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Technology Adoption and Product Diversification in the Brewing Industry over the Nineteenth and Twentieth Centuries

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Technology Adoption and Product Diversification in the Brewing Industry over the Nineteenth and Twentieth Centuries

A dissertation submitted in partial satisfaction
of the requirements for the degree
Doctor of Philosophy in Economics

by

Carlos Eduardo Hernández Castillo

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Abstract of the Dissertation

Technology Adoption and Product Diversification in the Brewing Industry over the Nineteenth and Twentieth Centuries

by

Carlos Eduardo Hernández Castillo

Doctor of Philosophy in Economics

University of California, Los Angeles, 2016

Professor Leah Michelle Boustan, Chair

This dissertation studies the effect of scientific discoveries, regulation, and changes in market access on the American and Japanese brewing industries over the nineteenth and twentieth centuries. Breweries adapted to these shocks by switching to new technologies, products, and geographical markets. In the long run, this adaptation process shaped the structure of the brewing industry and introduced competition and new production techniques in the soft-drink and biotechnology industries. Using detailed data at the brewery-level, coupled with natural experiments, I study the repercussions of this adaptation mechanism across industries and over time.

In the first chapter, I study how private trade costs affect the relocation of industries in response to market integration. I focus on the relocation of the American brewing industry during the late nineteenth century, when migration and the expansion of the American railroad network reduced the costs of reaching consumers troughout the US. Using a brewery-level database that I constructed, I show that the endogenous adoption of bottling –a private reduction in marginal trade costs that required the payment of a one-time cost– amplified the effect of market integration on the relocation of the brewing industry from the East Coast to the Midwest of the United States. Such relocation occurred mainly through the growth of intra-regional trade of beer within the Midwest.

In the second chapter, I study whether early exposure to demand reductions improves the performance of firms during future demand shocks. I focus on the American brewing industry during prohibition in the early twentieth century. Some breweries faced early reductions in demand when nearby counties introduced prohibition at the local level. Other breweries were insulated from local prohibitions until the start of federal prohibition, when the entire US prohibited the production and distribution of alcoholic drinks. I follow 1,300 breweries throughout both local and federal prohibitions, using firm-level data that I collected. Breweries that faced early reductions in demand were 12% more likely to survive the full prohibition period, from before local prohibition until the end of federal prohibition, than breweries that did not face early reductions in demand. This increase in survival occurred because a group of breweries made early investments in machinery that later facilitated product switching into soda and other foodstuffs.

The third chapter is coauthored with Michael Darby and Lynne Zucker. Scientists affiliated to Japanese breweries authored 81% of the academic articles produced by breweries all over the world between 2000 and 2005 –50 percentage points more than twenty years earlier. Most of this increase in academic production occurred between 1986 and 1996, when the number of published articles affiliated to Japanese breweries increased sixfold. We show that this increase in academic production is the result of product diversification towards the pharmaceutical and biochemical sectors in which collaboration with academic scientists is common. Product diversification was possibly driven by reductions of barriers to entry in the Japanese market for beer. Diversification and innovation became persistent over time because the new sectors were intensive in knowledge that was tacit and therefore excludable.

The dissertation of Carlos Eduardo Hernández Castillo is approved.

Dora Luisa Costa

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Edward E. Leamer

Romain T. Wacziarg

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University of California, Los Angeles

2016

To my mother, who taught me three times how to do long division.

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CHAPTER 1

Industrial Relocation and Private Trade Costs: How Brewing Moved West in the United States

1.1 Introduction

The relocation of industries in response to market integration is both an empirical regularity and a fundamental implication of economic theory.[1] As a result, relocation plays an important role in the analysis of policies that reduce trade costs, like infrastructure development and trade liberalization. But public investments and policy are not the only source of reductions in trade costs: firms can also reduce their private trade costs through investments in transportation and distribution. These investments can respond endogenously to market size, amplifying or weakening the effect of economic policy on the location of economic activity.

In this paper I study the relocation of the American brewing industry during the late nineteenth century, when the invention of pasteurization made it feasible to distribute beer in bottles that did not need refrigeration. As a result, the marginal cost of shipping beer fell for those breweries willing to build a bottling plant. Using a novel dataset that I constructed, I observe which breweries built bottling plants during the next decades, as the share of bottling plants increased from virtually zero in the 1860s to 21% in 1880 and 51% in 1898 while the center of gravity of the brewing industry moved from the East Coast towards the Midwest.

[1] Relocation is also important for welfare: as industries shrink in some locations and grow in others, the gains from specialization and agglomeration increase

I show that this locational shift is not explained by an increase in interregional trade. In particular, it is not explained by the growth of the national shippers – six breweries that shipped beer at the national level and became the largest brewers in the industry by the end of the century, but only constituted 8% of output in 1898. Instead of being explained by interregional trade, the shift towards the Midwest in American brewing was initially driven by intraregional trade. Beer output increased disproportionately in the MidWest as regional breweries adopted bottling earlier than breweries in the East Coast.

My paper contributes to the literature on trade, investment and the location of economic activity. Lileeva and Trefler (2010) and Bustos (2011) show that increases in market access induce firms to increase investment and innovate in order to start exporting or export more. My paper contributes to this literature by showing that investments that reduce private trade costs can amplify the effect of market integration on the location of economic activity. For example, Kim (1995) shows that, despite the expansion of the railroad network, regional specialization in the US slightly declined between 1860 and 1890. Regional specialization only increased substantially towards the turn of the twentieth century. My paper shows that the brewing industry had an early shift towards the Midwest thanks to the invention of pasteurization and the endogenous adoption of bottling by breweries in the late 1870s.

My paper also contributes to the historical literature on the American brewing industry during the pre-prohibition era. Most of the literature focuses on the national shippers (Cochran, 1948; Baron, 1962; Plavchan, 1969; Kerr, 1998; Stack, 2010). An exception is Stack (2000), who studies the local and regional breweries of the time, and how they competed with the national shippers. My main contribution to this literature is to show that most of the shift in the geography of the industry in the late nineteenth century occurred through the growth of regional breweries. My historical work was made possible by my the novel dataset that I collected. Such dataset includes information on output, bottling and location at the brewery level.

1.2 Data

My data contains the output of each brewery in 1874, 1880 and 1898. Output is defined as the "number of barrels of beer sold and removed" from the breweries. In addition, the data contains information on whether each brewery was bottling their beer in 1880 and 1898. My primary sources for both output and bottling are brewery directories published by industry journals of the time. The publishers of the directories obtained their information from the Bureau of Internal Revenue, which itself collected the information in order to tax the breweries.

My source for 1874 is *The Brewers' Handbook for 1876*, a directory compiled by the attorney of the United States Brewers' Association and published by *The Washington Sentinel*. This directory contains the output of each brewery for 1874 and 1875. My source for 1880 is the *Wing's Brewers' Hand Book of the United States and Canada for 1880*, a directory published by *The Western Brewer*, an industry journal of the time. This directory contains the output of each brewery for 1880 divided into 20 categories of production. My source for 1898 is the *Brewers' Guide for the United States, Canada and Mexico*, a directory published by *The American Brewers' Review*, an industry journal of the time. This directory contains the output of each brewery for 1898 divided into 46 categories of production.

The population of each county was obtained from census data, which was downloaded from the NHGIS website (Minnesota Population Center, 2011).

1.3 How Brewing Moved West

At the start of the 1870s, the brewing industry consisted of small breweries serving their own local markets (Kerr, 1998). Breweries distributed their beer to nearby saloons, which bought beer in barrels and sold it by the glass. Shipping beer to distant markets was prohibitively expensive due to the need of refrigeration to prevent spoilage (Plavchan, 1969, p.79). Beer had to be brewed near consumers, and consumers were concentrated in the large cities of the

East Coast. In consequence, most brewing took place in the large cities of the East Coast (Figure 1.1).

In the late 1870s, the brewing industry moved West. Define the center of beer production as the average of coordinates for the centroids of each county, weighted by beer output.[2] The center of beer production is a summary of the location of the brewing industry in the contiguous United States. In 1874, the center of beer production was only 300 miles away from the East Coast, near Pittsburgh (PA). Between 1874 and 1880, beer production moved 53 miles towards the Midwest –77% more than total population and 130% more than German population (Figure 1.2). The movement of the brewing industry was six times faster between 1874 and 1880 than during the remainder of the century.[3]

This substantial movement towards the Midwest occurred as a subset of breweries adopted two novel technologies that reduced transportation costs: refrigerator cars and pasteurization. Refrigerator cars prevented beer from going stale during transportation, allowing breweries to ship beer to distant markets. Despite the use of refrigerator cars, shipping beer in barrels was still expensive because breweries had to fill railroad cars with ice and set up ice depots along railroad lines (Cochran, 1948, p. 163; Plavchan, 1969, p. 81). Furthermore, destination markets had to be close enough to railroads to prevent beer from warming up during transportation, and large enough to compensate for the fixed costs of maintaining the ice depots required for beer distribution. Hence, refrigerators cars were mostly used to serve large markets along the rail network.

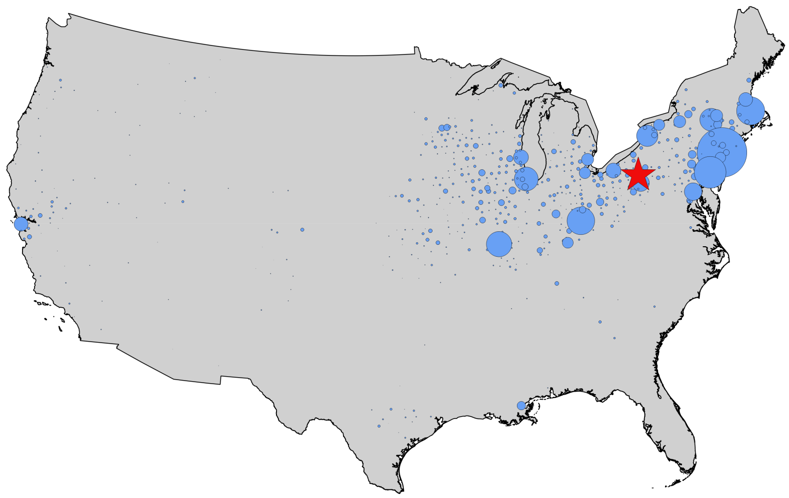
Pasteurization allowed brewers to reach smaller and isolated markets by eliminating the need for refrigeration. In 1865, Louis Pasteur patented a technique to prevent the spoilage

[2]The center of beer output is the point with latitude $(\bar{\phi})$ and longitude $(\bar{\lambda})$ such that:

$$\bar{\phi} = \frac{\sum_{i \in I} y_i \phi_i}{\sum_{i \in I} y_i}, \qquad \bar{\lambda} = \frac{\sum_{i \in I} y_i cos\left(\frac{\pi}{180}\phi_i\right)\lambda_i}{\sum_{i \in I} y_i cos\left(\frac{\pi}{180}\phi_i\right)}$$

where y_i is the beer output of county i, ϕ_i is the latitude of county i, and λ_i is the longitude of county i. This definition of center of beer output parallels the definition of center of population in USCB (2011).

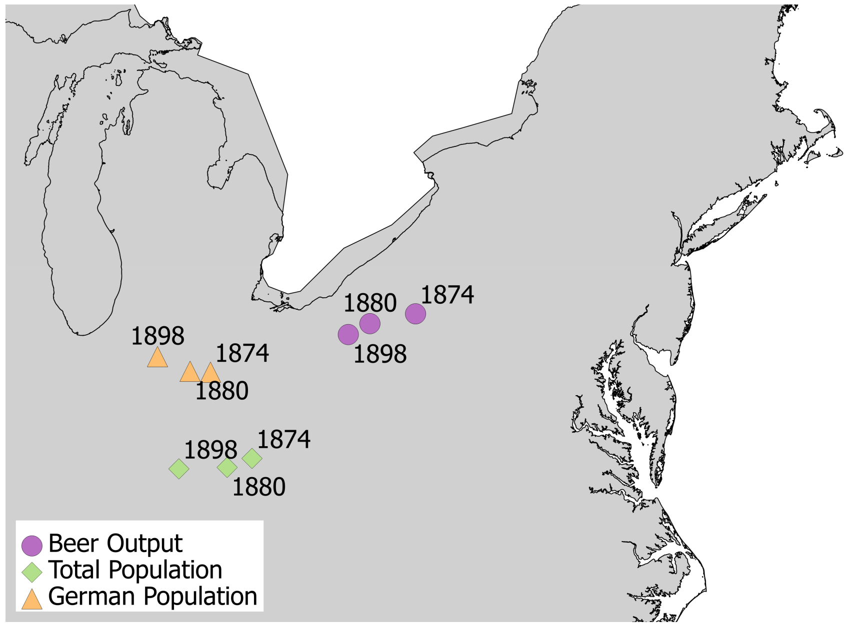
[3]The center of output moved 9 miles per year between 1874 and 1880, but only 1.5 miles per year between 1880 and 1898, which is the last year for which output data is available at the brewery level



The area of the circles is proportional to the total beer output of each county. For example, the beer output of New York County (NY) was 1.4 million barrels, whereas the beer output of Cook County (IL), where Chicago is located, was 0.3 million barrels. The red star is the Center of Beer Output for the contiguous United States, calculated as the average of coordinates for the centroids of each county, weighted by beer output (with meridian correction). In 1874, the Center of Beer Output was near Pittsburgh (PA)

Figure 1.1: Output per county and national center of beer output. 1874

of wine by increasing its temperature (Bowden et al., 2003, p. 6). In the following decade, Pasteur studied how fermentation and spoilage occurred in beer and published his results in 1876 (Barnett, 2000). American Brewers implemented Pasteur's technique –later known as pasteurization– by submerging bottled beer into water that was gradually heated to 160 °F (Baron, 1962, p. 241). This process killed the bacteria in the beer and therefore prevented the spoilage of beer during non-refrigerated transportation. Hence, pasteurization allowed brewers to reduce refrigeration costs and reach markets for which refrigerated transportation was not feasible. Crucially, pasteurization required beer to be bottled because the wood of barrels does not transmit heat as well as the glass of bottles. In consequence, breweries interested in shipping beer to other markets started to bottle their beer. Pabst, which would become the largest brewer 20 years later, started bottling beer in 1875 (Cochran, 1948, p.



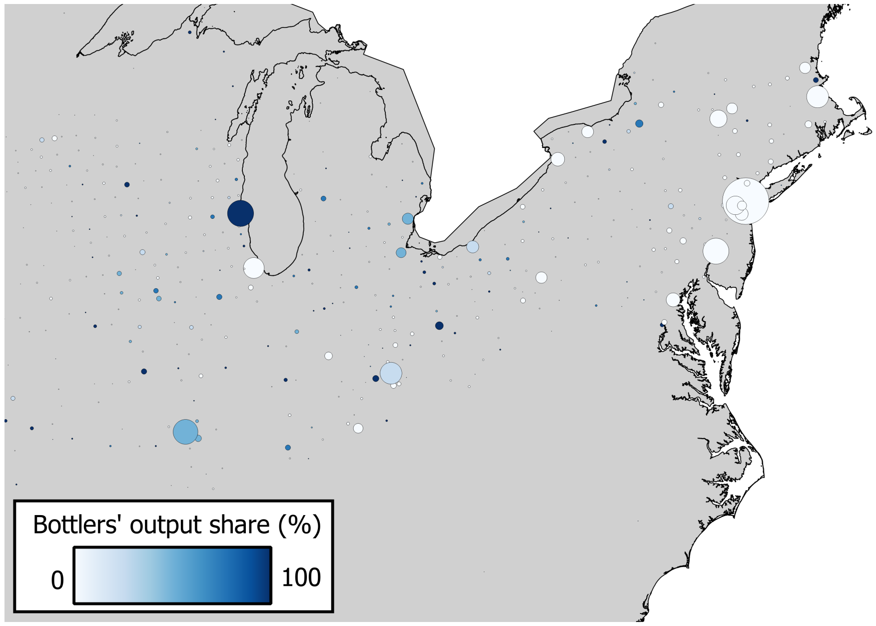
Brewing moved to the West earlier than population

Figure 1.2: Centers of population and centers of output. 1874-1898

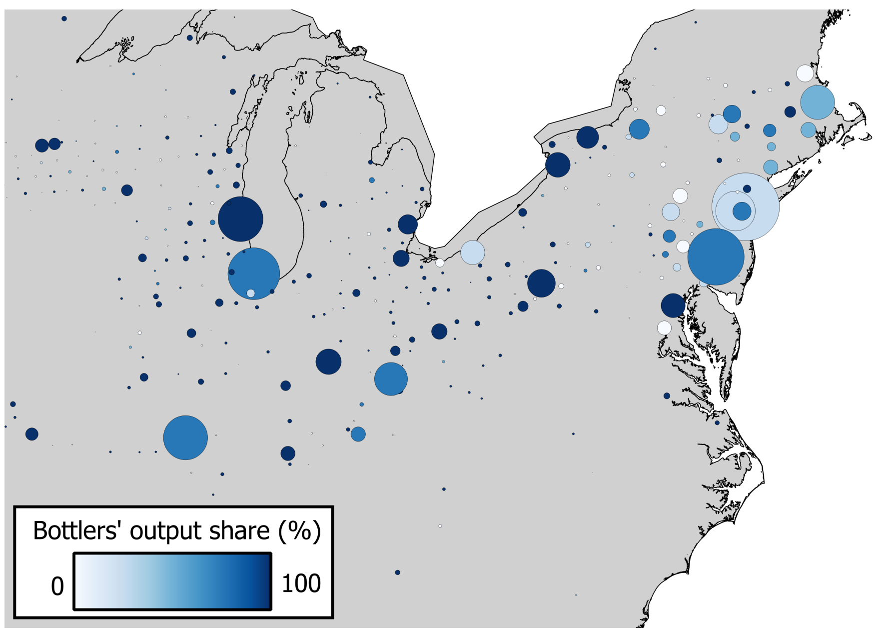
123). By 1880, the participation of bottlers in national brewing output had reached 22%.

