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IMPACTS ON U.S. BEER PRODUCTION: EVIDENCE FROM STATE PANEL DATA 2008-2019

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Abstract

Few studies have empirically examined the responsiveness of beer production to changes in factor inputs. This paper exploits a unique and expansive balanced panel of time-series, cross-section data from 2008-2019 to explore factor impacts on state level beer production. The examination relies heavily on the rich production function literature and uses the "first order condition" approach with respect to inputs. Two-way fixed-effects estimates suggest that, after controlling for latent state and year factors, rising labor costs, water supply costs, wastewater charges, and electricity rates negatively impact changes in state level brewery production year to year. Brewing history, brewery firm growth and recent brewery closures are also examined.

Keywords: *Beer production, Production function, Input costs*

JEL Classifications: *D22, D24, E23*

INTRODUCTION

A vast literature exists regarding the evolution of beer production and the industrial organization of breweries throughout history. Some of the earliest evidence that beer was produced for consumption stems from Sumeria (southern Mesopotamia) more than 8000 years ago. A clay tablet dated 6000 BC etched with one of the oldest known beer recipes was unearthed in the Mesopotamia region (Patroons, 1979). During the rein of King Narmer, around 3,100 BC, beer production spread to Egypt. In the city of Abydos, the oldest and largest beer production facility was unearthed by an archaeological team lead by Matt Adams (2021) from New York University. The team estimates that the ancient brewery could produce roughly 5,800 gallons (187 U.S. barrels) per batch. Figure 1 depicts three of the ceramic vats used to mash grains and water.

FIG. 1. THREE OF THE CERAMIC VATS USED TO MASH GRAINS AND WATER
Source: Provided by and reproduced with permission from Greg Maka of the North Abydos Project.

The earliest indications of beer production in Europe date from 3000 BC. According to the historian Pliny, the Romans learned brewing techniques from the Egyptians (Patroons, 1979). European monasteries served as large scale producers until roughly the end of the 14th century (Poelmans & Swinnen, 2011). A summary of ancient factor impacts to beer production are illustrated in the Table 1 timeline.

TABLE 1. IMPACT TIMELINE

6000 BC	Sumerian recipe formation and documentation
3500 BC	Sumerians improving grain farming methods
3100 BC	Egyptians scaling up beer production for the masses Egyptian women employed in the production process
3000 BC	Beer production technology spreads to Europe Intense competition evolving with wine Production is localized
500 BC	Beer becoming a substitute for water due to purity
AD 800	Monasteries emerging as scale beer producers Use of hops in the process Taxation of beer emerging
AD 1450	Beginning the golden age of brewing Role of monasteries declining Quality of beer improves Regulations like Reinheitsgebot appear; "Purity Law"

Fast forward to AD 1933, Prohibition is over and in the U.S. beer production makes a rapid comeback. By 1980, beer production increased to 190 million barrels per year and has hovered around that level annually for the last four decades. Figure 2 depicts U.S. beer production from 1980 to 2019. Note that the production peak was in 1990 (203 million barrels).

