the static strategy: for example, when using live hogs as an instrument, a 10% reduction in price would lower the cartel market share by 6.5%. Meanwhile, the estimated coefficient is not statistically different from zero under dynamic manipulation, which implies an even more inelastic spot-market supply. Estimations support the narrative evidence that the cartel manipulated the market to benefit from the inelastic spot-market supply.

I compare the effect of dynamic versus static cartel strategies on the input market with the same event study as before:

$$y_{kt} = \alpha_1 \mathbb{I}(\text{manipulation}_{1903-1912}) + X_{kt} + \epsilon_{kt} \tag{3.9}$$

where y_{kt} are the elasticity, markdown, and the corresponding cattlemen's share of marginal product at stockyard k. Table 3.6 summarizes the results. Compared to the market under the static strategy, the cattle price markdown is on average 6.2 higher, which implies that the cattlemen received 27.5% less of their marginal contribution to marginal product.

Table 3.6: Effects of Dynamic Manipulation on the Input Market

	Supply Elasticity (1)	Markdown (2)	Input Share of Marginal Product (3)
Dummy for Dynamic Period	-0.529***	6.204***	-0.275***
	(0.005)	(0.069)	(0.002)
Time Controls	Yes	Yes	Yes
Weather Controls	Yes	Yes	Yes
Cost Controls	Yes	Yes	Yes
Observations	1319	1319	1319
Adjusted R-squared	0.93	0.92	0.96

Note: The dynamic period covers March 1903 to June 1912. Input market outcome measures (elasticity, markdown, input share of marginal products) are calculated using the estimation with Live Hog as the instrument. Time controls include stockyard-by-week fixed effects and year trend. Weather controls include quarterly lagged weighted average temperature and rainfall, as well as the current temperature and rainfall in the counties where the stockyards were located. Cost controls include quarterly lagged No.4 Corn and Hay prices at the Chicago Commodity Exchange. The data exclude period when the stockyards were closed due to quarantine or extreme weather. Standard errors are in parentheses.
$p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Spot-market supply is more elastic in larger stockyards. Table 3.7 tabulates the elasticity, markdown, and corresponding cattlemen's share of marginal product, by stockyard. The top panel summarizes the results for the dynamic manipulation period; the bottom panel for the static non-manipulation period. The supply-elasticity measures are slightly larger in Chicago and Kansas City. Intuitively, the larger stockyards were situated in major railroad hubs. This provided cattlemen with easier access to outside markets, and thus relatively more elastic spot-market supply.

Table 3.7: Average Spot-Market Estimation by Stockyard

		(1) Chicago	(2) Kansas City	(3) Omaha	(4) St. Louis	(5) Total
Dynamic Manipulation	Supply Elasticity	0.15	0.13	0.11	0.12	0.13
		(0.02)	(0.02)	(0.03)	(0.02)	(0.03)
	Markdown	7.63	9.09	10.84	9.35	8.95
		(0.89)	(1.53)	(2.37)	(1.02)	(2.04)
	Input share of marginal output	0.13	0.11	0.10	0.11	0.12
		(0.02)	(0.02)	(0.02)	(0.01)	(0.02)
Static Non-manipulation	Supply Elasticity	0.57	0.73	0.70	0.49	0.65
		(0.09)	(0.14)	(0.17)	(0.18)	(0.16)
	Markdown	2.80	2.41	2.53	3.32	2.64
		(0.30)	(0.25)	(0.44)	(0.86)	(0.49)
	Input share of marginal output	0.36	0.42	0.41	0.32	0.39
		(0.04)	(0.04)	(0.06)	(0.08)	(0.06)

Note: The table shows the average estimated elasticity, markdown, and cattlemen's share of marginal output, by stockyard.

3.6.2 Cartel Demand

I estimate the demand for beef $D(.)$ separately using the Almost Ideal Demand System (Deaton and Muellbauer, 1980) and the *1917–1919 Consumer Expenditure Survey*. The demand model corresponds to a two-stage budgeting process: at the higher level, households first choose to allocate expenditures across broad segments of food (meat, dairy, starch, vegetables). At the lower level, households allocate the expenditures for different products in each segment. For example, given the expenditure on meat, a household may choose between beef, pork, mutton, and poultry. Appendix 3.A.2 describes the two-stage budgeting process for estimation.

The survey samples 12,817 "families of wage earners or salaried workers" in 99 U.S. cities. The average household spent \$544 a year on food, 38.4% of its total annual expenditure. The average household consumed 183 pounds of beef per year (see Table 3.8). For comparison, in 2017, Americans consumed 54 pounds of beef per person, or 216 pounds of beef per year for a family of four.[27]

[27] U.S. Department of Agriculture "Food Availability and Consumption" data series

Table 3.8: Summary Statistics for Household Income and Expenditure

	Mean	SD
Annual Household Expenditure		
Main Food Groups (meat, dairy, starch, vegetables)	303.37	34.55
All Food (includes coffee, candy, etc.)	544.37	149.66
Total Expenditure	1419.45	394.84
Income		
Weekly Wage Rate of Husband	26.61	8.25
Annual Household Total Income	1434.04	411.38
Annual Total Consumption (lbs.)		
Beef	183.95	113.47
Pork	41.37	54.73
Starch	1562.62	686.53
Dairy	506.53	285.83

Note: Summary statistics calculated from the *1917–1919 Consumer Expenditure Survey* (Bureau of Labor Statistics, 1992). Values represent the average of 12,817 households in the survey. "Starch" products includes wheat and corn flour, rice, pasta, and other carbohydrates. "Dairy" products include milk, cream, butter, and cheese, etc.

This modeling choice is appropriate from both conceptual and practical perspectives. As a wholesaler, the cartel cared about the general demand for refrigerated beef with respect to other food items such as pork and vegetables. AIDS model is a good first-order approximation for these broad product categories. And though the consumer expenditure survey data contain household demographic and expenditure information, the reported prices on the household level exhibit little variation. In many cases, the implied price of a certain product is identical across all households within a city. This suggests that the surveyor may have imputed total cost or quantity variables using a fixed price. Therefore, for my analysis, I aggregate the data at the city level. The empirical environment restricts me from using other demand models that are feasible only with high-quality micro data.

(https://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/food-availability-and-consumption/) accessed on October 7, 2020.

Table 3.9 presents the summary statistics for price and expenditure share for the items I use in the estimation. Beef contributed to 66% of total household expenditure on meat products. Among all food categories, households allocated more than a third of their food expenditure to dairy and starch (e.g.,flour, rice, pasta), and 26.5% to meat.

Table 3.9: Summary Statistics for Prices and Market Shares

	Price ($/lb)		Expenditure Share (%)	
	Mean (1)	SD (2)	Mean (3)	SD (4)
Meat Products				
Beef	0.29	0.04	66.17	7.08
Pork	0.34	0.03	19.07	7.94
Mutton	0.30	0.05	4.65	5.26
Poultry	0.35	0.04	10.10	3.29
Food Segments				
Meat	0.31	0.03	26.50	3.25
Dairy	0.31	0.04	32.61	5.45
Starch	0.09	0.01	32.12	4.52
Vegetable	0.18	0.05	8.77	1.49

Note: Prices are aggregated up to the city level by expenditure share weight. The upper panel shows the prices and expenditure of the products under the "meat" segment; the lower panel shows the prices and expenditures of the four segments in the food market.

Following Hausman, Leonard and Zona (1994), I use the average price at the census region as an instrument for city-level prices to address the classic endogeneity problem in demand estimation. Suppose regional prices reflect local cost factors such as wages and transportation; they are correlated with city-level prices but uncorrelated with unobserved demand shocks and can therefore be a valid instrument. I report the analysis of variance of prices in Table 3.10. As shown in columns (4) and (5), a significant fraction of the total variance in prices can be attributed to regional variation.[28]

[28] The survey questionnaire asked for annual average quantity and cost on food. The survey was conducted in different months, and respondents might base their answers on recent purchases, but only a small fraction of the variation in price can be explained by time.

Table 3.10: Analysis of Price Variance

Product group/segment	SS Region (1)	SS Month (2)	Total SS (3)	Percentage Explained by Region (4)	Percentage Explained by Time (5)
Meat Products					
Beef	0.079	0.002	0.147	54%	1%
Pork	0.019	0.007	0.104	18%	6%
Mutton	0.061	0.013	0.210	29%	6%
Poultry	0.042	0.003	0.163	26%	2%
Food Segments					
Meat	0.060	0.002	0.115	52%	2%
Dairy	0.061	0.007	0.133	46%	5%
Starch	0.002	0.000	0.007	27%	6%
Vegetable	0.123	0.004	0.203	60%	2%

Note: Prices are aggregated up to city level by expenditure share weight.

Table 3.11 reports the compensated own-price and cross-price elasticity for the lower-level.[29] The own-price elasticity for beef is -1.91.[30] Demand for other meat items appears to be more elastic, which may reflect a general preference for beef, as households spent two-thirds of their meat budget on beef.

[29]Estimates for higher-level elasticities are in Table 3.14. Demand coefficients are reported in Table 3.15 and Table 3.16.

[30]Other researchers find that the own-price elasticity of beef ranges from -0.998 in the U.S. in 1993 (Kinnucan, Xiao and Hsia, 1996) to -1.19 in the 1970s (Eales and Unnevehr, 1993), to -1.95 in post-WWII Australia (Murray, 1984).

Table 3.11: Lower-Level Price Elasticity

	Price			
	(1) Beef	(2) Pork	(3) Mutton	(4) Poultry
Beef	-1.913***	0.998***	0.216	-0.300
	(0.329)	(0.289)	(0.180)	(0.199)
Pork	5.782***	-2.285	-1.974*	-1.522
	(1.680)	(2.702)	(1.120)	(2.229)
Mutton	3.650	-5.759*	-14.308***	16.417***
	(3.024)	(3.248)	(2.072)	(2.421)
Poultry	-1.588	-1.390	5.136***	-2.158
	(1.047)	(2.027)	(0.760)	(1.633)

Note: Standard errors in parentheses. * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$

3.7 Counterfactuals

To quantify the effect of dynamic monopsonistic market manipulation, I calculate counterfactual outcomes for the cattle spot-market and the downstream wholesale beef market by solving (3.8) for the dynamic period. I first quantify the effect on the wholesale cattle market price and quantity by comparing the observed market outcome under the dynamic cartel strategy with the simulated counterfactuals under a static monopsony. In addition, from a policy perspective, antitrust regulators may also care about how disrupting cartel manipulation could influence downstream consumers. Therefore, I also calculate the counterfactual wholesale refrigerated beef price. These two measures together allow me to evaluate the effect of cartel manipulation on both the aggregate market outcome and the distributional effect on individual sellers and buyers. Because the manipulation was interrupted by regulatory enforcement, this result can also be seen as the economic benefit from regulating inter-firm communication.

As discussed in Section 3.5.3, this counterfactual is of partial equilibrium in nature: the model focuses primarily on the spot-market and does not account for adjustment in aggregate cattle production or supply to sthe pot-market. The result is, however, a lower bound for the effect of dynamic cartel manipulation, as the higher counterfactual price should lead to higher aggregate supply at the spot-market.

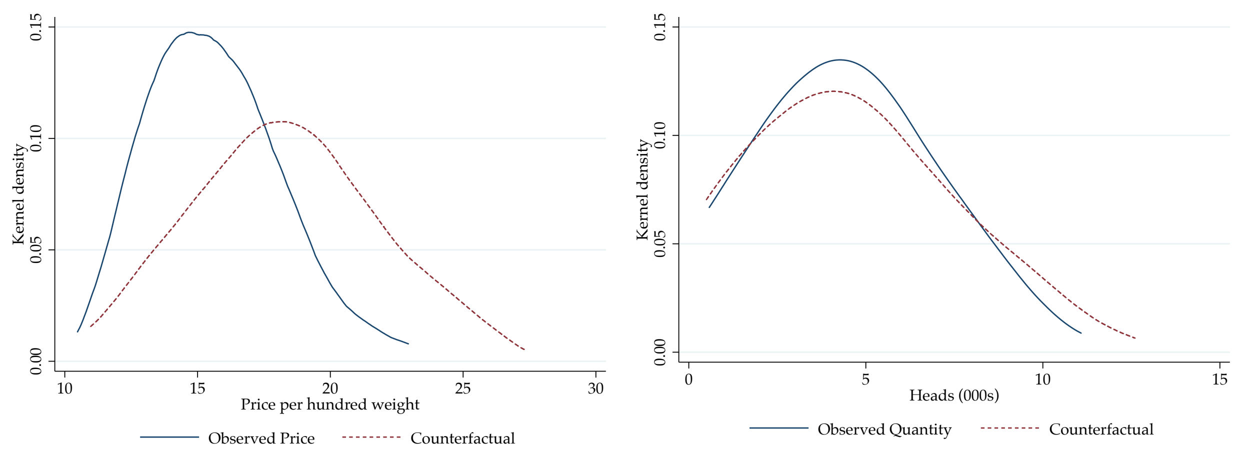
3.7.1 The Livestock Market Suffered Larger Losses Under Manipulation

The cartel's dynamic manipulation strategy reduced the spot-market price and the total quantity traded at the stockyards. Figure 3.8 presents the distribution of observed and counterfactual wholesale cattle prices and quantities at the stockyards. Under dynamic manipulation, cattlemen received on average 14.1% less than they would have under a static strategy, or $32.4 per head.[31] By comparison, cattlemen's average profit in 1909 was $28.00 (in 1920 dollars). In other words, interrupting the dynamic manipulation can more than double the profit margin for cattlemen.

Meanwhile, 13.8% fewer cattle were traded at the stockyards. This is equivalent to 26 fewer pounds of beef consumed by an average urban household per year. For Chicago Union Stock Yards, the largest spot-market, this is equivalent to 10,440 fewer head of cattle purchased by the cartel per week.

[31] Average spot-market price is $2.7 lower (in 1920$) per hundred weight. For an average cattle weighs 1,200 lb, this leads to $2.7 \times 12 = 32.4$ loss.

Figure 3.8: Distribution of Counterfactual and Observed Prices and Quantities



(a) Cartel Price

(b) Cartel Quantity

The dynamic strategy has heterogeneous effects across markets. Table 3.12 tabulates the observed and counterfactual average wholesale prices and quantities by stockyard. Prices at the larger markets were less influenced by the dynamic strategy than prices at the smaller ones. Meanwhile, the larger stockyards, like Chicago, saw larger cartel quantity changes under the static counterfactual scenario. This is consistent with the elasticity estimates that the spot-market supply is more elastic in larger markets, and thus would experience both larger reduction in quantity and smaller price increases.[32]

[32] Figure 3.16 and Figure 3.17 show the distribution of price and quantity changes by stockyard.

Table 3.12: Empirical and Counterfactual Market Outcomes by Stockyard

		(1) Chicago	(2) Kansas City	(3) Omaha	(4) Total
Spot-market Price	Observed	15.8	15.1	14.9	15.4
		(2.37)	(2.53)	(2.21)	(2.46)
	Counterfactual	17.6	18.6	19.1	18.3
		(3.40)	(3.37)	(3.02)	(3.34)
	Observed/Counterfactual,%	91.9	82.8	79.0	85.9
Quantity Purchased by Cartel	Observed	5.98	4.37	2.21	4.39
		(1.36)	(1.47)	(0.61)	(1.97)
	Counterfactual	7.29	5.08	2.45	5.21
		(1.50)	(1.87)	(0.78)	(2.46)
	Observed/Counterfactual,%	81.8	86.9	91.6	86.2

Note: Price and quantity data are from *The National Provisioner* for the three stockyards. St. Louis is omitted for too few observations.

3.7.2 Manipulation Increased Downstream Refrigerated Beef Prices

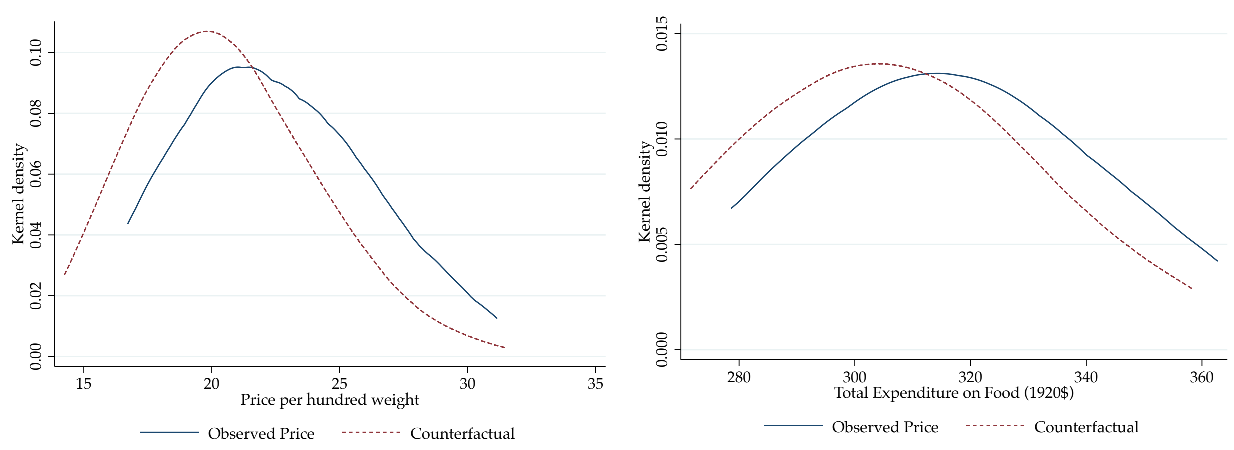
Next, I compare the effect of dynamic cartel manipulation in the cattle market on downstream wholesale refrigerated beef prices. Under a static strategy, the cartel purchased more cattle at the input market, which led to lower prices for refrigerated beef in the downstream market.

