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A Bayesian analysis of hop price fluctuations

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Abstract: This paper quantifies the correlation between U.S. season average prices for hops with U.S. hop stocks and U.S. hop hectarage. The Hop Equilibrium Ratio, a measure of the supply/demand relationship for U.S. hops, was introduced. Through the Bayesian inference method, the authors used these data to calculate the effect an incremental change to one metric had on the probability of directional changes of future U.S. season average prices (SAP). Between 2010 and 2020, the dominance of proprietary varieties created unprecedented cartel-like powers offering opportunities for supply- and price-management. Research results will enable more accurate forecasting and greater price stability in the hop industry.

Keywords: alpha-acids; Bayesian theorem; brewing industry; economies of scale; equilibrium; hop market

Breweries consume 98% of global hop production (Cooberg and Hintermeier 2012). Without hops, beer cannot be made, causing inelastic demand. Small volumes of hops can bitter, preserve and flavour large volumes of beer meaning the market can quickly fall into disequilibrium. Substitutability between competing hop varieties produced solely for their high alpha-acid contents creates cross elasticity between producer groups, the largest of which were the U.S. and Germany in 2019 (George 2019). In 2018, the U.S. hop industry represented 48.3% of the global alpha acid supply (BarthHaas 1948–2019).

Large buyers use their bargaining power to lower input prices (OECD 2012). The world's largest brewing conglomerates (big brewers) consolidated during the 20th century. The ten largest controlled 72.5% of beer production by 1981 (BarthHaas 1948–2019). This created an oligopsonistic dynamic between brewers and hop merchants. Big brewers used their influence to get favourable pricing. Pricing under an oligopsony, however, does not behave the same way as under free market competition. Prices can increase as supply increases (Chen and Lent 1992). Hop merchants often match a competitor's price via tacit collusion to retain or capture market share in a zero-sum game. A Nash equilibrium of the Bertrand model often prevailed as competition was primarily price based (Hermalin 2003).

Brewers signed future contracts during shortages at premium prices. Contract levels often exceeded demand. Future contracts, perceived as financially beneficial for growers and merchants, were priced well above the cost of production, creating false demand signals and triggering unnecessary production. Subsequent renegotiations following market corrections resulted in a near constant state of disequilibrium as may be inferred from fluctuations in hectarage over the decades (Figure 1). Given the cost to change hectarage and subsequent lost revenue, forward contracts may result in lower profits than spot market competition (Cabral and Villas-Boas 2005).

Three times during the 20th century, under the authority of the U.S. Department of Agriculture (USDA) American hop farmers regulated saleable quantities through Federal Marketing Orders (FMOs). The Hop Advisory Committee (HAC), from the third and last FMO, used elaborate equations to make forecasts (Folwell et al. 1985). Their techniques proved only marginally effective. Between 1966–1986 the mean fluctuation of Washing-

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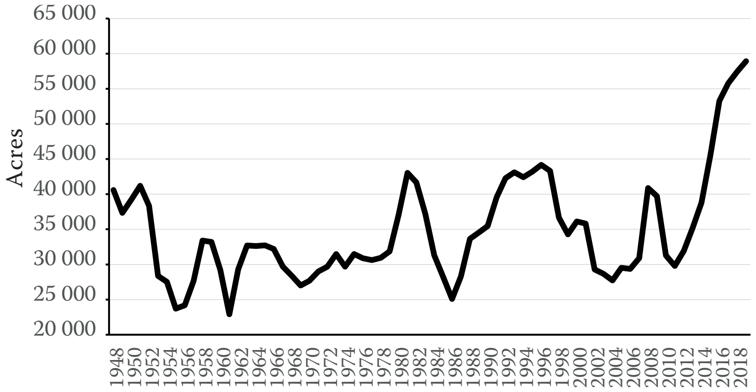

Figure 1. United States hop hectarage, 1948–2019

One acre equals 0.405 hectare
Source: BarthHaas (1948–2019), NHR (2019)

ton State hop season average price (SAP) was 7.71% with median fluctuation of 6.25% (USDA NASS 2013). When a shortage occurred in the late 1970's due to crop failures, the HAC did not adhere to its guidelines (Folwell et al. 1985). Committee members sought greater global market share by increasing saleable volumes in response to the deficit. Their efforts resulted in a massive surplus. Season average price (SAP) plummeted (NHR 2019). By 1986, farmers terminated the order.

