Technology adoption and industrial leadership: How Brewing Moved West in the United States

Carlos Eduardo Hernández*
School of Management, Universidad de los Andes

December 26, 2017

Abstract

I study the connection between the invention of new technologies and the rise and incumbency of leaders within an industry. I focus on the rise of Midwestern breweries in the US after the invention of pasteurization in the late nineteenth century. Pasteurization reduced the marginal cost of shipping beer for breweries willing to build bottling plants. Using a brewery-level dataset that I constructed, I show that the endogenous adoption of bottling allowed for the early expansion of breweries that later became leaders in the industry. These breweries were located in the Midwest because of their low transportation costs to nearby markets with weak competitors that were mostly isolated before pasteurization was invented. In the Northeast, breweries were unlikely to adopt bottling and focused on their home markets instead. The early expansion of Midwestern breweries occurred mainly through shipments within the Midwest, as opposed to shipments from the Midwest to the Northeast. My results are consistent with an extension of the endogenous sunk cost framework developed in Sutton (1991, 1997).

*Most recent version: `http://www.cehernandez.info/research`. This paper was part of my doctoral dissertation at UCLA. I am thankful for the encouragement and guidance of Leah Boustan, as well as the detailed feedback that I have received from Walker Hanlon, Dora Costa, Romain Wacziarg, Edward Leamer, Lynne Zucker, Michael Darby, and Xavier Durán as well as participants at the Economic History Society meetings and the Beeronomics Conference. This project is supported by the Center of Economic History at UCLA, the All-UC Group in Economic History, the Economic History Association, the Institute for Humane Studies, Colfuturo and Banco de la República. E-mail: *cehernandez.econ@gmail.com*

1 Introduction

Changes in leadership within an industry are unlikely (Sutton, 2007)[1]. The invention of new technologies might trigger changes in leadership that later might become persistent through process improvements to the previously novel technologies. Insofar as firm mobility is associated to the social mobility of their stakeholders, understanding the role of technology adoption on industrial mobility might provide new insights on the sources of social mobility. Nevertheless, studying this relationship in the data is often difficult because technology adoption is endogenous to the size and capabilities of firms.

This paper solves this difficulty by using the discoveries of Louis Pasteur in the 1870s as a historical experiment on the US brewing industry. Pasteur discovered the biological mechanism behind beer fermentation and spoilage. Before the inventions of Pasteur, the industry consisted of isolated geographical markets served by local brewers that used artisanal production techniques (Plavchan, 1969; Kerr, 1998). The discoveries of Pasteur allowed brewers to (i) ship beer to nearby, previously isolated locations by pasteurizing their beer beforehand (Cochran, 1948; Baron, 1962; Plavchan, 1969; Kerr, 1998; Stack, 2000) and (ii) produce beer of reliable taste across batches, which allowed brewers to charge a higher price than the local breweries at destination locations that still used old brewing technologies (McGahan, 1991; Stack, 2010). The application of Pasteur's discoveries required the acquisition of scientific knowledge, instruments and machinery that was novel and costly to acquire. In addition, pasteurization required the use of bottles rather than kegs. In consequence, the share of bottling plants increased from virtually zero in the late 1860s to 21% in 1880 and 51% in 1898.

The adoption of bottling is potentially endogenous to other determinants of firm growth like liquidity constraints. I use access to large or multiple markets with weak competitors as an

[1] In 27 out of 47 Japanese industries, the identity of the largest producer remained the same over 23 years. This persistence in leadership is much more likely than predicted by a Markovian model

instrument for the adoption of bottling by regional shippers. The instrument is exogenous because destination markets were isolated before the discoveries of Pasteur, so they had no previous economic connection with the size and capabilities of potential beer shippers. The instrument is relevant because the main purpose of bottling after the discoveries of Pasteur was to ship beer to markets that were previously isolated.

I find that breweries in the Midwest adopted bottling earlier and to a greater extent than breweries in the Northeast because breweries in the Midwest benefitted the most from shipping beer to nearby markets. In particular, breweries in the Midwest were close to (i) small and previously isolated towns where local brewers had not yet invested in quality and standardization, or (ii) Chicago, where water quality was low and a fire had destroyed breweries in 1871 (Cochran, 1948; Baldwin, 1966; Ferrie and Troesken, 2008).