The early adopters of bottling –and hence beer shipping– were located in the Midwest. Figure 1.3a shows the share of output by bottlers in each county by 1880. Bottling was frequent in multiple cities in the Midwest, but practically absent in the East Coast. 18 years later, bottling was still more frequent in the Midwest than in the West Coast, although the difference was not as stark as in the early years of pasteurization (Figure 1.3b).

Brewing moved West through the adoption of bottling by breweries in the Midwest. Figure 1.4 compares the location of non-bottlers and bottlers, summarized by the center of output for each group. In 1874, when almost all breweries were non-bottlers, the center of output was located near Pittsburgh. Six years later, in 1880, the center of output for non-bottlers remained near the same place. In contrast, the center of output for bottlers was located 300 miles to the West, at the same longitude of Indianapolis. Because bottlers grew faster than non-bottlers, the center of output for the brewing industry moved West. After 1880, breweries in the East Coast started to bottle beer. In consequence, the center of output



(a) 1880

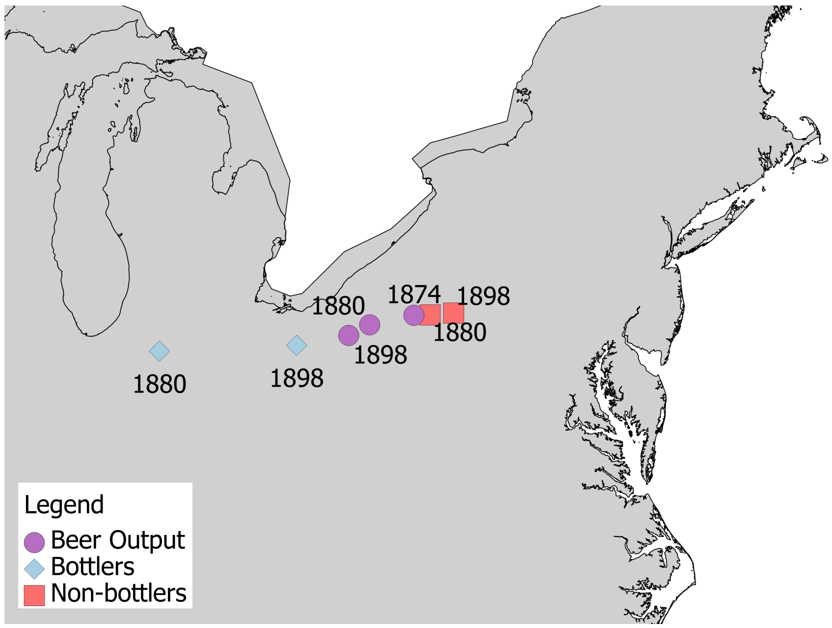


(b) 1898

The area of the circles is proportional to the total beer output of each county. The beer output of Milwaukee County (WI) was 0.8 million barrels in 1880 and 2.3 million barrels in 1898. The color of the circles represents the share of beer produced by bottlers in each county

Figure 1.3: Total output and bottler's share of output. County level

for bottlers had moved towards the East by 1898 (Figure 1.4). However, the center of output for bottlers remained to the West of the center of output of the industry. Furthermore, the share of production of bottlers increased until it reached 67% in 1898. In consequence, the center of output for the industry still moved West, although six times slower than between 1874 and 1880, when most of the shift towards the West occurred[4].



Centers of output for the contiguous United States, calculated as the average of coordinates for each county, weighted by beer output. In 1880, the center of beer output for bottlers was at the same geographical longitude of Indianapolis (IN), whereas the center of beer output for non-bottlers was near Pittsburgh (PA)

Figure 1.4: Center of output: bottlers vs. non-bottlers. 1874-1898

1.4 Interregional vs. Intraregional trade

Breweries bottled beer in order to ship it to other locations. One possible explanation of the early adoption of bottling in the Midwest (instead of the East Coast) is that the Midwest had a resource-based comparative advantage in the production of beer. After the expansion of railroads, the development of refrigerated cars and the invention of pasteurization, such

[4]See footnote 3

comparative advantage would have induced breweries to ship beer to the East Coast. Indeed, a subset of breweries started to ship beer at the national level, including the East Coast (Stack, 2000, 2010). The National Shippers –as those breweries are known in the literature– were all located in the Midwest.[5] However, the size of these breweries was not large enough to explain the overall pattern of location in the industry. By 1880, when most of the relative shift between East and West had already occurred, national shippers were producing only 6% of national output. By 1898, when 67% of the brewers had adopted bottling, national shippers were producing only 8% of national output. Furthermore, if interregional trade had induced a pattern of specialization at the regional level, beer output would have fallen in the East Coast. Instead, output per capita in the East Coast increases after 1880 (Figure 1.5).

There was no specialization at the regional level because transportation costs were much lower for grain than for beer. For example, grain was traded in international markets whereas beer was not.[6] The average price of barley between 1870 and 1900 in Massachusets, New York, and Pensilvania was only 24% higher than in Illinois, Missouri, Ohio and Wisconsin.[7] If we take into account that as late as in the 1930s brewers were spending 50% more on transportation than on grain (McGahan, 1991), a back of the envelope calculation reveals that the cost of shipping grain was at most 16% of the cost of shipping beer.[8].

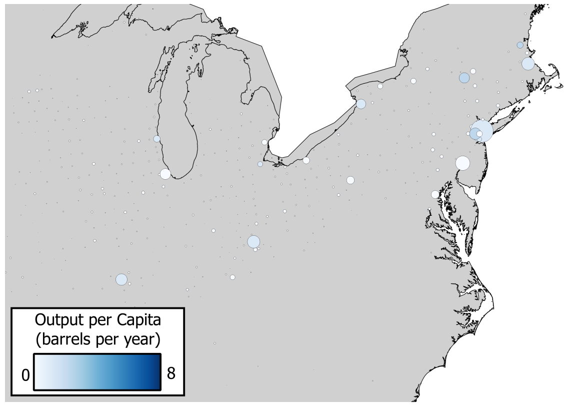
While the increase of brewing in the Midwest relative to the East Coast is not explained by inter-regional trade, it is explained by a higher prevalence of intra-regional trade within the Midwest. The brewing industry in the Midwest was dominated by regional breweries taking advantage of economies of scale, whereas the brewing industry in the East Coast was dominated by local breweries using the production and distribution methods of the past.

[5] Pabst, Schlitz, and Blatz were located in Milwaukee; Anheuser-Busch and Lemp were located in St. Louis; and Christian Moerlein was located in Cincinnati (Stack, 2000, p. 439)

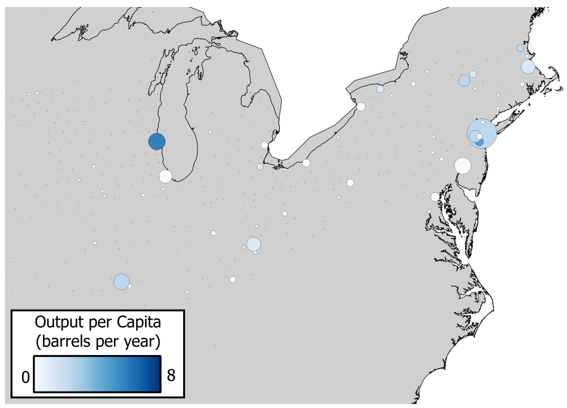
[6] In 1906, exports were only 0.07% of beer output, whereas imports were only 0.34% of beer consumption. Own calculations from United States Brewers' Association (1907).

[7] The data for this calculation was kindly shared by Paul Rhode. By the start of the twentieth century, localized wheather shocks had limited effects on state-level prices in the price of wheat Fox et al. (2011).

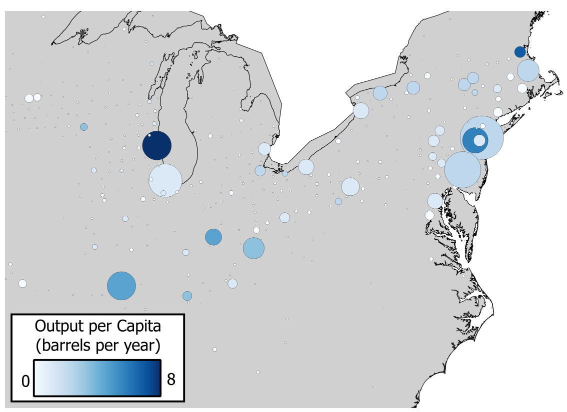
[8] $0.24/1.5 = 0.16$



(a) 1874



(b) 1880



(c) 1898

The area of the circles is proportional to the beer output of each county. The beer output of Milwaukee County (WI) was 0.1 million barrels in 1874, 0.8 million barrels in 1880 and 2.3 million barrels in 1898. The color of the circles represents the beer output per capita in each county.

Figure 1.5: Output and Output per Capita. County Level. 1874 - 1898

This mechanism is consistent with the early adoption of bottling in the Midwest (Figure 1.3, above) and the large increase in output per capita in the same region (Figure 1.5, above).

The rise of regional breweries is also consistent with the large drop in the number of breweries in the Midwest between 1874 and 1880, when most of the shift towards the West occurred. The number of firms fell by 20% in Illinois, 11% in Indiana, 8% in Ohio, and 4% in Missouri. In contrast, the number of firms grew in the East Coast: by 1% in Pennsylvania, 4% in New York, 11% in Massachusets, and 14% in New Jersey. The large decrease in the number of firms in the Midwest is consistent with the least productive firms closing down in response to the rising competition of the regional brewers. But, why did regional brewers thrive in the Midwest but not in the East Coast?

1.5 Discussion: Why Brewing Moved West

Regional brewers thrived in middle sized cities in the Midwest like Milwaukee, St. Louis, Indianapolis, Cincinnatti and Toledo –not in Chicago. In 1874, before the initial diffusion of bottling and refrigerated cars, Milwaukee produced 1.2 barrels per capita and Chicago produced 0.7 barrels per capita. Six years later, after the initial diffusion of bottling and refrigerated cars, Milwaukee's output had grown to 5.7 barrels per capita and Chicago's output was stagnated at 0.8 barrels per capita. Furthermore, Milwaukee's bottlers produced 97% of the beer produced in their county, whereas Chicago's bottlers only produced 2% of the beer produced in their county.

The lack of regional breweries in Chicago suggests a potential source of comparative advantage for other cities in the Midwest: good quality water. Quality water is a non-tradeable input that affects the taste and stability of beer. Before 1893, the primary source of water in Chicago was contaminated with sewage (Ferrie and Troesken, 2008). Breweries in cities with better water sources than Chicago would enjoy cost and quality advantages over breweries in Chicago. By shipping beer to Chicago, these breweries might be able to reach the minimum scale necessary to acquire technologies –like mechanical refrigeration and pneumating malting– that reduce marginal costs and improve the quality of beer. Low marginal costs would allow these breweries to grow in markets other than Chicago and might explain the rise of regional brewers in the Midwest. However, such a mechanism should also be consistent with the lack of regional brewers in the East Coast before 1880. In particular, the heterogeneity in water quality should be higher within the Midwest than within the East Coast. This difference in resource heterogeneity across regions can be tested in future research.

Two other mechanisms are consistent with the rise of regional breweries in the Midwest. First, breweries were more likely to ship beer within the Midwest than within the East Coast because destination markets where younger and therefore less likely to have competitors. Second, breweries in the Midwest had an incentive to build bottling plants in order to reduce their marginal trade costs and ship beer to other locations, while breweries in the large cities of the East Coast focused on their local markets and therefore did not experience the economies of scale involved in shipping beer to other counties. This mechanism, conjectured by (Cochran, 1948, p. 74), is consistent with the large growth in output of the mid-sized cities in the Midwest, as opposed to the largest cities in the East Coast –where most consumers were located. Both mechanisms can be tested in future research.

CHAPTER 2

Adaptation and Survival in the Brewing Industry during Prohibition

2.1 Introduction

Firms often face reductions in demand for their products due to government regulations, trade reforms or the innovation of their competitors. One way that firms can adapt to demand reductions is by switching to new products. The flexibility necessary to switch between products is possibly the outcome of investment decisions that firms have made in the past (e.g. to adopt new machinery). In that case, exposure to small demand shocks can make firms more resilient to future, potentially larger demand shocks by encouraging firms to make investments that facilitate product switching. Despite its potential implications for policy gradualism and long-term protectionism, we lack an empirical understanding of how this adaptation process occurs when firms experience multiple demand shocks over time.

An empirical analysis of the adaptation of firms to sequential demand shocks imposes several requirements on the data. First, there must be an initial demand reduction that is heterogeneous across firms but uncorrelated with other determinants of future performance, like productivity or input prices. Second, there must be a subsequent demand reduction that is common across firms. Third, the data must provide information on the response of firms to both demand reductions.

This paper approaches this problem by studying the American brewing industry during the gradual enactment of Prohibition (1914-1933). Breweries experienced two sequential shocks. Between 1914 and 1918, many states and counties became dry.[1] That is, they chose to prohibit the sale and production of alcohol. Breweries located *in wet counties* experienced a reduction in demand during local prohibition, because they could no longer ship beer *to dry counties*. This first shock was heterogeneous across breweries, because the transportation costs to dry counties differed across breweries. The second shock came with federal prohibition in 1919, when all breweries were prohibited from selling beer.[2] The enactment of federal prohibition required a constitutional amendment and lasted for 14 years, until it was repealed (again by constitutional amendment) in 1933. The experimental variation in this study arises in the era of local prohibition, when some breweries were exposed to large demand shocks, while others were insulated from these local shocks. Later, all breweries faced the common shock of federal prohibition.

I collected a dataset of 1300 breweries between 1914 and 1933 to study the adaptation of breweries to local and federal prohibition. In particular, I observe the machines that breweries buy, the goods that breweries produce and the decisions that breweries make in regard to remaining in business or closing down. I link this dataset to county-level information on exposure to reductions in demand during local prohibition, and follow the adaptation and survival of breweries throughout both local and federal prohibition.

Breweries survived federal prohibition by switching to other products that shared inputs with the production of beer, like soft drinks and malt extract. Yet, some breweries were more likely to adapt and survive than others. I find that breweries that faced larger reductions in demand during local prohibition reduced their investment in beer-specific capital and bottling, but increased their investment in soda-specific capital. When federal prohibition arrived, those breweries were more likely to produce alternative products and survive. Furthermore, among the breweries alive before local prohibition started, those who faced early

[1] By 1914, some states and counties in rural areas and in the south were already dry. However, the level of demand from those counties was low in the first place, due to the prevalence of religious denominations opposed to the consumption of alcohol.

[2] After December 1918, breweries were not allowed to produce beer (Arnold and Penman, 1933, p. 178) After July 1919, breweries were not allowed to sell beer (idem, p. 171).

reductions in demand were 6 percentage points more likely to survive *both local and federal prohibition*. In other words, breweries that faced 5 additional years of hardship adapted earlier and survived the entire period.