With the development of higher-yielding hop varieties in the 1980's and 1990's, merchants differentiated themselves through lines of proprietary processed products. These new products provided a temporary advantage to the innovator while creating a Bertrand supertrap (Cabral and Villas-Boas 2005) as they decreased the size of the overall market.

Prior to the shortage of 2007, increases in SAP began as early as 2004. An accurate forecasting model to measure the disequilibrium could have prevented the 2007 shortage, which cost brewers hundreds of millions of dollars. SAP increased 45% in a single year (NHR 2019). The volume of forward contracts in 2009 (IHGC 2009) was 65% greater than in 2005 (IHGC 2005). By 2010, the production of privately owned patented and branded varieties expanded rapidly. Constrained Pareto optimality led to the counterintuitive expansion of varieties with greater inelasticity while more elastic varieties were restricted (Stiglitz et al. 1977). U.S. production increased 15 603 MT (57%). global surplus of alpha-acids developed (BarthHaas 1948–2019). By 2012, many contracts had been renegotiated. SAP decreased 30% from its 2008 high while production returned to 2007 levels (NHR 2019).

Empirical evidence between 2010 and 2012 suggested American craft brewers wanted a closer working relationship with their suppliers and would pay premium prices, unlike the big brewers. Craft brewers represented an opportunity to circumvent the big brewer oligopsony. Non-price competition between branded proprietary varieties exploded in response to soaring demand by craft brewers between 2010 and 2016 (NHR 2019). Between 2011 and 2019, American hop acreage increased by 97.8% (George 2019).

In the most extreme cases, craft brewers used 500–700 times more hops per hectolitre than the big brewers. The growing size of the maturing segment combined with the premium prices they paid granted them a disproportionate influence on the market. The number of craft breweries in the U.S. surged from 1 813 in 2010 to nearly 8 000 in 2019 (Brewers Association 2020). Their effect on global hop usage was significant (Figure 2) (BarthHaas 1948–2019). The craft revolution, as it became known, was led in the U.S. by rapidly increasing demand for India Pale Ales (IPAs) (Watson

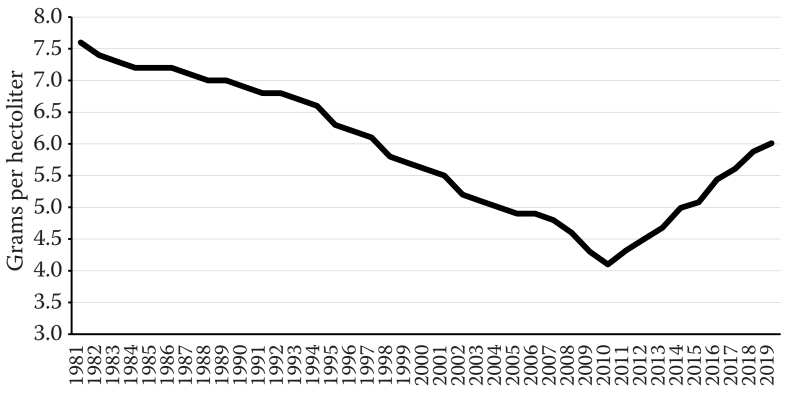

Figure 2. The global hopping rate, 1981–2019

Hopping rates are in grams of alpha-acids per hectoliter of world beer production 1981–2019
Source: BarthHaas (1948–2019)

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2015). The rapid reorientation toward proprietary hop varieties between 2010 and 2019 represented efforts by growers and craft brewers to differentiate from their competitors (MacKinnon and Pavlovič 2019).

Production of proprietary hop varieties rose from zero in 1997 to 66% of the 51 256.4 MT produced in the U.S. in 2019 (NHR 2019). These were primarily the intellectual property (IP) of six entities. The demand for new varieties created incentives for private breeders to invest in innovation, because they could define it and thus seek to protect and enforce their rights in it (Bugos and Kevles 1992). IP facilitated cartel-like power among a very few the FMOs of the previous generation could never have offered. The presence of IP constrained the market in new ways, which affected planting decisions (Stiglitz et al. 1977). Rather than restricting growth of proprietary varieties to their farms, IP owners license 3rd party farms as production units. They control production, marketing, and in some cases, retain ownership of the plant material produced. Between 2000 and 2019, proprietary varieties, each of which enjoyed a monopoly, became a vector for regulating production and saleable quantities. Prices soared.