The early adoption of bottling in the Midwest allowed for changes in leadership within the Midwest that did not occur within the Northeast. Early adopters of bottling replaced late adopters of bottling as industry leaders within the Midwest. In contrast, there were little changes in leadership in the Northeast. In fact, most industry leaders in the Northeast had not yet adopted bottling by 1898, 22 years after the publication of Pasteur's findings (Pasteur, 1876). In addition, the early adoption of brewing in the Midwest moved the center of gravity of the industry towards the Midwest thanks to an increase in beer shipments within the Midwest –as opposed to an increase in trade between the Midwest and the East Coast. Future versions of this paper will examine whether the early adoption of bottling in the Midwest allowed for changes in leadership within regional markets in the Midwest that did not occur within regional markets in the Northeast.

Most of the change in leadership and the location of beer output occurred during the early adoption period, before 1880. I also examine whether a series of process improvements to brewing technology that occurred after 1880 perpetuated the new leadership through lower incremental costs of adoption. I find that, after controlling for firm size in 1880, early

adoption of bottling does not explain firm size in 1898. In other words, bottling did not perpetuate leadership after 1880 through first-mover advantages in the adoption of process improvements.

My paper contributes to multiple literatures. It contributes to the persistence of leadership debate (Chandler, 1990; Christensen, 1997; Sutton, 2007; Metcalf, 2011) by showing that new technologies can induce changes in leadership but not necessarily become a source of first mover advantages for the new leaders. My paper contributes to the literature on the role of technology adoption and sunk costs on market structure by showing that the empirical predictions of economic theory hold when an industry moves from an exogenous cost technology to an endogenous cost technology Sutton (1991, 1997); Ellickson (2007). My paper also contributes to the literature on the effect of trade on investment and innovation (Lileeva and Trefler, 2010; Bustos, 2011) by showing that firms can endogenously increase their own market access before making additional investments to take advantage of potential economies of scale.

The paper also contribures to the historical literatures on the location of economic activity during the late nineteenth century. 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 results are consistent with Kims. In particular, the brewing industry featured a decline in regional specialization between the East Coast and the Midwest, at the same time as an increase in intra-regional specialization within the Midwest. Only later, after 1890, the industry experienced an increase in regional specialization as interregional trade in the industry became more common.

Finally, my paper also contributes to the historical literature on the American brewing industry during the pre-prohibition era (Cochran, 1948; Baron, 1962; Plavchan, 1969; Kerr, 1998; Stack, 2000, 2010). 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 intraregional trade, rather than interregional trade. My historical work was made possible by a novel dataset that I collected, which allows me to follow breweries over time and observe output and bottling capabilities on a yearly basis.

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).

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).

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 2). The movement of the brewing industry was six times faster between 1874 and 1880 than during the remainder of the century.[3]

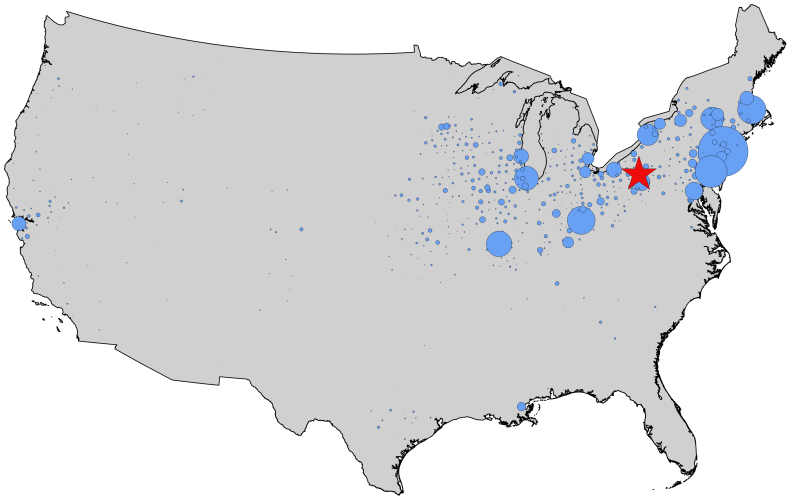
This substantial movement towards the Midwest occurred as a subset of breweries adopted two novel technologies that reduced transportation costs: refrigerator cars and pasteurization. Refrigerator cars prevented beer from going stale during transportation, allowing breweries to ship beer to distant markets. Despite the use of refrigerator cars, shipping beer in barrels

