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RESEARCH ARTICLE

What Makes Hemp Economically Attractive? A Case of Kentucky Hemp Farmers

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Abstract: Industrial hemp is a versatile plant that can be grown for fiber, grain, and extraction. Over the past decade, hemp has generated significant interest because of its environmentally friendly and sustainable production practices. Kentucky has been one of the pioneer states to reintroduce hemp production in the United States. This paper aims to explore the factors affecting hemp production in Kentucky using a farm-level panel dataset accounting for county-specific economic, environmental, and agronomic factors. The main objective of this study is to provide preliminary insights into the relationship between variables rather than establishing causal relationships due to data constraints. A reduced form econometric model on farm-level hemp acres was developed using unique Kentucky data on hemp production from 2017 to 2019. The regression analysis results show that Kentucky hemp acreage positively responds to an increase in cannabidiol (CBD) biomass price. When CBD prices increase by 10%, hemp acreage would increase by approximately 1%. Based on the "with" and "without" county-level weather information model results, the study demonstrates that weather is an important determinant of Kentucky's total hemp acreage. Our analysis concludes that the hemp acreage response is due to changes in farm-specific, plant-specific, county-specific factors, and market information availability, meaning that a platform for CBD biomass price reporting and a friendly regulatory environment are critical for producers seeking to plan their hemp production. In addition, inconsistencies in state regulations and reporting standards may create additional challenges for hemp production. Thus, additional support through university extension programs and other statewide support services may help hemp producers to expand their production.

Keywords: Hemp, THC content, CBD prices, Quantile regression, Weather

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1. Introduction

1.1 Overview of Hemp Industry

Hemp has been considered one of the first cultivated crops. Its cultivation and use have been originated from China, 4,000–6,000 years ago [1]. By the sixteenth century, hemp had become an important European cash crop [2]. The Puritans brought hemp to the United States in 1645 to grow for fiber, with the first cultivation in New England and then Virginia, Pennsylvania, and Kentucky [2]. Although industrial hemp was a major agronomic crop in Kentucky [3], hemp was primarily desired for U.S. Navy cordage and sailcloth [2]. However, in the late 1800s, the U.S. hemp industry began to decline, and hemp was restricted in the United States until recently [4]. After decades of hiatus, the Agricultural Act of 2014 reintroduced industrial hemp production through state pilot programs, and hemp production and marketing restrictions were relaxed [4,5]. The pilot programs were administered by state departments of agriculture or universities [3]. Under these programs, industrial hemp acreage increased from zero in 2013 to more than 90,000 acres in 2018 [5].

Hemp is an eco-friendly, highly sustainable crop [6]. Botanically, hemp is the plant species *Cannabis Sativa*, a summer annual species strongly photoperiod sensitive, meaning it flowers according to day length [3]. Although a few commercial varieties are monoecious (i.e., male and female flowers on the same plant), hemp is mostly dioecious, meaning male and female flowers grow on separate plants [3]. Industrial hemp is a versatile plant that can be grown for fiber, grain, and floral [7,8]. Example hemp products include but are not limited to the following. Hemp fiber used to produce high-tech electrical supercapacitors manufactured from biochar and alternative wood in construction materials [3]. Hemp can be added to concrete to create extra-strength hempcrete [9]. Hemp grain is also widely used for dietary supplements due to its desirable omega-3 and omega-fatty acids ratio and high protein content [3]. Hemp grain can be processed to produce a wide array of consumer products, including raw hemp hearts, toasted hemp seed, hemp seed oil, hemp flour, hemp coffee and hemp milk. Hemp grain is also a popular livestock feed widely used in Europe [3]. The common practice in Europe is to harvest hemp grain with combines and then harvest the remaining stems for fiber in a dual crop format. However, Canada has the most similarities with the U.S. hemp industry and the competition would be tough [5]. Hemp seed oil, commonly known as cannabinoids, is distinct from aromatic essential oils distilled from hemp foliage [10]. Cannabinoids are plant-generated molecules. Delta-9 tetrahydrocannabinol, or THC, is the most familiar molecule obtained from hemp. The THC content in *Cannabis* distinguishes industrial hemp from marijuana. If a *Cannabis* plant has more than 0.3% THC by dry weight, it is considered marijuana; if it has 0.3% or less THC, it is considered industrial hemp. Besides THC, the other most popular cannabinoids are cannabidiol (CBD). Current research is focused on pharmaceutical and medical research using CBD [3].