Like other commodities, hops have significant seasonality and require a far more elaborate time-series specification of price dynamics of the underlying asset (Foster and Whiteman 1999). According to Cromarty and Meyers (1975), useful model would be designed to allow for subjective judgment. A statistical forecasting approach that could be implemented in concert with a priori knowledge would create a more thorough understanding of hop market dynamics. The goal of this research was to quantify for the first time the relationship between different publicly available statistics and determine which could be used in building such a model.

MATERIAL AND METHODS

We referenced annual season average price, production, and acreage data for the U.S. market converted into hectarage (USDA NASS 2013). For other production regions, we referred to annual BarthHaas Reports (BarthHaas 1948–2019) and International Hop Growers Convention (IHGC) economic committee reports (IHGC 2005, 2009).

To analyse the effects of the change in raw prices from year to year, we used SAP data unadjusted for inflation from 1948–2019. We omitted pre-1948 data due to our belief that the two World Wars, the U.S. prohibition, and the Great Depression artificially constrained markets and would have produced anomalous results that could skew the subsequent 70 years of data. We analysed three sets of data: *i*) the total data set, 1948–2019, *ii*) the subset of 1980–2019, a period after which the third FMO was dysfunctional and *iii*) the subset of 2000–2019, the period documenting the rise of proprietary varieties in the U.S. The calculations on the shorter time periods yielded stronger probabilities than those for the 1948–2019 period. To generate a more conservative forecasting model, we focused on reporting only the results from the total data set in this article.

Bayesian analysis. Several authors including Cyert and Degroot (1970), and Kihlstrom and Mirman (1975) have attempted, using the Bayes process and historical data, to infer values of unknown parameters when dealing with an incomplete world view. We used Bayes' theorem and Bayesian inference to calculate probabilities due to the accuracy of the test and the richness of the data provided. Bayesian calculations produce an *ex post* perspective and offer the probability of an event occurring based on historical data. According to Foster and Whiteman (1999), a procedure that makes use of numerical Bayesian techniques to develop an underlying predictive density holds significant promise. Bayesian estimation provides much richer information than the null hypothesis significance testing (NHST) *t*-test and sometimes comes to different decisions (Kruschke 2013).

We applied the theorem to industry data in 266 analyses. Season average price was used as both the dependent and independent variables resulting in 25 802 calculations using Microsoft Excel for Mac version 16.42. Each analysis featured three unique independent variables and three unique dependent variables with a series of calculations including prior, conditional, joint, marginal and posterior probability values for each set of circumstances measured. Ultimately, a Bayesian hierarchical modelling offers the opportunity to combine estimates based on historical data with information gathered via ex ante methods and weight them based on their perceived importance (Cabrini et al. 2010).

$$P(A|B) = \frac{P(B|A)}{P(B)} P(A) \tag{1}$$

where: $P(A|B)$ – probability of A occurring given that B is true; $P(B|A)$ – probability of B occurring given that A is true; $P(B)$ – probability of observing B; $P(A)$ – probability of observing A; A and B – unique events.

For example:

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$$P\,(SAP\,|\ \text{increase in Sept. 1 stocks}) = \frac{P\,(\text{increase in Sept. 1 stocks}|\,SAP\ \text{increase})}{P\,(\text{increase in Sept. 1 stocks})}\,P\,(SAP\ \text{increase}) \tag{2}$$

where: P – probability; SAP – season average prices; Sept. 1 – September 1.

We used the Bayesian inference method to calculate the probabilities of directional changes in our dependent variable for possible future years based on consecutive identical changes to our independent variable. We focused on *SAP* in the role of both dependent and independent variables and measured identical changes to dependent variables after two, three, and four years of successive identical changes.

Hop equilibrium ratio. We created the hop equilibrium ratio (*HER*) to measure the appropriateness of the supply from year n relative to the demand in year $n + 1$, a measurement previously lacking. The *HER* yielded the distance from market equilibrium in percent, from which an aggregate surplus or deficit could be calculated. The ratio may be used as an early indicator of the effects of demand on the price of years n and $n + 1$.