The left panel of Figure 3.9 shows the distribution of observed and counterfactual downstream refrigerated beef prices in New York City. On average, the downstream beef price is 10% higher under the dynamic strategy, or \$1.98 per hundred weight.

I measure the changes in consumer welfare by the compensating variation (CV), defined as the additional expenditure a household needs in order to achieve the same utility level as under the static monopsony strategy. This calculation hold the prices of other food items constant, implicitly assuming perfect competition in other agricultural product markets. The changes in total household food expenditure is driven partly by the higher beef prices and partly by the substitution effect.

The right panel of Figure 3.9 shows that, under dynamic cartel manipulation, average household total food expenditure on the four main food groups increased by \$7.34, or 2%. Though the change is small in absolute scale, this is equivalent to 50% of annual household savings[33]. It is also comparable to the inflation rate for the same period.[34]

Figure 3.9: Distribution of Counterfactual and Observed Beef Price and Household Food Expenditure



(a) Refrigerated Beef Price

(b) Total Expenditure on Food

3.8 Conclusion

In this paper, I study the effect of dynamic monopsonistic cartel manipulation on the input market. My results show that the dynamic cartel strategy created larger welfare loss than what a typical static monopsony model would suggest. Under its dynamic manipulation strategy, the meatpacking cartel purchased fewer cattle and at lower prices than it would have under a static strategy, while also increasing downstream wholesale beef prices and total household expenditure on food. Regulatory changes imposed on the cartel benefited

[33]As shown in Table 3.8, average household income is \$1434, while average total expenditure is \$1419.5. This leads to \$14.59 in savings.

[34]Consumer price index changed by 2.4% from 1912 to 1913. Historical inflation data from the Federal Reserve Bank of Minneapolis, https://www.minneapolisfed.org/about-us/monetary-policy/inflation-calculator/consumer-price-index-1800- (Access September 30, 2020).

both upstream cattlemen and downstream consumers, even without breaking up the cartel through forced divestiture.

The historical case has important implications for contemporary markets. Without a functioning contract market, which is often the case in developing countries, small sellers usually rely on spot markets for sales (Chatterjee, 2019). Without effective supervision over large buyers, the market can suffer significant distortions. My results also highlight the difficulties in regulating monopsony power. Though the cartel also harmed consumers, their losses were much smaller than those of the cattlemen. For policymakers focus primarily on consumer welfare, this can imply low political will to regulate the market.

Finally, by documenting a manipulation strategy that lasted for decades, this paper provides new evidence to support regulations against coordinated market manipulation. Given the prevalence of such behavior (Shiller, 1990; Assenza, Bao, Hommes and Massaro, 2014), this gap between policy and empirical evidence has significant legal and economic implications. Further research into the prevalence of such manipulation is needed to properly assess cartel damages.

3.A Appendix

3.A.1 Data Collection

Cattle market data from the trade journal is verified by checking the monthly and annual aggregates against *Chicago Union Stockyard Annual Report* during the same period.

Number of cattle shipped into and out of Chicago excludes calves. Though cattle prices are available by type and grade (see Figure 3.14), I only use the average price for top-grade steers (”Prime” or ”Choice”) in the analysis for two reasons. First, the price for the top grade is the only category consistently reported over the whole time period. Second, refrigerated beef primarily came from the most heavy-weight ones and thus most relevant to the cartel manipulation The Commissioner of Corporation reported in 1905 that the average weight of cattle purchased a major packer in Chicago between 1902 and 1904 is 1,168 lbs, close to the standard for ”Choice” steer of 1,100 to 1,200 lbs.

Heifers and bulls were either purchased by cattlemen for breeding or sold to local butchers since the smaller size does not justify being shipped afar as refrigerated beef. Few Texas cattle were sold in Chicago market, and would either be bought as feeders or as low-quality local butcher meat.

3.A.2 Demand Estimation

The lower-level demand of different meat products can be simplified by expressing the Marshallian demand as expenditure shares:

$$\omega_i = \alpha_i + \Sigma_j \gamma_{ij} \ln p_j + \beta_i \ln(\frac{X_s}{P_s}) + \varepsilon_i \tag{3.10}$$

where P_s is the Stone price index defined as

$$\ln P_s = \Sigma_i \omega_i \ln p_i \tag{3.11}$$

ω_i is the expenditure share of product i in the meat segment. X_s is the total expenditure on the meat segment, and the error term ε_i accounts for both measurement error and potential demand shocks.

Following the literature, I also impose the three sets of restrictions on the coefficients:

Adding-up: the expenditure shares always sum up to 1, implying

$$\Sigma\alpha_i = 1; \Sigma\beta_i = 0; \Sigma_i\gamma_{ij} = 0 \ \forall j \tag{3.12}$$

Homogeneity: Marshallian demand is homogeneous of degree zero in prices.

$$\Sigma\gamma_{ij} = 0 \ \forall i \tag{3.13}$$

Symmetry: follows from Shepard's Lemma,

$$\gamma_{ij} = \gamma_{ji} \ \forall i, j \tag{3.14}$$

At the higher-level, allocation of expenditure among broad food segments (meat, dairy, starch, etc.) follow the same structure:

$$\omega_S = \alpha_S + \Sigma_H\gamma_{SH}\ln p_S + \beta_S\ln(\frac{X}{P}) + \varepsilon_S \tag{3.15}$$

where all variables denoted by S refer segment rather than product level values. X is the total food spending, and P is the Stone price index at the segment level. The analogous restrictions of (3.12) to (3.14) also apply to the higher-level.

The estimated demand parameters allow me to calculate the unconditional elasticities for counterfactual analysis (Anderson and Blundell 1983). The own- and cross-price elasticities at the lower level are:

$$\epsilon_{ij} = -\delta_{ij} + \frac{1}{\omega_i}(\gamma_{ij} + \beta_i(\alpha_i + \Sigma_k \gamma_{kj} \ln p_k)) + \omega_j(1 + \frac{\beta_i}{\omega_i}) \tag{3.16}$$

where $\delta_{ij} = 1$ if $i = j$ and $\delta_{ij} = 0$ otherwise. The higher level has the analogous expression with parameters estimated from the segment level expenditure decisions.

3.A.3 Dynamic Discrete Choice Model for Cattle Shipment

Every period, cattlemen observe the state of the stockyard market (last week's price), ω_t, and decide whether to ship the cattle to the stockyard, $i \in \{-1, 0, 1\}$.

$$i = \begin{cases} -1 & \text{outside market} \\ 0 & \text{wait} \\ 1 & \text{ship to stockyard} \end{cases}$$

Assumption: (Small seller, competitive outside market.) Individual sellers are price takers, and their shipment decisions do not affect the stockyard market state; i.e. $G(\omega_{t+1}|\omega_t, i) = G(\omega_{t+1}|\omega_t)$ for all i. The outside market is competitive, where the price is determined only by the average input factors X_t such as feed prices and seasonality, or $b(X_t)$.

The payoff of choice i is:

$$u(i, \omega_t, \nu_{it}; \theta) = \begin{cases} b(X_t; \theta_0) + \xi_{it}(\omega_t) + \nu_{it} & i = -1 \\ 0 & i = 0 \\ \mathbb{E}(p_t|\omega_t; \theta_1) + \xi_{it}(\omega_t) + \nu_{it} & i = 1 \end{cases} \tag{3.17}$$

where $\mathbb{E}(p_t|\omega_t)$ is the expected price at the stockyard market conditional on the observed state ω_t. $\xi_{it}(\omega_t)$ is the unobserved shocks to the utility and potential source of endogeneity. Note here that $i = 1$ is the absorbing state: the cattlemen can only sell the livestock once.

The Bellman equation can then be written as:

$$V(\omega,\nu) = \max_{i=-1,0,1}\{u(i,\omega,\nu_i;\theta) + \beta\,\mathrm{E}[V(\omega',\nu')]\} \tag{3.18}$$

$$= \max\{u(-1,\omega,\nu_i;\theta); \beta\,\mathrm{E}[V(\omega',\nu')]; u(1,\omega,\nu_i;\theta)\ \} \tag{3.19}$$

$$= \max\{\tilde{V}(\omega,\nu,-1); \tilde{V}(\omega,\nu,0); \tilde{V}(\omega,\nu,1)\} \tag{3.20}$$

Assume that ν_{it} is the i.i.d idiosyncratic shocks that follow a Type-I extreme value distribution, then the probability of choosing i is

$$\Pr(i|\omega;\theta) = \frac{\exp(\tilde{V}(\omega,\nu,i))}{\Sigma_i \exp(\tilde{V}(\omega,\nu,i))} \tag{3.21}$$

which can be estimated through a nested fixed-point algorithm, given observed choices. However, except for the aggregate shipment to stockyards, there is not historical records on either the total number of cattle available or the number of cattle sold in local markets.

3.A.4 Cartel's Dynamic Strategy

Consider the case when cartel incorporates the dynamic supply response. I omit the stockyard k notation for simplicity.

Every week, the cartel chooses q_t, the amount of cattle to purchase in the market. Given the total shipment Z_t and cartel's quantity decision q_t, the spot-market supply curve $p(.)$ determines the realized market price

$$p_t = p(q_t, Z_b(p_{t-1}, X_t)) \tag{3.22}$$

Under the Leontief production function assumption, the per-period profit can be simplified only in terms of input cattle quantity q_t:

$$\Pi(q_t, \omega_t) = D(q_t, \omega_t)q_t - p_t q_t \tag{3.23}$$

where $D(.)$ is the demand for beef and ω_t is exogenous demand shocks revealed to the cartel before the market decisions; p_t is the realized cattle price at the stock yard.[35]

Cartel makes quantity decisions to maximize the long-run total profit. In recursive form, we have

$$\begin{aligned} V(p_{t-1}, \omega_t) &= \max_{q_t} \Pi(q_t, \omega_t) + \beta\, \mathrm{E}[V(p_t, \omega_{t+1})] \qquad (3.24) \\ &= \max_{q_t} D(q_t, \omega_t)q_t - p_t q_t + \beta\, \mathrm{E}[V(p_t, \omega_{t+1})] \\ \text{s.t. } & \Pi(q_t, \omega_t) = D(q_t, \omega_t)q_t - p_t q_t \\ \text{total shipment to stockyard } & Z_t = Z(p_{t-1}) \\ \text{spot-market supply: } & p_t = \Gamma(q_t, Z(p_{t-1})) \\ & \omega_{t+1} = \rho_0 + \rho_1 \omega_t + \varepsilon_t \\ & \varepsilon_t \sim \text{ i.i.d } N(0, \sigma_z^2) \end{aligned}$$

$\Gamma(.)$ is the mapping across states.[36] Suppose the law of motion of the state, $\Gamma(.)$ is invertible, such that $q_t = \gamma(p_t, Z(p_{t-1}))$. Then

$$V(p_{t-1}, \omega_t) = \max_{p_t} \Pi\big(\gamma(p_t, Z(p_{t-1})), z_t\big) + \beta\, \mathrm{E}[V(p_t, \omega_{t+1})]$$

The Euler equation for cartel is: [37]

[35] Technically p_t includes the price of other inputs V. Because cost of other inputs were considered exogenous, assuming $p(.)$ to be linear, it will be absorbed in the constant term.

[36] The expression is re-organized from (3.22).

[37] To simplify the expression, $\gamma_t = \gamma(p_t, Z(p_{t-1}), \omega_t), Z_t = Z(p_{t-1})$

$$\underbrace{\frac{\partial \pi_t}{\partial \gamma_t}\frac{\partial \gamma_t}{\partial p_t}}_{\text{(A) direct effect of } p_t} + \underbrace{\beta\, \mathrm{E}[\frac{\partial \Pi_{t+1}}{\partial \gamma_{t+1}}\frac{\partial \gamma_{t+1}}{\partial Z_{t+1}}\frac{\partial Z_{t+1}}{\partial p_t}]}_{\text{(B) effect of } p_t \text{ on next period}} = 0 \tag{3.25}$$

When the cartel is making the quantity decision at t, sellers' response to the realized market price p_t created the inter-temporal trade-off. If sellers are not responsive to past price, then $\frac{\partial Z_{t+1}}{\partial p_t} = 0$, and cartel's problem becomes the static monopsony case.

Suppose the cartel increases the price today by purchasing more of the cattle in the stock yard. (A) captures the direct effect as it changes the marginal profit scaled by the marginal supply on the spot-market, $\frac{\partial \gamma_t}{\partial p_t}$; meanwhile, sellers respond to higher price now by shipping more cattle to the stock yard next period by $\frac{\partial Z_{t+1}}{\partial p_t}$ and change the profit next period represented by (B).

The difference between the spot-market elasticity and shipment elasticity to past price determines how much the cartel can manipulate the market. To see this, first define

$$\begin{aligned} e_s &= \frac{\partial q_t}{\partial p_t}\frac{p_t}{q_t} \text{ , spot-market price elasticity} \\ e_l &= \frac{\partial Z_{t+1}}{\partial p_t}\frac{p_t}{Z_{t+1}} \text{ , shipment elasticity to past price} \\ e_q &= \frac{\partial q_t}{\partial Z_t}\frac{Z_t}{q_t} \text{ , elasticity of purchase to shipment} \end{aligned} \tag{3.26}$$

Euler equation (3.25) can be written in terms of elasticities:

$$\frac{\partial \pi_t}{\partial q_t} q_t + \beta[\frac{\partial \pi_{t+1}}{\partial q_{t+1}} q_{t+1}]\frac{e_l}{e_s} e_q = 0 \tag{3.27}$$

The larger the shipment elasticity is to the spot-market elasticity (higher e_l/e_s ratio), the higher the effect of p_t is on the next period. This leaves more room for the cartel to manipulate in the current market. Cartel can reduce the price paid for cattle under the dynamic scenario. This effect can be captured by the “markdown”, or the wedge between marginal revenue of product and the input price. Under static monopsony case, cartel’s profit maximization problem leads to the expression:

$$
\begin{aligned}
MR &= \left(\frac{\partial p(q)}{\partial q} \frac{q}{p(q)} + 1 \right) p(q) \\
&= (\tilde{\varphi}_s + 1) p
\end{aligned}
\tag{3.28}
$$

where $\tilde{\varphi}$ is the (inverse) spot-market elasticity.

Under the dynamic scenario, the “markdown” changed into:

$$
\begin{aligned}
MR_t + \beta \, \mathrm{E} \left[\frac{\partial V(p_t)}{\partial p_t} \frac{\partial p_t}{\partial q_t} \right] &= \left(\frac{\partial p(q_t)}{\partial q_t} \frac{q_t}{p(q_t)} + 1 \right) p_t(q_t) \\
&= (\varphi_s + 1) p_t
\end{aligned}
\tag{3.29}
$$

Compared to the static case, if the cartel faces a smaller spot-market elasticity by manipulating the total shipment, or $\varphi_s > \tilde{\varphi}_s$, the markdown will be larger under manipulation. In other words, the cartel can potentially outperform a static monopsonistic pricing strategy by manipulating the market. In practice, cartel manipulated price signals to attract more cattle to the stock yard. The marginal ones being manipulated are the cattlemen further away (higher cost) that would not have made the shipment decision without the falsely high prices. Such cattlemen are therefore more constrained on their choices of taking the cattle off the market, making the the spot-market supply less elastic under manipulation.