Because hemp has not been grown in the United States for an extended period, hemp farmers face significant challenges, such as the acquisition of production inputs, access to credit, lack of information regarding market structures, and competitive pricing for the world market. The 2018 Farm Bill addressed many of these challenges, but there is room for improvement. Kentucky was one of the first states to reintroduce industrial hemp production in the United States and has some of the most comprehensive farm level hemp production data. In 2014, the Kentucky Department of Agriculture legalized hemp and developed pilot programs for research [8]. If hemp is unsuccessful as a commodity crop in Kentucky, producers can still produce certified hemp seed since soils, climate, and existing infrastructure in the state are advantageous for hemp seed and grain production [3].

The period from 2017 to 2019, was a significant time for the hemp industry in the USA due to the passage of the 2018 Farm Bill. The Farm Bill legalized the cultivation of industrial hemp at the federal level, removing it from the list of controlled substances. This change had a profound impact on the hemp industry, leading to increased interest and growth in hemp cultivation. The removal of legal barriers encouraged farmers to explore hemp cultivation as a viable crop. Increasing demand for hemp-derived products, such as CBD (cannabidiol), played a role in the expansion of hemp acreage. CBD gained popularity for its potential health and wellness benefits, leading to a surge in demand for hemp as a raw material. Since hemp offers diverse applications beyond CBD, including textiles, paper, construction materials, and more, farmers saw economic opportunities in diversifying their crops with hemp. While the Farm Bill legalized hemp at the federal level, states were responsible for developing their own regulations. Some states embraced hemp cultivation more quickly than others, contributing to variations in acreage expansion across the country. The growing interest in hemp prompted increased research and education initiatives. Farmers sought knowledge about best practices for hemp cultivation, and agricultural extension services played a role in disseminating information.

1.2 Literature Review

In the pursuit of decision-making regarding hemp acreage, our study draws insights from a comprehensive review of literature focusing on various decision models within agriculture. Mathematical models are commonly employed for optimizing crop rotations, with an emphasis on sustainability in agricultural practices [11]. Crop rotation, on the other hand, plays a crucial role in maintaining soil fertility and mitigating pest and disease pressures. Additionally, factors such as crop yield, economic returns, and environmental sustainability are integral components of these models. In the literature, techniques for modeling land-use and land-cover change are discussed, utilizing cellular automata, agent-based models, and GIS-based approaches [12]. These studies focus on simulating land-use changes and assessing their environmental impacts, offering valuable insights into the evolving dynamics of agricultural landscapes. Moreover, the role of decision support systems (DSS) in precision agriculture is highlighted, aiding farmers in making informed decisions related to planting, fertilization, and irrigation based on real-time data [13].

Considering the economic aspects of crop selection, models assessing the economic implications of changing climate conditions on crop choice and land use decisions are crucial. They provide valuable insights into adaptation and mitigation strategies for sustainable agricultural practices [14]. Additionally, the application of machine learning models is prevalent in the literature. Decision tree models are a popular choice for land-use classification using remote sensing data [15]. Global crop modeling efforts, which assess the potential impacts of climate change on crop yields and land use, emphasizes the importance of integrated modeling approaches to comprehend the intricate interactions between climate, agriculture, and land use on a global scale [16].

Numerous studies have indicated that climate change can adversely impact crop production; therefore, weather information is an important variable for production decision-making. Many studies have incorporated the climate's impact on crop yields. Crop production modeling should specifically include harvested area and cropping intensity [17] because considering the climate's influence on all components of crop production is vital. However, it is suggested that land use decisions should be categorized based on producer size, such as market-oriented smallholders, professional commercial producers, and survival and livelihood-based producers [18,19]. Land-use decisions could vary significantly depending on producers' objectives and cropland size; thus, analyzing them separately could provide deeper insights into land-use decision-making. Not only do cropland sizes impact decision-making, but also the financial status of producers significantly influences their decision-making power regarding changes and legislation, thereby influencing the design of better land-use change assessments and policies toward sustainable land use. It is important to notice that these decisions have repercussions for markets, local communities, national economies, and environmental quality. Farmer decisions are constrained by social, economic, and cultural institutions, both formal and informal. For instance, in hemp production, production area and THC threshold levels are restricted by licensing, and there are social issues surrounding hemp production due to its association with marijuana.

Deciphering farmers' land-use decision-making is crucial not only for farmers but also for policymakers, as it impacts the economy of a state or region [20]. Moreover, understanding the determinants of land use and crop diversification decisions made by small-scale farmers would provide valuable information for promoting particular crops and rural economic development [20]. Such findings are important for the design of rural development programs tailored specifically for small-scale farmers to improve rural economic conditions [20].