The *HER* for any given year n is as follows:

$$HER^n = \frac{D^n}{C'^{\,n-1}} \tag{3}$$

where: *HER* – hop equilibrium ratio; D – depletion rate; C' – volume of the crop produced post processing.

To achieve this, we calculated the depletion rate of U.S. inventory by taking the September U.S. hop stocks value for the previous year $n - 1$, (S^{n-1}) adding in the total production of the U.S. crop (accounting for processing loss) for year $n - 1$, ($C'^{\,n-1}$) and finally subtracting the September U.S. hop stocks value for year n, (S^n).

$$D^n = S^{n-1} + C'^{\,n-1} - S^n \tag{4}$$

where: D – depletion rate; C' – volume of the crop produced post processing; S^n – value of S for any given year n.

To account for the quantity of hop production lost during processing for any given year n, referred to herein as ($C'^{\,n}$), we estimated three percent of the crop remained in bale form for which we assumed no loss. We estimated 97% of hops produced were processed into pellets and experienced a three percent loss during processing. These assumptions may be adjusted as necessary to test an alternate set of beliefs. Because we did not feel comfortable assuming a similar ratio of processed hops to raw hops prior to 1979 due to the change in varietal characteristics at that time, we calculated the *HER* from 1979–2019. We did not add any additional loss for processing pellets into extract or downstream products as we believed those calculations would not materially affect the results. The formula we used for calculating the crop available post processing was as follows:

$$C'^{\,n} = ((C^n \times 0.97) \times 0.97) + (C^n \times 0.03) \tag{5}$$

where: C' – volume of the crop produced post processing; C^n – value of C for any given year n.

When we calculated the *HER* for each year using the data from 1948–2019, we observed that the *HER* value of 0.98 yielded the highest probability of accurate results when forecasting the direction of future pricing.

RESULTS AND DISCUSSION

We calculated the probability of a positive, negative, and zero change, in our dependent hop industry variables such as U.S. Stocks, U.S. hectarage and U.S. hop equilibrium ratio (*HER*) following a positive, negative, or zero change of the independent variable, U.S. season average price. We determined results to be significant if a change in the independent variable yielded a change to the posterior probability of the dependent variable by 10% or more in a single year, or if a multi-year series of identical changes lead to a change of 25–30% of the posterior probability relative to the original prior probability of year n. As part of the Bayesian process, our calculations also yielded the probability of the correctness of the test result.

We omitted results regardless of the apparent significance of the posterior probability if the probability of a correct test result was 60% or less. Twelve situations met these criteria and were worthy of greater attention as research results (Table 1).

Correlation between U.S. September 1 hop stocks and U.S. *SAP*. The increase in September 1 U.S. hop stocks represents the amount of hops produced and waiting in reserve for breweries. The increase or decrease of the stocks number must be analysed in concert with production figures, export numbers, the *HER*

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Table 1. Significant probabilities of variable changes and trends 1948–2019

	Description	Prior probability of change	Posterior probability of change	Probability of correct result
1	Stocks* year *n* decrease, *SAP* increase	0.6479	0.8077	0.8077
2	Stocks decreases 2 years, *SAP* increase	0.8077	0.9004	0.8148
3	Stocks decreases 3 years, *SAP* increase	0.9004	0.9522	0.8214
4	Stocks decreases 4 years, *SAP* increase	0.9522	0.9782	0.8276
5	*HER* year *n* > 0.98, *SAP* increases year *n*	0.6571	0.8261	0.8261
6	*HER* > 0.98 for 2 years, *SAP* increases year *n*	0.8261	0.9238	0.8333
7	*HER* > 0.98 for 3 years, *SAP* increases year *n*	0.9238	0.9695	0.8400
8	*HER* > 0.98 for 4 years, *SAP* increases year *n*	0.9695	0.9885	0.8462
9	*SAP* year *n* increase, hectarage increase	0.5352	0.6304	0.6304
10	*SAP* increases 2 years, hectarage increase	0.6304	0.7181	0.6383
11	*SAP* increases 3 years, hectarage increase	0.7181	0.7931	0.6458
12	*SAP* increases 4 years, hectarage increase	0.7931	0.8531	0.6531

*All stock figures refer to September 1 hop stocks reported by the USDA NASS; data pertains to the U.S. only unless otherwise mentioned
HER – hop equilibrium ratio; *SAP* – season average price
Source: Own study results based on USDA NASS (2013, 2014)

and other factors to paint a more complete picture of the appropriateness of the supply situation.