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

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

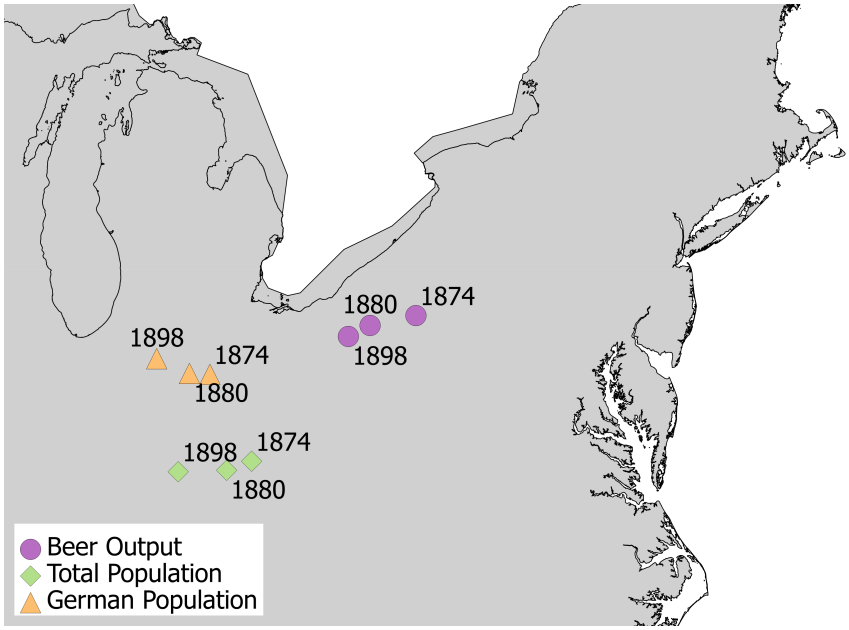
where y_i is the beer output of county i, ϕ_i is the latitude of county i, and λ_i is the longitude of county i. This definition of center of beer output parallels the definition of center of population in **?**.

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



Brewing moved to the West earlier than population

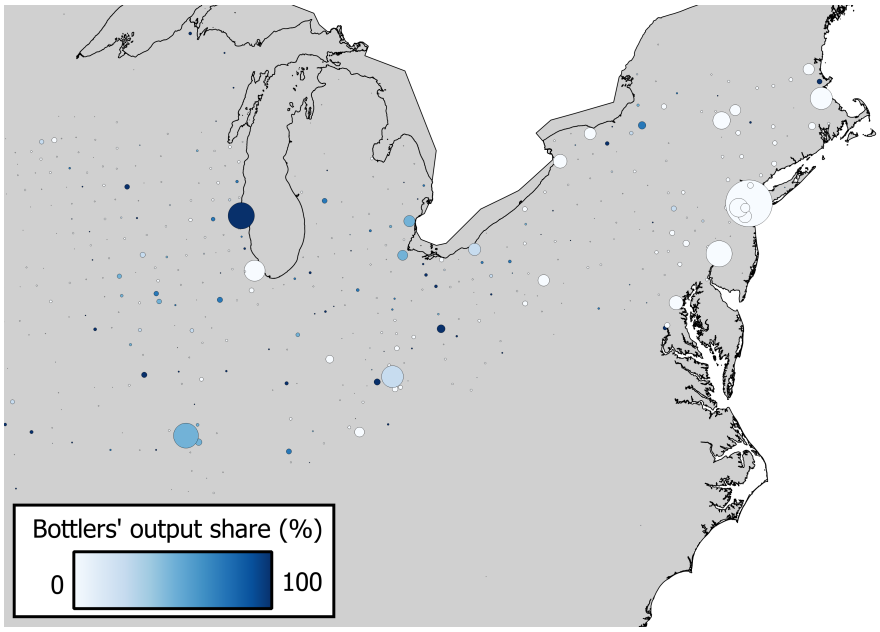
Figure 2: Centers of population and centers of output. 1874-1898

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.

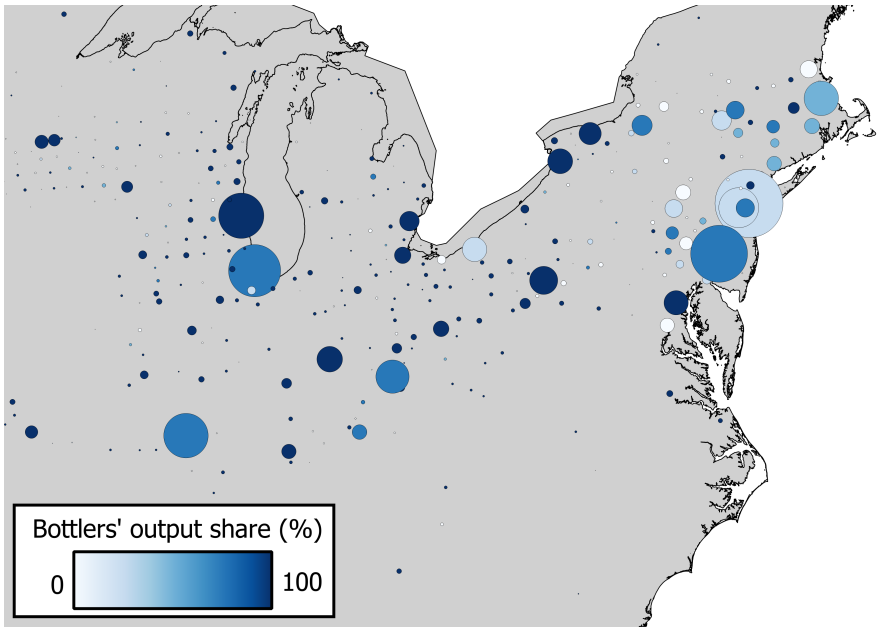
Pasteurization allowed brewers to reach smaller and isolated markets by eliminating the need for refrigeration. In 1865, Louis Pasteur patented a technique to prevent the spoilage of wine by increasing its temperature (Bowden et al., 2003, p. 6). In the following decade, Pasteur studied how fermentation 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. 123). By 1880, the participation of bottlers in national brewing output had reached 22%.