3.B Appendix Tables

Table 3.13: Robustness-Test, Prices vs. Shipments, With Different Samples

Dependent variable: Cattle Price	Early and Later Dynamic Manipulation Period		Panel with data from ≥ 3 stockyards			
	1903–1907	1908–1912	Dynamic		Static	
	(1)	(2)	(3)	(4)	(5)	(6)
Daily Average Shipment	0.017	0.003	-0.031	0.028	0.100***	0.111***
	(0.037)	(0.043)	(0.036)	(0.034)	(0.036)	(0.035)
Time Controls	Yes	Yes	Yes	Yes	Yes	Yes
Cost Controls	Yes	Yes	No	Yes	No	Yes
Weather Controls	Yes	Yes	No	Yes	No	Yes
Observations	453	844	1113	1109	789	789
R-squared	0.69	0.77	0.78	0.81	0.65	0.70

Note: The table shows the regression coefficients α_z of price on average daily shipment, $p_{kt} = \alpha_z Z_{kt} + X_{kt} + \eta_{kw} + \tau_y + \epsilon_{kt}$. Weather controls include quarterly lagged weighted average temperature and rainfall, as well as the current temperature and rainfall in the counties where the stockyards were located. The cost controls include quarterly lagged No.4 Corn and Hay prices at the Chicago Commodity Exchange. Data exclude period when the stockyards were closed due to quarantine or extreme weather. Columns (1) and (2) cover the first and second halves of the manipulation period. The point estimates for the manipulation period are both statistically zero. Columns (3) to (6) use only the sample with data from at least three stockyards. Results are consistent with the estimation in Table 3.4. Standard errors are in parentheses.
$p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.14: Higher-Level Price Elasticity

	Price			
	(1) Meat	(2) Dairy	(3) Starch	(4) Vegetable
Meat	-0.822	-0.075	0.831***	0.067
	(0.646)	(0.950)	(0.197)	(0.210)
Dairy	-0.072	-0.614	0.236	0.451
	(0.916)	(1.450)	(0.371)	(0.346)
Starch	0.733***	0.216	-0.839***	-0.111
	(0.175)	(0.341)	(0.165)	(0.099)
Vegetable	0.203	1.417	-0.381	-1.239***
	(0.639)	(1.091)	(0.339)	(0.322)

Note: Standard errors in parentheses. * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$

Table 3.15: Coefficient Estimates for Lower-Level AIDS System

Meat Products	Constant	Cross-Price Coefficient				Expenditure
		Beef	Pork	Mutton	Poultry	
	(1)	(2)	(3)	(4)	(5)	(6)
Beef	-2.363***	-1.275***	1.970***	0.202	-0.898	0.288***
	(0.388)	(0.356)	(0.342)	(0.186)	(0.232)	(0.037)
Pork	5.060***	1.970***	-2.352***	-0.373	0.754*	-0.464***
	(0.499)	(0.342)	(0.553)	(0.229)	(0.452)	(0.049)
Mutton	0.268	0.202	-0.373	-0.563***	0.734***	-0.027
	(0.277)	(0.186)	(0.229)	(0.096)	(0.143)	(0.026)
Poultry	-1.966***	-0.898***	0.754*	0.734***	-0.590*	0.203***
	(0.392)	(0.232)	(0.452)	(0.143)	(0.340)	(0.038)

Note: Standard errors in parentheses. * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$

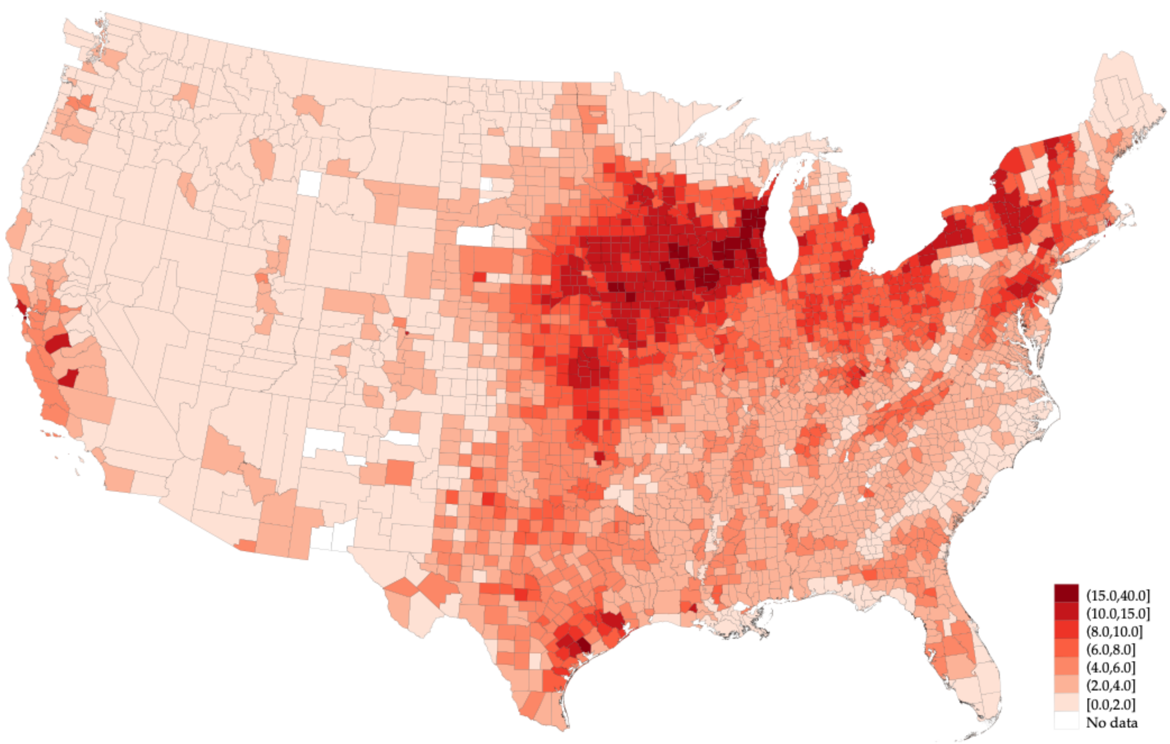
Table 3.16: Coefficient Estimates for Higher-Level AIDS System

Food Segments	Constant	Cross-Price Coefficient				Expenditure
		Meat	Dairy	Starch	Vegetable	
	(1)	(2)	(3)	(4)	(5)	(6)
Meat	-1.340	-0.266*	0.254	0.098**	-0.085	0.138
	(1.198)	(0.152)	(0.212)	(0.044)	(0.055)	(0.096)
Dairy	3.075*	0.254	-0.523	0.046	0.223***	-0.212
	(1.723)	(0.212)	(0.319)	(0.073)	(0.084)	(0.136)
Starch	-0.140	0.098**	0.046	-0.062	-0.082***	0.028
	(0.474)	(0.044)	(0.073)	(0.047)	(0.023)	(0.038)
Vegetable	-0.596	-0.085	0.223***	-0.082***	-0.057**	0.045
	(0.459)	(0.055)	(0.084)	(0.023)	(0.026)	(0.037)

Note: Standard errors in parentheses. * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$

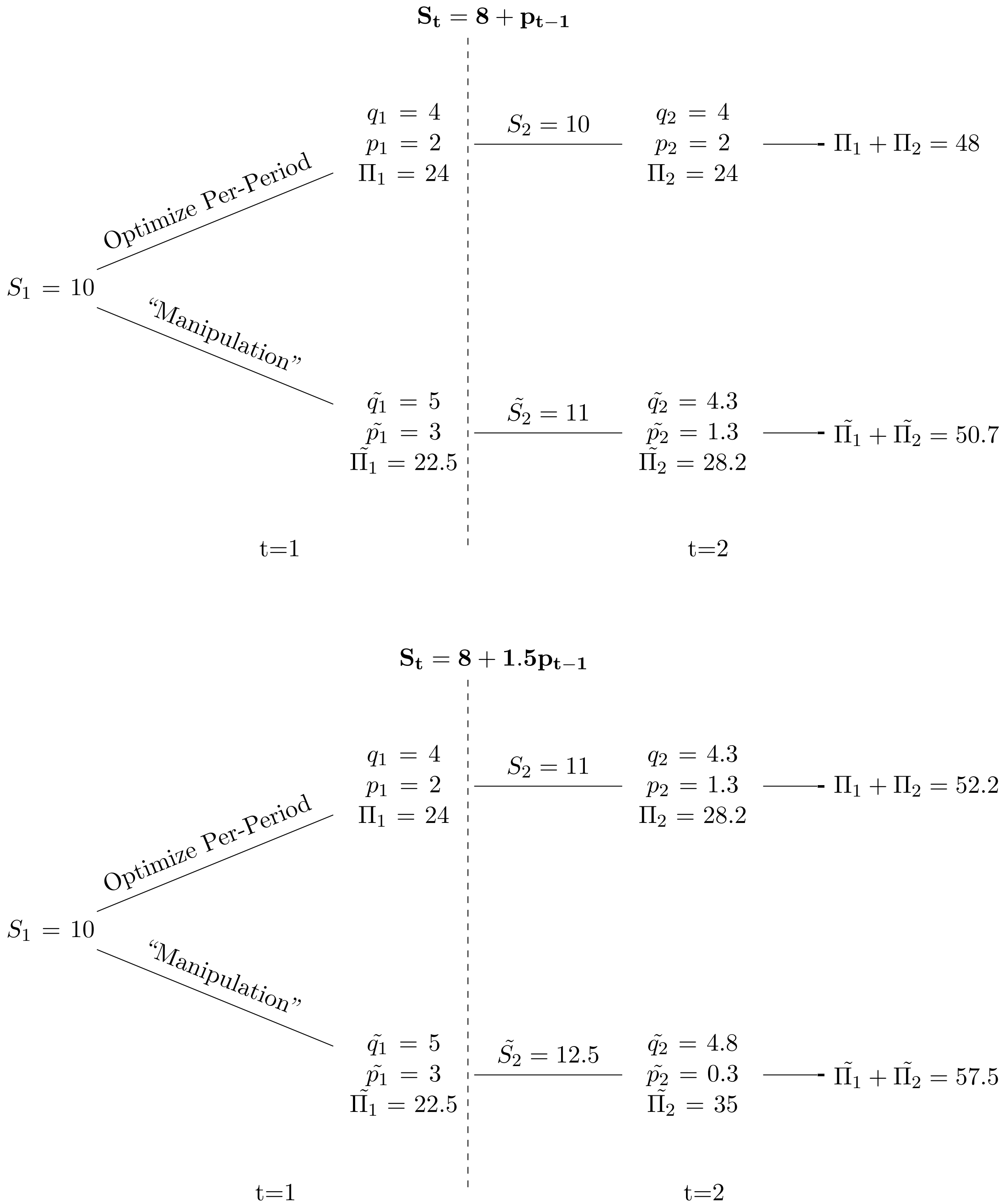
3.C Appendix Figures

Figure 3.10: Spatial Distribution of Cattle Production in 1910



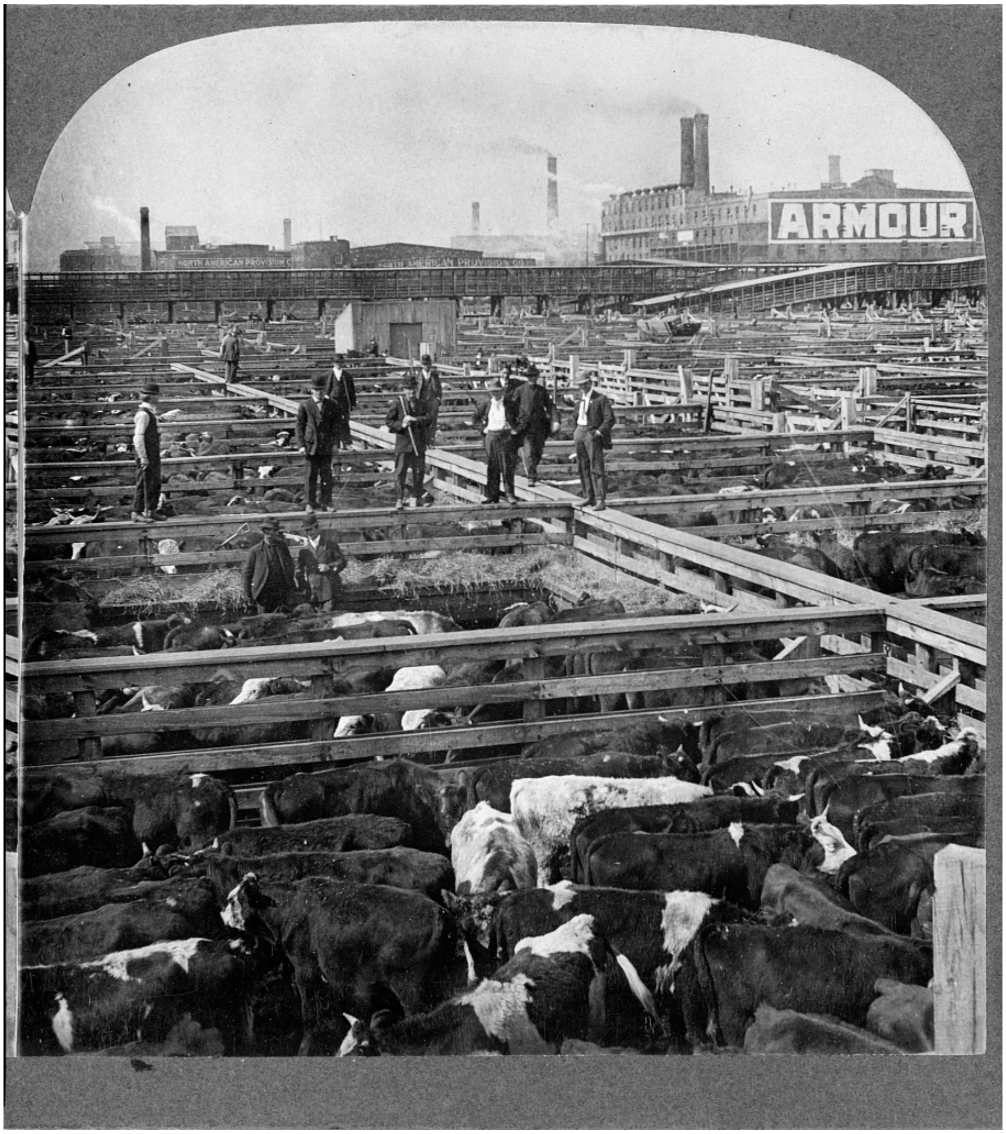
Note: Data from the 1910 Census of Agriculture. Values exclude milk cows and working oxen. The data is plotted with 2010 county boundaries.

Figure 3.11: Numeric Two-Period Market Example



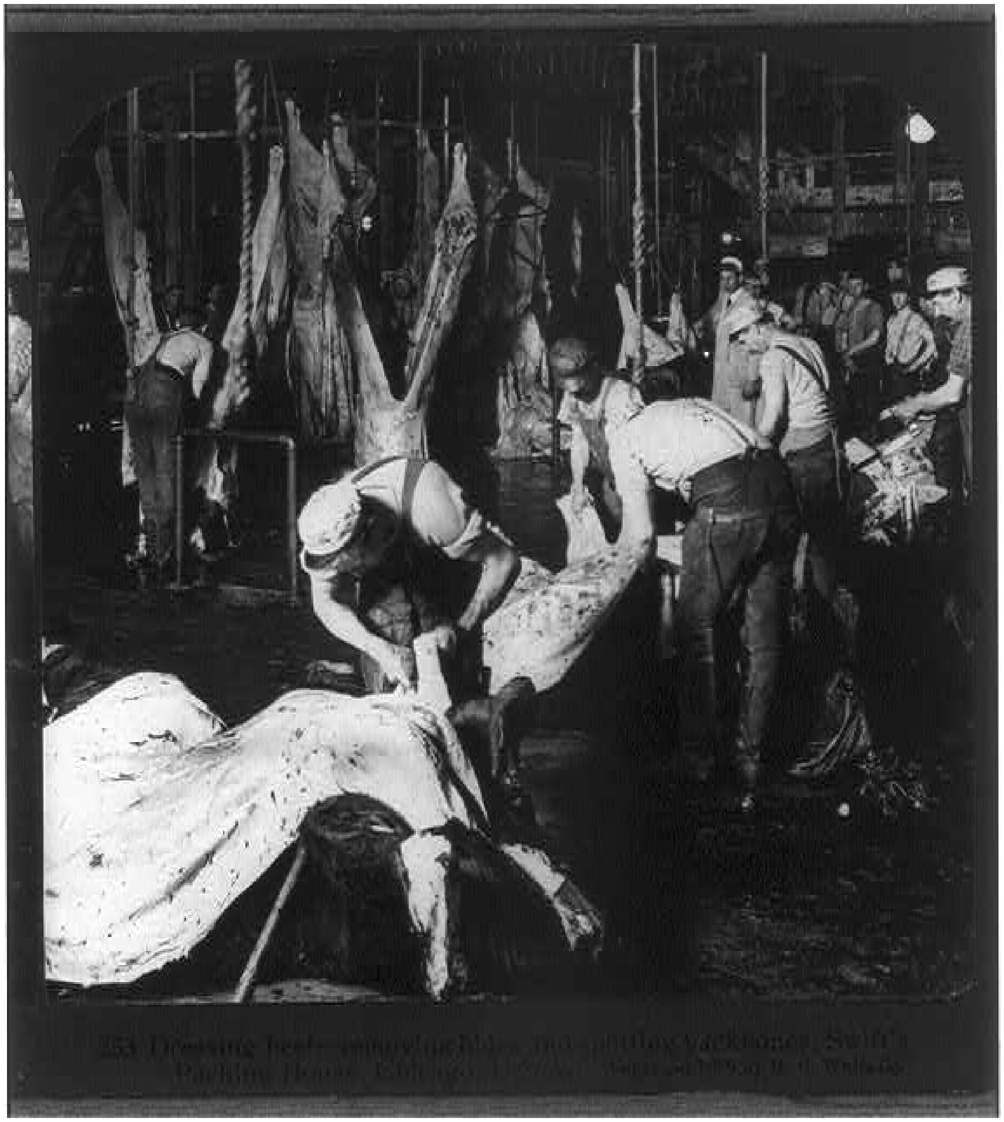
Note: The strategy to "optimize per-period" is the solution to the cartel's static profits maximization problem in each period, given the downstream demand $D_t = 10 - 0.5q_t$ and the spot-market supply $p_t = 8 + q_t - S_t$. The "manipulation" strategy illustrated here is not the optimal quantity path. The above calculation is one example where manipulation can outperform the static strategy.