When we used stocks as the independent variable and *SAP* as the dependent variable, the results demonstrated the strength of the positive correlation (Table 1). When stocks decreased one year, the probability of a decrease in *SAP* rose from 64.79% to 80.77%. After two, three, and four consecutive years of price decreases, the probability of *SAP* decreasing was 90.04%, 95.22%, and 97.82%, respectively. The probability of these results being correct was 80.77% for year one, 81.48% for year two, 82.14% for year three, and 82.76% for year four (Figure 3).

The significance of the correlation between U.S. September 1 stocks and *SAP* cannot be understated. It is the only known statistic that provides clues to the appropriateness of the supply situation, which, due to the inelastic demand for hops, affects price and the supply situations of foreign countries.

Correlation between U.S. hop equilibrium ratio and U.S. *SAP*. In Table 1, the *HER* for year *n*, our independent variable, demonstrated a value greater than 0.98 in year *n*.

The probability of an increase in *SAP* in year *n* + 1, our dependent variable, changed from 66.67% to 77.78% in year one. With two, three, and four consecutive years of *HER* displaying a value greater than 0.98, the probability *SAP* increases were 86.53%, 92.49%, and 96.09% respectively. The probability of these results being correct was 77.78% for year one, 78.95% for year two, 80.00% for year three, and 80.95% for year four (Figure 4).

The *HER* provides a method for evaluating the appropriateness of the supply from year *n* for year *n* + 1,

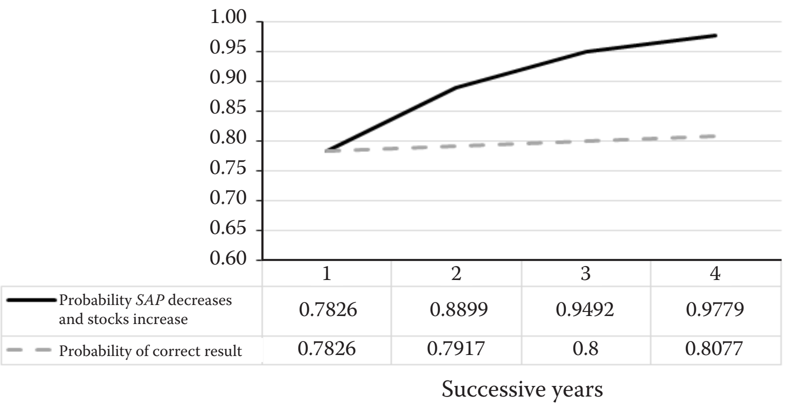

Figure 3. Probability *SAP* decreases after successive Sept. 1 U.S. stock increase and the probability of correct test results for each period based on 1948–2019 data

Source: USDA NASS (2013), USDA NASS (2014), BarthHaas (1948–2019), NHR (2019)

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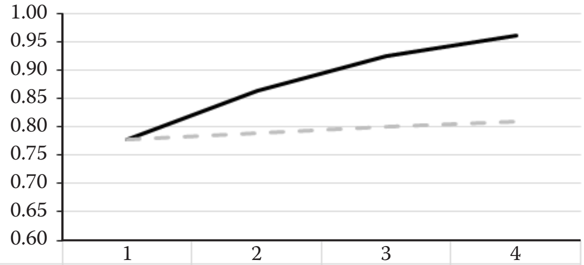


	1	2	3	4
Probability that U.S. *SAP* increases when stocks decrease	0.7778	0.8653	0.9249	0.9609
Probability of correct result	0.7778	0.7895	0.8	0.8095

Successive years

Figure 4. Probability U.S. *SAP* increases after successive U.S. *HER* values > 0.98 and the probability of correct test results for each period based on 1948–2019 data

Source: USDA NASS (2013), USDA NASS (2014), BarthHaas (1948–2019), NHR (2019)

the year for which it was produced, which has a subsequent effect on price.