I study two mechanisms that drive the survival of firms throughout multiple demand reductions: selection and adaptation. Selection is the exit of the least productive firms in response to a reduction in demand. Adaptation is the making of irreversible investments in response to a reduction in demand. These investments can improve the ability of firms to respond to future reductions in demand. I develop a theoretical model that generates testable implications from adaptation that would not occur if selection was the only mechanism at work.[3] These testable implications drive my empirical strategy.

In the model, a subset of firms adapt to demand reductions by diversifying their product mix, as in the theoretical work of Penrose (1959, p. 140), Helfat and Eisenhardt (2004), Levinthal and Wu (2010) and Bloom et al. (2014). Diversification is accompanied by irreversible investments in machinery that is specific to the new products. This machinery reduces the incremental cost of switching to other products in the event of a new demand reduction, because part of the cost is already sunk when the new demand reduction occurs. Hence, firms are more likely to survive future demand reductions if they have experienced demand reductions in the past.

Prohibition provides a test for adaptation and its subsequent effect on survival, even when selection is occurring at the same time as adaptation. If only selection is at work and adaptation does not occur, survival throughout the full prohibition period –from the start of local prohibition until the end of federal prohibition– does *not* depend on exposure to early demand reductions.[4] In contrast, when adaptation is also at work, survival throughout the

[3] Firms in the model: (i) pay a fixed cost of production each period (ii) can introduce additional products by paying a non-recoverable cost (iii) exogenously differ in their marginal costs and (iv) have a limited capacity with rival uses across products, so reductions in demand diminish the opportunity cost of producing other goods. An example of the last assumption is a plant that can be used for bottling beer or soft drinks. Another example is an entrepreneur that must prioritize their time across products.

[4] Survival from the *end* of local prohibition would be higher among breweries exposed to early demand reductions. However, survival from the *start* of local prohibition does not depend on exposure to early demand reductions: federal prohibition is a larger shock than local prohibition, so breweries that survived

full prohibition period can be higher among breweries exposed to early demand reductions. I test this implication of adaptation using data on brewery survival, and corroborate my mechanism using data on machine acquisition and product switching.

The adaptation mechanism described in this paper can generalize to other industries where irreversible investments play an important role. For example, at the start of World War I, Dupont obtained 97% of its sales from the market for explosives (Chandler, 1990, p. 175). When the demand for explosives fell at the end of the War, Dupont used its existing capacity to expand into other chemical products. Six years later, the share of explosives on Dupont's sales had fallen to 50%. The company's report for that year noted that diversification "tends to avoid violent fluctuations in total sales, should one industry suffer a severe depression" (ibid, p. 176). Irreversible investments play two roles in this mechanism. First, they create capital that can be used towards the manufacture of alternative products when demand falls for the first time. Second, because the initial shock induces irreversible investments in product switching, diversification becomes persistent and increases resilience in the long run.

This paper contributes to the literature on how firms and industries evolve in response to reductions in demand. A strand of the literature focuses on the exit of the least productive firms (Bresnahan and Raff, 1991; Caballero and Hammour, 1994; Foster et al., 2014). Instead, this paper focuses on the adaptation process that occurs within the surviving firms. Demand reductions liberate resources within firms, reducing the opportunity cost of producing alternative products or making investments (Helfat and Eisenhardt, 2004; Levinthal and Wu, 2010; Holmes et al., 2012; Bloom et al., 2014). This mechanism might explain why firms change managerial practices, innovate and switch products in response to reductions in demand and increased competition (Chandler, 1990; Freiman and Kleiner, 2005; Agarwal and Helfat, 2009; Aghion et al., 2015; Bloom et al., 2015; Medina, 2015; Steinwender, 2015). My paper builds on this mechanism in order to answer the following question: does exposure to demand reductions make firms more resilient to future, potentially larger demand

federal prohibition would have survived local prohibition as well, regardless of the intensity of the latter.

reductions? The main contribution of this paper is to show that exposure to early, mild demand reductions can endogenously increase the performance of firms during future demand reductions.

My work builds on existing findings by economic and business historians. Kerr (1985), Sechrist (1986) and García-Jimeno (2015) study the political economy of prohibition. McGahan (1991), Kerr (1998) and Stack (2000, 2010) describe the structure of the brewing industry during the Prohibition era. Local prohibition increased brewery mortality (Wade et al., 1998), increased the birth rate of soft drink producers (Hiatt et al., 2009), and induced Anheuser-Busch to produce non-alcoholic beverages (Plavchan, 1969). Furthermore, multiple breweries survived federal prohibition by switching products (Feldman, 1927; Cochran, 1948; Baron, 1962; Plavchan, 1969; Ronnenberg, 1998; Tremblay and Tremblay, 2005). My contribution to the historical literature is to study the entire brewing industry using longitudinal data at the firm level, as opposed to the current focus on the largest breweries or state-level data. My historical work was made possible by the novel dataset that I collected by visiting brewery archives, public archives and collaborating with breweriana collectors.

My results contribute to the analysis of policies that can influence demand at the industry level, like regulation, trade policy, and sectoral changes in government spending. My results also have potential implications for the literatures on policy gradualism (Leamer, 1980; Dewatripont and Roland, 1992, 1995), the evolution of competitive advantage (Porter, 1990, 1996; Teece et al., 1997), the distribution of productivity across firms (Hopenhayn, 1992; Bernard et al., 2010, 2011), the geographical location of industries (Fujita et al., 2001), and the performance of firms during demand reductions (Aggarwal and Wu, 2015; Aghion et al., 2015). I examine these implications in the concluding remarks of the paper.

This paper is organized as follows. In section 2.2, I describe my dataset. In section 2.3, I provide an overview of the American brewing industry during the early twentieth century, the evolution of Prohibition over time and space, and the adaptation of breweries to Prohibition. In section 2.4, I present a theoretical framework that generates testable implications that guide my empirical strategy. Finally, I present my identification strategy and explain my empirical results. I conclude by discussing the implications of my results for contemporary policy.

2.2 Data

I collected a dataset of 1300 breweries over 19 years to measure the adaptation of breweries to Prohibition. I use the dataset to measure the adaptation of breweries to both local and federal prohibition, as well as the persistent effects of adaptation on survival and product diversification. In addition, I use secondary sources to measure the exposure of breweries to local prohibition.

I calculate the exposure of breweries located in wet counties to local prohibition in surrounding areas by combining information from three county-level sources: the prohibition status of each county between 1914 and 1918, the population of each county in 1914 and 1918 (calculated as a linear interpolation between the census years of 1910 and 1920), and the transportation costs between each pair of counties in 1890.[5] These sources are combined into a measure of the "wet market access" for each county. This measure adapts the formula of Donaldson and Hornbeck (2015) by including the internal market for each county, excluding destination counties were the distribution of beer is not allowed, and using a different parameter for the elasticity of shipments with respect to transportation costs. The calculation is explained in detail in section 2.5.

The prohibition status of each county was originally collected by Robert P. Sechrist (2012). The population of each county was obtained from census data, which was downloaded from the NHGIS website (Minnesota Population Center, 2011). The transportation costs between each pair of counties in the US were kindly provided by Dave Donaldson and Richard Hornbeck (2015). Their calculation of transportation costs uses information on the railroad and waterway networks from Atack (2013) and Fogel (1964).

My brewery-level dataset contains information on machinery acquisition, product choice,

[5]The use of transportation costs from 1890 favours my identification strategy, as I argue in section 2.5.

bottling, canning and the decision to stay in or exit the market froh 1914 to 1937. I also observe the production of each brewery in 1898. I collected this data from directories and industry journals published during the prohibition era. The journals provide news items reporting when breweries acquire new machines or buildings. I consider that a brewery has acquired a machine related to a product if the brewery and the machine/product are mentioned in the same news item of the journal. The journals also published lists of breweries with information on whether they were producing sodas or soft-drinks and whether they had bottling or canning plants. For 1898, the lists also contain the output of each brewery in that year. I consider that a brewery is alive if it appears both in the journals' brewery lists and in the database of breweries of the American Breweriana Association, which also contains a list of names that I used as the initial step for matching breweries across sources and over time.

My data on machinery acquisition was collected from two sources. Between 1914 and 1918, the data is taken from the *New Plants and Improvements* section of the *Western Brewer*, and industry journal of the time. Between 1919 and 1932, the data is taken from an index of the same journal (or its successor journal). The index was constructed by Randy Carlson. I collected information on the product mix of breweries in 1923 from the *Beverage Blue Book*, a directory of soft drink producers, cereal beverage producers and former brewers published by *H.S. Rich & Co.* I collected information on bottling in 1914 from the *American Brewing Trade List and Internal Revenue Guide for Brewers*, a directory of brewers published by the *American Brewers' Review.* My information on bottling and canning for 1937 comes from the *Buyer's Guide and Brewery Directory*, a directory of brewers published by *Brewery Age.* Finally, my production data for 1898 was obtained from the *Brewers' Guide*, a directory of brewers published by the *American Brewers' Review.*

2.3 Historical Background: How Breweries Survived Prohibition

At the turn of the twentieth century, brewing was the fifth largest manufacturing industry in the United States, as measured by value added.[6] In 1905, there were 1847 breweries producing 50 million barrels of beer per year in a country of 84 million people.[7,8,9] On average, each brewery produced 27 thousand barrels per year and employed 37 workers.[10]

Breweries were heterogeneous in their scale and production methods. 27 percent of breweries produced one thousand barrels per year or less, whereas 4 percent of breweries produced one hundred thousand barrels per year or more.[11]

Large breweries —like Pabst and Anheuser-Busch— used laboratories, mechanical refrigerators and pasteurizers. This machinery allowed for large scale in production, as well as low variability in the quality of beer across batches, seasons and geographic markets (McGahan, 1991; Kerr, 1998; Stack, 2010)[12] A subset of the large breweries, known as the National Shippers, distributed beer at the national level.[13] Beer was brewed in a single location and distributed by railroad to a network of branches and agencies that covered most of the country (McGahan, 1991; Stack, 2000).[14] Wisconsin's Pabst, for example, sold over one

[6]Breweries produced 3% of the value added, used 4% of the capital, and employed 1% of the workers in the manufacturing sector. Own calculations from United States Bureau of the Census (1907)

[7]Sources: Bureau of Internal Revenue (1905), United States Bureau of the Census (1907) and United States Bureau of the Census (2000)

[8]Almost all the beer was sold in the US market: Exports were only 0.07% of output, whereas imports were only 0.34% of consumption. Own calculations from United States Brewers' Association (1907)

[9]1 barrel = 31 gallons ≈ 117 liters ≈ 331 servings of 12 fl/355 ml ≈ 6 batches of Manning Brewery.

[10]Own calculations from United States Bureau of the Census (1908).

[11]The interquartile range of the annual output distribution was 29 thousand barrels per year. Own calculations from Wahl and Henius (1898).

[12]The low variability in quality was an integral part of the differentiation strategy of large brewers. In fact, it was widely emphasized in their national advertising campaigns (Stack, 2010).

[13]Six breweries distributed their beer at the national level: Schlitz, Pabst, Blatz, Lemp, Anheuser-Busch and Christian Moerlein (Stack, 2010).

[14]Single plant production was the norm in the industry until the early 50s, when water treatment inno-

million barrels per year using a national network of fifty branches and five hundred agencies (Cochran, 1948).[15]

Distant locations were served using bottles —as opposed to kegs— because bottles did not require refrigeration while being transported, so their transportation costs were lower (Kerr, 1998) In contrast, close locations were mainly served using kegs because beer in kegs was considered to have a better taste and was cheaper to produce (Stack, 2010)

Despite enjoying lower marginal costs of production, large breweries co-existed with medium and small breweries. Co-existence was allowed by large transportation costs, product differentiation, and a distribution system based on saloon ownership and exclusivity contracts with saloon owners (Kerr, 1998; Stack, 2000). Small, craft breweries were able to survive by selling beer to in-town saloons using kegs.[16] Medium-sized breweries, in contrast, distributed beer at the regional level using both bottles and kegs. Overall, geographical markets were served by a mixture of national, regional and local breweries. For example, consumers in Kansas City bought their beer in 348 saloons supplied by 22 breweries from 6 states (Maxwell and Sullivan, 1999)

Most breweries were located in the Mid-Atlantic, the Mid-West and California (Figure 2.1). There were few breweries in the South because the main religious denominations in the South were opposed to the consumption of alcohol.[17] In contrast, breweries were common in large population centers in the North and West. Chicago, with its large population

vations allowed brewers to produce beer of similar quality across plants (Tremblay and Tremblay, 2005, p. 33).

[15] By 1910, 4% of its beer was sold in Texas (Cochran, 1948)

[16] In fact, there were only 8 retailers per brewery on average (Own calculations from Bureau of Internal Revenue, 1905, p. 56).

[17] For example, 70% of members of all religious denominations in the South were Baptists or Methodists (Own calculations from the Census of Religious Bodies, obtained through Minnesota Population Center, 2011) The Southern Baptist Convention denounced the consumption of Alcoholic Beverages in 1896 (Southern Baptist Convention, 1896) John Welley, the founder of Methodism, denounced the consumption of alcohol in 1743 (Fox and Hoyt, 1852, p. 200) Religion continues to shape the location of breweries today (Gohmann, 2015)

of German immigrants, had 58 breweries in 1903.

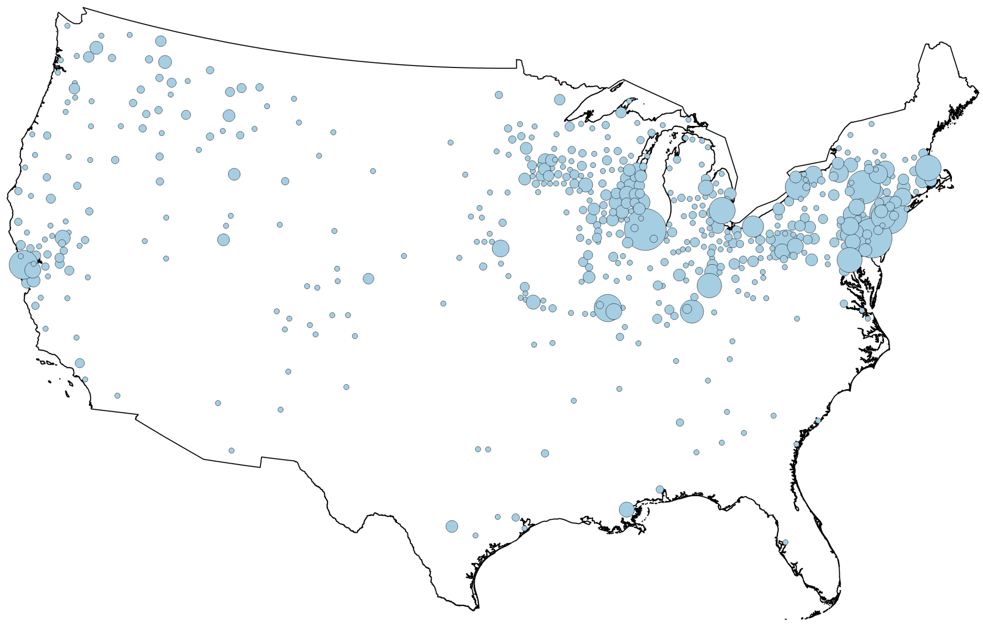


Figure 2.1: Number of Breweries in 1903, per County

Starting in the second half of the nineteenth century, coalitions of religious and women's rights groups —like the Woman's Christian Temperance Union— campaigned to restrict the distribution of alcoholic beverages. In some states, their lobby gave rise to state bans on the distribution of alcoholic beverages, or, alternatively, the permission of local options, which allowed for decisions at the county, town or even the ward level (Rowntree and Sherwell, 1900, p. 255)[18] By 1914, 38 percent of Americans lived in dry locations.[19] However, most

[18]For example, Kentucky's constitution of 1891 allowed for local options in the following terms: "The General Assembly shall, by general law, provide a means whereby the sense of the people of any county, city, town, district or precinct may be taken, as to whether or not spirituous, vinous or malt liquors shall be sold, bartered or loaned therein, or the sale thereof regulated."(Legislative Research Commission of Kentucky, 2015, p. 9)

[19]Own calculations using local prohibition data from Sechrist (2012) and a linear interpolation of census population data from Minnesota Population Center (2011)

dry locations were located in the religious South and in rural areas were the demand for beer was low in any case. This situation changed between 1914 and 1918, when many state and counties with higher population density and proximity to the breweries became dry. By 1918, the percentage of Americans living in dry counties had increased to 55 percent.[20] The map of Figure 2.2 shows the gradual advance of prohibition over space and time.