The early adopters of bottling –and hence the first regional shippers– were located in the Midwest. Figure 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, in 1898, 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 3b).

Breweries in the Midwest adopted bottling earlier than breweries in the Northeast because



(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 3: Total output and bottler's share of output. County level

breweries in the Midwest benefitted the most from shipping to nearby markets. In particular, breweries in the Midwest were close to (i) small and previously isolated towns where local brewers had not yet invested in quality and standardization, (ii) towns with large influence of temperance movements, were bottles allowed customers to drink beer while avoiding the stigma associated with saloons, and (iii) Chicago, where water quality was low and a fire had destroyed breweries in 1871 (Cochran, 1948, p. 55; Baldwin, 1966, p. 44; Ferrie and Troesken, 2008). In contrast, breweries in the Northeast benefited the most from selling beer in their large local markets.

As a result, the pattern of adoption of bottling also differs between regions. In the Midwest, bottling was adopted earlier by medium and large breweries that were followed by small breweries after 1880 (Figure 4a). In contrast, none of the 10 leading brewers in the Northeast in 1874 had adopted bottling before 1880 and only two had adopted bottling in 1898 (Figure 4a). In fact, larger output levels in 1874 are associated with larger rates of adoption by 1880 in the Midwest, but lower rates of adoption in the Northeast (Table 1).

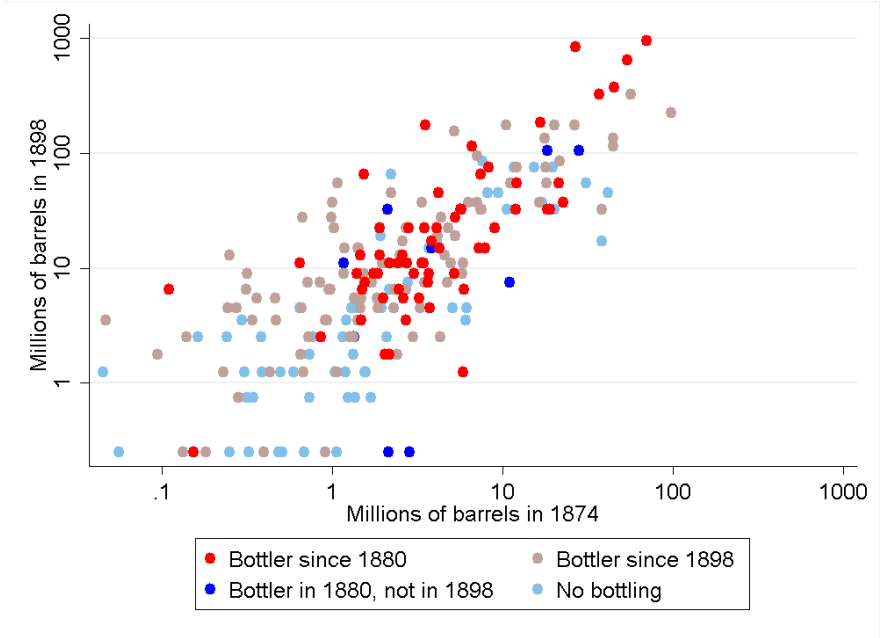
Table 1: Firm size in 1874 vs. Bottling adoption by 1880

	Midwest		Northeast		Full sample	
	(1)	(2)	(3)	(4)	(5)	(6)
ln(q_1874)	0.07***	0.05**	-0.04***	-0.09***	-0.00	-0.03***
	(0.01)	(0.03)	(0.01)	(0.01)	(0.01)	(0.01)
Constant	0.24***	0.25***	0.20***	0.25***	0.21***	0.22***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)
Town fixed effects	no	yes	no	yes	no	yes
N	471.00	471.00	422.00	422.00	1094.00	1094.00