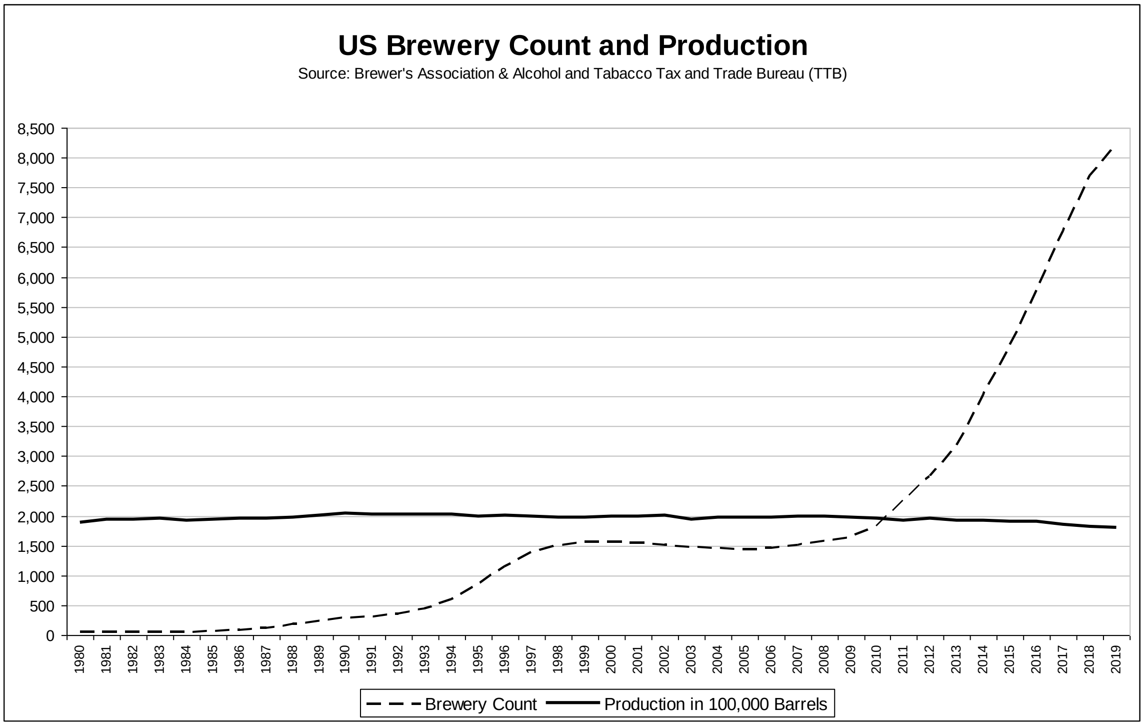

FIG. 2. U.S. BREWERY COUNT AND PRODUCTION 1980-2019

U.S. brewery growth, on the other hand, dawns from a far more interesting back story. In 1980, 48 breweries produced roughly 190 million barrels. In 2019, over 8,000 breweries produced around 180 million barrels, yet 80 breweries produced 93% of the 2019 total. A natural follow up question in response is, "why so many breweries then?" Three significant forces changed the competitive landscape allowing new, smaller scale, firms to enter the industry and become profitable; the popularity of home brewing, federal and local law changes, and reduced scale equipment availability.

Inspired by the likes of authors Fred Eckhart and Charlie Papazian, home brewing exploded through the late 1970s and forward (Tremblay & Tremblay, 2005). In 1978, the U.S. Congress decriminalized home brewing making the already immensely popular hobby legitimate. Self-proclaimed Brewmeisters around the country honed their craft and impressed their friends with differentiated, kitchen-made ales and lagers. Home brewing acquainted many with the quest for authenticity, shifting preferences away from the modern mass-produced fizzy corn and rice water they were used to.

Changes in state laws and regulations were also crucial for brewery growth. In 1982, the state of Washington changed their on-premises consumption law. At the time, all states generally followed three-tiered beer distribution statues that banned the retail sale and consumption of product on brewery premises. With Washington state allowing on premise retail sales and self distribution, small brewing enterprises could now capture all tiers of potential revenue thus increasing the likelihood of profitability. Through the 1980s, twenty-nine states followed suit and by 1999 all states allowed on premise consumption (Elzinga et al., 2015).

Third, early on (1970s) one key impediment to new entrants was a market for scaled-down capital equipment. New entrants often used modified equipment from other industries (e.g., dairy) or fabricated vats and fermenters on their own. In 1976, Jack McAuliffe started New Albion Brewing Company in Sonoma, California. Jack was an avid home brewer, skilled stainless-steel welder and trade electrician who used these skills to build his brewery from scratch. Sadly, New Albion shuttered in 1982 due to scale deficiencies (Tremblay & Tremblay 2005). Ironically, the first company to manufacture brewing equipment for smaller brewers was Oregon based JV Northwest in 1981. Others followed soon after, allowing entrants the ability purchase turnkey brewing equipment capable of brewing generally one to twenty barrels per batch.