Figure 3.12: Buyers at Chicago's Union Stock Yards, 1909



Note: *In the heart of the Great Union Stock Yards, Chicago, U.S.A.* Chicago Illinois, ca. 1909. Photograph. https://www.loc.gov/item/89711602/.

Figure 3.13: Cattle Slaughter Relied Primarily on Manual Labor



Note: H.C. White Co. *Chicago - Meat Packing Industry: dressing beef–removing hides and splitting backbones, Swift's Packing House, Chicago, U.S.A.* Chicago Illinois, 1906. North Bennington, Vt.: H.C. White Co., Publishers. Photograph. https://www.loc.gov/item/2006679958/.

Figure 3.14: Example of *The National Provisioner* Market Information

CHICAGO LIVE STOCK

RECEIPTS.

	Cattle.	Calves.	Hogs.	Sheep.
Monday, Dec. 29	22,001	1,076	34,203	24,969
Tuesday, Dec. 30	5,183	1,239	36,549	22,891
Wednesday, Dec. 31	11,841	1,482	43,603	20,174
Thursday, Jan. 1—Holiday.				
Friday, Jan. 2	3,289	467	30,661	20,729
Saturday, Jan. 3	199	36	15,820	2,198
Total last week	42,513	4,300	160,836	90,961
Previous week	30,542	3,046	120,103	73,311
Cor. time, 1913	49,876	6,170	163,595	106,405
Cor. time, 1912	60,490	8,367	137,920	128,294

SHIPMENTS.

	Cattle.	Calves.	Hogs.	Sheep.
Monday, Dec. 29	6,569	69	13,977	2,345
Tuesday, Dec. 30	3,057	184	10,140	4,274
Wednesday, Dec. 31	6,693	227	14,149	4,724
Thursday, Jan. 1—Holiday.				
Friday, Jan. 2	2,141	73	7,726	2,546
Saturday, Jan. 3	23	...	6,097	175
Total last week	18,483	553	52,089	14,082
Previous week	13,245	313	30,376	10,625
Cor. time, 1913	17,742	621	35,221	18,319
Cor. time, 1912	24,339	1,133	35,847	18,185

WEEKLY AVERAGE PRICE OF LIVE STOCK.

	Cattle.	Hogs.	Sheep.	Lambs.
This week	$8.35	$7.95	$5.35	$7.95
Previous week	8.30	7.75	5.10	7.80
Cor. week, 1913	8.05	7.90	4.90	8.25
Cor. week, 1912	6.95	6.17	4.10	6.35
Cor. week, 1911	6.15	8.07	4.05	6.35

CATTLE.

Steers, good to choice heavy	$8.10@ 9.25
Steers, fair to good	7.50@ 8.50
Yearlings, good to choice	8.25@ 9.25
Distiller steers	8.65@ 9.00

PACKERS' PURCHASES

Purchases of livestock by packers at principal centers for the week ending Saturday, January 3, 1914, are reported as follows:

Chicago.

	Cattle.*	Hogs.	Sheep.*
S. & S. Co.	5,124	12,300	9,177
Armour & Co.	5,075	15,700	18,632
Swift & Co.	4,098	12,100	18,621
Morris & Co.	3,812	6,300	7,024
G. H. Hammond Co.	1,614	5,700	...
Libby, McNeill & Libby	693	...	...

Anglo-American Packing Co., 8,500 hogs; Boyd, Lunham & Co., 6,200 hogs; Western Packing & Provision Co., 9,700 hogs; Roberts & Oake, 4,200 hogs; Miller & Hart, 3,300 hogs; Independent Packing Co., 8,200 hogs; Brennan Packing Co., 4,000 hogs; others, 10,000 hogs.

*Incomplete.

Kansas City.

	Cattle.	Hogs.	Sheep.
Armour & Co.	2,842	9,143	6,071
Fowler Packing Co.	697	...	2,597
S. & S. Co.	2,735	7,444	4,875
Swift & Co.	3,712	6,985	7,781
Cudahy Packing Co.	3,256	6,057	7,587
Morris & Co.	2,646	5,543	3,831
Butchers	104	921	13

Omaha.

	Cattle.	Hogs.	Sheep.
Morris & Co.	1,414	5,731	3,709
Swift & Co.	2,149	7,705	9,897
Cudahy Packing Co.	3,101	11,194	6,973
Armour & Co.	2,056	11,391	7,720
Swartz & Co.	...	779	...
J. W. Murphy	...	4,161	...

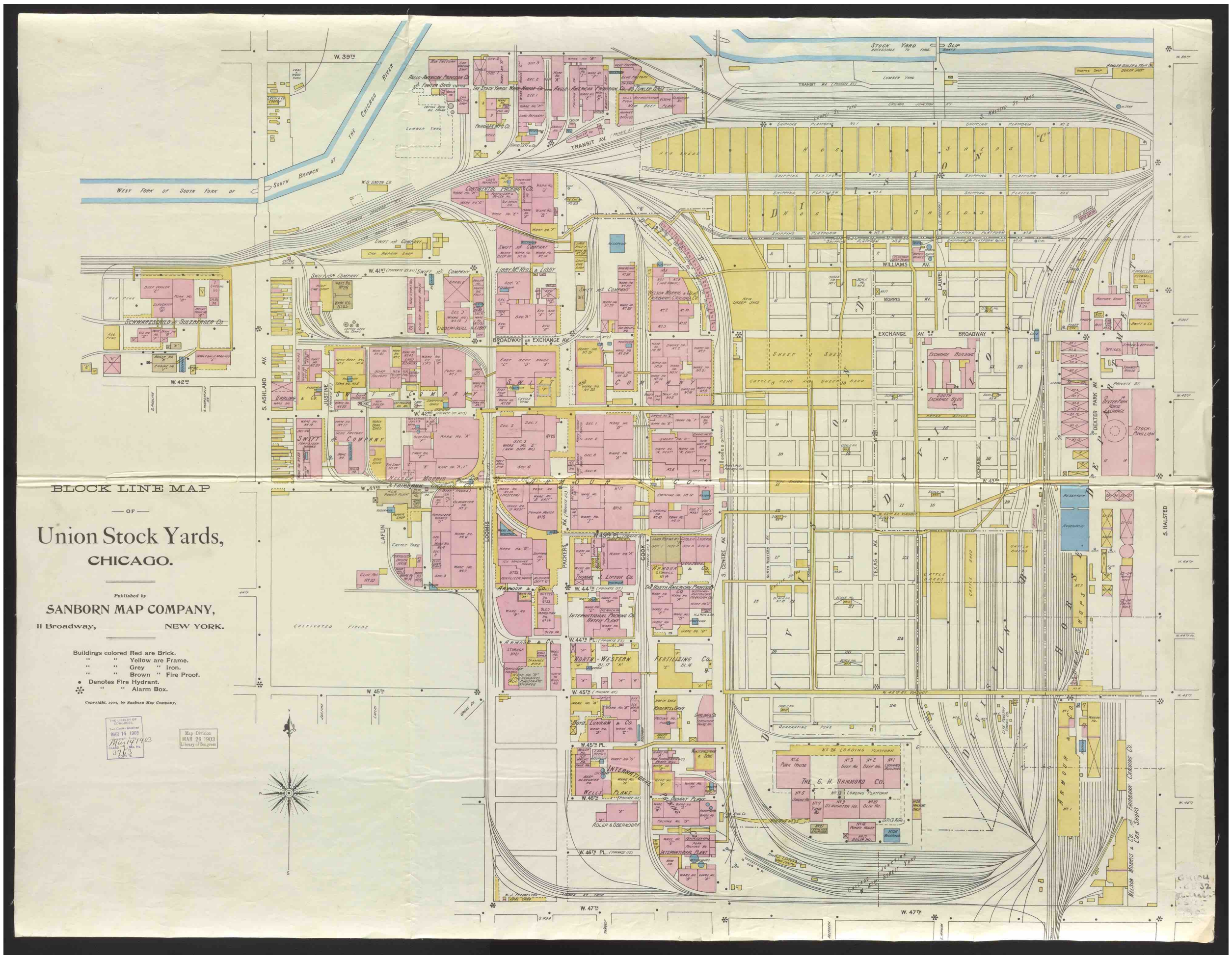
Lincoln Packing Co., 119 cattle; John Morrell & Co., 32 cattle; South Omaha Packing Co., 11 cattle.

St. Louis.

	Cattle.	Hogs.	Sheep.
Morris & Co.	1,949	5,779	3,983
Swift & Co.	2,997	7,256	5,789
Armour & Co.	2,151	6,270	5,630
St. Louis D. B. Co.	528	145	...
Independent Packing Co.	791	2,172	150
East Side Packing Co.	115	3,139	...
Bels Packing Co.	...	1,005	...
Hell Packing Co.	5	517	...
Carondelet Packing Co.	...	134	...
Krey Packing Co.	...	2,546	...

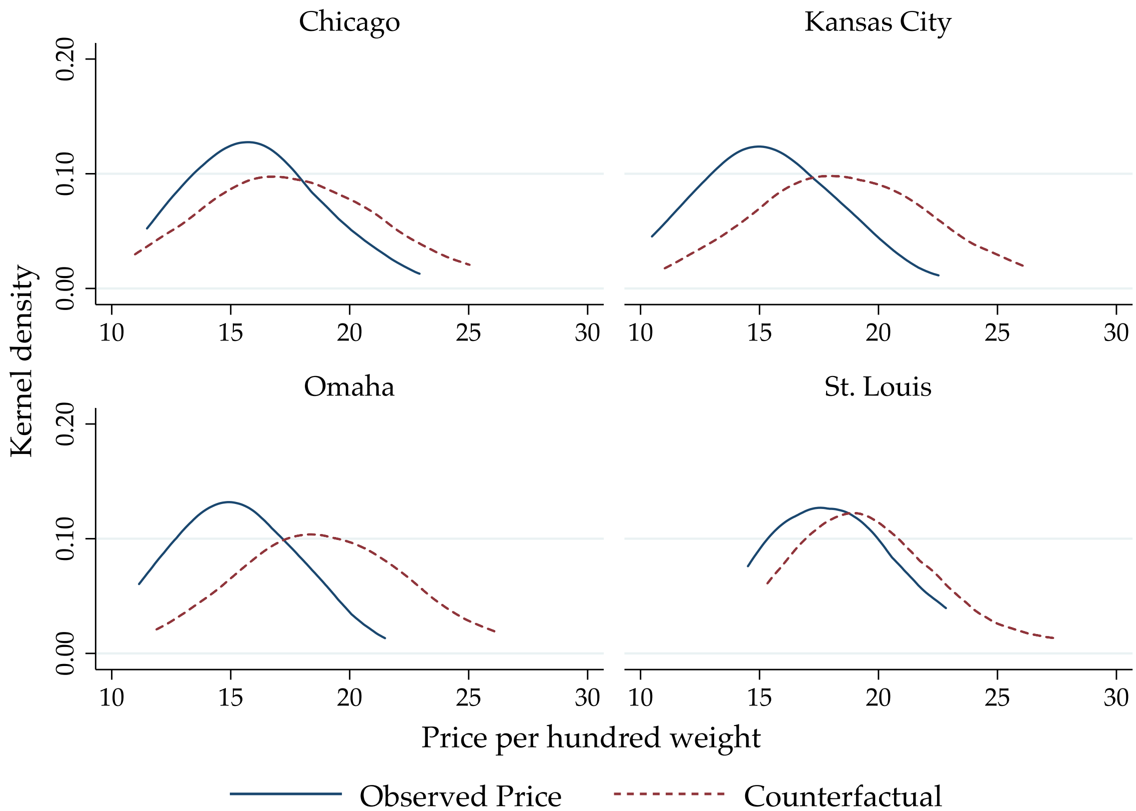
Note: Images from *The National Provisioner*, January 10, 1914

Figure 3.15: 1903 Map of Chicago's Union Stock Yards



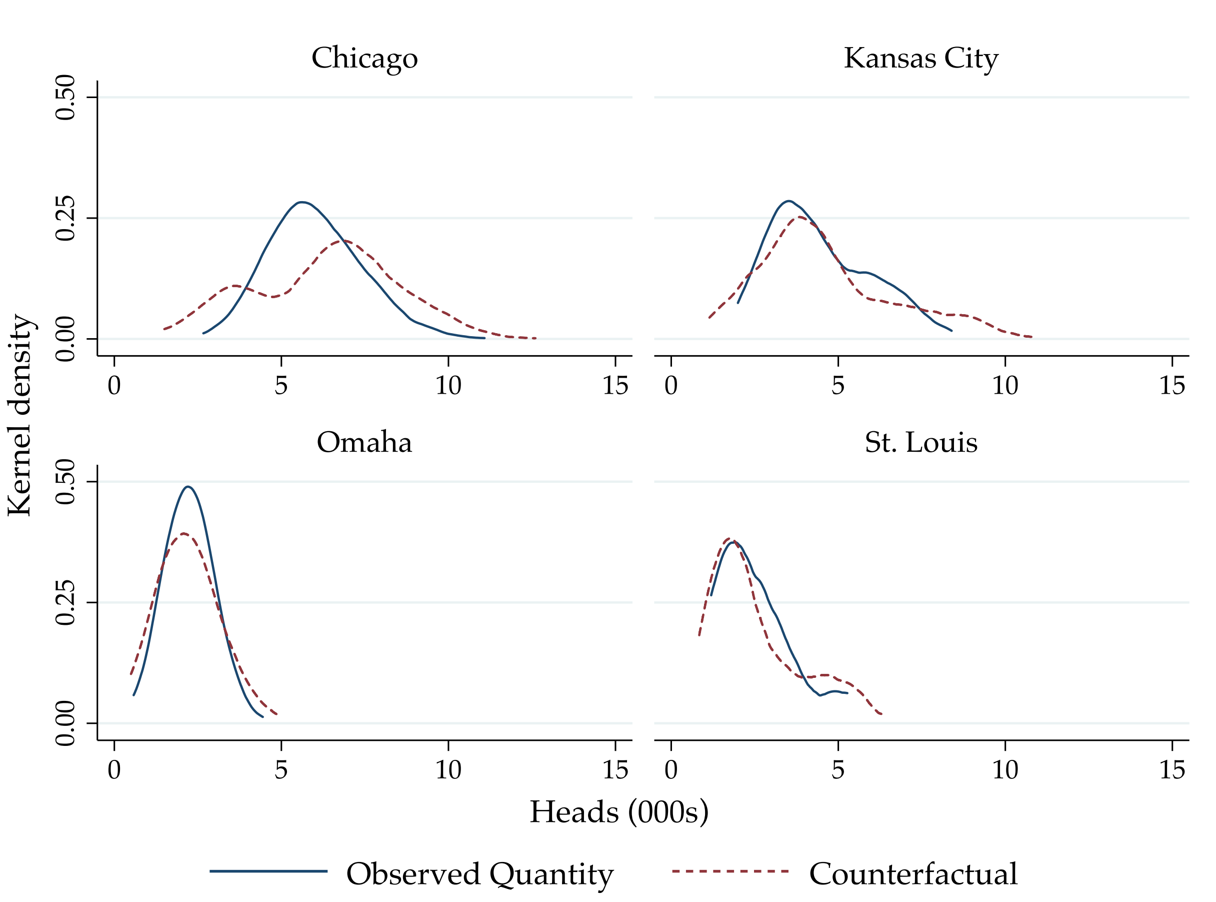
Note: The pink areas were meatpacking plants and other by-product manufacturing facilities. Sanborn fire insurance map provided courtesy of the Map Library at the University of Illinois at Urbana-Champaign at https://digital.library.illinois.edu/items/ca7a6e50-c451-0133-1d17-0050569601ca-c.

Figure 3.16: Distribution of Counterfactual and Observed Cartel Price by Stockyards



Note: The value of the counterfactual prices is calculated by solving (3.8), with estimated elasticities during the dynamic manipulation period.

Figure 3.17: Distribution of Counterfactual and Observed Cartel Quantities by Stockyards



Note: The value of the counterfactual quantity is calculated by solving (3.8), with estimated elasticities during the dynamic manipulation period.

CHAPTER 4

Fence Laws: Liability Rules and Agricultural Productivity

4.1 Introduction

In his seminal article, Coase (1960) uses an example between a farmer and a rancher adjacent to each other to illustrate that the liability rules do not affect the allocation of resources. Regardless of who is liable for damages done by cattle trespassing, the allocation of land between the two types of production should reach the same equilibrium, as long as property rights are enforced and can be traded at zero cost. The Coase Theorem has since being applied in various fields and policy areas, including economic development (Alston, Libecap and Schneider, 1996; Anderson and Hill, 2004; Hornbeck, 2010), environment protection (Anderson and Libecap, 2014; Libecap, 2007), political institutions (Acemoglu, 2003), and marriage markets (Wolfers, 2006).

Past research acknowledges that costless transaction is a strong and usually unrealistic assumption. Significant transaction cost usually implies that the rule of liability will have allocative effects, as noted by Coase (1960) and Demsetz (1972). However, despite the wide application in research and policy, few empirical works study whether and how liability rules influence resource allocation.