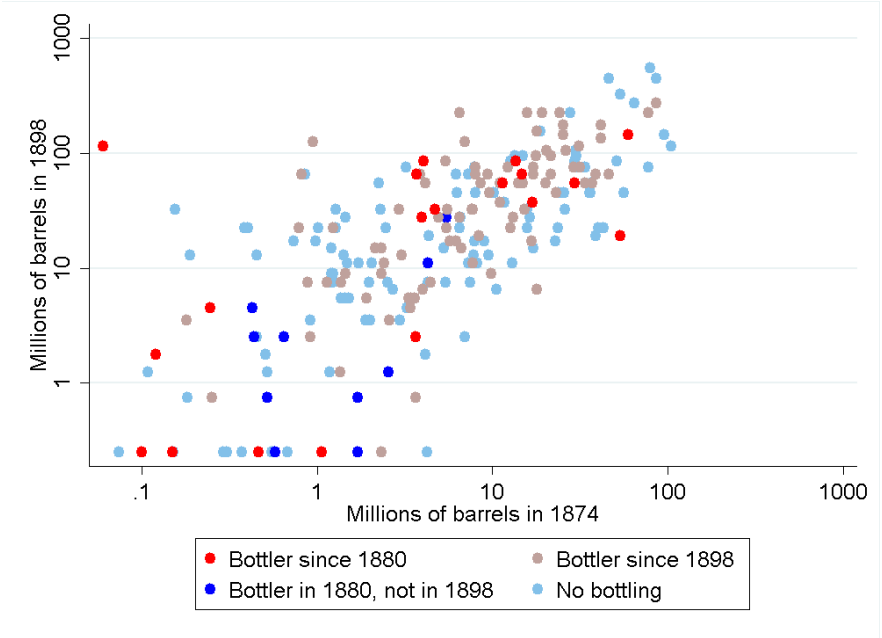
Standard errors in parentheses

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

Two exceptions to the pattern of adoption in the Midwest corroborate the importance of nearby markets as an incentive for bottling adoption. Although most large brewers in the Midwest in 1874 became early adopters, the largest brewer in the Midwest was a late adopter: The Conrad Seipp Brewing Company. Furthermore, the second largest brewery from Chicago



(a) Midwest



(b) Northeast

"Studies on beer", by Pasteur, was published in 1876.

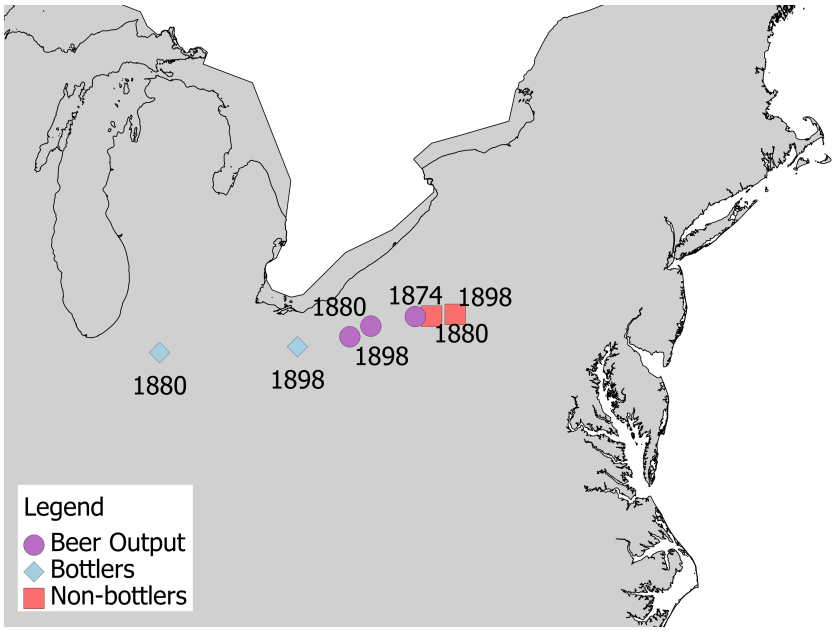
Figure 4: Bottling adoption and changes in leadership in the US. 1974 - 1898

never adopted bottling: The Downer and Bemis Brewery. Breweries in Chicago had access to large local markets and hence did not need to adopt bottling at an early stage. Furthermore, presumably both breweries were not competitive in other markets because of their inability to produce beer of consistent taste due to the low quality of water in Chicago.

The early adoption of bottling by Midwestern breweries allowed for two large changes in the industry. First, brewing moved West through the adoption of bottling by breweries in the Midwest. Figure 5 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 for bottlers had moved towards the East by 1898 (Figure 5). 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].