With major barriers to entry dismantled, more breweries entered the industry. As depicted in Figure 2, brewery growth began in the mid 1980s, leveled off from the late 1990s to the late 2000s then increased 4.5 fold into 2019. A breakdown of the 2019 brewery count offers interesting insights. First, 75% of the breweries in 2019 produced 1,000 barrels or less for the year (TTB 2019). As a comparison, the Molson Coors flagship brewery in Golden, Colorado has the capacity to brew 54,000 barrels per day (Elzinga et al., 2015). Second, 37% of the breweries had accompanying restaurants (known as brewpubs), 36% offer bar like "taprooms" usually with a non-associated food truck parked outside, leaving 27% of the breweries in 2019 categorized as standard production breweries - packaging and distributing to end users with little to no on premise sales, akin to all breweries before 1982.

The salient increase in the brewery count from 2010 has had little impact on overall industry output growth. Conversely, industry output from 2010 to 2019 has declined by 8%. Generally, incumbent breweries lose output when new firms enter as overall industry output is in decline. The outside observer sees all the new breweries popping up across the country and declares "that industry is really producing" but in fact overall output is sliding. What is not transparent to this observer is the market constraints, technological constraints, and the input (economic) constraints facing the industry. The focus of this analysis is on the latter two constraints which impact the supply side. Specifically, a unique and expansive balanced panel of time-series, cross-section data from 2008-2019 over all 50 states plus the District of Columbia is used to explore factor impacts on state level beer production. Few studies have empirically examined the responsiveness of beer production to changes in right-hand-side determinants. Two are noteworthy, Elzinga et al., (2015) examined mostly demand side impacts to a small segment of the beer industry at the state level. Pokrivcak et al., (2019) used Slovakian brewery owner/operator survey data to explore determinants impacting firm expansions.

Herein, the examination relies heavily on the rich production function literature and uses the "first order condition" approach with respect to inputs (Ackerberg et al., 2015). The remainder of this paper is divided into four sections. Section 2 provides the theoretical framework for the empirics, which is an adaptation of the widely applied first order condition construct. Section 3 describes the data, presents the empirical model and discusses econometric issues. Section 4 interprets the empirical results with conclusions and implications drawn in Section 5.

THEORETICAL UNDERPINNINGS

A production function is a description of a production technology that links the physical output of a process to the inputs or factors of production. Consider the following general representation,

$$q = f(L, K, \theta, P, A) \tag{1}$$

where q is a measure of output, L and K are the standard neo-classical labor and capital inputs, θ denotes material and energy inputs, P is a vector of output prices, while A represents technological efficiencies, agglomeration impacts, quality, and any pecuniary externalities. The brewing industry is generally characterized, as coined by Joan Robinson (1933), imperfectly competitive. Firms choose inputs to maximize profits where marginal revenue equals marginal cost. This first order condition for profit maximization yields a system of equations that define the optimal choices of production inputs. Substituting the optimal input choice rules back into equation (1) yields an expression for the optimal output for the firm q^*. Industry production geometrically is the sum of each firm's q^* yielding Q^*. The principal interest of this paper is to estimate the marginal impacts to production, Q^*, when inputs or their costs change. Irrefutable implications of the primal comparative statics of interest are not necessarily settled by the profit maximization hypothesis alone. Therefore, empirical methods can shed much needed light on the signs and magnitude of key comparisons.

DATA DESCRIPTION AND EMPIRICAL MODEL

Data on production, inputs and costs at the individual firm level are indeed very rare. Longitudinal collection that follows the same individual firms over time rivals the quest for the unicorn. Consequently, the use of averaged or aggregated data is commonplace in the literature (Felipe & Fisher, 2003). Many studies have focused specifically on the aggregation issues at all levels (Stroker, 1993; Chung & Kaiser, 2002). This paper, however, does not directly address the implications of using aggregated data on production estimation. Accordingly, the goal of this analysis is to examine key primal comparative statics of Q^* by using state level production data for the brewing industry. The U.S. Department of the Treasury, Alcohol and Tobacco Tax and Trade Bureau (TTB) provides aggregated production, for all states and the District of Columbia, by way of the Brewer's Report of Operations completed by every brewery in the U.S. each month or quarter. The Brewer's Report of Operations is each brewery's production excise tax return and provides perhaps the most accurate collection of industry output data available.