Decreases in *SAP* resulted in the probability of increased stocks from 61.43% to 78.26% in the first year alone. Following consecutive years of decreasing *SAP*, the probability increased further. This signals that *SAP* had a counterintuitive inverse relationship to stock levels (i.e., when prices are higher, customers take delivery of more product). This is evidence of the lagged supply response in the wake of a price spike. The lag quantifies the degree to which breweries over-contract for product and is responsible for a perpetual state of disequilibrium.

Forecasting directional changes of price movements one year in advance is possible with a high degree of confidence by measuring the balance of the U.S. hop production of year n relative to demand for hops in the U.S. in year $n + 1$. Using the *HER* value of 0.98 revealed a method to measure annual surpluses and deficits.

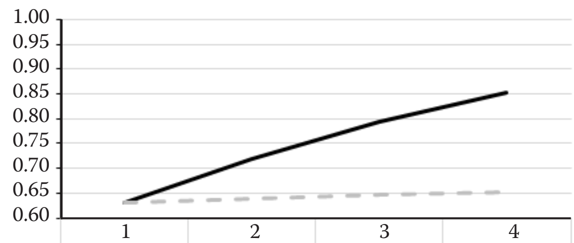
Correlation between U.S. hectarage and U.S. *SAP*. In Table 1, the *SAP* for year n, in this case our independent variable, increased. The probability of U.S. hectarage increasing changed from 53.52% to 63.04% in year one. With two, three, and four consecutive years of price increases, the probability of U.S. hectarage increased to 71.81%, 79.31%, and 85.31% respectively. The probability of these results being correct was 63.04% for year one, 63.83% for year two, 64.58% for year three, and 65.31% for year four (Figure 5).

There was a weaker relationship between *SAP* and U.S. hectarage. We assessed it was worth highlighting due to the counterintuitive nature of the trend, where supply and price are both moving together in unison. This happened for two reasons: *i*) small increases in season average price corresponded with increases in hectarage prior to a price spike that were insufficient to satisfy any existing deficit and led to a situation where price and planting were increasing prior to and during price spikes caused by large deficits or shortages, and *ii*) *SAP* and hectarage behaved differently after price spikes due to the macro buyer oligopsony, the over contracting going into a deficit and their ability to renegotiate contracts following the subsequent market decline once a surplus has developed. This led to falling prices as the production area was decreasing during surplus times.

CONCLUSION AND DISCUSSION

Publicly available statistical hop data provide sufficient information to forecast future directional movements of hops prices, the threat of upcoming shortages and the scale of surpluses.

The ability to accurately track hop inventory will enable an observer to determine the degree of disequilibrium in the market, to anticipate shortages and foresee price spikes.



	1	2	3	4
Probability *SAP* increase and acreage increases	0.6304	0.7181	0.7931	0.8531
Probability of correct result	0.6304	0.6383	0.6458	0.6531

Successive years

Figure 5. Probability U.S. hectares increases after successive increases of *SAP* and the probability of correct test results for each period based on 1948–2019 data

Source: USDA NASS (2013), USDA NASS (2014), BarthHaas (1948–2019), NHR (2019)

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The lack of such forecasting model in the past has cost the brewing industry and hop producers hundreds of millions of dollars during the past 20 years alone.

Data showed a strong positive correlation between September 1 U.S. hop stocks when used as the independent variable and U.S. *SAP* as the dependent variable. A positive change in stocks one year meant an 80.77% likelihood that U.S. *SAP* increased for that year with higher probabilities for such an increase in subsequent years demonstrating similar movements in stocks. The positive correlation between the U.S. *HER* and the U.S. *SAP* demonstrated a 77.78% chance in an increase in the U.S. *SAP* of the following year ($n + 1$) increasing with an increase of September 1 stocks in year n. This is the first known documented case of future price prediction ability in the hop industry. Forecasts are limited to directional price movements due to the use of aggregate data reported by the USDA NASS.

The owner of a proprietary variety with complete control of and access to price and sales data for a variety could produce forecasts with greater accuracy. Beyond the economic turmoil created by Covid-19 that will cause thousands of American craft breweries to close (Watson 2020), there will be opportunities for growth of proprietary variety market share at the expense of public varieties.

The challenges and variability associated with producing an agricultural commodity will always remain. A forecasting model employing the Bayesian method offers the best opportunity to calculate probabilities of future events.

These data, however, when combined with an a priori knowledge of market dynamics, make hop market forecasting future price movements possible.

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