In this chapter, I use the historical evolution of fence laws in the western states to analyze the long-term effect of liability rules on resource allocation and efficiency. Farmers under the "fence-out" rule can claim damage from trespassing livestock only if they have constructed fences that satisfy specific regulatory requirements. Meanwhile, under the "fence-in" rule, ranchers are liable for damages done by their livestock regardless of whether the damaged farms have fences. In other words, the liability for livestock trespassing is assigned to farmers in some areas and ranchers in others. Ranchers and farmers have long contested fence regulations. Prolonged public debates and occasional violent conflicts between farmers and ranchers suggest that this supposedly innocuous rule had profound economic implications.

The analysis uses newly compiled data on the timing of all county-level fence-related regulation changes from the first state (or territorial) legislature until 1920. This data covers all the states west of the Mississippi River except the Pacific coastal states.[1] To the best of my knowledge, this is the first dataset that fully captures the legal environment on property rights protection during this period. Combined with land use, land value, and other output values from the decennial censuses, I can quantify the effect of the liability rules by comparing adjacent locations with similar natural endowments but different fence laws.

This chapter exploits the variation in the adoption of fence laws at the county level over time to examine the effects of liability rules on agricultural productivity. The baseline analyses first compare counties with fence-in versus fence-out rules before and after adoption, controlling for time-invariant differences across counties and common shocks to all counties for each census year. The estimation results indicate that the fence-in rule increased agricultural development by increasing the density of farmland by 13.4 percent and the share of improved farmland by 18.3 percent.

In addition to influencing farmland development, fence laws also changed production decisions. With the fence-in rule that shifted the liability for trespassing to livestock owners, farmers could expect less damage and thus higher marginal return to more intensive crop cultivation. Estimation results show that fence-in counties saw 24 percent more of the farmland devoted to corn production, with higher per acre corn output. The increase in grain

[1]Preliminary results include only AR, AZ, CO, ID, KS, NE.

production did affect animal husbandry, as both the fodder acreage, output, and livestock density remained indistinguishable between the fence-in and fence-out counties. Finally, changes in production decisions translated to changes in product values. Compared to the fence-out counties, the total value of farm products was 31 percent higher for fence-in counties. This increase is driven by both crop and livestock production, for which the average value of output increased by 20.6 percent and 35.9 percent respectively.

This research contributes to the growing literature on the role of property rights in economic development (Besley and Ghatak, 2010; Edwards, Fiszbein and Libecap, 2020), and more broadly, the long-term influence of legal frameworks on economic outcomes (La Porta, Lopez-de Silanes and Shleifer, 2008; Acemoglu, Johnson and Robinson, 2005). The historical case from the US frontier development suggests that the liability rules may distort resource allocation. Transaction costs incur when private agents decide to enforce property rights (de Meza and Gould, 1992), and such costs are the usual sources of inefficiency in the market (Demsetz, 1968). Assigning the burden of liability on a particular side created inefficiency when the enforcement process came at considerable transaction cost, and the economic loss cannot be restored even after a long period.

The fence law example also suggests that, for contemporary policies regarding property protection and damage liability, regulations that determine liability rules are likely to cause sub-optimal outcomes. By highlighting the effects of liability rules, this chapter also contributes to contemporary policy discussions on intellectual property (Posner, 2005), radio spectrum allocation (Hazlett and Muñoz, 2009), and pollution regulations (Greenwood and Ingene, 1978).

Finally, I also contribute to a large literature on the fence laws and agricultural development in the US. Fence laws have long been a contentious policy issue in the US (Sanchez and Nugent, 2000; Vogel, 1987). Historians have found that many prairie farmers supported the fence law changes that held livestock owners responsible for trespassing damages (Bogue, 1963).[2] Empirical works have found that, by making stock owners liable, fence laws can significantly increase farm values in the South (Kantor, 1998). This chapter is the first to document the evolution of local fence law changes over a long period of time. The empirical strategy provides clear identification of the causal relationship between the fence laws and long-term development.

The rest of the chapter is organized as follows. Section 4.2 reviews the evolution of fence laws in the western states and historical accounts of how the laws affected farmers and ranchers. Section 4.3 describes the data and provides descriptive evidence on the impact of fence laws. Section 4.4 develops the empirical strategy and Section 4.5 presents the main results. Section 4.6 discusses the interpretation of the results and concludes.

4.2 Historical Background

4.2.1 Discontent over Fence Laws Grew with Western Expansion

American colonies adopted local regulations that required farmers to enclose their crops while livestock were allowed to run at large. Compared to the English common law practice of requiring livestock owners to *fence in* their animals (also known as "herd law"), the *fence out* rule was a logical choice when settlers faced the vast open range that lay free for grazing. However, as farmland grew and squeezed out the uncultivated open range, fence law became an increasingly contentious issue between farmers and ranchers (Hayter, 1963; Bennett and Abbott, 2017).

The high cost of fencing was one cause for the growing discontent of frontier farmers. In response to the heated public debate, the Department of Agriculture conducted a survey of fences in 1871 (Department of Agriculture, 1872). The report echoed the concern that the prohibitively high cost of fencing, combined with the fence-out rules that required farmers

[2] Ellickson (1991) studies a modern California county and shows that farmers and ranchers appeal more to social norms rather than formal legal rules for property rights conflicts.

to enclose their land, may likely deter future settlement in the west:

> "When a score of young farmers "go West", with strong hands and little cash in them, but a munificent promise to each of a homestead [...] for less than $20 in land-office fees, they often find that $1,000 will be required to fence scantily each farm, with little benefit to themselves, but mainly for mutual protection against a single stock-grower, rich in cattle, and becoming richer by feeding them without cost upon the unpurchased prairie."

More importantly, contrary to what Coase suggests in the hypothetical scenario, it did not appear feasible for frontier farmers to negotiate and re-arrange the fencing liability with the stock-grower. As described in the same 1871 report:

> "This little community of twenty families cannot see the justice of the requirement which compels the expenditure of $20,000 to protect their corps from injury by the nomadic cattle of their unsettled neighbor, which may not be worth $10,000 altogether."

In other words, although the cost of enclosing the farmland may exceed the value of livestock, for reasons unspecified in the report, farmers could only choose between paying for the fences and not settling on the frontier. Paying the stock-raiser to fence in the cattle, as suggested by Coase, did not appear to be a feasible option. The large number of settlers it may take to reach and maintain the agreement, as well as the inability to enforce such contracts, may attribute to the lack of private transactions and negotiations.

The high cost was exacerbated as the frontier moved further into the timberless prairie where fencing materials were scarce. Historians point out that "the scarcity of timber for fencing and other farm construction prevented whole areas of the prairie from being settled" (Rice, 1937). Crumbling fences could not protect the farm against livestock trespassing. It is not unusual for such devastation to lead to permanent hostility and brutal conflicts between neighbors (Hayter, 1963).

The introduction and wide adoption of barbed wire since 1875 did not resolve all the conflicts over fencing rules, despite that it largely reduced fencing cost, especially in the Great Plains with less timber supply (Hornbeck, 2010). Historical accounts show after the introduction of barbed wire, "there ensued a conflict, violent and sanguinary, between fence men and non-fence men" (Webb, 1959). The increasing conflicts may be driven by the westward expansion of farming: people could now settle in places that were too expensive to fence before barbed wire, thus putting farmers closer to stock raisers in the western states. The conflicts spread throughout the Great Plains, ranging from skirmishes between neighbors to large-scale "fence cutter wars". Local sentiment can be so strong that many did not oppose cutting others' fences and the "lawless element of the fence-cutters were held up in glowing colors"(Hayter, 1939).[3]

4.2.2 Fence-in versus Fence-out Rules

Local regulations gradually shifted from the *fence-out* rules that make farmers bear the burden of fencing and protecting crops to *fence-in* rules that require ranchers to restrain the stock from running at large. A typical *fence-out* rule would (1) define the legal fence, and (2) state that stock owners are liable for trespassing damages only if the land was enclosed by a legal fence. For example, in Arizona, the 1889 regulation required that"no persons or person shall be entitled to damages for stock trespassing upon cultivated or improved land unless such land is enclosed within a lawful fence." In contrast, a *fence-in* law prohibits livestock from "running at large", and stock owners are liable for all damages regardless of whether the injured land was enclosed or not. An 1870 Kansas regulation specified that "if the owner of stock of any description shall allow the same to trespass upon the premises of

[3]In addition to farmers and ranchers, other groups were also influenced by the adoption of barbed wire. Cowboys may lose their jobs when a ranch became effectively fence with barbed wire; small stock owners were unhappy about illegal fences on public land that kept them away from water sources.

another person such owner shall be liable in damages to the person whose property is so injured."[4]

Moreover, although most regulations opted for either fence-in or fence-out, the two regulations were not exclusive. In Jefferson County, Arkansas, the 1913 regulation[5] stated that "it shall be unlawful to [...] permit any hogs or geese to run at large." The offenders "shall be deemed guilty of a misdemeanor, and upon conviction shall be fined." In the meantime, it also required the landowner may seek compensation if the animals"shall enter the lands of any person enclosed with a lawful fence." In other words, although the stock owners were guilty of allowing certain animals to "run at large", they would not be financially liable for any damages unless the land was enclosed with a legal fence.

Historians attribute the evolution of liability rules to rising population density, land values, the expansion of agricultural production, and the decrease in unoccupied land (Hayter, 1963). Even after the cheap barbed wire fence became available, farmers and stock-raisers usually had opposing views on how to assign the liability and pushed for different fence laws. As a result, regulations can vary drastically to accommodate local public sentiment. For example, in Kansas, counties may choose to adopt different fence laws. Kansas State Board of Agriculture (1878) reports that in Montgomery County, "the herd law as in operation since 1872. A majority of the farmers are reported as being in favor of its continuance." Meanwhile, in the adjacent Chautauqua County,"(the herd law) is decidedly not wanted for Chautauqua County. It is urged that while it saves the expense of fencing and stimulates the raising of small grain for shipment, it practically prohibits the raising of stock."

Local liability rules on livestock trespassing vary not only in terms of which party is required to build the fence. Some local fence laws would explicitly prohibit injuring the animals, even when an animal broke into a farm enclosed by legal fences.[6] Other fence law

[4]See Section 4.A for the full text of the two regulations.

[5]Arkansas 39th General Assembly, Regular Session, Act 100

[6]When adopting the fence-out rule in 1885, Cochise County, Arizona, specified that "If the owner, occupier

requirements can also increase the cost for landowners to recover their potential damage from trespassing. For example, In Nebraska, counties set specific timeframe and methods to notify the stock owner about the damage, to publish announcements when the owner is unknown, and to call on a designated third party to assess the damages (State of Nebraska Legislative Assembly, 1870). Such strict rules further limited farmers' ability to protect their crops when facing livestock trespassing. Even with cheap fences, the liability rules can increase the cost of farmers seeking compensation.

4.3 Data and Descriptive Evidence

In this section, I describe the construction of fence law variables and the outcome measures from the decennial Census of Agriculture used for the analysis. The fence law data is the first comprehensive collection of the historical evolution of state and county level fence laws and codified both the broad liability rules (i.e. "fence in " versus "fence out") and specific requirements that can influence the transaction cost when recovering damages. For preliminary analysis, I collected data from six states, Arkansas, Arizona, Colorado, Kansas, Nebraska, Idaho. The data covers 265 regulation changes from the inception of each state (or territory) to 1920.[7] Though some past research has used local regulations[8] to study the effect of fence laws, this data is the first that documents the complete legislative history of local fence laws.

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or manager of any grounds or crops injured by any animal or animals breaking into or entering on grounds inclosed or not inclosed by a lawful fence shall kill, maim or materially hurt or injure any animal so breaking into or entering said grounds, he shall be liable to the owner for double the actual damages sustained, and also for all costs incurred in a suit for such damages." The Territory of Arizona Thirteenth Legislative Assembly, No. 82.

[7]Because a regulation change can influence multiple counties, there are more than 265 county-level regulation changes available for the analysis.

[8]Sanchez and Nugent (2000) use the county fence laws in 1875 to conduct a cross-section analysis.

4.3.1 Legislative History of Fence Laws

I first collect data on fence liability regulations from state session laws. I then use the legislative history to construct a panel that assigned a fence law status to each county and year cell between 1855 and 1920.[9]

For each state, I track the history of fence law policy changes by collecting the original text of state session laws from HeinOnline, which provides a digitized and text-searchable collection of all session laws. Because session laws include all legislation enacted during a session of a state or territory legislature, it provides the full history of regulation changes that ever occurred for a given state. For each state, I chronologically search the session laws from the earliest available record, usually under the territorial government, for references relevant to fence liability.[10]

Comparing to states' statutory codes, the main advantage of session laws is that they provide a complete history of the regulatory changes. Session laws are published for every legislative session, usually on an annual or biennial basis. They document the precise time and content of the regulatory change, for both new adoption or repeals, as well as amendments. In comparison, statutory codes are published much less frequently, which only reflect a snapshot of the regulations at the time of publication, thus do not track all the regulatory changes, especially repeals and amendments, between the publications.

I hand-code the variables that describe the fence liability rules based on the text.[11] The main variable of interest is the fence-in versus fence-out dichotomy, though I also code additional requirements that can influence the cost for seeking compensation for damages.[12]

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[9]The starting year varies for each state, depending on when the state (or territorial government) first held the legislative session.

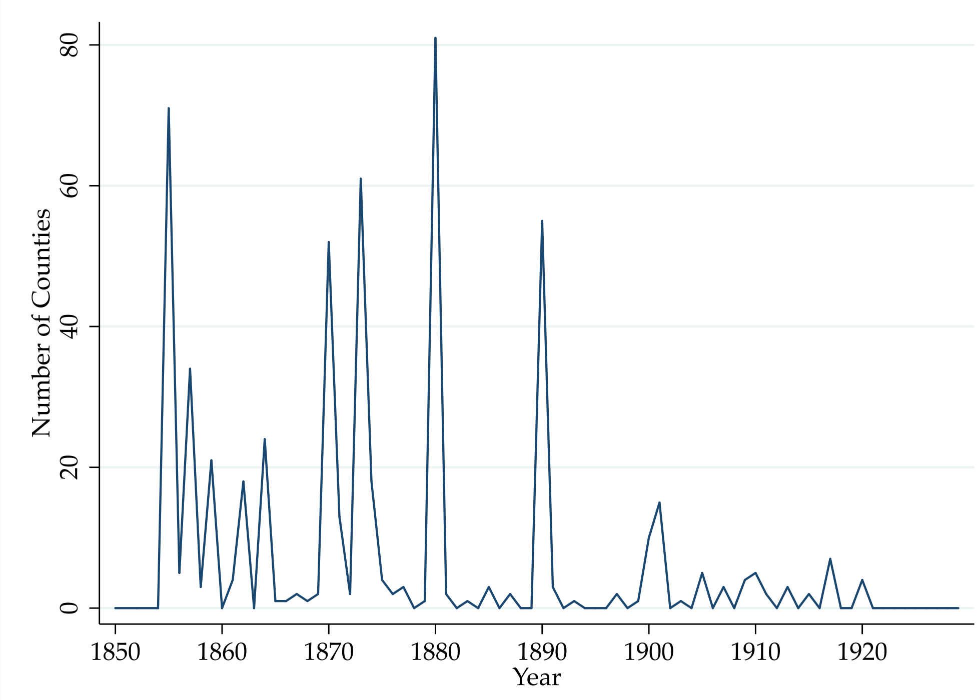
[10]I used "fence", "run at large", "herd law", "enclose" as keywords for the search.

[11]Section 4.A provides sample text for fence-in and fence-out regulations I collect from state session laws.

[12]Such regulations include whether the law required a third-party assessor to evaluate the damage, whether the injured landowner can hold and sell the trespassing animal for compensation, whether adjacent landowners need to share the cost for partition fences, or whether there are fines or criminal punishment

State regulation maps Figure 4.6 through Figure 4.10 provide a visual representation of the evolution of county-level fence laws.

Figure 4.1: Number of Counties with Regulation Changes by Year



Note: For each county, I define each case where the fence rule is different from the previous year as a "regulation change". The above figure plots the aggregate number of regulations changes for each calendar year.