Selected research in the industrial organization literature fails to recognize that firm outputs and inputs may be determined simultaneously. To control for this potential endogeneity, factor variables faced by firms in time t are presumed to impact output changes from t to $t + 1$ (e.g., 2008 to 2009). A Durbin-Wu-Hausman test (Davidson & MacKinnon, 1993) will be used to test for exogeneity of right-hand-side variables and output changes.

The model estimated becomes:

$$Y_{it} = \alpha + \beta' X_{it} + \mu_i + \lambda_t + \nu_{it} \tag{2}$$

where Y_{it}, is measured as the percentage change in state level beer production from year t to $t + 1$, α is a scalar intercept term, β is a vector of coefficients, X_{it} are observable explanatory variables that vary across states i and over years t, μ_i and λ_t are latent state and year specific effects, respectively, and ν_{it} is the remainder error term. The latent state specific effects, μ_i, will capture any unobserved, time-invariant factors between states. The latent year specific effects, λ_t, will capture any unobserved, time-varying factors common to all states (e.g, effects of business cycles and technological advancement). The properties of estimators for equation (2) depend significantly on whether the latent state and time effects are specified as randomly distributed components of the error term (random-effects) or parametric shifts in the constant term (fixed-effects). The generalized least squares (GLS) estimator (random-effects) is efficient and consistent when the latent state and time effects are uncorrelated with the explanatory variables, X_{it}. The least squares dummy variable (LSDV) estimator (fixed-effects) is consistent regardless of any potential correlation with regressors but is not fully efficient since it ignores variation across states and/or time periods. The choice of estimator specification rests on statistical considerations and hypothesis testing. To test for the orthogonality of the random effects and the regressors, a chi-squared test based on the Wald criterion (Hausman, 1978) is used.

TABLE 2. DESCRIPTION OF VARIABLES AND DESCRIPTIVE STATISTICS

Variable	**Definition and Source**
%CHANGE IN PRODUCTION Mean 15.53 Standard Deviation 64.67	Percentage change in State beer production year *t* to *t* + 1. Source, U.S. Department of the Treasury, Alcohol and Tobacco Tax and Trade Bureau, 2008-2019.
Mean State Production 3,461,311 barrels annually. U.S. barrel is 31 gallons.	
WAGES Mean 47.657 Standard Deviation 7.713	Mean annual wage in a State in 1000s of 2018 dollars. Source, U.S. Bureau of Labor Statistics, 2008-2018 Wage Estimates.
WATER AND SEWER RATES Mean 6.717 Standard Deviation 2.802	Marginal water and wastewater rates for each state presented in 2018 dollars per 1,000 gallons. Surveys of commercial/industrial customers, 2008-2018. Source, Pacific Northwest National Laboratory conducts this study for the U.S. Department of Energy's Federal Energy Management Program to identify trends in annual water and wastewater price escalation rates across the United States.
ELECTRIC RATES Mean 10.58 Standard Deviation 3.681	Average commercial electric rates by state in 2018 cents per kilowatt hour, 2008-2018. Source, U.S. Energy Information Administration, State Electricity Profiles.
AGGLOMERATION Mean 18.1 Standard Deviation 17.3	Breweries per million in population by state and year. Source, Brewer's Association and U.S. Department of the Treasury, Alcohol and Tobacco Tax and Trade Bureau. Population by state and year sourced from the U.S. Census Bureau.
QUALITY/PRICE PROXY Mean 84.6 Standard Deviation 144.6	Cumulative Great American Brew Fest Medal count by a brewery's location state from 1983 to each successive year 2008-2018. Source, Brewer's Association.

Correlation Matrix				
	WAGES	WATER/SEWER	ELECTRIC	AGGLOM.
WAGES	1.00			
WATER/SEWER	0.54	1.00		
ELECTRIC	0.39	0.36	1.00	
AGGLOM.	0.16	0.19	0.11	1.00
QUALITY	0.25	0.24	0.04	0.23

Table 2 describes, provides data sources and depicts descriptive statistics for all variables in Equation (2). Mindful of the multicollinearity issues inherent in factor input data, attention is paid to the orthogonality of covariates entered in X_{it}. A correlation matrix for the right-hand-side is provided at the bottom of Table 2. Moreover, variance inflation factors (VIF) are estimated for each regressor and shown in the far-right column of Table 3. Equation (2) is estimated using balanced panel data spanning the 2008-2019 time-period over all 50 states and the District of Columbia yielding a sample size of 561.