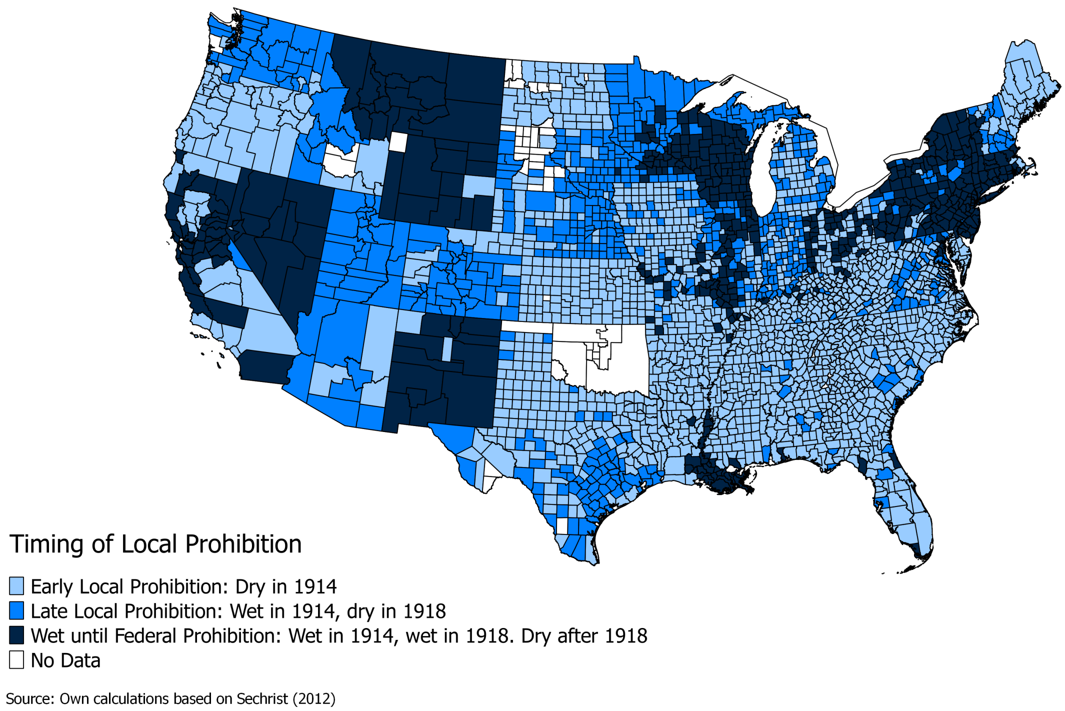


Figure 2.2: Gradual advance of prohibition over space and time

Most breweries were located in counties that remained wet until federal prohibition. However, the advance of local prohibition imposed a substantial reduction on these breweries, because they were no longer allowed to ship beer to dry counties.[21] Even for those breweries

[20]Ibid.

[21]Shipments not intended for distribution were also forbidden: "The shipment or transportation, in any manner or by any means whatsoever of any spirituous, vinous, malted, fermented, or other intoxicating liquor of any kind from one State, Territory, or District of the United States, or place noncontiguous to, but subject to the jurisdiction thereof, into any other State, Territory, or District of the United States, or place noncontiguous to, but subject to the jurisdiction thereof, which said spirituous, vinous, malted, fermented, or other intoxicating liquor is intended by any person interested therein, to be received, possessed, sold, or in any manner used, either in the original package, or otherwise, in violation of any law of such State, Territory,

that decided to illegally ship their beer, the costs of evading the Law and the disappearance of the main distribution channel at destination —the saloon— implied a reduction in demand.

The effect of local prohibition on demand was acknowledged by the brewers themselves. For example, the third vice-president of Anheuser-Busch blamed local prohibition as the cause of the reduction in sales between 1913 and 1914 (Plavchan, 1969, p. 133) In 1916, Anheuser-Busch released a nonalcoholic cereal beverage made with barley malt, rice, hops, yeast and water —the same ingredients as beer. The company spent 15 million dollars developing this new product (Plavchan, 1969, p. 163)[22] The empirical section of this paper shows that, more generally, breweries affected by local prohibition were more likely to buy machinery that could be used in the production of other products.

Federal prohibition began in December 1918, when a national ban on beer production came into effect (Arnold and Penman, 1933, p. 178).[23,24] Although breweries were not allowed to produce beer, they were still allowed to sell their inventories. However, after July 1919, breweries were not allowed to sell beer either (idem, p. 171). Federal prohibition became permanent in January 1920, when a constitutional amendment banned "the manufacture, sale, or transportation of intoxicating liquors within, the importation thereof into, or the exportation thereof from the United States and all the territory".[25,26] federal prohibition

or District of the United States, or place noncontiguous to, but subject to the jurisdiction thereof, is hereby prohibited." Webb-Kenyon Act of 1913.

[22]About 212 million dollars of 2013, using the Historical Consumer Price Index for all Urban Consumers.

[23]The efforts of the Temperance Movement towards federal prohibition had started in 1913, when the Anti-Saloon League —the leading temperance organization— made a series of organizational changes towards that goal (Kerr, 1985). The efforts, including a failed attempt at changing the constitution in 1914, were unsuccessful until the entrance of the US into World War I. The war switched public opinion against industries related to German immigrants, like the brewing industry.

[24]The original purpose of the ban had been to save cereal towards the war effort. However, the ban entered into effect one month after the signature of the Armistice with Germany and was formally kept in place until the start of federal prohibition on the grounds that the mobilization of troops had not ended yet.

[25]Eighteenth Amendment to the United States Constitution. The Amendment was passed by the Senate in August 1917, was passed by the House of Representatives on December 1917, was ratified by the states in January 1919 and entered into effect in January 1920

[26]The Volstead Act (1919) defined intoxicating liquor as any beverage containing more than 0.5% alcohol

lasted for 14 years, until it was repealed in 1933 by a new constitutional amendment.[27]

Federal prohibition had a substantial impact on brewery survival. Most exit decisions took place during the early years of federal prohibition: Out of the 1091 breweries alive in 1918, only 561 survived to 1923, and 517 survived until the end of prohibition, in 1933.

Most surviving breweries switched to products that shared inputs with the production of beer, like cereal beverages, sodas, malt extract and ice cream.[28,29] By 1923, 58 percent of breweries were producing cereal beverages, 35 percent were producing soft drinks and only 5 percent were idle.[30,31,32] The low percentage of idle plants suggests that breweries in 1923 saw federal prohibition as a permanent shock.

Illegal brewing had, if anything, a negative impact on the survival of pre-prohibition breweries. The illegal alcohol market was ultimately dominated by new entrants with comparative advantage in evading the law, rather than by the highly visible pre-prohibition brewers. Bootleggers received high profit rates —1.150% in Chicago, according to contemporary accounts (Beman, 1927, p. 106)— but also faced high probabilities of closing down by the force of other bootleggers or the State. The risk was particularly high during the initial years of federal prohibition, when the law was enforced the most (García-Jimeno, 2015). Just in 1921, 125 cereal beverage producers were placed under seizure for violations

[27]Repeal was the consequence of a gradual change in public opinion driven by the disastrous consequences of Prohibition on crime and law enforcement (García-Jimeno, 2015)

[28]The production process for cereal beverages largely overlapped with the production process for beer. For example, one techinque involved producing beer first, and then extracting the alcohol with a dealcoholizing plant. The production of sodas used the same bottling equipment as the production of beer. The production of malt extract involved the same malting process as the production of beer. Ice cream production made use of the refrigeration equipment used for the lagering and transportation of beer

[29]For example, Anheuser-Busch (Plavchan, 1969, p. 154)

[30]Plants are considered idle if they were not manufacturing goods, but had not disposed of their equipment yet.

[31]Own calculations from H.S. Rich & Co. (1923)

[32]That year, the output of cereal beverages containing less than one percent of alcohol by volume was 5.3 million barrels (Bureau of Internal Revenue, 1923)

of the law.[33]. In any case, most alcoholic beer was not manufactured by bootleggers, but brewed at home by the consumers themselves (Ronnenberg, 1998)

When federal prohibition ended in 1933, breweries started producing beer again. The end of federal prohibition was accompanied by the adoption of the beer can (McGahan, 1991).[34] Before Prohibition, breweries did not can their beer due to technical problems.[35] These problems were solved in 1933 (Maxwell, 1993). Four years later, in 1937, 9 percent of the breweries were already canning their beer. Cans be used to produce sodas as well, so breweries that were already producing soda had a larger incentive to adopt canning [The empirical implications of this incentive will be checked in the empirical section of future versions of this paper].

This historical overview shows that breweries adapted to prohibition by switching to other products. Two major empirical questions remain: i) Did local prohibition increase the resilience of breweries to federal prohibition? (and how?). ii) Did local prohibition influence the adoption of canning after federal prohibition ended? (and how?).

2.4 Theoretical Framework

This section provides a dynamic model in which multi-product firms experience shifts in the demand for their products. An initial demand shift leads firms to diversify and diversification increases the probability that they survive future demand shifts. The model provides a testable implication that cannot be generated by selection alone (i.e. the exit of the least productive firms on the basis of exogenous productivity), but can be generated by adaptation (i.e. irreversible investments that endogenously increase the survivability of firms). This

[33](Bureau of Internal Revenue, 1922, p. 31)

[34]Beer cans reduce transportation costs because they weight less, are easier to keep cool and block the light better than bottles. Furthermore, unlike bottles, beer cans are not returned to the brewery to be recycled (McGahan, 1991)

[35]The metal in pre-prohibition cans reacted with the beer, altering its flavor. Furthermore, cans were not capable to withstand the pressure induced by pasteurization (Maxwell, 1993)

testable implication guides the empirical analysis of the remaining sections of this paper.

The model has two periods: $t \in \{1, 2\}$. Each period, firms can manufacture two products: the main product –which I call beer (b)– and the alternative product –which I call soda (d, for soft drink). For simplicity, I assume that each firm is a monopolist on a variety of each of the products. The inverse demand for product k that firm i experiences in period t is given by the function $p(q_{k,i,t}; a_{k,t})$, which is decreasing in the quantity produced ($q_{k,i,t}$) and increasing in a demand shifter ($a_{k,t}$) that is common across firms but changes over time. We can think of prohibition as shifting the demand for beer by reducing $a_{b,t}$. Each period, $a_{b,t}$ is randomly drawn from a support that contains three values: high (α_H), medium (α_M) and low (α_L). In contrast, the demand shifter for soda is fixed over time at a lower-medium level ($a_{d,t} = \alpha_D$, with $\alpha_L < \alpha_D < \alpha_M$).

Firms differ in their marginal costs of production. In particular, the marginal costs for firm i are constant, equal across products, fixed over time, and heterogeneous across firms ($c_{b,i} = c_{d,i} = c_i$). The cumulative distribution of marginal costs across firms is strictly increasing. In addition to the marginal costs, firms pay a fixed cost every period (f). This fixed cost incorporates maintenance costs (e.g. \$3,000 at one of Anheuser-Busch's bottling plants in 1918), as well as the opportunity cost of firm resources with market value (e.g. the alternative uses of the entrepreneur's time). The heterogeneity in marginal costs, together with the fixed cost, incorporates a selection mechanism into the model: reductions in demand induce the exit of those firms with the largest marginal costs.

Firms have a limited capacity that must be shared across product lines. In particular, $q_{b,i,t} + q_{d,i,t} \leq \overline{q}$. One can think of this restriction as the result of scarce resources within the firm that have rival uses across product lines, like a plant that can be used for bottling beer or soft drinks, or the limited time of the entrepreneur. The shadow value of these resources decreases when de production of a given good decreases. As a result, the (marginal) opportunity cost of producing soda falls when the production of beer falls. This limited capacity restriction incorporates the concept of non-scale resources used by the management literature (Helfat and Eisenhardt, 2004; Levinthal and Wu, 2010). Because capacity cannot be sold, one can also think of this restriction as incorporating trapped factors of production as in Bloom et al. (2014).

In order to enter the soda market for the first time, firms pay a non-recoverable diversification cost denoted by (ρ). The payment of this cost can represent the irreversible investments that firms make in soda-specific machinery and distribution methods. For example, Anheuser-Busch used de-alcoholization machines to produce Budweiser near-beer in 1920 (Plavchan, 1969). These machines had few alternative uses other than the production of near-beer.

At the start of each period, the firm observes its survival status at the end of last period, whether it already paid the diversification cost, and the current demand shifter for beer. Each period, the firm makes three choices in order to maximize profits. If the firm is still alive, the firm chooses whether to close down or survive. Exit is irreversible. If the firm has not paid the diversification cost yet, the firm chooses whether to remain specialized on beer or enter the soda market by paying the diversification cost. Finally, the firm chooses how much to produce of each good.

The essence of the model comes from the interaction between two forces. On the one hand, the fixed cost (f) generates economies of scope between the main and the alternative products.[36] On the other hand, the limited plant capacity induces firms to specialize when the demand for beer is high, because the opportunity of producing soda is too high in that case.[37] Whether the firm diversify, specialize or exit, depends on its exogenous endowment of marginal costs (c) and the evolution of demand. Because diversification requires irreversible investments, the history of demand reductions influences the survival of firms in the future.

Let $\pi_S(a_{b,t}, c_i)$ denote the static profits of a firm that has not paid the diversification cost,

[36]Under regularity conditions, economies of scope are equivalent to the existence of sharable inputs between products (Panzar and Willig, 1981)

[37]Teece (1980) presents a more detailed discussion on how the gains from diversification are limited by congestion and transaction costs within the firm.

and therefore can only produce beer in a given period.[38] Let $\pi_D(a_{b,t}, c_i)$ denote the static profits of a firm that has already paid the diversification cost, and therefore can produce both beer and sodas in a given period.[39] In period 1, a firm choose to diversify, specialize or exit depending on whether the following conditions hold:

$$\pi_D(a_{b,1}, c_i) + E_{a_{b,2}}\left[max\{\pi_D(a_{b,2}, c_i), 0\}\right] - \rho \\ \geq \\ \pi_S(a_{b,1}, c_i) + E_{a_{b,2}}\left[max\{\pi_S(a_{b,2}, c_i), \pi_D(a_{b,2}, c_i) - \rho, 0\}\right] \tag{2.1}$$

$$\pi_D(a_{b,1}, c_i) + E_{a_{b,2}}\left[max\{\pi_D(a_{b,2}, c_i), 0\}\right] - \rho \geq 0 \tag{2.2}$$

$$\pi_S(a_{b,1}, c_i) + E_{a_{b,2}}\left[max\{\pi_S(a_{b,2}, c_i), \pi_D(a_{b,2}, c_i) - \rho, 0\}\right] \geq 0 \tag{2.3}$$

In condition 2.1, the profits under diversification are larger than the profits under specialization. In condition 2.2, the profits under diversification are positive. In condition 2.3, the profits under specialization are positive. If conditions 2.1 and 2.2 hold, the firm pays the diversification cost and survives by producing both products in each period. If condition 2.1 does not hold, but condition 2.3 holds, the firm survives, specializes in beer and does not pay the diversification cost. If conditions 2.2 and 2.3 do not hold, the firm closes down.