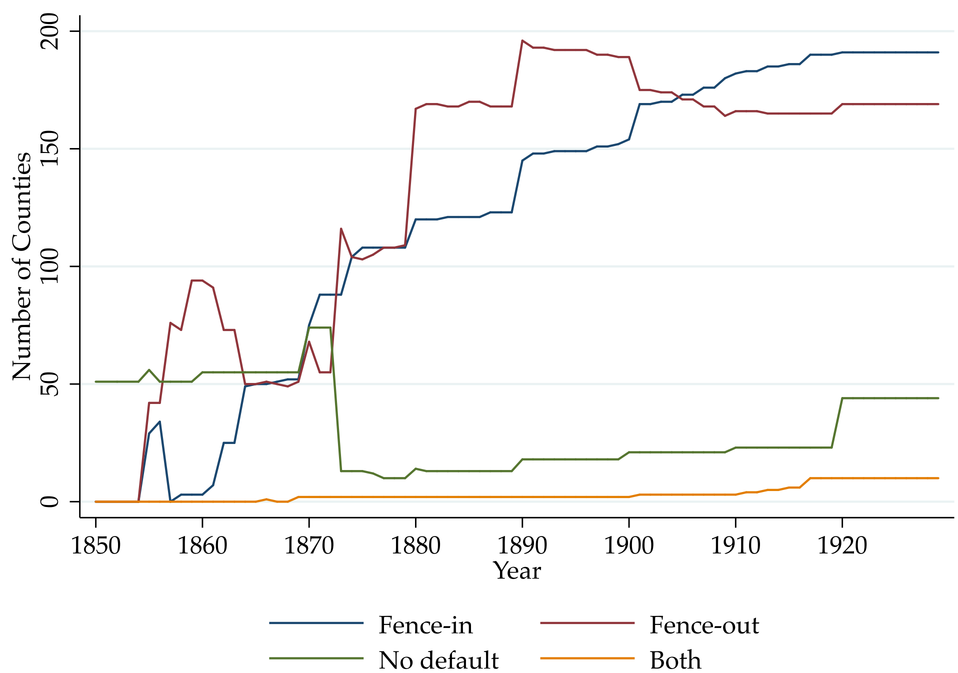
Fence law changes predated the invention of barbed wire and continued long after its wide adoption. Figure 4.1 shows the total number of regulation changes for each year between 1855 and 1920. Though barbed wire was first commercially produced around 1875, and became widely available during the 1880s, a large number of fence laws were adopted before 1875. This is consistent with the narrative evidence in Section 4.2 that the conflicts over property damage liabilities arise as farming expanded in the western frontier and put farmers in direct contact with ranchers. In addition, until the late 1910s, thirty years after cheap barbed wire became available, many counties still observed fence law changes, suggesting

in addition to the civil damage.

that the low fencing cost did not replace the importance of the liability rules.

A growing number of counties adopted some form of fence laws since the 1850s. Figure 4.2 shows that, over time, counties switched from the legal void that did not provide any default liability rule to some form of fence laws. This is consistent with the historical accounts that, as more people continue to settle at the western frontier, a clear legal definition of property damage liability became an essential institutional tool to settle conflicts over property rights (Hayter, 1963).

Figure 4.2: Number of Counties with Fence-in vs Fence-out Rules by Year



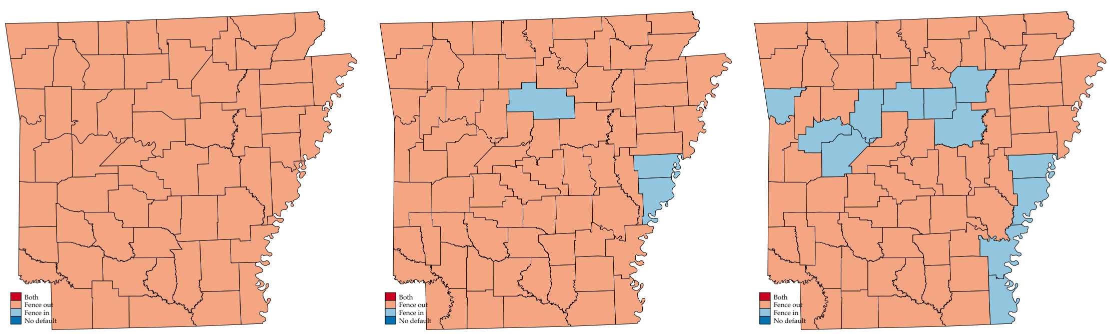
However, there was no clear preference between fence-in versus fence-out rules. Neither form of the fence law dominated the local regulations, as the number of counties under fence-in and fence-out rules grew at a similar pace and eventually reached parity.[13] This ambiguity

[13]Figure 4.5 shows the number of counties under fence-in versus fence-out rules as a share of total number of counties. By the early 1900s, about half of the counties were under fence-in rules, while the other half were under fence-out rules.

also reflects on the local level, since many counties switched between the two regulations. Kansas State Board of Agriculture (1874) reported that in Davis County, “herd law is not in force, but a movement to that end is now in progress.” By 1876, Davis County had adopted the herd law that required stockmen to fence-in the livestock. However, “public sentiment is divided, the farmers on the high prairies believing it to be a benefit, while those in the valleys, who own considerable stock, are adverse”(Kansas State Board of Agriculture, 1876).

Local fence law changes came from different sources. In Arkansas, for example, the state first passed state-wide legislation in 1873 that imposed fence-out rules on all counties. However, local residents pushed back on the regulation. Over time, many counties chose to adopt fence-in rule. As shown in Figure 4.3, some counties chose to switch the fence rule, even when many of their neighbors stayed with the state-wide fence-out requirement.

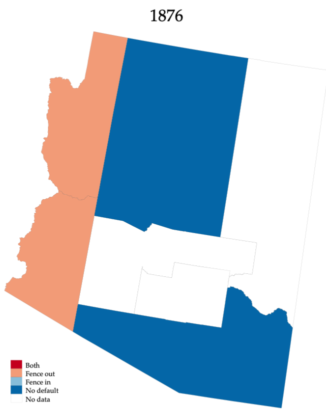
Figure 4.3: Arkansas Changed from State-wide Fence-out to Local Fence-in



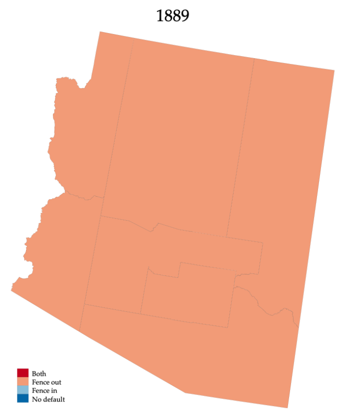
(a) 1873 (b) 1883 (c) 1897

The regulations can also start from the local level before the state legislature pushed for a state-wide regulation. In Arizona, the first fence-out law was adopted in Mohave and Yuma county in 1876, while other counties operated with no clear default liability rules. It was not until 1889 that the state legislature adopted a state-wide regulation on fence liability (see Figure 4.4).

Figure 4.4: Arizona Started with Local Fence Laws



(a) 1876



(b) 1889

4.3.2 Agricultural Productivity

I collect the main outcome measures, including land use pattern, land value, and quantity of livestock and other farm output, from the county level decennial *Census of Agriculture* from 1840 to 1920 (Haines et al., 2018). These data provide a consistent measure of agricultural production at the county level over the long run.

Local regulations are likely to be associated with the natural endowment and the corresponding popular mode of agriculture production. Intuitively, fence-in regulations would create higher marginal returns to farmers in counties more suitable for farming than ranching. Therefore, farmers in such counties would have a stronger incentive to push for the fence-in rules. I use the"naturally attainable yield" from the Global Agro-Ecological Zones (GAEZ) project created by the Food and Agriculture Organization (FAO) to measure each county's "suitability" for different types of agricultural products.[14] I aggregate the data at the county level and calculated the average yield level for each county. I approximate grain

[14]The FAO first collects a set of input measures, including the soil types and conditions, the elevation, climatic variables (i.e. rainfall, temperature, sun exposure), etc. The input measures are then fed through an agronomic model to predict the attainable yield for each type of crop (Fischer et al., 2021; Costinot and Donaldson, 2016; Nunn and Qian, 2011). The GAEZ data reports yield levels for different input scenarios. I use "intermediate" input intensity with "irrigated" water supplies for all the crops in the analysis.

productivity using the yield of wheat. For the analysis, I focus on four main types of crops: wheat, maize, alfalfa, and pasture grass.

4.4 Identification Strategy

I exploit the variation in the adoption of fence laws at the county level to examine the effects of fence laws on agricultural production. Limited by the sample size, this preliminary analysis restricted the sample to the subgroup of counties with either fence-in or fence-out rule. In addition, I also exclude counties with multiple regulation changes that switched back and forth between fence-in and fence-out. Such cases require stronger assumptions on the treatment effects, which cannot be properly estimated with the current sample. 84 percent of the original sample satisfied both restrictions.

Specifically, I estimate the OLS difference-in-differences regression:

$$y_{it} = \beta \mathbb{I}(F_{it}) + \sigma_i + \tau_t + \epsilon_{it} \tag{4.1}$$

where y_{it} is the outcome measure for county i at year t; $\mathbb{I}(F_{it})$ is the indicator for county i at year t with "fence-in" rules; σ_i is county fixed effects that control for time-invariant characteristics such as natural conditions; τ_t is the year fixed effects that control for variations in the outcome that are common to all counties for the year t, which includes any general technological change that may affect all agricultural production over time. The coefficient of interest, β, can thus be interpreted as "on average, how did counties with fence-in rules differ from counties with fence-out rules?"

The identification strategy relies on the assumption that fence laws adoptions are not endogenous to local natural endowments. However, counties more suitable for ranching may be more likely to adopt fence-out rule, or vice versa. If the fence laws are endogenous to local conditions, the comparison between counties with different fence requirements may not provide credible identification for the causal effects of fence laws on agricultural productivity.

I test directly whether counties that adopted different fence laws were statistically indistinguishable in terms of their suitability for different types of crops.[15] I estimate a cross-sectional regression for each type of crop (wheat, maize, and fodder[16]), where I regress the naturally attainable yield of each crop on the indicators for each type of fence laws and state fixed effects. Compared to the counties with the no-default liability rule, which is the omitted category, none of the other three fence-law categories are statistically different in terms of attainable yield (Table 4.1). In addition, the coefficients for fence-in versus fence-out groups are also not statistically different. I conclude that, for counties within the same state, the fence law adoptions were not endogenous to local natural endowments.

Table 4.1: Comparing Average Attainable Yield by Fence Law Types

Dependent variable Attainable yield	(1) Wheat	(2) Maize	(3) Fodder
Fence in	-0.050	-0.039	0.001
	(0.055)	(0.095)	(0.010)
Fence out	0.008	0.027	0.015
	(0.024)	(0.040)	(0.008)
Both	-0.157	0.426	0.009
	(0.215)	(0.241)	(0.024)
State FE	Yes	Yes	Yes
F (Fence-in = Fence-out)	0.55	0.24	1.32
N	2217	2217	2217

Note: "No Default" as omitted category. Standard errors clustered at state level. * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$

[15] The narrative evidence from Section 4.2.2 suggests that this is less of a concern: adjacent counties with plausibly similar environmental conditions may often end up with different fence laws.

[16] I use the sum of alfalfa and prairie grass as the measure for fodder yield.

4.5 Effects of Fence Laws

In this section, I analyze the effect of fence laws on land use patterns, production choice, and output values. I then introduced the robustness check which compares adjacent counties with different fence laws. Results suggest that fence-in rule incentivized more farmland development and improvement and created higher output values. However, it did not change settlement or the density of livestock.

4.5.1 Settlement and Land Use

Fence-in rule did not lead to more settlement. Though on average population density is 6.7 percent higher in fence-in counties after the adoption, the coefficient is not statistically significant (column (1) in Table 4.2). This potentially may be attributable to the relatively short time window for the analysis, while settlement decisions may take longer to realize.

Table 4.2: Difference in Settlement and Land-use Between Fence-in and Fence-out Counties

	(1) Population Density	(2) Farmland Per Acre	(3) Improved Land % Farmland
Fence-in	0.002	0.063**	0.088***
	(0.007)	(0.029)	(0.029)
Year FE	Yes	Yes	Yes
County FE	Yes	Yes	Yes
Mean	0.03	0.47	0.48
% of mean	6.67	13.40	18.33
N	1668	1712	1681
R^2	0.97	0.87	0.74

Note: Sample limited to counties with at most 1 regulation changes. Standard errors clustered at county level. * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$

In contrast, fence-in rule facilitated agricultural development on the extensive margin even without substantial changes in settlement. By shifting the cost of property protection to ranchers, the fence-in rule lowered the marginal cost of production for farmers. Counties under fence-in rule saw 13.4 percent more of the land areas that are converted to farmland than counties under fence-out rule (column (2) in Table 4.2).

The fence-in rule also changed land-use patterns on the intensive margin by increasing the total improved farmland as a share of the total farmland area. Compared to fence-out counties, fence-in counties had 18.3 percent more improved farmland (column (3) in Table 4.2). This result is robust to controlling for county fixed effects and thus is not influenced by time-invariant local conditions such as climate, soil, and other national endowments, as well as initial acreage of woodland that may influence fencing cost before the barbed wire.

4.5.2 Production Decision

Fence laws also changed production decisions. Facing lower risks of animals trespassing and damaging crops, farmers under fence-in rule may be more inclined to cultivate grains, which were most vulnerable to trespassing. The difference-in-differences results show that, compared to fence-out counties, the share of farmland allocated to maize is 24.6 percent higher. The expansion of grain production, however, did not come at the cost of reducing livestock production: the share of farmland used for fodder growth is not statistically different between fence-in and fence-out counties (columns (1) and (2) in Table 4.3).

Table 4.3: Difference in Production Decisions

	(1) Corn	(2) Fodder	(3) Corn(bu.)	(4) Fodder (ton)	(5) Cattle	(6) Swine
	Cultivation Area as Share of Farmland		Output Per Acre		Heads Per Acre	
Fence-in	0.032***	0.008	1.616***	0.002	0.002	0.009
	(0.006)	(0.005)	(0.378)	(0.011)	(0.003)	(0.006)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Mean	0.13	0.10	3.26	0.14	0.03	0.05
% of mean	24.62	8.00	49.57	1.43	6.67	18.00
N	1499	1501	1665	1610	1698	1698
R^2	0.86	0.79	0.76	0.74	0.75	0.79

Note: Sample limited to counties with at most 1 regulation changes. Standard errors clustered at county level. * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$

Lower liability costs also induced higher input into grain production, as farmers expected higher marginal returns from the land absent of trespassing loss. The average yield of corn in fence-in counties increased by 49.6 percent (columns (3) in Table 4.3). Though there is no direct measure of labor or capital input for a particular type of product, the higher per-acre output suggests that non-land input was also higher for counties with fence-in rules. Similar to the results in land use, fodder crops did not appear to have different yields between counties under different fence rules (columns (4) in Table 4.3).

Because livestock production also relied on non-cultivated resources, such as the free public forest or prairie, fodder growth and yields may not be a good measure for the influence of fence laws on livestock production. Columns (5) and (6) in Table 4.3 show the estimation results for the density of cattle and swine. The estimated coefficients are small in magnitude and not statistically significant for both types of livestock. In other words, livestock production did not suffer under the fence-in rule.

4.5.3 Land and Output Value

Fence laws eventually influenced the value of agriculture output by changing the production decisions. Table 4.4 presents the results for average land value, the value of the total product, and the value of livestock. Though fence-in rules have increased the productivity of grain production, the effect did not translate into land value. The average farm price per acre between the fence-in and fence-out counties is not distinguishable (column (1) in Table 4.4). This unexpected result may due to the data structure: the panel data has a relatively short time span, which ends in 1920. This implies that the slow private land market may not be able to fully realize the gains from the new regulations yet.

Table 4.4: Difference in Land and Output Value

Dependent Variable: Value Per Acre, in 1920$	(1) Farm value	(2) Total Product	(3) Crop	(4) Livestock
Fence-in	-6.575	9.877**	2.099***	7.777*
	(4.727)	(4.612)	(0.750)	(4.390)
Year FE	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes
Mean	49.15	31.86	10.18	21.67
% of mean	-13.38	31.00	20.62	35.89
N	1667	1667	1667	1667
R^2	0.72	0.21	0.46	0.21

Note: Sample limited to counties with at most 1 regulation changes. Standard errors clustered at county level. * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$

Though there was no observable change in land value, the productivity gains were reflected in the annual value of output. Compared to fence-out counties, fence-in counties saw a 31 percent increase in the total value of product, or 9.8$ per acre (column (2) in Table 4.4). For an average farm of 358 acres, this means the family would have $3,500 more in total output. The increase in output value came from both the increase in livestock and non-livestock (recorded as "crop" in column (3)) products, with the value of livestock increased at a higher rate (35.9 percent).

4.5.4 Robustness: Neighboring County Comparison

I use the neighboring counties with different fence laws as a robustness check. One potential challenge to the based-line identification is that, even after controlling for time-invariant characteristics through county fixed effects, the average fence-in and fence-out counties still may not be comparable. Adjacent counties, however, were more similar, both in terms of natural conditions and other aspects that may influence agricultural production, such as railroad coverage and access to an operational judicial system. The comparison between neighboring counties with different fence laws can thus provide stronger support to the baseline results.

Specifically, I estimate the following reduced-form regression:

$$y_{ijt} = \beta \mathbb{I}(F_{ijt}) + \sigma_{ij} + \tau_t + \epsilon_{ijt} \tag{4.2}$$

where the subscript j denotes the neighboring county pair. All standard errors are clustered at the county-pair level.

Table 4.5: Neighboring County Comparison

	(1) Farmland	(2) Improved Farmland	(3) Total Product	(4) Livestock
	Per Acre	% of Farmland	Value Per Acre in 1920 $	
Fence-in	0.043***	0.046***	0.960***	0.230**
	(0.007)	(0.009)	(0.218)	(0.092)
Year FE	Yes	Yes	Yes	Yes
Border Pair FE	Yes	Yes	Yes	Yes
Mean	0.50	0.50	10.15	4.82
% of mean	8.60	9.20	9.46	4.77
N	8693	8544	8693	8693
R^2	0.86	0.71	0.83	0.83

Note: Sample limited to counties with at most 1 regulation changes. Standard errors clustered at border-pair level. * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$

Table 4.5 shows that, even within each pair of adjacent counties, the fence-in rule still appears to increase agricultural productivity. Compared to the neighboring counties with a fence-out rule, counties under fence-in rule had more land area being developed as farmland and a larger share of farmland being improved. The average value of the total product and the value of livestock were also higher for counties under fence-in rule.