Second, firm mobility within the industry increased in the Midwest, but not in the Northeast. In the Midwest, breweries that adopted bottling before 1880 were larger in that year than breweries that had not adopted bottling yet, both between and within towns, even after controlling for brewery size in 1874 (Table 2). Furthermore, the largest brewery in the industry in 1874 –a non-bottler– was replaced as the largest brewer in 1880 by a bottler (Figure 6a, future versions of this paper will check whether this transition also occurred within regional markets in the Midwest). In the Northeast, in contrast, bottlers shrinked

[4]See footnote 3



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)

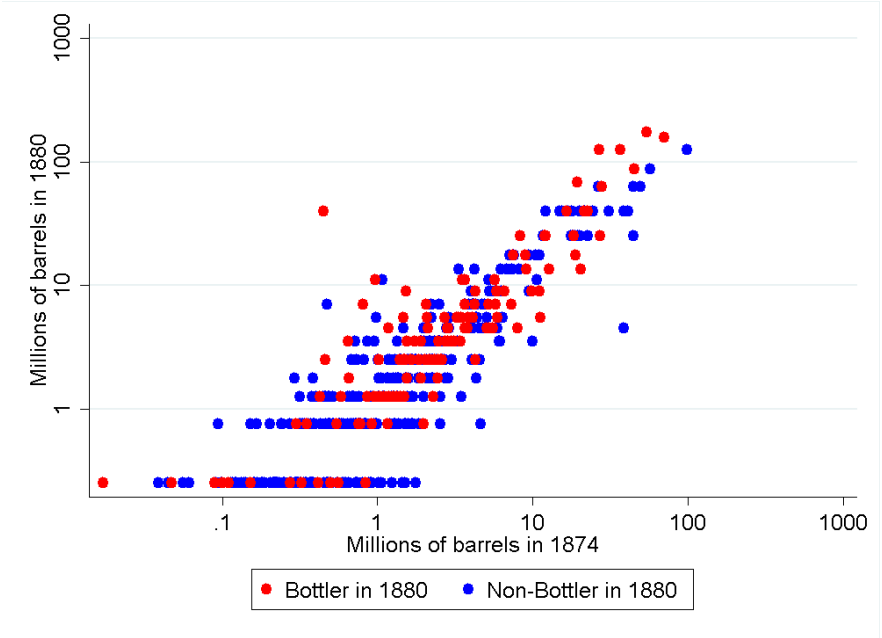
Figure 5: Center of output: bottlers vs. non-bottlers. 1874-1898

and non-bottlers continued to be the largest brewers (Table 2, Figure 6b, future versions of this paper will use an instrument for bottling adoption as described in the introduction).

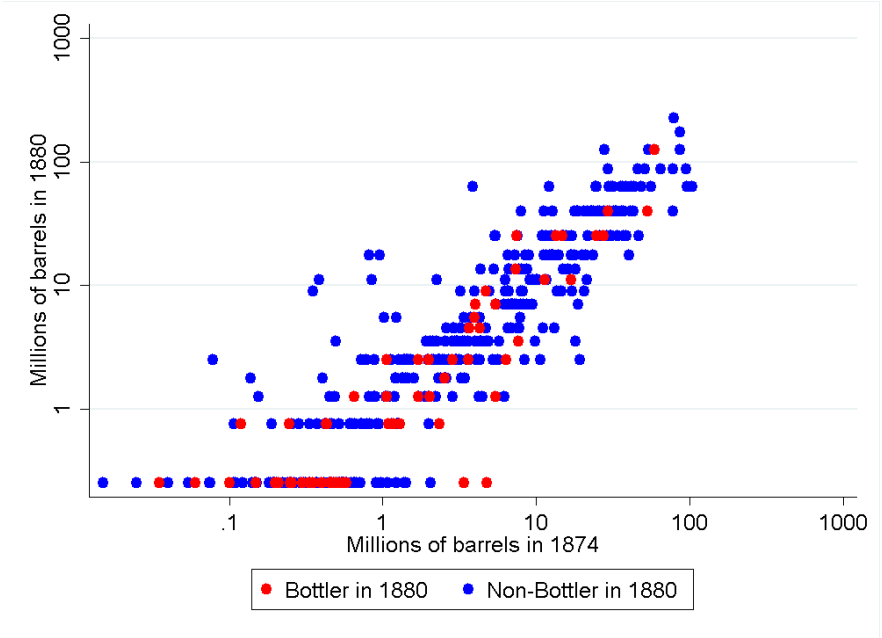
4 Early bottling as a source of first-mover advantages

After 1880, the industry experienced a series of process improvements that built upon the earlier investments made by bottlers. These improvements allowed for even lower transportation costs and even higher standardization. Did early bottling become a source of first-mover advantages through lower incremental costs of adopting the new technologies?