Because profits from both soda and beer are decreasing in marginal costs, conditions 2.1 - 2.3 define thresholds of marginal costs below which firms choose to survive and diversify. These thresholds depend on the level of demand in period 1. If beer demand is high enough,

[38] $\pi_S(a_{b,t}, c_i)$ is given by:

$$\begin{aligned} \pi_S(a_{b,t}, c_i) = & \max_{q_b}. \quad p(q_b; a_{b,t})q_b - c_i q_b - f \\ & \text{s.t.} \quad q_b \leq \overline{q} \end{aligned}$$

[39] $\pi_D(a_{b,t}, c_i)$ is given by:

$$\begin{aligned} \pi_D(a_{b,t}, c_i) = & \max_{q_b, q_d}. \quad p(q_b; a_{b,t})q_b - c_i q_b + p(q_d; a_d)q_d - c_i q_d - f \\ & \text{s.t.} \quad q_b + q_d \leq \overline{q} \end{aligned}$$

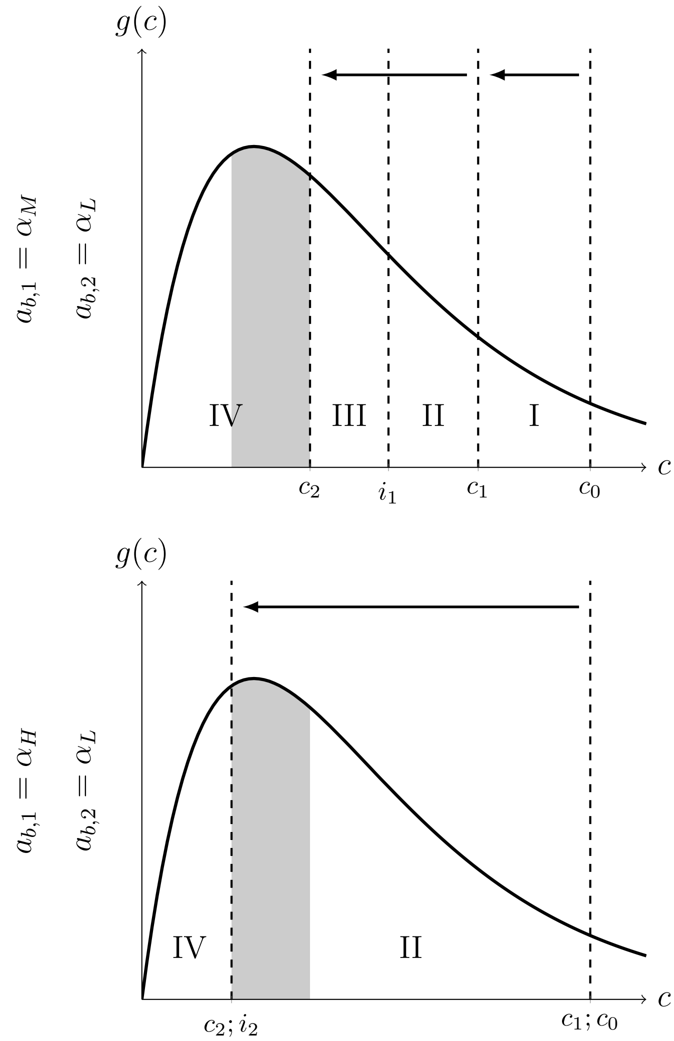
the [marginal] opportunity cost of producing soda is too high, and most firms specialize in beer. Decreases in beer demand liberate resources, reducing the [marginal] opportunity cost of producing soda for diversified firms, and increasing the threshold under which condition 2.1 holds. However, reductions in demand also decrease the threshold under which the survival condition (2.2) holds. For high and medium levels of demand, the first effect dominates and there is an increase in the share of firms that diversify, unconditional on survival. For low levels of demand, the second effect dominates and there is a decrease in the share of firms that diversify, unconditional on survival.

In what follows, I discuss the effect of sequential reductions in beer demand on the investment and survival decisions of firms. In particular, I compare two scenarios. In the first scenario, firms experience an initial reduction in beer demand from α_H to α_M, followed by a further reduction in beer demand from α_M to α_L (i.e. $a_{b,1} = \alpha_M$ and $a_{b,2} = \alpha_L$). This scenario represents the demand sequence experienced by breweries affected by local prohibition in other counties. In the second scenario, firms do not experience an initial reduction in beer demand, and instead experience a large reduction in beer demand from α_H to α_L in period 2 (i.e. $a_{b,1} = \alpha_H$ and $a_{b,2} = \alpha_L$). This scenario represents the demand sequence experienced by breweries not affected by local prohibition. In both scenarios, the demand for sodas remain fixed at $a_{d,t} = \alpha_D$. I show that the gradual reduction in beer demand (first scenario) generates higher two-period survival rates than the sudden reduction in beer demand (second scenario). [40]

Figure 2.3 illustrates how survival in period 2 depends *both* on the level of demand experienced by the firm in period 1 and the exogenous marginal costs of the firm. The top

[40]The main restriction on the demand function is to be additively separable on the demand shifter. This restriction simplifies the expressions that result from the application of the envelope theorem on the profit functions when finding derivatives. Most results are based on the following (derived) properties of the static profit functions, which allow for single-crossing conditions throughout the proof:

$$\frac{\partial \pi_S}{a_b} \geq \frac{\partial \pi_D}{\partial a_b} \geq 0$$
$$\frac{\partial \pi_D}{\partial c_i} \leq \frac{\partial \pi_S}{\partial c_i} \leq 0$$



Shaded area: share of additional breweries that survive due to an early reduction in demand

Figure 2.3: Survival pattern of breweries, if adaptation is allowed

plot represents the effect of a gradual reduction of demand, with $a_{b,1} = \alpha_M$ and $a_{b,2} = \alpha_L$. When demand falls from α_H to α_M in period 1, three outcomes can occur. Firms to the right of c_1 close down because profits from the beer market are not enough to cover the fixed cost for those firms (area I). Firms between c_1 and i_1 survive by specializing in beer (area II). For those firms, profits from the beer market alone are large enough to cover the fixed cost, but profits from the soda market are not large enough to cover the diversification cost.[41]

[41] For low values of (α_M), firms can only survive by diversifying, so area II is empty. In this case, the

Finally, firms to the left of i_1 pay the investment cost and survive by producing both beer and soda (areas III and IV). For these firms, profits in the soda market over two periods are large enough to cover the diversification cost.

When demand falls to a low level in period 2 ($a_{b,2} = \alpha_L$), variable profits from the beer market are too low to compensate for the fixed costs of the firms. Hence, firms can survive only by entering the soda market. Firms with large marginal costs close down, including the beer-specialized firms (area II) and a subset of the diversified firms (area III). Only firms with low marginal costs remain alive. The survival rate over both periods is given by area IV.

The bottom plot of figure 2.3 represents the decisions of firms that experience high demand in the first period, followed by a sudden reduction in demand in the second period ($a_{b,1} = \alpha_H$ and and $a_{b,2} = \alpha_L$). When demand in period 1 is high, surviving firms specialize in beer because the [marginal] opportunity cost of producing soda is too high. During period 2, the least productive firms exit (area II), whereas the most productive firms pay the investment cost and survive by producing both goods. The survival rate over both periods is given by area IV.

Figure 2.3 also shows that there is a set of firms that survive period 2 if $a_{b,1} = \alpha_M$, but close down if $a_{b,1} = \alpha_H$. Firms under the shaded area diversify when $a_{b,1} = \alpha_M$ in period 1. When demand is low during the second period, the diversification cost is already sunk so the firm does not have to pay it in order to survive. In contrast, the same firms do not diversify when $a_{b,1} = \alpha_H$ in period 1, because the opportunity cost of producing soda is too high in that period. These firms close down during period 2 because the variable profits from both markets are not enough to cover both the fixed cost and the investment cost. Hence, under certain values of the parameters, the share of firms that survive over both periods (area IV) is higher when $a_{b,1} = \alpha_M$ than when $a_{b,1} = \alpha_H$:

main testable implication on survival in the second period still holds. However, because multiple breweries survived local prohibition while still specializing in beer production, I ignore this case in the discussion.

$$P\left(S_2 = 1 \mid a_{b,1} = \alpha_M \cap a_{d,2} = \alpha_L\right) > P\left(S_2 = 1 \mid a_{b,1} = \alpha_H \cap a_{d,2} = \alpha_L\right) \qquad (2.4)$$

Testable implication (2.4) is the result of adaptation, and does not occur when firms select exclusively on the basis of exogenous marginal costs. To show this, I shut down the investment channel in the model by setting $\rho = 0$ or $\rho \to \infty$. In the first case, diversification is costless. In the second case, firms are unable to diversify because it is too expensive. In both cases, the early exit of firms with large marginal costs still occurs. Yet, implication (2.4) does not hold. When no adaptation is at work, the only effect of the initial demand reduction is to induce an early exit of firms that would have exited during the second demand reduction in any case (i.e. the firms with large marginal costs). The initial reduction in demand does not change the behaviour of firms in the second period. Hence, when no adaptation is at work, overall survival is not affected by the existence of an initial reduction in demand.

Figure 2.4 illustrates the survival decisions of firms in the absence of adaptation. In the top plot, an initial demand reduction shifts the cost threshold to the left, inducing the exit of firms. A subsequent demand reduction shifts the threshold further, inducing the exit of more firms. The fraction of firms that survive both periods is given by area IV. In the bottom plot, there is no initial reduction in demand. During period 2, a large reduction in demand shifts the survival threshold to the left, inducing the exit of firms. Because there are no irreversible investments, the threshold of survival at the end of period 2 does not depend on the level of demand in period 1. Hence, the fraction of firms that survive both periods (area IV) is the same in both plots, and implication (2.4) does not hold. It is still true that, conditional on survival in period 1, the probability of survival is higher when firms experience an initial reduction in demand (area IV divided by area II). However, the probabilities in implication (2.4) are *unconditional* on survival in period 1 (area IV). In the absence of adaptation, the unconditional probability of survival does not change when firms experience an initial reduction in demand.

The theoretical model in this section shows that firms adapt to reductions in demand by switching to other products. When switching to other products requires irreversible

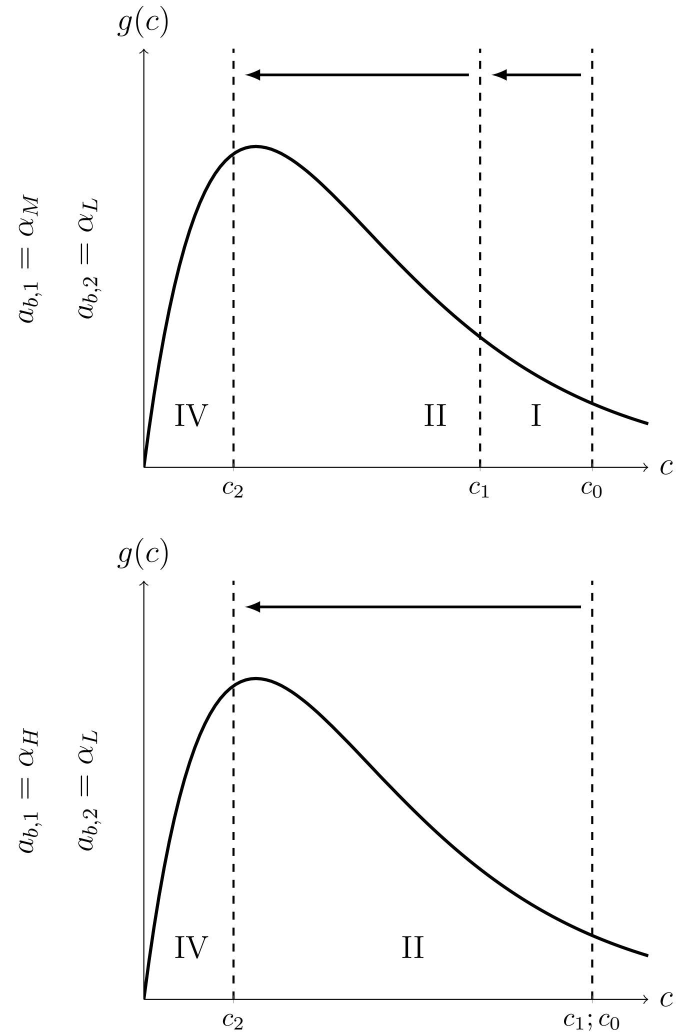


Figure 2.4: Survival pattern of breweries, if adaptation is not allowed

investments, these investments make firms more likely to survive future reductions in demand. In fact, overall survival can increase, as stated in implication (2.4). In contrast, when adaptation through irreversible investments is not allowed, implication (2.4) does not hold. The remaining sections of this paper show that implication (2.4) holds for the American brewing industry during the Prohibition era. This result, together with additional evidence from machine acquisition and product switching, confirms that adaptation was an important determinant of brewery survival during prohibition

2.5 Empirical Strategy

In the theoretical model from last section, initial shifts in demand induce changes in the capital structure and product scope, which can help firms survive later demand shocks. Local prohibition induces variation in demand over time and across breweries, providing an experimental setting to test the predictions from the theoretical model.

local prohibition shifted the demand experienced by breweries *in wet counties*, because they could not ship beer *to dry counties* any more.[42,43,44] The impact of this shift is heterogenous across breweries, because the transportation costs to dry counties are heterogeneous as well. A measure of the reduction in demand, therefore, has to take into account both the decisions of the newly dry counties and the transportation costs from the breweries to those counties.

I measure the size of the demand shift at the county level by estimating the effect of local prohibition in surrounding areas on market access. Market access is a measure of total potential demand that is commonly used in the economic geography literature (Harris, 1954; Head and Mayer, 2004). In trade models of differentiated products with CES preferences across varieties and economies of scale (e.g. Redding and Venables, 2004), changes in market access summarize the demand shifts that occur across different locations in space.[45] Following Donaldson and Hornbeck (2015), my empirical implementation of market access is a sum of

[42]More precisely: given a price schedule across markets, breweries would sell less beer during local prohibition than before local prohibition. Alternatively: during local prohibition, breweries would need to reduce their prices in wet markets in order to sell the same quantity as before local prohibition.

[43]Even though breweries were not able to sell beer in dry counties, they were still able to buy inputs from there. For example, breweries continued to buy hops from the Pacific Coast, even though most hops producing areas had became dry by 1916. By the time of local prohibition, the Pacific was already the leading hops-producing area in the United States (Edwardson, 1952)

[44]As mentioned in the historical framework, local prohibition induces reductions in demand even if breweries smuggle beer to dry counties, due to the costs of evading the Law and the disappearance of the main distribution channel at destination —the saloon.

[45]The formula for market access can also be derived from models with homogeneous products and productivity heterogeneity across firms (as in Donaldson and Hornbeck, 2015)

populations across counties, where each county is weighted by a function of its transportation cost to the county where the brewery is located. However, I adapt their implementation of market access for the purposes of this paper. In particular, I only include wet counties as destinations in the calculation, because beer could only be sold in wet counties.[46] In addition, I include the "home" county in the calculation, because the local market was an important sales destination for most breweries.[47] In consequence, the *Wet Market Access (WMA)* for breweries located in county i in year t is defined as:

$$WMA_{i,t} = \sum_{j \in J} \left(\frac{Pop_{j,t}}{\tau_{h,i}^{\theta}} \right) (Wet_{j,t}) \tag{2.5}$$

where J is the set of counties in the US, $Pop_{j,t}$ is the population in county j in year t, and $Wet_{j,t}$ is a binary variable that takes the value of one if county j was wet in year t and zero otherwise. $\tau_{i,j,t}$ is the iceberg transportation cost between county i and county j in 1890, as estimated by Donaldson and Hornbeck (2015) In trade models with product differentiation, CES preferences across varieties, and economies of scale, the structural interpretation of θ is one minus the elasticity of substitution between the different varieties of the good.[48] Hence, θ is negatively related to product differentiation in the industry of interest. With large numbers of varieties, like in the beer industry, θ can be estimated as the elasticity of trade with respect to trade costs. For my empirical application, I use $\theta = 2.55$, which is the estimate of Caliendo and Parro (2015) for the food industry. Note: For the estimations in this draft I actually used $\theta = 4$. I will update my estimations in the future.

Wet market access can change over time for three reasons: changes in transportation costs, changes in population, and changes in the dry status of counties. Because late local

[46] I consider the effects of beer smuggling on my estimates below

[47] I assume that distributing beer within counties is costless, so the iceberg transportation cost from a county to itself is one.