The use of panel data estimation techniques can provide accurate measures of factor impacts on output changes without requiring the collection of vast data sets on right-hand-side inputs (Baltagi, 1995 - Chapter 1). The choice of the right-hand-side covariates was based on three aspects:

i) The rich production function literature (Akerberg et al., 2015),
ii) Within state variation, and
iii) Data availability.

Observable regressors included represent controls for, or proxies of, labor costs, utility and energy costs, major material costs, agglomeration impacts and output quality and price.

Quality and price proxy

Unobservable product quality and output prices in relation to production function estimation is receiving growing attention in the literature (Mairesse & Jaumandreu 2005; Yang, 2021). Product quality is explicitly linked to firms’ pricing strategies, further complicating its right-hand-side omission. For output, information on quality and price is clearly essential, but the data are rarely available. Interestingly, the brewing industry, through its major trade organization, offers a unique proxy. Each year since 1982, the Brewers Association (BA) puts on the Great American Beer Festival (GABF) and competition. The BA touts this week-long event as the "premier U.S. beer competition" and describes the awarded medals as "the most coveted in the industry and heralded by the winning brewers in their national advertising" (GABF, 2021). Several judging panels award gold, silver and bronze medals that are "recognized around the world as symbols of brewing excellence."

In 2018, roughly 2,400 breweries from all over the U.S. entered 8,496 beers (83 beers per judged category) where 306 medals were awarded. From 1983-2018, breweries in California have won the most medals, 1,095, while one brewery in West Virginia won a single award. These awards are not costless to the breweries, participants must be dues paying members of the BA and each entry requires a specific fee along with the cost of transporting the beer to the competition's location, Denver, CO. This event is a large revenue source for the BA contributing handsomely to the over $30 million reported in 2018 (IRS, 2018 - Form 990 Part 1 Line 12). Accordingly, the organization provides award winners with guidance on how to promote their awards to yield the utmost impact.

ESTIMATION RESULTS

Results from two-way fixed-effects estimates (using the White robust heteroskedasticity covariance structure) of equation (2) are presented in Table 3. Both LSDV and GLS estimates statistically confirm state and year heterogeneity and verify the importance of controlling for latent state and year effects. First, the test statistic, $F(50,505)=1.83$ (and the dual log-likelihood result), is sufficient to reject the null hypothesis of state homogeneity at the <1% level. Second, the $F(61,495)=1.88$ statistic rejects the null hypothesis of state and year homogeneity, again at the <1% level. Likewise, the Lagrange multiplier test statistic (GLS construct) of 6.62, distributed as χ^2 with 2 degrees of freedom, rejects the null hypothesis that the variances of μ and λ are equal to zero at the < 5% level.

Faced with the statistical knowledge that μ_i and λ_t dominate the error structure, potential correlation between μ_i, λ_t and the observable input variables is important to consider. The Hausman (1978) orthogonality test statistic of 28.55, distributed as χ^2 with 5 degrees of freedom, soundly rejects the null hypothesis that the GLS estimator is consistent and efficient. Consequently, treating the state and year effects as fixed, in the fashion of a covariance model, appears to be the proper specification. Tests for simultaneity between production changes and each right-hand-side input are constructed. The augmented regression test (Durbin-Wu-Hausman) suggested by Davidson and MacKinnon (1993: 389-393) fails to reject the null hypothesis of exogeneity at the < 5% level for all specifications. Explaining annual production changes on the left-hand-side seems an appropriate correction.