After 1880 bottlers in the Midwest continued to growth at a faster pace than non-bottlers. Nevertheless, the higher growth rate is explained by an increase in the value of being larger compounded by the higher size that bottlers already had in 1880. Once brewery size in 1880 is taken into account, the early adoption of bottling does not influence growth after that year



(a) Midwest



(b) Northeast

"Studies on beer", by Pasteur, was published in 1876.

Figure 6: Bottling adoption and changes in leadership in the US. 1974 - 1880

Table 2: Firm size in 1880 vs. Bottling adoption before 1880

	Midwest		Northeast		Full sample	
	(1)	(2)	(3)	(4)	(5)	(6)
Bottler in 1880	0.30***	0.26**	-0.31***	-0.43***	0.11*	-0.10
	(0.08)	(0.12)	(0.11)	(0.14)	(0.06)	(0.09)
ln(q_1874)	0.93***	0.89***	0.92***	0.82***	0.85***	0.83***
	(0.02)	(0.04)	(0.02)	(0.03)	(0.01)	(0.02)
Constant	0.21***	0.23***	0.28***	0.40***	0.32***	0.37***
	(0.04)	(0.05)	(0.05)	(0.06)	(0.03)	(0.03)
Town fixed effects	no	yes	no	yes	no	yes
N	471.00	471.00	422.00	422.00	1094.00	1094.00

Standard errors in parentheses

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

(Table 3). I interpret this result as absence of evidence of first-mover advantages from the early adoption of bottling on the adoption of process improvements that occurred later.

Table 3: Firm size in 1898 vs. Bottling adoption before 1880

	Midwest			Northeast			Full sample		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Bottler in 1880	0.77***	0.01	0.04	-1.40***	-0.37**	-0.29	-0.16	-0.10	-0.15
	(0.19)	(0.12)	(0.18)	(0.28)	(0.18)	(0.23)	(0.16)	(0.09)	(0.13)
ln(q_1880)		0.92***	0.84***		0.82***	0.77***		0.93***	0.83***
		(0.04)	(0.06)		(0.04)	(0.06)		(0.02)	(0.04)
Constant	1.59***	1.02***	1.08***	2.81***	1.40***	1.46***	2.03***	1.07***	1.18***
	(0.10)	(0.07)	(0.08)	(0.11)	(0.10)	(0.12)	(0.08)	(0.05)	(0.06)
Town FE	no	no	yes	no	no	yes	no	no	yes
N	377.00	377.00	377.00	318.00	318.00	318.00	829.00	829.00	829.00

Standard errors in parentheses

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

5 Alternative explanations: Interregional trade

Breweries bottled beer in order to ship it to nearby locations. This paper argues that bottling allowed for an increase in beer trade within the Midwest that in turn explains the rise of the Midwest as a brewing powerhouse instead of the Northeast. An alternative explanation 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 comparative advantage would have induced breweries to ship beer to the East Coast.

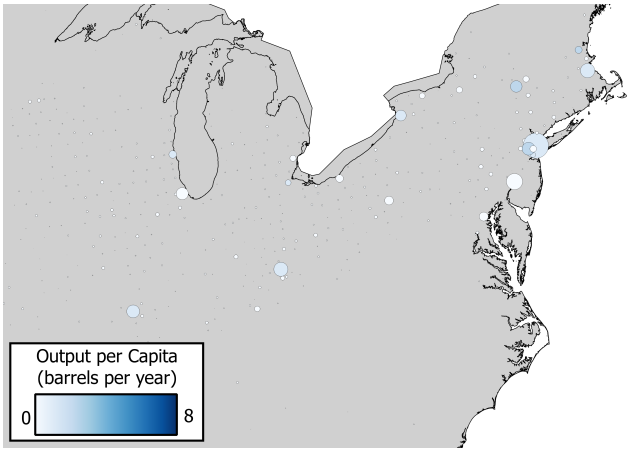
Indeed, a subset of breweries started to ship beer at the national level, including the East Coast (Stack, 2000, 2010). The National Shippers –as those breweries are known in the literature– were all located in the Midwest.[5] However, the size of these breweries was not large enough to explain the overall 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 7).