[48] In models with homogeneous products and productivity heterogeneity (e.g. Eaton and Kortum, 2002; Donaldson and Hornbeck, 2015), θ is a parameter that is inversely related to the spread of the distribution of productivities

prohibition only lasted four years, I assume that transportation costs do not change. In that case, changes in market access for breweries located in county i between year s and year t can be decomposed as follows:

$$\begin{aligned}
\Delta_{st} WMA_i = & \left. \begin{aligned} & -\sum_{j\in J}\left[\frac{Pop_{j,s}}{\tau^{\theta}_{i,j,s}}\right] Wet_{j,s}\left(1-Wet_{j,t}\right) \\ & +\sum_{j\in J}\left[\frac{Pop_{j,t}}{\tau^{\theta}_{i,j,t}}\right]\left(1-Wet_{j,s}\right) Wet_{j,t} \end{aligned} \right\} \text{Change due to Local Prohibition} \\
& \left. +\sum_{j\in J}\left[\left(\frac{Pop_{j,t}}{\tau^{\theta}_{i,j,t}}\right)-\left(\frac{Pop_{j,s}}{\tau^{\theta}_{i,j,s}}\right)\right] Wet_{j,s} Wet_{j,t} \right\} \text{Change due to population growth}
\end{aligned} \tag{2.6}$$

The first line is the decrease in market access induced by counties that switched from wet to dry between periods s and t. 615 counties (j) switched from wet to dry between 1914 and 1918. The second line is the increase in market access induced by counties that switched from dry to wet between periods s and t. Only 52 counties (j) switched from dry to wet between 1914 and 1918. The sum of the first and second line is the change in market access induced by local prohibition, keeping population constant. The third line is the increase in market access induced by population growth in counties (j) that remained wet throughout the period. 489 counties remained wet throughout the period.[49]

local prohibition induced large reductions in market access for the counties that remained wet between 1914 and 1918. All wet counties (489) experienced reductions in wet market access due to local prohibition, and 408 counties experienced overall reductions in wet market access. On average, wet counties lost 11% of their market access due to local prohibition and experienced a 9% reduction in their overall wet market access. At the brewery level, these average losses are 9% and 4%, respectively. Although all breweries experienced market access losses due to local prohibition, there is large variation across space in the intensity of the losses: 10% of breweries experienced losses in market access of 2% or less, whereas 10%

[49] 1570 counties, mostly rural and in the South, remained dry throughout the period

of the breweries experienced losses in market access of 19% or more.[50]

My empirical strategy uses local prohibition as an instrument for decreases in market access, allowing for the estimation of the effect of decreases in market access on changes in the capital stock (i.e. investment), the product scope and the survival status of breweries. For each of these outcomes (which are changes in state variables), I estimate the following system of equations at the brewery level ($\text{Outcome}_{h,i}$ denotes the outcome of brewery h in county i):

$$\text{Outcome}_{h,i} = \beta_0 + \beta_1 \left[-\Delta_{14,18} ln \left(WMA_{h,i}\right)\right] + u_{h,i} \tag{2.7}$$

$$\left[-\Delta_{14,18} ln \left(WMA_{h,i}\right)\right] = \gamma_0 + \gamma_1 \left[-\frac{\text{Change due to local prohibition}_{h,i,14,18}}{WMA_{h,i,14}}\right] + v_{h,i} \tag{2.8}$$

where "$\text{Change due to local prohibition}_{h,i,14,18}$" is the component of the change in Wet Market Access (WMA) that was induced by local prohibition, as defined in equation (2.6). From now on, I refer to the instrument in equation (2.8) as "Market Access Lost to Prohibition". The endogenous variable $\left[-\Delta_{14,18} ln \left(WMA_{h,i}\right)\right]$ is the log-reduction in wet market access during the local prohibition period.

I conduct this estimation on a set of breweries that satisfies three conditions: (i) being alive at the start of local prohibition (1914) (ii) being located in counties that remained wet throughout local prohibition (1914-1918) and (iii) being a bottler of beer. I focus on bottlers because the reductions in market access caused by local prohibition only had a first order effect on breweries that shipped beer to other counties. As mentioned in the historical overview, non-bottlers distributed their beer exclusively in kegs and were mostly focused in local markets.[51] At the start of local prohibition, 71% of the brewers were bottlers.

The main object of interest in equations (2.7) and (2.8) is β_1: the effect of reductions in market access induced by local prohibition on the outcomes of interest. I examine the following outcomes:

[50] At the brewery level, the descriptive statistics of the market losses due to local prohibition are as follows. Mean: 9%. Median: 7%. Standard deviation: 7%. Inter-quartile range: 10%. The map in Figure 2.5 (below) shows the spatial distribution of these losses.

[51] In the next section, I show that local prohibition had no effect *within* the set of non-bottlers, as expected

Beer-specific investment (e.g. keg washer) during local prohibition. Binary variable that takes the value of one if the brewery acquired beer-specific machinery between 1914 and 1918, and zero otherwise. Following the theoretical model, the predicted value of β_1 is negative in this case: reductions in market access caused by local prohibition induce reductions on the investment in beer machinery during local prohibition.

Bottling investment during local prohibition. Binary variable that takes the value of one if the brewery acquired bottling machinery between 1914 and 1918, and zero otherwise. Bottling machinery can be used to produce both soda and beer. Following the theoretical model, the predicted value of β_1 is negative in this case: reductions in market access caused by local prohibition induce reductions on the investment in bottling machinery during local prohibition.

Soda-specific investment (e.g. carbonator) during local prohibition. Binary variable that takes the value of one if the brewery acquired soda-specific machinery between 1914 and 1918, and zero otherwise. Following the theoretical model, the predicted value of β_1 is positive in this case: reductions in market access caused by local prohibition induce increases on the investment in soda machinery during local prohibition.

Soda production during federal prohibition.[52] Binary variable that takes the value of one if the brewery produced sodas in 1923, and zero otherwise. Following the theoretical model, the predicted value of β_1 is negative in this case: reductions in market access caused by local prohibition induce increases on the probability that a brewery will produce sodas during federal prohibition.

Overall survival: Binary variable that takes the value of one if the brewery survived between 1914 and 1933, and zero otherwise. The variable is named "overall survival" because the period 1914-1933 covers *both* local and federal prohibition. β_1 can be positive thanks to the investments of firms during local prohibition. This is, adaptation can increase the probability that a brewery will survive the *joint* period of local and federal prohibition. Very

[52] I have found no evidence that breweries were producing sodas before the start of local prohibition. For example, Anheuser Busch released its cereal beverage —Bevo— in 1916 (Plavchan, 1969, p. 160)

importantly, the sample is the set of breweries alive in 1914 (at the start of local prohibition), as opposed to the set of breweries alive in 1918 (at the start of federal prohibition).

The system of equations (2.7) and (2.8) is identified as long as the share of market access lost to local prohibition is uncorrelated with the error term $u_{h,i}$. In order to examine the plausibility of this assumption, consider the variables included in $u_{h,i}$ when the outcome of interest is overall survival.

As suggested by the theoretical model, the main component of $u_{h,i}$ is the exogenous component of marginal costs/productivity of firm h at the start of local prohibition. $u_{h,i}$ also contains variables that are not included in the theoretical model but that could plausibly influence survival, like the liquidity constraints that the firm faces and the prices of production inputs. A necessary condition for identification is, therefore, that changes in local prohibition *in other counties* are not correlated with these variables. In what follows, I argue that, in my setting, the potential violations of this condition drive the estimate towards zero. Hence, my estimates are a lower bound of the (positive) effects of local prohibition on the overall survival of firms.

The map in Figure 2.5 shows, at the county level, the reduction in market access induced by local prohibition decisions in other counties (illustrated via shading). The size of each bubble also shows the number of breweries in each county. One possible source of concern is that local prohibition had a *smaller* impact in counties with large home markets, because home markets cushioned breweries from the local prohibition decisions of other counties. Home market size might be positively correlated with the productivity of breweries due to the pro-competitive effects of larger markets, lower financial constraints, or economies of agglomeration. In all those cases, counties with large home markets will tend to have the most productive firms. Hence, local prohibition might have had the lowest impact in those counties with the most productive firms. This would generate a negative correlation between the instrument in Equation 2.8 and the error term in Equation 2.7 This negative correlation would asymptotically bias the estimate of β_1 downwards (i.e. towards zero; given my prediction that β_1 is positive).

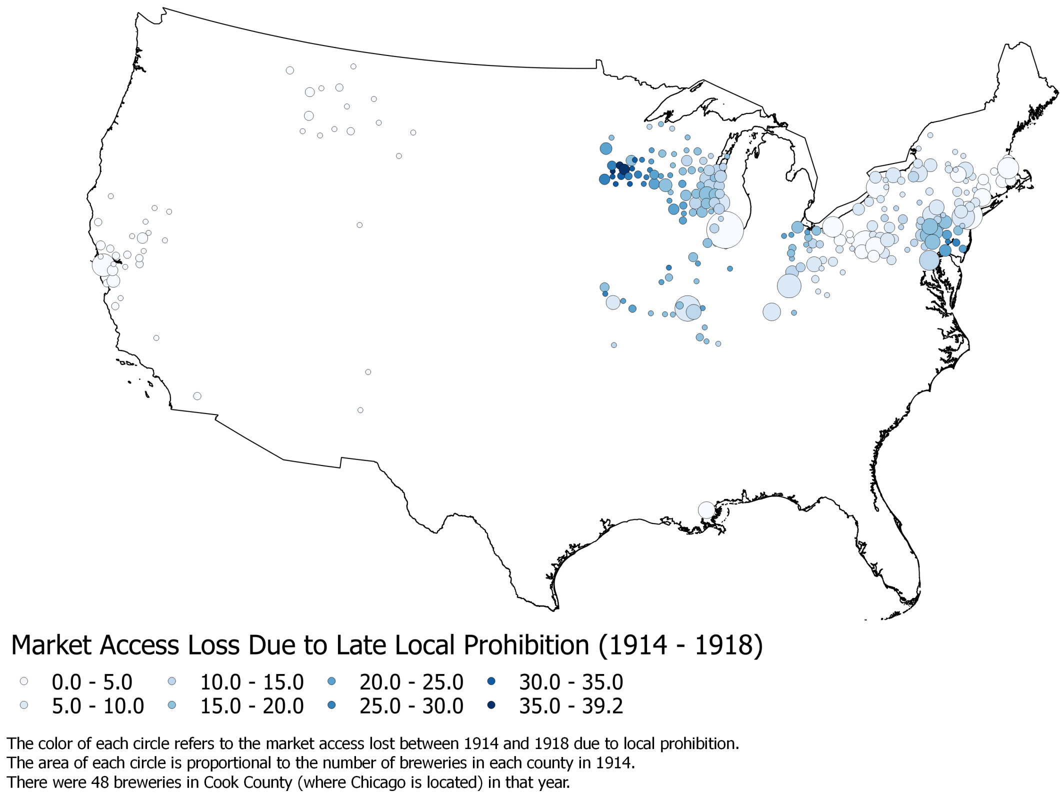


Figure 2.5: Market Access Loss due to Prohibition, by county, 1914-1918

Another possibility is that the most productive breweries may have had larger resources to make political lobby against local prohibition in nearby counties. In this case, market loss due to local prohibition would be negatively correlated with productivity. Again, this would bias the estimate of β_1 downwards (i.e. towards zero; given my prediction that β_1 is positive).

In order to check for other possible sources of endogeneity, I also run a placebo test by estimating the model from equations (2.7) and (2.8) on the sample of non-bottlers. Supply side factors —like within-county changes in input markets— have an effect in both bottlers and non-bottlers. In contrast, local prohibition should not have an effect on the demand experienced by non-bottlers, because non-bottlers did not ship beer to other counties.[53] In

[53]Alternatively, the transportation costs for non-bottlers are too high, so my measure of market access should not be correlated with the demand experienced by non-bottlers.

consequence, any impact on the outcomes of non-bottlers would be the result of correlations between the instrument and the error term, or the result of second order, positive effects through the price of factors, as in Melitz (2003)[54] As it will shown below, local prohibition does not generate variation in outcomes within the set of non-bottlers. This suggests that the variation in outcomes within the set of bottlers is effectively generated by reductions in demand.

2.6 Results

Figure 2.6 provides estimates of the reduced-form effect of local prohibition on the investment, product mix and survival choices of the bottlers.[55] The results are based on a linear probability model estimated in the sample of bottlers that were alive at the start of local prohibition (1914). All the results in Figure 2.6 are generated by variations in demand *within* the set of bottlers.

Compared with breweries that did not experience reductions in demand, breweries that experienced the average reduction in demand during local prohibition are less likely to invest in beer-specific machinery, less likely to invest in bottling (i.e. common-use machinery) and more likely to invest in soda-specific machinery during local prohibition. Furthermore, the same set of breweries is more likely to produce sodas during federal prohibition, and to survive the overall Prohibition period, including local and federal prohibition. The latter result is remarkable: breweries that faced five additional years of hardship were 5 percentage points more likely to survive the entire period because they adapted earlier. This increase

[54] If my treatment was a discrete variable, the intuition of my placebo test would be the same as the intuition of a dif-in-dif-in-dif estimator, in which (i) the difference between breweries measures de intensity of the demand shift (ii) the difference across time controls for fixed characteristics of breweries and (iii) the difference between bottlers and non-bottlers controls for supply shocks that are common across both groups.

[55] That is, the effect of loss of market access to local prohibition on each outcome, or an estimate of $\gamma_1\beta_1$ from equations 2.8 and 2.7. This term is obtained by replacing equation (2.8) into equation (2.7), which yields:

$$\text{Outcome}_{h,i} = \beta_0 + \gamma_0\beta_1 + \gamma_1\beta_1 \left[-\frac{\text{Change due to local prohibition}_{h,i,14,18}}{WMA_{h,i,14}} \right] + e_{h,i}$$

in survival represents 10% of the overall survival rate of the period. All the results are consistent with the predictions from the theoretical model.

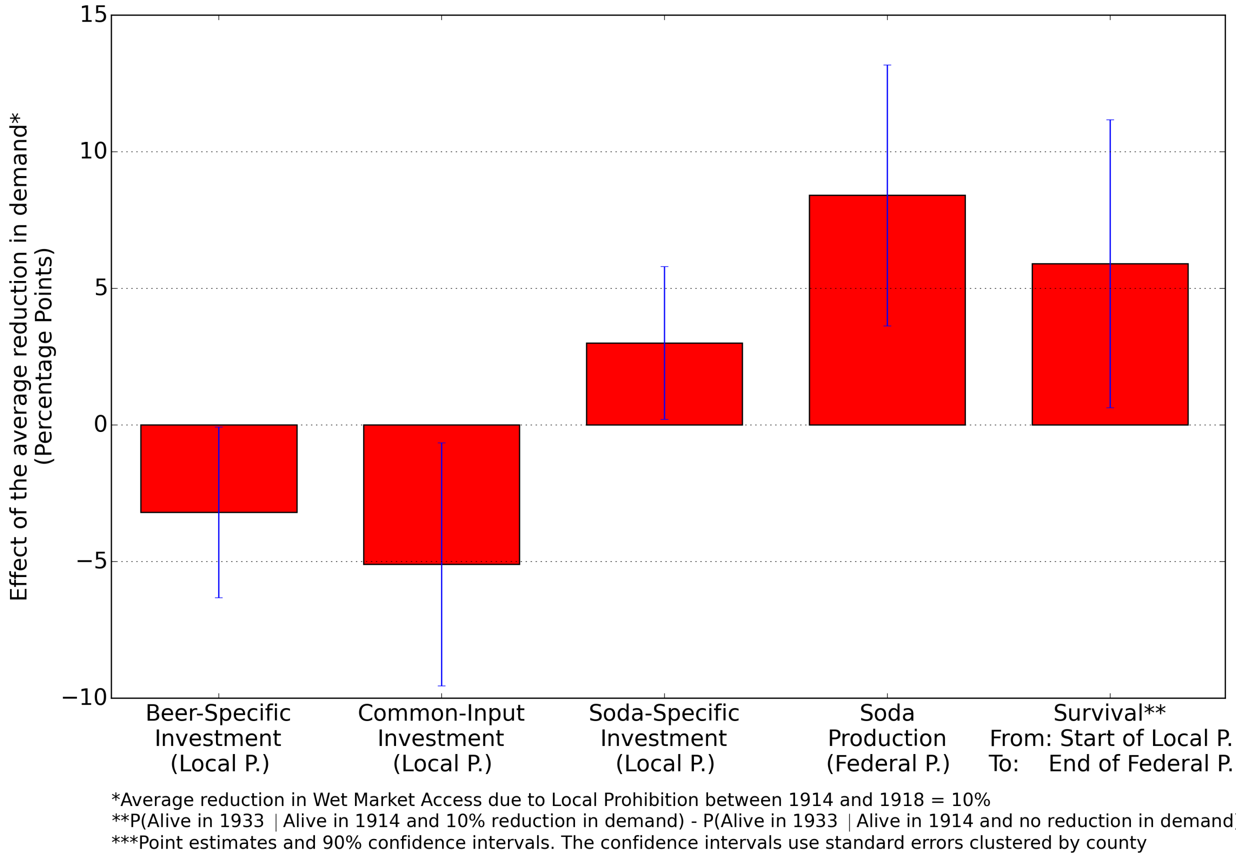


Figure 2.6: Effect of local prohibition on multiple outcomes for bottlers, 1914-1933

In order to confirm that local prohibition affects outcomes through reductions in market access, I use the share of market access lost to local prohibition as an instrument for reductions in market access; and then estimate the effect of market access on investment, product-mix and survival. In particular, I estimate γ_1 and β_1 from equations (2.7) and (2.8) using a two-stage least-squares procedure on a linear probability model.