TABLE 3. TWO-WAY FIXED EFFECTS ESTIMATES OF THE IMPACTS ON STATE BEER PRODUCTION

Variable	Coefficient	t-Stat	P-Value	VIF
Scalar Constant	82.837	3.19	0.0014	-
Wages	-0.432	-2.21	0.0274	1.54
Water/Sewer Rates	-1.388	-2.99	0.0027	1.49
Electric Rates	-0.600	-1.97	0.0483	1.23
Agglomeration	0.213	0.44	0.6564	1.09
Quality/Price Proxy	0.082	0.94	0.3482	1.14

Likelihood Ratio, State Effects (Chi-Sq)	93.38 (50 df)	P-Value 0.0002
F-test, State Effects vs. Pooled OLS	1.83 (50, 505)	P-Value 0.0007
Likelihood Ratio, State & Year Effects (Chi-Sq)	23.28 (10 df)	P-Value 0.0097
F-test, State & Year Effects vs. State Effects	2.10 (10, 495)	P-Value 0.0232
Likelihood Ratio, State & Year Effects (Chi-Sq)	116.66 (61 df)	P-Value 0.0000
F-test, State & Year Effects vs. Pooled OLS	1.88 (61, 495)	P-Value 0.0002
Lagrange Multiplier Test (Chi-Sq)	6.62 (2 df)	P-Value 0.0365
Hausman (Chi-Sq)	28.55 (5 df)	P-Value 0.00003
Variance Inflation Factor Threshold	1.25	
Durbin-Watson	1.82	
R^2	0.201	
N	561	

» Dependent variable is the percentage change in beer production in state *i* from year *t* to year *t* + 1.
» Estimates of state and year effects are numerous and suppressed from the table. Effects estimates reflect increments from the scalar constant.
» Estimated using the White robust heteroskedasticity covariance structure.

The two-way fixed-effects estimates suggest that, after controlling for latent state and year factors, rising labor costs, water/wastewater charges, and electricity rates negatively impact changes in state level brewery production. All three key inputs test significant at < 5% level. Breweries per capita (agglomeration) and the quality/price proxy (cumulative GABF medals) are insignificant at any conventional P-value. Results herein are intuitive and consistent with extant findings. The coefficient estimate for wages implies that for a $1,000 annual increase in a state's mean individual wage, breweries in the average state will reduce output (*t* to *t* + 1) by 0.432%. Evaluated at mean annual production for the average state, this is roughly a 15,000 barrel decrease in output. Likewise, for a one cent per kilowatt hour increase in commercial electricity rates, annual beer production in the average state will decrease 0.6%.

As one might expect, commercial/industrial water and wastewater utility charges impact beer production profoundly. Water use and discharge is critical in all stages of the brewing process. In the U.S., it is estimated that, on average, it takes roughly seven gallons of water to produce one gallon of finished beer (Brewer's Association, 2013).

Moreover, U.S. breweries discharge around 70% of the incoming water as effluent. In most states, wastewater marginal costs are much higher than water supply costs. Accordingly, the coefficient estimate for water/wastewater rates implies that a one dollar increase per 1,000 gallons, decreases annual beer production in the average state by 1.388%. This equates to roughly 48,000 barrels for the average state. The insignificance of the per capita brewery agglomeration variable is not surprising given the aggregate implications depicted in Figure 2. Overall production of beer has declined 8% in the last ten years when the number of breweries has increased 4.5 fold. Lastly, lack of statistical significance for the quality/price proxy is likely the result of data aggregation. Perhaps a more appropriate test of this effect would be best at the firm specific setting, an idea for future research.

CONCLUSION AND FUTURE IMPLICATIONS

Preliminary data from the TTB regarding production in 2020 indicates continued decline, by under 1%, from 2019. It is estimated that most of this loss is coming from the smallest brewers who were gravely impacted by the COVID-19 restrictions regarding on-premise and keg sales. Many of these small-scale operations, already faced with increasing input costs such as wages, energy, water, and wastewater, were likely to shutter before the pandemic fallout. For instance, in 2019, more than 300 small breweries closed - the largest total in a single year (Brewers Association, 2020). It is anticipated that several hundred more have closed in 2020, final numbers were not available at the time of publication. In late spring 2020, the Brewers Association surveyed over 500 small scale breweries regarding COVID-19 impacts. In response to the question, "Given current costs, revenues, and the current level of state and federal aid, how long do you project you can sustain your current business if social distance measures stay where they are now?", 60% responded 3 months or less (Watson, 2020). On-premises sales, the genesis of U.S. brewery expansion, appears central to the current and anticipated brewery closures.

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