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

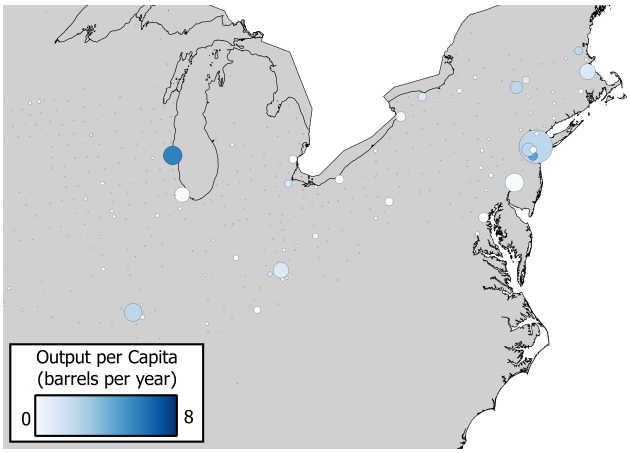
[5]Pabst, Schlitz, and Blatz were located in Milwaukee; Anheuser-Busch and Lemp were located in St. Louis; and Christian Moerlein was located in Cincinnati (Stack, 2000, p. 439)

[6]In 1906, exports were only 0.07% of beer output, whereas imports were only 0.34% of beer consumption. Own calculations from **?**

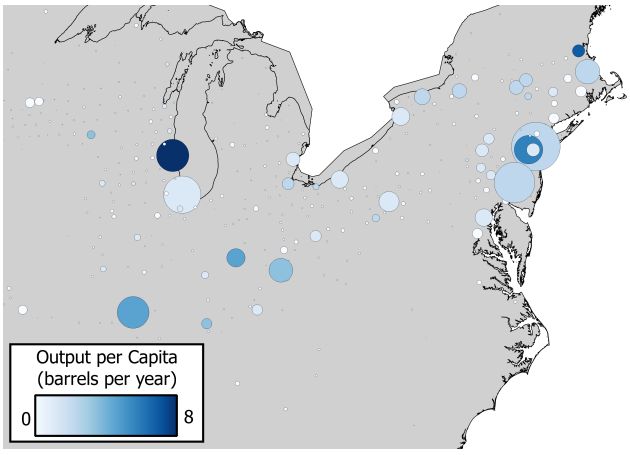
[7]The data for this calculation was kindly shared by Paul Rhode. By the start of the twentieth century, localized wheather shocks had limited effects on state-level prices in the price of wheat Fox et al. (2011).



(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 7: Output and Output per Capita. County Level. 1874 - 1898

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. This mechanism is consistent with the early adoption of bottling in the Midwest (Figure 3, above) and the large increase in output per capita in the same region (Figure 7, 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?

6 Conclusion

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

[8] $0.24/1.5 = 0.16$

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.

In this paper, I show that the large increase in output in midsized cities in the Midwest is explained by their early adoption of bottling. In turn, their early adoption of bottling is explained by their lower transportation costs to large and multiple markets with weak competitors.

Furthermore, the adoption of bottling induced changes in leadership in the locations were it was adopted. In particular, bottlers replaced non-bottlers as the leaders of the industry in the Midwest, but non-bottlers remained the leaders in the Northeast. This change in leadership occurred during the early period of adoption of bottling -before 1880- and expanded afterwards. Nevertheless, bottling itself did not play an additional role in the later expansion, once brewery size in 1880 is taken into account. I interpret this result as absence of evidence of first-mover advantages from the early adoption of bottling on the adoption of process improvements that occurred later.

References

Baldwin, W. O. (1966). *Historical Geography of the Brewing Industry: Focus on Wisconsin*. PhD thesis. Copyright - Copyright UMI - Dissertations Publishing 1966; Last updated - 2014-01-14; First page - n/a; M3: Ph.D.

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.

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

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.

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

Christensen, C. M. (1997). *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*. Harvard Business Review Press.

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

Ellickson, P. B. (2007). Does sutton apply to supermarkets? *RAND Journal of Economics*, 38(1):43 – 59.

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

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.

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.

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.

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.

Metcalf, C. (2011). Persitence of technological leadership: Emerging technologies and incremental innovation. *The Journal of Industrial Economics*.

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

Pasteur, L. (1876). *Studies on Fermentation: The Diseases of Beer, Their Causes, and the Means of Preventing Them. A Translation, Made with the Author's Sanction, of Études Sur la Bière; with Notes, Index, and Original Illustrations*. Macmillan.

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

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.

Sutton, J. (1991). *Sunk Costs and Market Structure: price competition, advertising and the evolution of concentration*. MIT press.

Sutton, J. (1997). Gibrat's legacy. *Journal of Economic Literature*, 35(1):pp. 40–59.

Sutton, J. (2007). Market share dynamics and the "persistence of leadership" debate. *American Economic Review*, 97(1):222–241.