Table 2.1 contains estimates of the first stage (equation 2.8) for both bottlers and non-bottlers. In this section I focus on the results for bottlers —I will use the results for non-bottlers in the next section. The instrument is strong: the share of market access lost to prohibition have a large predictive power on log-reductions in market access. The variation in the instrument explains 89% of the variation in the endogenous variable and the F-statistic of the first stage is 881. Most of the variation in market access between 1914 and 1918 is due to local prohibition.

Table 2.1: Dependent variable: ↓ Ln(Wet M. A.) (1914-1918)

	(1) Non-Bottler 1914	(2) Bottler 1914
Share of M.A. lost to proh. (1914-1918)	1.20***	1.22***
	(0.05)	(0.04)
Ln(Wet M. A.) (1914)	-0.01	-0.00
	(0.01)	(0.00)
Constant	0.05	-0.04
	(0.08)	(0.05)
Observations	193	511
R^2	0.888	0.883

First stage of the instrumental variables estimates

Breweries alive in 1914, in locations that were wet in both 1914 and 1918

Non-Bottler 1914: Subsample of breweries that were no bottlers in 1914

Bottler 1914: Subsample of breweries that were bottlers in 1914

Standard errors in parentheses and clustered by county

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2.2 shows that breweries that faced larger reductions in demand during local prohibition were less likely to invest in beer-specific capital or common-input capital, but more likely to invest in soda-specific capital during local prohibition. When federal prohibition arrived, these breweries were more likely to produce alternative products (sodas). Overall, breweries that faced larger reductions in demand during local prohibition were more likely to survive the whole period, including local and federal prohibition.[56]

The results in this section all point in the same direction: bottlers adapted to local prohibition by investing in capital that provided flexibility later, when federal prohibition arrived. As a result, bottlers that faced reductions in demand during the local prohibition period were more likely to survive the whole period, including local and federal prohibitions.

[56]All dependent variables in table 2.2 only take the values of 0 or 1.

Table 2.2: Bottlers: Effect of reductions in market access

	Beer-Specific Investment (Local P.)	Common Input Investment (Local P.)	Soda-Specific Investment (Local P.)	Soda production (Federal P.)	Survival From: Start of Local P. To: End of Federal P.
↓ Ln(Wet M. A.) (1914-1918)	-0.27*	-0.42*	0.25*	0.69***	0.49*
	(0.15)	(0.22)	(0.14)	(0.24)	(0.26)
Ln(Wet M. A.) (1914)	0.04***	0.06***	-0.01	-0.03*	0.04**
	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)
Constant	-0.35***	-0.48***	0.24*	0.63***	0.01
	(0.10)	(0.17)	(0.13)	(0.21)	(0.23)
Observations	511	511	511	511	511

Instrumental variables estimates. Instrument: Share of M.A. lost to proh. (1914-1918)

Breweries alive in 1914, in locations that were wet in both 1914 and 1918

Standard errors in parentheses and clustered by county

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

2.7 Placebo Test

My results from last section rely on the interpretation of local prohibition as a demand reduction for the bottlers. In turn, this interpretation relies on an identification assumption: prohibition decisions in nearby counties are uncorrelated with the productive amenities where the breweries are located. I provide empirical support for that assumption by running the same regressions on the set of non-bottlers.

Most non-bottlers did not ship beer to other counties. In consequence, exposure to local prohibition should not induce (first-order) variation in demand within the set of non-bottlers. However, if exposure to local prohibition were correlated with productive amenities, changes in wet market access would capture the effect of productive amenities on non-bottlers.

Figure 2.7 shows that exposure to local prohibition had *no effect* on investment, product-mix or survival among non-bottlers. This result sugggests that the changes in investment, product-mix and survival among bottlers were induced by a shift in demand, as opposed to differences in productive amenities among the bottlers.

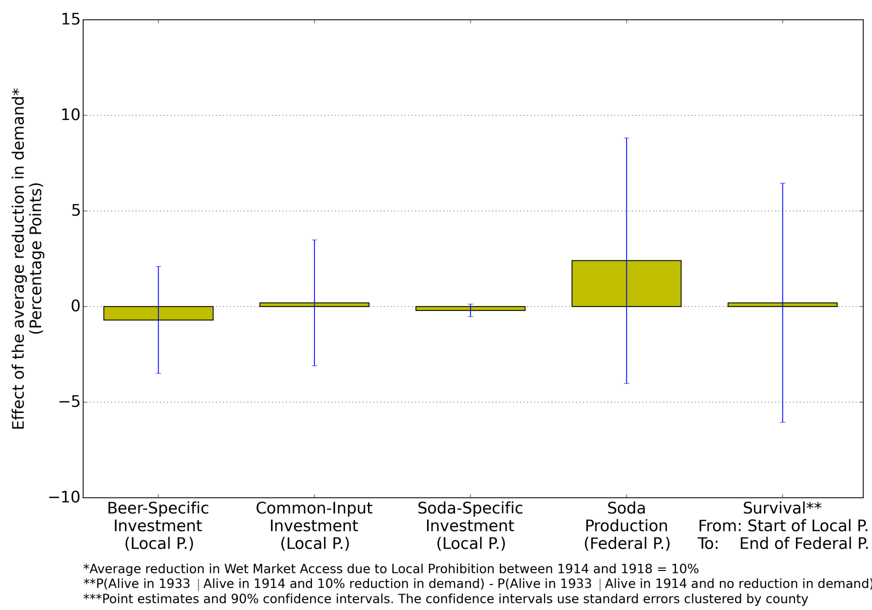


Figure 2.7: Effect of local prohibition on multiple outcomes for Non-bottlers, 1914-1933

2.8 Conclusions

This paper shows that demand reductions in the early history of a firm can affect its trajectory and response to future demand reductions. In particular, exposure to small demand reductions can make firms more resilient to future, potentially larger demand reductions by encouraging firms to make investments that facilitate product switching. I reach this conclusion by studying the American brewing industry during prohibition.

This historical context allows me to follow breweries throughout an initial shock of heterogeneous intensity (local prohibition), followed by a common, larger, shock (federal prohibition). By studying survival throughout both shocks, I show that adaptation –the making of irreversible investments in response to the first shock– increases the ability of firms to survive the second shock, even if selection –the exit of the least productive firms– also occurs in response to the first shock. My novel dataset on machinery acquisition and product diversification corroborates the testable implications of the adaptation mechanism.

The key components of my mechanism –irreversible investments and multi-product firms– are present in many industries of today. For example, firms that span multiple industries account for 81 percent of the manufacturing output and 28 percent of the number firms in the US (Bernard et al., 2010).[57]

Firms in these industries can experience reductions in demand due to regulation, trade reforms, and sectoral changes in government spending. Policy makers often care about the survival of firms for its own sake, due to political economy considerations or possible externalities induced by firm exit. My results suggest that increased gradualism in the implementation of these policies can facilitate the adaptation and survival of firms to the policy at hand.

[57]Industries are defined as four-digit SIC categories in the US manufacturing census (ibid).

CHAPTER 3

Knowledge as a Source of Persistent Renewal: Why Japanese Breweries Publish so Many Academic Articles (with Michael Darby and Lynne Zucker)

3.1 Introduction

Which firms reinvent themselves in response to increased competition and how persistent is reinvention? The answer to this question brings light to the distributive effects of regulation, trade-reform and innovation policy. We study an industry of centenary firms that have survived multiple episodes of regulation, market integration and new alternative products: the brewing industry.

We focus on the response of Japanese breweries to a fall of competitive barriers in the Japanese market. In the 1980s, the entrance of foreign competition and changes in distribution channels reduced the market power of Japanese breweries. Breweries responded by introducing new beer brands at a rate 10 times faster than in the previous 20 years (Craig, 1996). But breweries did not only innovate by introducing new brands of beer. Breweries also changed the nature of their research and increased its amount.

Between 1986 and 1996, the number of academic articles authored by scientists affiliated to Japanese breweries increased sixfold. No change of a similar order of magnitude occurred in other countries (Figure 3.1). By 1996, Japanese breweries were publishing 83% of the academic articles published by all breweries in the world. In this paper, we show that this increase reveals a shift of Japanese breweries towards the pharmaceutical and other bio-related industries. This shift was possible because breweries were already doing research in fermentation before this period, developing tacit knowledge that was later useful while doing research in pharmaceutical and bio-related topics. The existence of tacit knowledge also explains why diversification became persistent over time, even after the structure of the Japanese beer market had already stabilized.

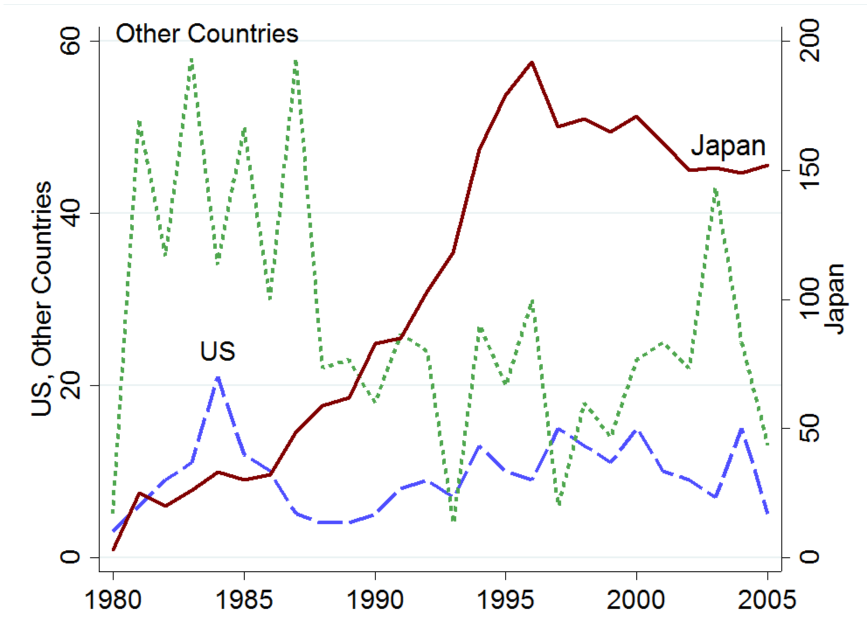


Figure 3.1: Academic Articles Published by Breweries per Country. 1980 - 2005

This paper contributes to the literature on how changes in the economic environment induce firms to innovate in new products. For example, increased competition in the computing hardware market induced IBM to switch to business computing services (Agarwal and Helfat, 2009), compositional shifts in demand since 2011 induced defence contractors to switch towards counter-terrorism products (Aggarwal and Wu, 2015), the Great Depression induced large manufacturing firms to diversify their product mix (Chandler, 1969), the end of World War I induced Dupont to diversify from explosives to other chemical products (Chandler, 1990, p. 175), and increased competition from Chinese imports induced European and Peruvian firms to innovate into new products (Bloom et al., 2015; Medina, 2015). Our paper contributes to this literature by showing that initial increases in diversification can become persistent when diversification involves innovation in fields characterized by the presence of tacit knowledge.

3.2 The Research Agenda of Japanese Breweries

In contrast to breweries from other countries, Japanese breweries are unique in their propensity to publish academic articles. The three most published breweries in the world between 1980 and 2005 were Japanese (Table 3.1). Furthermore, the ratio of articles to patents was higher for breweries from Japan than for breweries from other countries.

Table 3.1: Breweries with the most articles published between 1980 and 2005

Name	Country	Articles	Patents	Art to Pat
Kirin Brewery	Japan	1632	19	85.9
Sapporo Breweries	Japan	231	71	3.3
Asahi Breweries	Japan	221	24	9.2
Labatt Brewing	Canada	101	38	2.7
Adolph Coors	USA	59	211	0.3
Miller Brewing	USA	47	57	0.8
S African Breweries	South Africa	44	0	NA
Carlton United Breweries	Australia	31	4	7.8
Bass Brewers	England	22	0	NA
Guinness Brewing Worldwide	Ireland	22	14	1.6

Japanese breweries also differ from other breweries in their research agenda. While Japanese breweries publish academic articles on medical and bio-related topics, US breweries publish articles on topics more directly related to the operation of a brewery, including Law (Table 3.2).

Patents indicate a similar research agenda as academic articles. Japanese breweries patent

Table 3.2: Journals in which breweries most published between 1980 and 2005

Japan

Journal Name	Articles
Bioscience Biotechnology And Biochemistry	154
Blood	121
Agricultural And Biological Chemistry	112
Journal Of Fermentation And Bioengineering	78
Journal Of Antibiotics	68
Journal Of Bioscience And Bioengineering	67
Journal Of The Society Of Fermentation Technology	67
Journal Of Biological Chemistry	64
Journal Of The American Society Of Brewing Chemists	62
Experimental Hematology	43

US

Journal Name	Articles
Journal Of The American Society Of Brewing Chemists	19
Abstracts Of Papers Of The American Chemical Society	14
Cereal Foods World	9
Urban Lawyer	7
Journal Of The Institute Of Brewing	6
Solid State Technology	6
Transactions Of The Asae	4
Journal Of Food Science	4
Monatsschrift Fur Brauwissenschaft	4
Interface Age	4

processes and organisms related to biology, whereas US breweries patent processes and machinery directly related to the production and distribution of beer (Table 3.3).

3.3 The Rise of Medical and Biochemical Research

Japanese breweries were already publishing in biochemistry journals related to fermentation or agriculture since the beggining of the 1980s[1]. However, starting in the mid-1980s, there was a substantial increase in publications related to medical and biochemical research not directly related with beer production (Figure 3.2). This quantitative and qualitative transformation in the research output of Japanese breweries drove the increase in the overall number of articles from 1986 to 1996. By the latter year, biology and medical related journals were publishing 37% and 44% of the articles authored by scientists affiliated to Japanese Breweries.

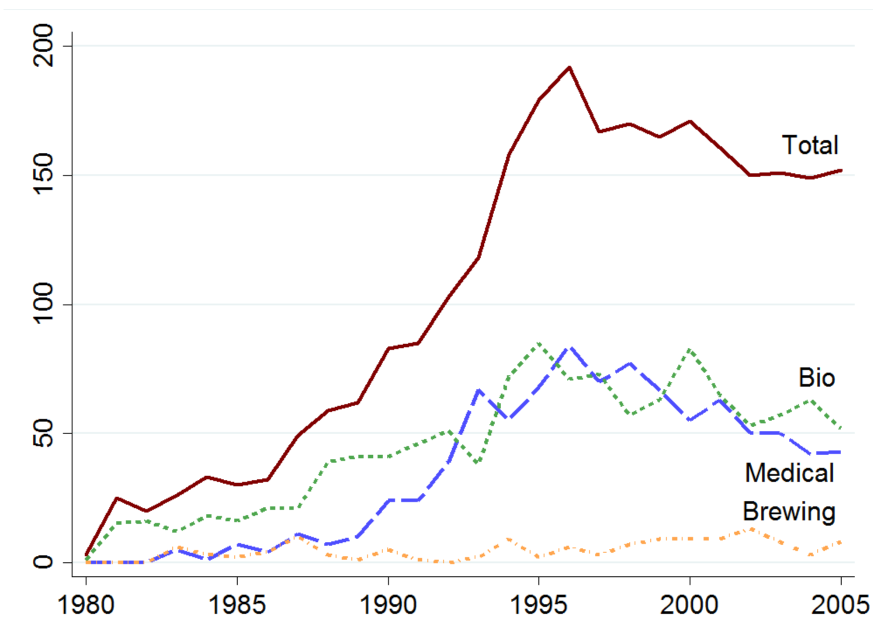


Figure 3.2: Academic Articles Published by Japanese Breweries, by research area. 1980 - 2005

[1]In 1981, the three journals in which Japanese breweries published the most articles were Agricultural And Biological Chemistry (8 articles), the Journal Of The Society Of Fermentation Technology (7 articles) and the Journal Of The Agricultural Chemical Society Of Japan (6 articles)

Table 3.3: Patent subclasses most granted to breweries between 1980 and 2005

Japan

Class	Class name	Patents
C12N	Micro-Organisms Or Enzymes (. . .) Genetic Engineering	19
A61K	Preparations For Medical, Dental, Or Toilet Purposes	15
G01N	Investigating Or Analysing Materials (. . .)	9
C12Q	(. . .) Processes Involving Enzymes Or Micro-Organisms	8
C12P	Fermentation Or Enzyme-Using Processes (. . .)	5
C12M	Apparatus For Enzymology Or Microbiology	4
B01D	Separation (Evaporation, Distillation (. . .)	4
C12H	Pasteurisation, Sterilisation, Preservation, (. . .)	3
B67D	Dispensing, Delivering, Or Transferring Liquids (. . .)	3
C09D	Coating Compositions, e.g. Paints, (. . .)	3

US

Class	Class name	Patents
B21D	Working Or Processing Of Sheet Metal (. . .)	31
B65D	Containers For Storage Or Transport (. . .)	30
B65B	Machines (. . .) Or Methods Of, Packaging (. . .)	24
C12C	Brewing Of Beer	21
G01N	Investigating Or Analysing Materials (. . .)	17
G03F	Photomechanical Production Of (. . .) Surfaces (. . .)	17
B05D	Processes For Applying Liquids (. . .) To Surfaces (. . .)	14
G03C	Photosensitive Materials For Photographic Purposes (. . .)	14
B41F	Printing Machines Or Presses	12
B65G	Transport Or Storage Devices (. . .)	11

3.4 Discussion: Knowledge as a Source of Persistence

Japanese breweries became heavily involved in medical and biological related research after a reduction in barriers to entry in the beer market. Breweries in other countries did not experience similar changes in the nature of their research. On the contrary, most research by breweries in other parts of the world remained focused on the production and distribution of beer.