4.6 Conclusion

This chapter has used the spatial and inter-temporal variation in local fence laws to investigate the effects of liability rules on agricultural productivity. Comparing counties that put the liability for livestock trespassing on either farmers or ranchers, I show that fence-in rule encouraged agricultural development in the frontier by expanding the farmland. Moreover, I find that fence-in rule changed the production decisions by encouraging farmers to shift more land to produce corn. The fence-in counties eventually saw higher values of output, though the productivity gains were not reflected on land values. The main results are also robust to comparing only the neighboring counties with different fence laws.

Understanding the implications of liability rules has direct policy implications today. Growing evidence from the development literature suggests that property rights and liability rules may distort market allocation and create persistent inefficiency. This chapter complements the literature by providing empirical evidence to quantify the effect of a particular type of liability rule. The results highlight both the importance of liability rules, as well as the potential economic damage created by the institutional failure.

In future research, I plan to expand the spatial and temporal coverage of the data. The larger sample size will allow me to employ the event-study design with distributed-lag models, which can better accommodate different treatment timing with time-varying treatment effects. In addition, the reduced form results do not provide a complete counterfactual to quantify the welfare loss. I will use the difference between empirical land allocation and the optimal allocation suggested by the market price vector to quantify the aggregate welfare loss resulting from different liability rules.

4.A Historical Fence Laws

Fence-in versus Fence-out Sample Text

Below is an example of **fence-out** rule from Arizona in 1889, which includes definition of legal fences, fines for repeated offense, and prohibiting land owners from injuring the trespassing animals:[17]

> "An Act to Regulate Lawful Fences and Trespass within the Same
>
> Section 1. Every enclosure shall be deemed under a lawful fence when the said fence is constructed as follows: All fences not less than fifty-four inches high, consisting of boards firmly fastened to posts well set, not more than nine feet apart, the space between the ground and bottom board and each space between the boards, not more than eight inches, shall be considered lawful and sufficient fence, and all fences fifty-four inches high, consisting of four barbed wires, firmly fastened to posts well set, not more than thirty feet apart, with good stays extending from the top wire to the ground, placed every eight feet between the posts, each wire being firmly fastened to such stays, the bottom wire being placed not less than eighteen inches from the ground and the other three wires about equi-distant apart from the bottom wire to the top of the fence, shall be deemed a legal and sufficient fence. When barbed wire is used for a fence, a board or pole may be used in place of the top wire when properly and securely fastened and stayed; and all fences consisting of rail,, timbers, stone walls, brush, hedge, adobe, or other material, which shall be equivalent to the board or barbed wire fence herein described, shall be deemed a legal and sufficient fence.
>
> Section 2. No persons or person shall be entitled to damages for stock trespassing upon cultivated or improved land unless such land is enclosed within a lawful fence.
>
> Section 3. When any stock shall break into any enclosure enclosed by a lawful fence and damage the crops or property in any way, including the breaking of the fence, the said stock shall be liable to the owner of the said premises for the said damages, and may be held, advertised and sold for the same, the damages to be assessed by three uninterested persons, and notice of sale be posted in three public places in the precinct where such damage occurs for at least five days prior to said sale.

[17] 15th Legislative Assembly of the Territory of Arizona, No 21

Section 4. The Board of Supervisors of the Counties of the Territory are hereby empowered, authorized, and it is made their duty, within thirty days after the passage of this Act, at a special meeting called for that purpose, to designate districts within their respective Counties within which owners or persons in possession of lands shall or shall not fence the same. They shall designate such districts by numbers and well marked boundaries, according to natural objects or government.lines, which action shall be spread upon their minutes and become apart of the records of the Board.

Section 5. After they have designated and marked the exterior boundaries of said districts, they shall cause to be published in some newspaper published in the County, a copy of such proceedings as are provided for in the preceding section, once a week for four successive weeks. after which last said publication, said fence districts, or no fence districts, as established by the Board of Supervisors under this Act, shall be the law of this Territory governing the same, and in all suits, civil or penal, that may arise after said publication, shall be the law to govern the Courts in which such suits may be brought under this Act.

Section 6. All Acts and parts of Acts in conflict with the provisions of this Act, so far as they affect any County or part thereof designated by order of the Board of Supervisors to come within the provisions of this Act, are hereby repealed.

Section 7. This Act shall take effect and be in force from and after its passage.

Approved March 19, 1889.

The second example is the county level **fence-in** rule from Kansas in 1870,[18] which specified the applicable counties, the default liability regardless of fence conditions around the damaged land, as well as the procedure for the injured land owner to seek compensation.

"An Act to Provide for a Herd Law in the Counties of Saline, Ottawa, Washington Cloud, Cherokee and McPherson.

Section 1. That the counties of Saline, Ottawa, Washington, Cloud, Cherokee and McPherson shall be exempt from the provisions of an act entitled " an act in relation to fences," for the period of five years from the date of the approval hereof.

Section 2. That during said period of time, if the owner of stock of any

[18] 10th Legislature of the State of Kansas, Regular Session, Chapter 115

> description shall allow the same to trespass upon the premises of another person such owner shall be liable in damages to the person whose property is so injured.
>
> Section 3. That there shall a lien exist upon any stock so trespassing upon the premises of another person, and injuring or destroying the crops, trees or other property of such person to the amount of the damages he may sustain under section two of this act, and for the purpose of making said lien inure to his benefit, any party so injured may take into his possession any animal while on his premises and keep the same until the amount of damages shall have been ascertained and established by a court of competent jurisdiction, when said animal or animals shall, by order of the court hearing the cause and rendering judgment therein, be sold as under an order of execution, and after satisfying the judgment in such case, and all cost, the balance shall be paid over to the owner or owners of said animal or animals sold, or the persons in charge of the same at the time the damages are committed[...]

The regulatory data focuses on state and county level regulatory changes, which corresponds nicely to the census data on outcome measures. One caveat is that it does not fully capture local regulations that applies only to certain areas of a county. Because the regulations were coded as categorical variables, some minor policy difference, such as exemption for the winter months or certain types of livestock, are not reflected in the data.

4.B Appendix Figures

Figure 4.5: Share of Counties under Fence-in versus Fence-out Laws

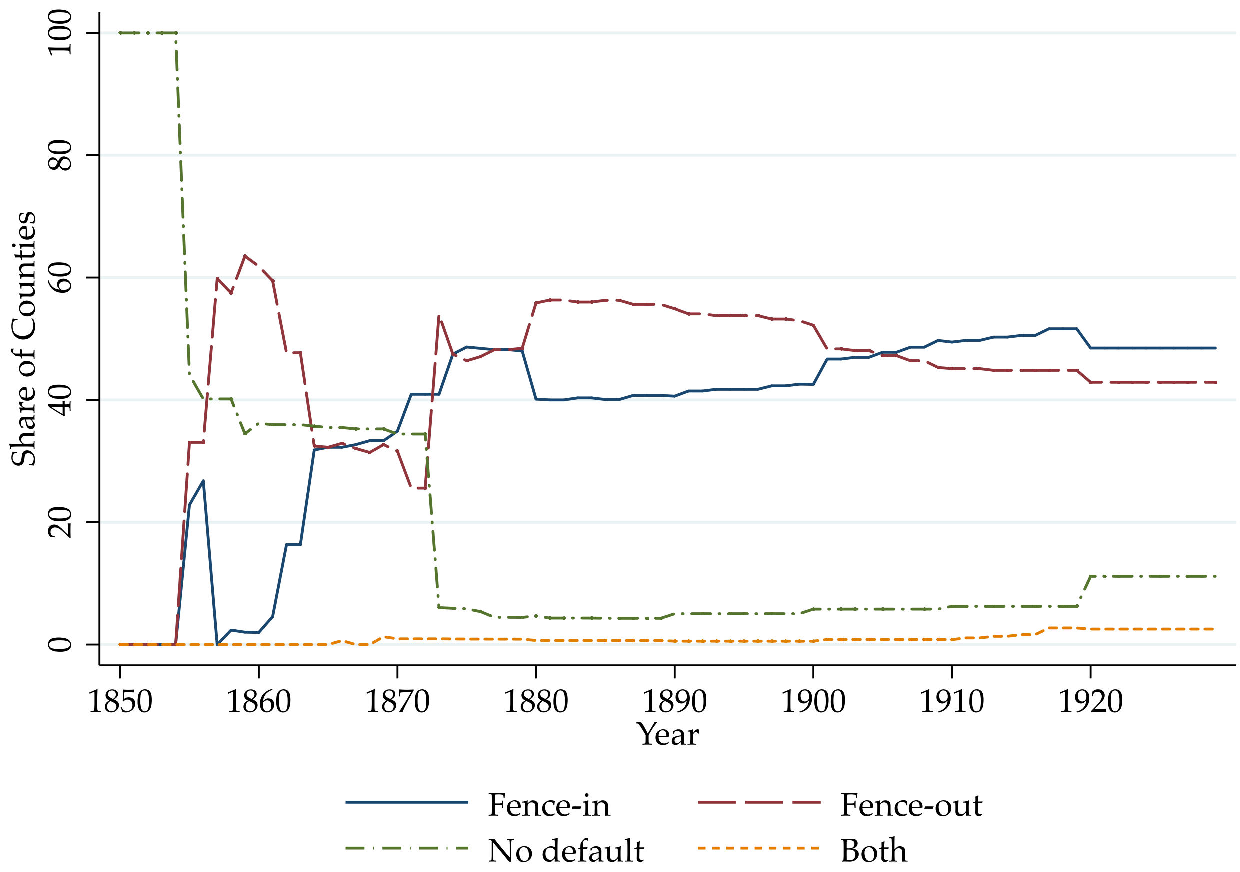
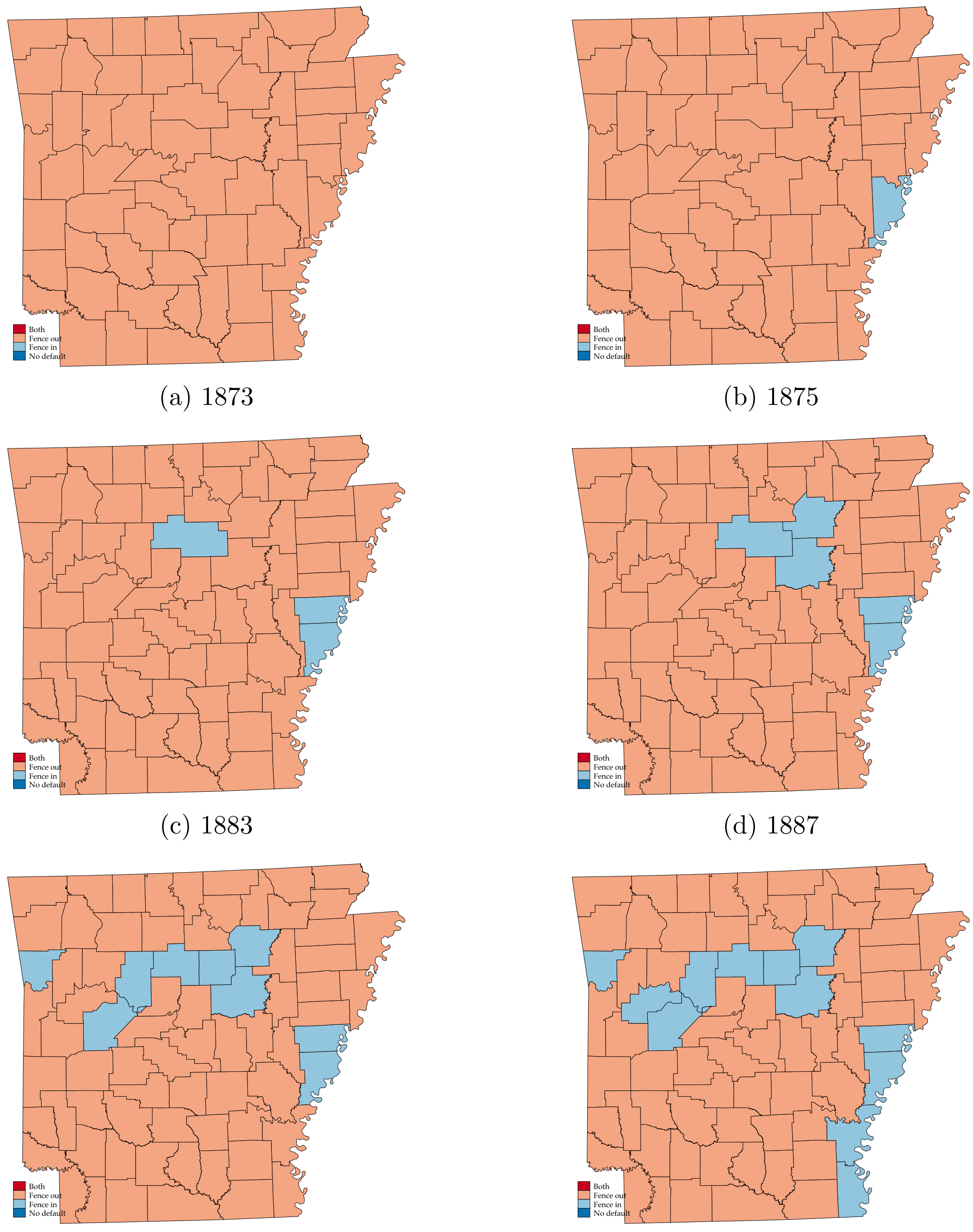


Figure 4.6: Evolution of Fence Laws in Arkansas



(a) 1873

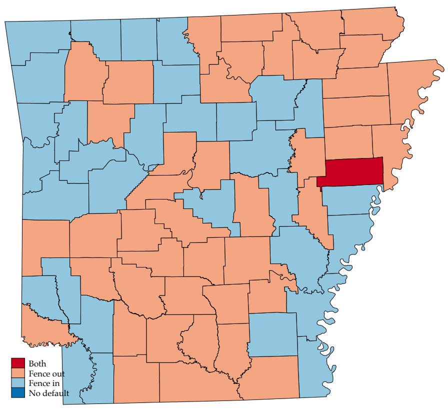
(b) 1875

(c) 1883

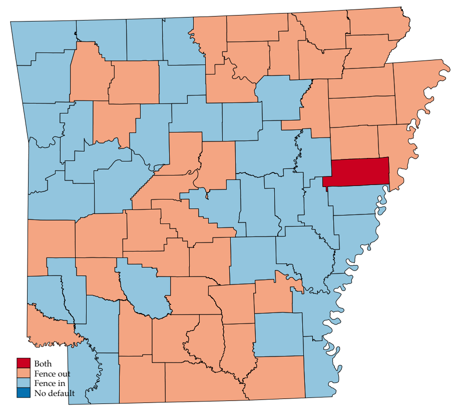
(d) 1887

(e) 1891

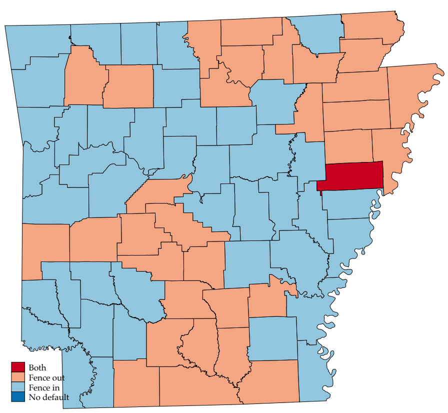
(f) 1897



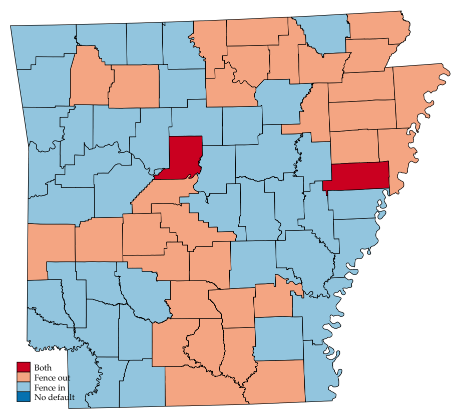
(g) 1901



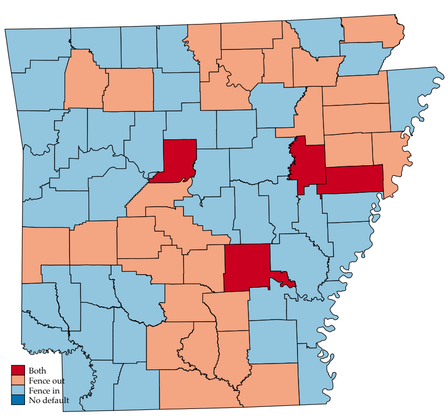
(h) 1905



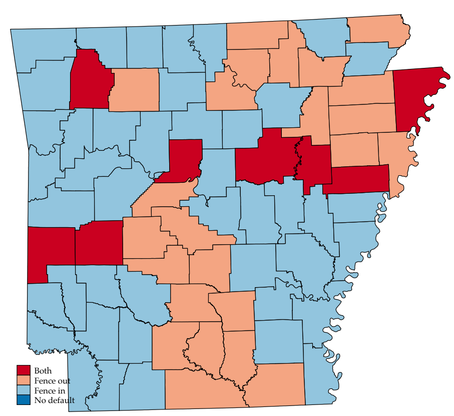
(i) 1909



(j) 1911



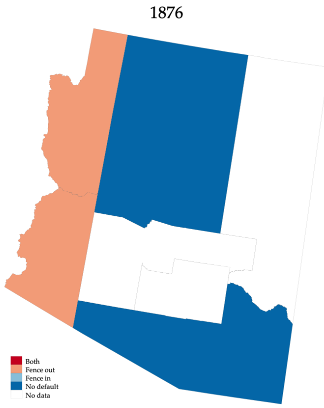
(k) 1915



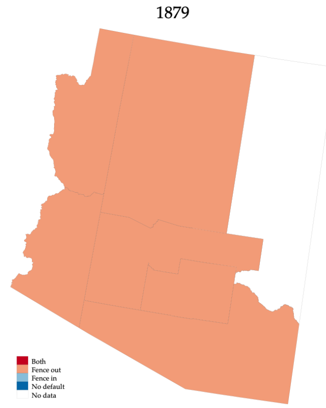
(l) 1919

Note: Counties marked as “no data” are counties that are defined in the Census map, but do not have decennial census records.