By 1990, the market shares of domestic breweries in the Japanese beer market had already stabilized (Craig, 1996). Yet, the number of publications in academic journals by Japanese breweries continued to grow until 1996. Even after a steady decline over the next 10 years in the absolute number of articles publised (Figure 3.2, above), Japanese breweries accounted for 89% of all academic articles published by breweries in 2005. The initial shock of intensified competition had persistent effects over the scientific output of japanese breweries.

What is the source of such persistence? The diversification from beer production towards the pharmaceutical and biochemical sectors occured during the early years of the biotechnology industry. At this early stage, innovation in the industry was characterized by the existence of naturally excludable knowledge whose diffusion was difficult due to its complexity or tacitness (Zucker et al., 1998). The practical use of this knowledge required the collaboration between academic scientists and firm scientists (Zucker and Darby, 1996). Having done research on fermentation, Japanese breweries were in a privileged position to take part of this exchange. Necessity mixed with opportunity.

Once Japanese breweries started to perform research on these areas, tacit knowledge itself became a source of competitive advantage. The competitors of breweries in biotechnology had yet to acquire the tacit knowledge and the links with academic scientists that breweries already had. The existing knowledge and research infrastructure provided economies of scale towards future research. After the 1980s, Japanese breweries were no longer just breweries.

Bibliography

Agarwal, R. and Helfat, C. E. (2009). Strategic renewal of organizations. *Organization Science*, 20(2):281–293.

Aggarwal, V. A. and Wu, B. (2015). Organizational constraints to adaptation: Intrafirm asymmetry in the locus of coordination. *Organization Science*, 26(1):218–238.

Aghion, P., Bloom, N., Lucking, B., Sadun, R., and van Reenen, J. (2015). Growth and decentralization in bad times. Working paper.

Arnold, J. and Penman, F. (1933). *History of the Brewing Industry and Brewing Science in America*. BeerBooks.com. Reprinted in 2006.

Atack, J. (2013). On the use of geographic information systems in economic history: The american transportation revolution revisited. *The Journal of Economic History*, 73(02):313–338.

Barnett, J. A. (2000). A history of research on yeasts 2: Louis Pasteur and his contemporaries, 18501880. *Yeast*, 16(8):755–771.

Baron, S. (1962). *Brewed in America: a history of beer and ale in the United States*. Little, Brown.

Beman, L. (1927). *Selected Articles on Prohibition: Modification of the Volstead Law. Supplement*. Number v. 2 in Reference shelf. Wilson.

Bernard, A. B., Redding, S. J., and Schott, P. K. (2010). Multiple-product firms and product switching. *American Economic Review*, 100(1):70–97.

Bernard, A. B., Redding, S. J., and Schott, P. K. (2011). Multiproduct firms and trade liberalization. *The Quarterly Journal of Economics*, 126(3):1271–1318.

Bloom, N., Draka, M., and van Reenen, J. (2015). Trade induced technical change: The impact of chinese imports on innovation, diffusion and productivity. *Review of Economic Studies*.

Bloom, N., Romer, P. M., Terry, S. J., and Reenen, J. V. (2014). Trapped factors and china's impact on global growth. Working paper.

Bowden, M., Crow, A., and Sullivan, T. (2003). *Pharmaceutical Achievers: The Human Face of Pharmaceutical Research*. Chemical Heritage Press.

Bresnahan, T. F. and Raff, D. M. G. (1991). Intra-Industry Heterogeneity and the Great Depression: The American Motor Vehicles Industry, 1929-1935. *The Journal of Economic History*, 51(2):pp. 317–331.

Bureau of Internal Revenue (1905). *Annual Report for the Commissioner of Internal Revenue*. Number 2424 in Document. Government Printing Office. Fiscal Year Ended June 30, 1905.

Bureau of Internal Revenue (1922). *Annual Report for the Commissioner of Internal Revenue*. Government Printing Office. Fiscal Year Ended June 30, 1922.

Bureau of Internal Revenue (1923). *Annual Report for the Commissioner of Internal Revenue*. Number 2929 in Document. Government Printing Office. Fiscal Year Ended June 30, 1923.

Bustos, P. (2011). Trade liberalization, exports, and technology upgrading: Evidence on the impact of mercosur on argentinian firms. *American Economic Review*, 101(1):304–40.

Caballero, R. J. and Hammour, M. L. (1994). The Cleansing Effect of Recessions. *The American Economic Review*, 84(5):pp. 1350–1368.

Caliendo, L. and Parro, F. (2015). Estimates of the trade and welfare effects of nafta. *The Review of Economic Studies*, 82(1):1–44.

Chandler, A. (1990). *Scale and Scope: The Dynamics of Industrial Capitalism*. Belknap Press.

Chandler, Alfred D., J. (1969). The structure of american industry in the twentieth century: A historical overview. *The Business History Review*, 43(3):pp. 255–298.

Cochran, T. C. (1948). *The Pabst Brewing Company: the History of an American Business*. New York University Press.

Craig, T. (1996). The japanese beer wars: Initiating and responding to hypercompetition in new product development. *Organization Science*, 7(3):302–321.

Dewatripont, M. and Roland, G. (1992). Economic reform and dynamic political constraints. *The Review of Economic Studies*, 59(4):703–730.

Dewatripont, M. and Roland, G. (1995). The design of reform packages under uncertainty. *The American Economic Review*, 85(5):pp. 1207–1223.

Donaldson, D. and Hornbeck, R. (2015). Railroads and american economic growth: A "market access" approach. Working paper.

Eaton, J. and Kortum, S. (2002). Technology, Geography, and Trade. *Econometrica*, 70(5):1741–1779.

Edwardson, J. (1952). Hopstheir botany, history, production and utilization. *Economic Botany*, 6(2):160–175.

Feldman, H. (1927). *Prohibition, its economic and industrial aspects.* D. Appleton and company, New York, London.

Ferrie, J. P. and Troesken, W. (2008). Water and chicagos mortality transition, 18501925. *Explorations in Economic History*, 45(1):1 – 16.

Fogel, R. W. (1964). *Railroads and American economic growth: essays in econometric history*, volume 296. Johns Hopkins Press Baltimore.

Foster, L., Grim, C., and Haltiwanger, J. (2014). Reallocation in the great recession: Cleansing or not? Working Paper.

Fox, H. and Hoyt, W. (1852). *Fox and Hoyt's Quadrennial Register of the Methodist Episcopal Church: And Universal Church Gazetteer, 1852-6*. Case, Tiffany & Company.

Fox, J. F., Fishback, P. V., and Rhode, P. W. (2011). *The Effects of Weather Shocks on Crop Prices in Unfettered Markets: The United States Prior to the Farm Programs, 1895-1932*, pages 99–130. University of Chicago Press.

Freiman, R. B. and Kleiner, M. M. (2005). The last american shoe manufacturers: Decreasing productivity and increasing profits in the shift from piece rates to continuous flow production*. *Industrial Relations: A Journal of Economy and Society*, 44(2):307–330.

Fujita, M., Krugman, P. R., and Venables, A. (2001). *The Spatial economy: Cities, regions, and international trade*. MIT press.

García-Jimeno, C. (2015). The political economy of moral conflict: An empirical study of learning and law enforcement under prohibition. Working paper.

Gohmann, S. F. (2015). Why are there so few breweries in the south? *Entrepreneurship Theory and Practice*, pages n/a–n/a.

Harris, C. D. (1954). The market as a factor in the localization of industry in the united states. *Annals of the Association of American Geographers*, 44(4):pp. 315–348.

Head, K. and Mayer, T. (2004). Chapter 59 the empirics of agglomeration and trade. In Henderson, J. V. and Thisse, J.-F., editors, *Cities and Geography*, volume 4 of *Handbook of Regional and Urban Economics*, pages 2609 – 2669. Elsevier.

Helfat, C. E. and Eisenhardt, K. M. (2004). Inter-temporal economies of scope, organizational modularity, and the dynamics of diversification. *Strategic Management Journal*, 25(13):pp. 1217–1232.

Hiatt, S. R., Sine, W. D., and Tolbert, P. S. (2009). From pabst to pepsi: The deinstitutionalization of social practices and the creation of entrepreneurial opportunities. *Administrative Science Quarterly*, 54(4):635–667.

Holmes, T. J., Levine, D. K., and Schmitz, J. A. (2012). Monopoly and the incentive to innovate when adoption involves switchover disruptions. *American Economic Journal: Microeconomics*, 4(3):1–33.

Hopenhayn, H. A. (1992). Entry, exit, and firm dynamics in long run equilibrium. *Econometrica*, pages 1127–1150.

H.S. Rich & Co. (1923). *The Beverage Blue Book 1923*. H.S. Rich & Co.

Kerr, K. (1985). *Organized for Prohibition: A New History of the Anti-Saloon League*. Yale University Press.

Kerr, K. A. (1998). The american brewing industry, 1865-1920. In Wilson, R. and Gourvish, T., editors, *The Dynamics of the International Brewing Industry Since 1800*, chapter 11, pages 176 – 192. Routledge.

Kim, S. (1995). Expansion of markets and the geographic distribution of economic activities: The trends in u. s. regional manufacturing structure, 1860-1987. *The Quarterly Journal of Economics*, 110(4):881–908.

Leamer, E. E. (1980). The leontief paradox, reconsidered. *Journal of Political Economy*, 88(3):pp. 495–503.

Legislative Research Commission of Kentucky (2015). The constitution of the commonwealth of kentucky. Frankfort, Kentucky.

Levinthal, D. A. and Wu, B. (2010). Opportunity costs and non-scale free capabilities: profit maximization, corporate scope, and profit margins. *Strategic Management Journal*, 31(7):780–801.

Lileeva, A. and Trefler, D. (2010). Improved access to foreign markets raises plant-level productivityfor some plants. *The Quarterly Journal of Economics*, 125(3):1051–1099.

Maxwell, D. B. S. (1993). Beer cans: A guide for the archaeologist. *Historical Archaeology*, 27(1):pp. 95–113.

Maxwell, H. and Sullivan, B. (1999). *Hometown Beer: A History of Kansas City's Breweries*. Omega Innovative Marketing.

McGahan, A. M. (1991). The emergence of the national brewing oligopoly: Competition in the American market, 1933-1958. *The Business History Review*, 65(2):pp. 229–284.

Medina, P. (2015). Within-firm responses to import competition: Quality upgrading and exporting in the peruvian apparel industry. Working paper.

Melitz, M. J. (2003). The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity. *Econometrica*, 71(6):pp. 1695–1725.

Minnesota Population Center (2011). National historical geographic information system: Version 2.0. Url: `https://www.nhgis.org/`. Accessed: 2015-06-29.

Panzar, J. C. and Willig, R. D. (1981). Economies of scope. *The American Economic Review*, 71(2):pp. 268–272.

Penrose, E. (1959). *The Theory of the Growth of the Firm*. Oxford: Oxford University Press, 4th ed (2009) edition. Retrieved 28 Aug. 2015, from `http://www.oxfordscholarship.com/view/10.1093/0198289774.001.0001/acprof-9780198289777`.

Plavchan, R. J. (1969). *A history of Anheuser-Busch, 1852-1933*. PhD thesis, St. Louis University.

Porter, M. (1990). *The Competitive Advantage of Nations*. Free Press.

Porter, M. (1996). America's green strategy. In Welford, R. and Starkey, R., editors, *Business and the Environment: A Reader*, pages 33–35. Taylor & Francis Washington, DC.

Redding, S. and Venables, A. J. (2004). Economic geography and international inequality. *Journal of International Economics*, 62(1):53 – 82.

Ronnenberg, H. W. (1998). The american brewing industry since 1920. In Wilson, R. and Gourvish, T., editors, *The Dynamics of the International Brewing Industry Since 1800*, chapter 11, pages 176 – 192. Routledge.

Rowntree, J. and Sherwell, A. (1900). *The Temperance Problem and Social Reform*. Hodder and Stoughton.

Sechrist, R. P. (1986). *A Comparative Analysis of Multidimensional Diffusion Models: The Diffusion of the Prohibition Movement in the United States of America, 1876-1919*. PhD thesis, Louisiana State University.

Sechrist, R. P. (2012). Prohibition movement in the United States, 1801-1920. Url: `http://www.icpsr.umich.edu/icpsrweb/ICPSR/studies/08343/version/2`. Accessed: 2013-06-29.

Southern Baptist Convention (1896). Resolution. `http://www.sbc.net/resolutions/46/untitled`. Online; accessed 2015/07/17.

Stack, M. (2000). Local and regional breweries in America's brewing industry, 1865 to 1920. *The Business History Review*, 74(3):pp. 435–463.

Stack, M. (2010). Was big beautiful? the rise of national breweries in America's pre-prohibition brewing industry. *Journal of Macromarketing*, 30(1):50–60.

Steinwender, C. (2015). The roles of import competition and export opportunities for technical change. Working paper.

Teece, D. J. (1980). Economies of scope and the scope of the enterprise. *Journal of Economic Behavior & Organization*, 1(3):223 – 247.

Teece, D. J., Pisano, G., and Shuen, A. (1997). Dynamic capabilities and strategic management. *Strategic Management Journal*, 18(7):pp. 509–533.

Tremblay, V. and Tremblay, C. (2005). *The U.S. Brewing Industry: Data and Economic Analysis*. MIT Press.

United States Brewers' Association (1907). *Proceedings of the Annual Convention*. United States Brewers' Association.

United States Bureau of the Census (1907). *Manufactures 1905. United States by Industries*, volume 1 of *Manufactures, 1905*. U.S. Government Printing Office.

United States Bureau of the Census (1908). *Manufactures 1905. Special Reports on Selected Industries*, volume 3 of *Manufactures, 1905*. U.S. Government Printing Office.

United States Bureau of the Census (2000). Historical national population estimates. Url: `http://www.census.gov/popest/data/national/totals/pre-1980/tables/popclockest.txt`. Accessed: 2015-06-29.

USCB, U. C. B. (2011). Centers of population computation for the united states 1950 - 2010. Technical report, Geography Division, U.S. Census Bureau.

Wade, J. B., Swaminathan, A., and Saxon, M. (1998). Normative and Resource Flow Consequences of Local Regulations in the American Brewing Industry, 1845-1918. *Administrative Science Quarterly*, 43(4):pp. 905–935.

Wahl, R. and Henius, M., editors (1898). *Brewers' Guide*. American Brewers' Review.

Zucker, L. and Darby, M. (1996). Star scientists and institutional transformation: Patterns of invention and innovation in the formation of the biotechnology?industry. *Proceedings of the National Academy of Sciences*, 93(23):12709–12716.

Zucker, L. G., Darby, M. R., and Brewer, M. B. (1998). Intellectual Human Capital and the Birth of U.S. Biotechnology Enterprises. *The American Economic Review*, 88(1):pp. 290–306.