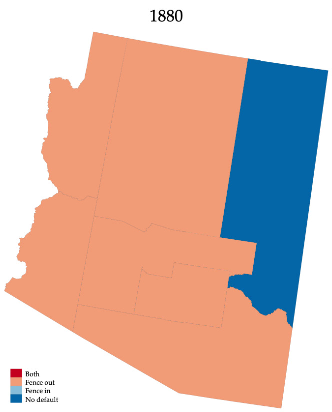
Figure 4.7: Evolution of Fence Laws in Arizona



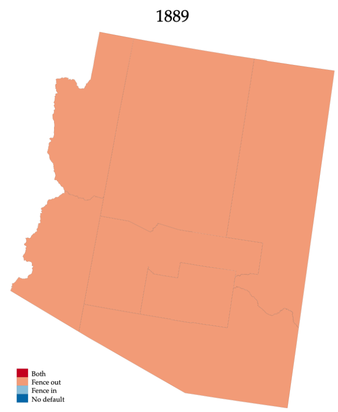
(a) 1876



(b) 1879

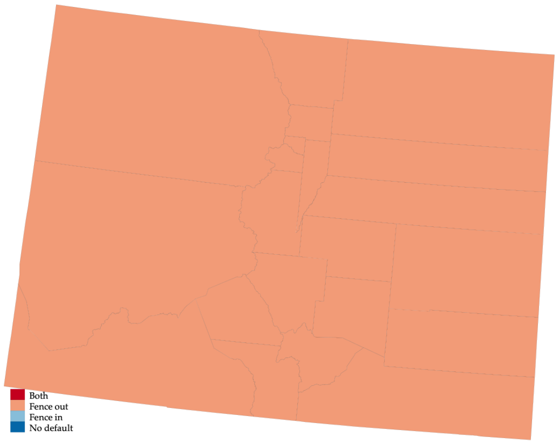


(c) 1880

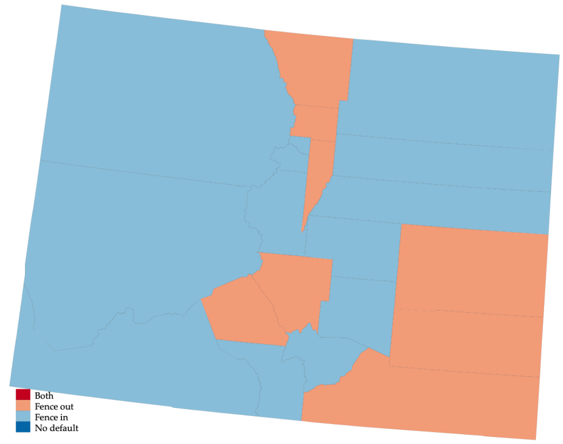


(d) 1889

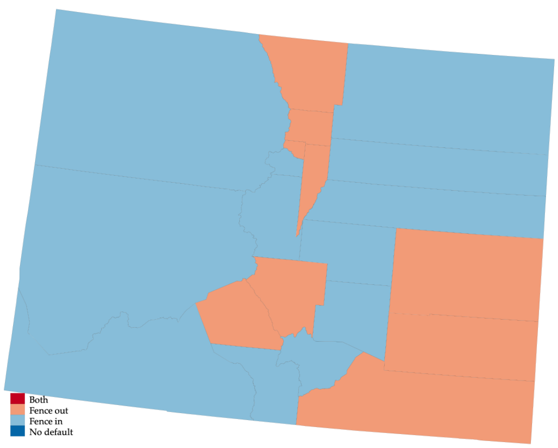
Figure 4.8: Evolution of Fence Laws in Colorado



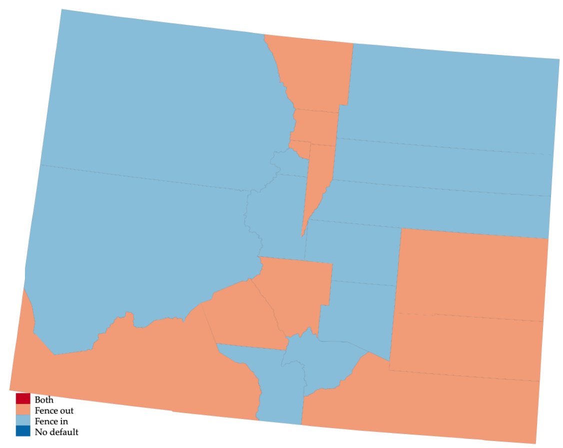
(a) 1859



(b) 1862



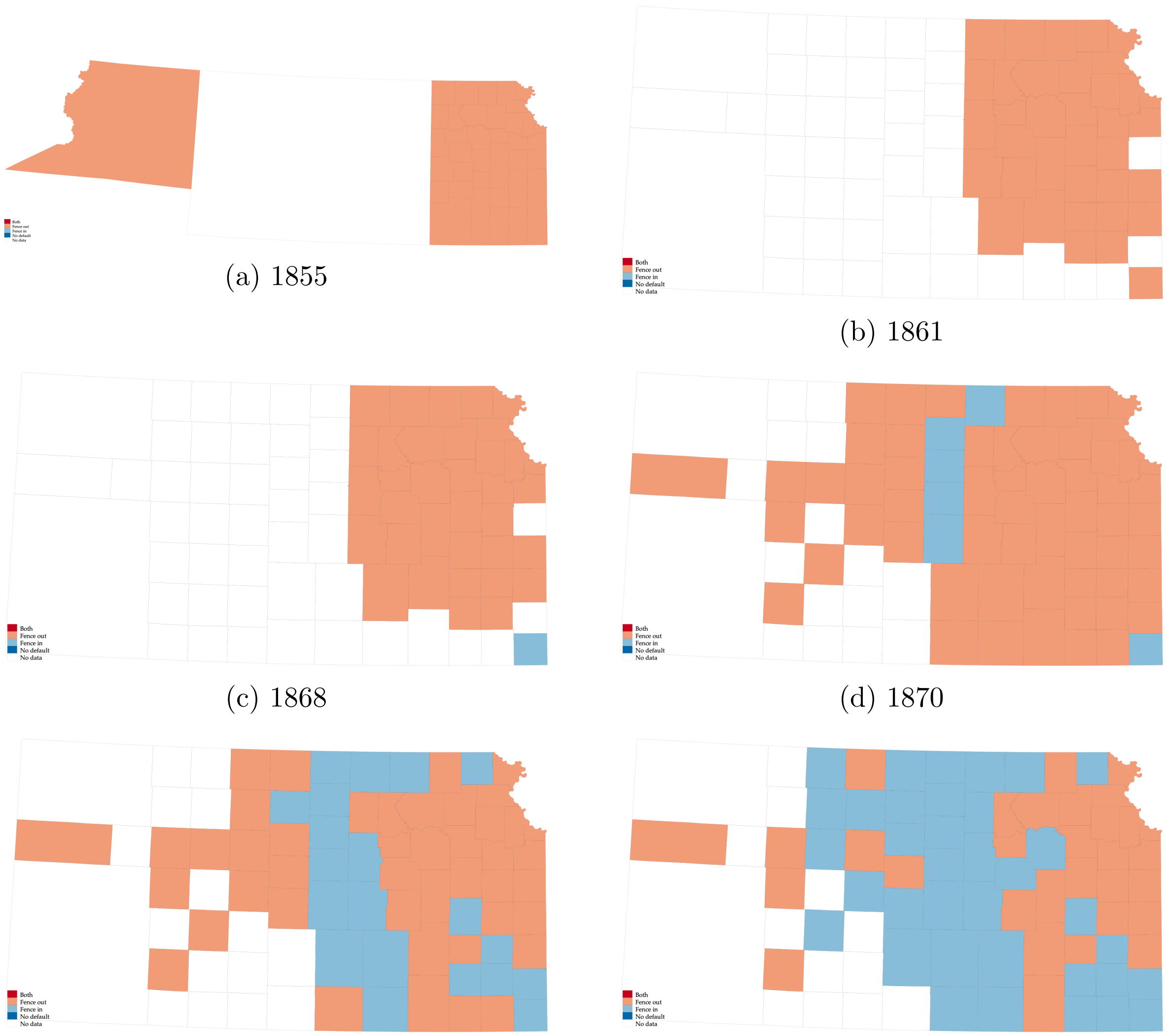
(c) 1872



(d) 1874

Note: Counties marked as “no data” are counties that are defined in the Census map, but do not have decennial census records.

Figure 4.9: Evolution of Fence Laws in Kansas



(a) 1855

(b) 1861

(c) 1868

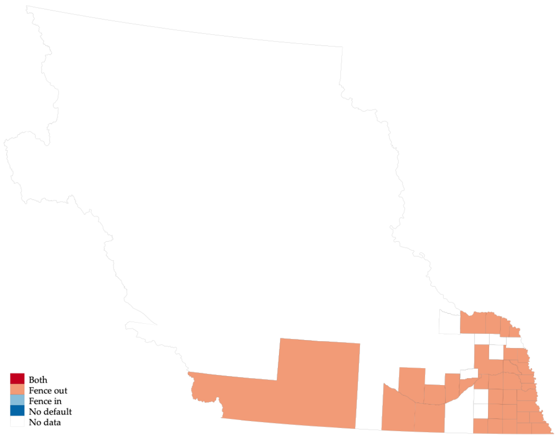
(d) 1870

(e) 1872

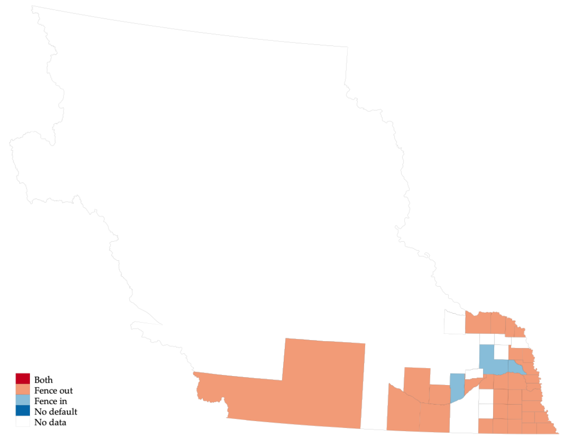
(f) 1874

Note: Counties marked as “no data” are counties that are defined in the Census map, but do not have decennial census records. Kansas state was admitted in 1861. Maps show the boarder of Kansas Territory for 1855-1861.

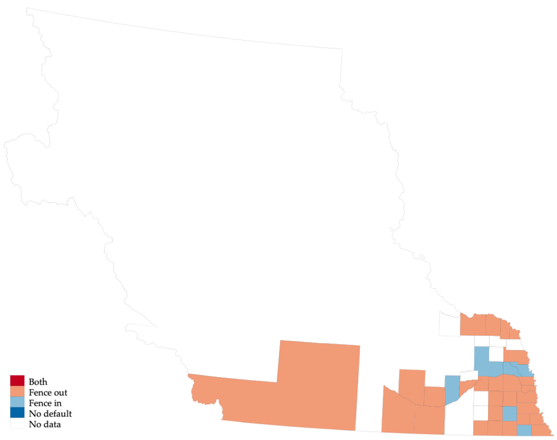
Figure 4.10: Evolution of Fence Laws in Nebraska



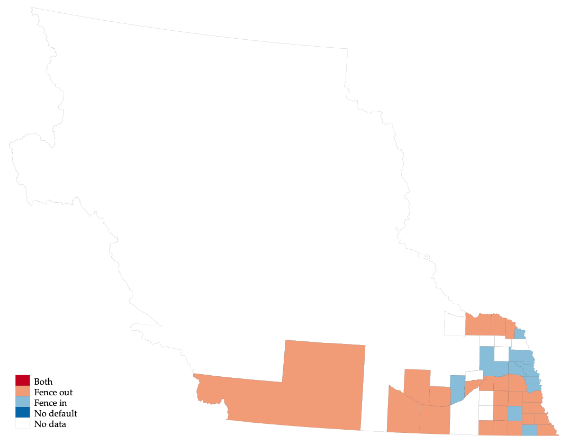
(a) 1857



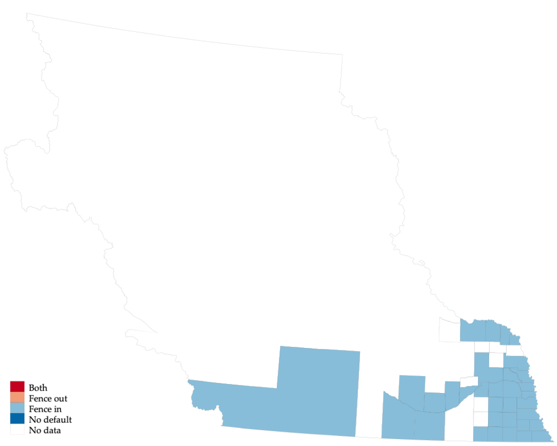
(b) 1858



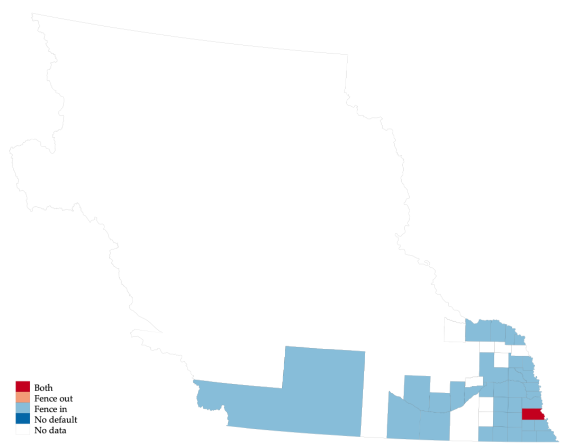
(c) 1861



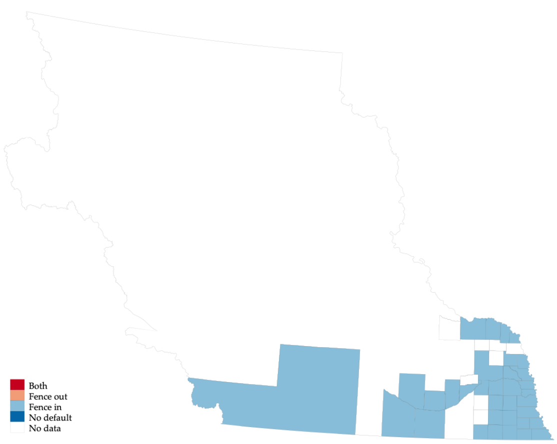
(d) 1862



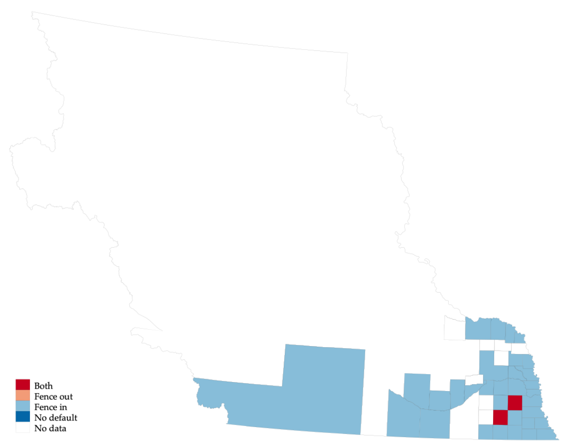
(e) 1864



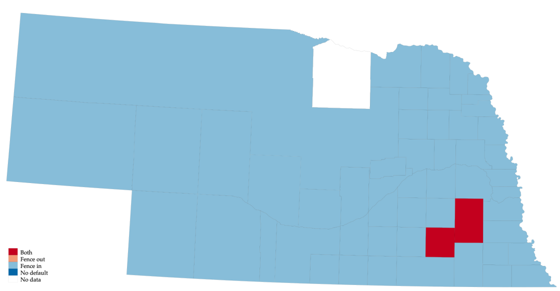
(f) 1866



(g) 1867



(h) 1869



(i) 1871

Note: Counties marked as "no data" are counties that are defined in the Census map, but do not have decennial census records. Nebraska state was admitted in 1867. Maps show the boarder of Nebraska Territory for 1855-1867.

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