Crop output prices and crop input prices are another important determinant of land use decisions, as they affect the economic margin of crop production. As farm size increases, respondents exhibit higher sensitivity of land use to policy issues, suggesting that scale effects render land units more sensitive to land use change drivers [21]. Finally, crop diversification is regarded as a risk management strategy and an important tool for poverty reduction [22,23]. Factors such as landholding size, age, educational level, farming experience, off-farm income, distance of the farm from the main road, distance of the farm from the main market, and farm machinery are important determinants affecting crop diversification decisions. These studies collectively represent a fraction of the extensive literature on planting decision models, crop selection, and land-use changes. The field is continuously evolving, driven by advances in technology, increased data availability, and growing environmental concerns, making it a dynamic area of ongoing research and development.

Understanding the factors that affect hemp production is essential for producers and policymakers. The objective of this study is to determine the factors that influence hemp production in Kentucky. Even though the current study focused only on Kentucky hemp production only the correlation relationships between factors, the results can be generalized for other states that produce hemp and don't have the data to estimate these models. Many potential growers are new to hemp production, and research focused on the needs for hemp production is limited. In addition, the economic, agronomic, and legal environments for hemp are rapidly changing. Thus, reliable information regarding hemp production is unavailable. This current study fills the literature gap using Kentucky hemp production data to investigate factors influencing hemp production.

While this framework has been extensively utilized in prior literature (as outlined in our literature review section), none of the studies have investigated the factors influencing hemp production decisions in the US. To the best of our knowledge, this study represents the inaugural effort to explore the significant relationships between hemp production and agronomic, socio-economic, and farm-specific factors, shedding light on the scale of operation. Despite several limitations, such as the unavailability of reliable market pricing, the small-scale nature of operations, limited data availability spanning only a few years, and legislative restrictions, we endeavored to leverage the available information to best capture the dynamics of the hemp industry and its implications for land-use decisions.

The paper is structured as follows. In the next section, we describe our econometric model. We then present the data and variable construction and report our findings. We conclude with a discussion of the implications for industry.

2. Materials and Methods

2.1 Econometric Model

The aim of this study is to provide preliminary insights into the relationship between economic, agronomic and weather variables and the hemp acreage decisions. Correlation studies are often the first step in investigating complex causality type relationships allowing researchers to identify potential patterns and associations. Thus, this study is mainly exploratory in nature, aiming to explore potential connections between variable rather than causal relationships. This can help guide future research efforts towards more targeted investigations and can generate hypothesis for further investigation.

The study empirically applied the econometric model using a unique farm-level panel dataset (Kentucky Department of Agriculture [KDA] Dataset) on hemp production from 2017 to 2019 to delineate the relationship of county-specific economic, environmental, and agronomic factors on hemp production. Farm level planted hemp acres in a county are used as a proxy for the optimal hemp production in that county. Factors affecting hemp acres are examined using the reduced form of the equation (1) as follows:

$$y_{jit} = \alpha_i + \beta X_{it} + \varepsilon_{jit} \tag{1}$$

where y_{jit} is farm-level hemp acres of farm *j*, county *i* in year *t*, and X_{it} is county-level time-variant characteristics for county *i* in year *t*. β represents unknown parameters to be estimated. Time-invariant fixed effects are controlled by including county-level fixed effects.

Quantile Regression Analysis

We also use a quantile regression (QR) approach to examine hemp production distribution among farmers. A QR model provides a better understanding of production distribution. It also allows for production factors to vary across quantiles. Estimating QR models of hemp acreage also provides the information needed to understand how farm specific, regional specific economic factors and weather affect small scale, medium scale and large-scale farmers thus, a better understanding of success of hemp in the short run and in the long run.

We measure the effects of production factors across quantiles to test whether these factors affect differently across quantiles. Consider an agricultural production $y_t \in R$ at time t

$$q(\tau|X_i) = X_i^{'}\beta(\tau) \tag{2}$$

where $q(.)$ is the quantile function defined as $P\big(y_i < q(\tau|X_i)\big) = \tau\epsilon[0,1]$. The coefficient β vary with the quantile τ. Consequently, τ will result in different covariate effects at different quantiles. Using the maximum likelihood techniques, we can estimate the coefficient of equation (2). We are interested in the quantile function given by

$$\min_{\beta \epsilon R^K} \left[\sum_{i|y_{jit} \geq X_i^{'}\beta} \tau \left| y_{jit} - X_{it}^{'}\beta \right| + \sum_{i|y_{jit} < X_{it}^{'}\beta} (1-\tau) \left| y_{jit} - X_{it}^{'}\beta \right| \right] \tag{3}$$

where K is the number of covariates.

2.2. Data and Variable Construction

We consider several variable categories, such as local economic conditions, agglomeration economies, climate conditions, and socioeconomic factors, that affect the firm's optimal output. Hemp planted acres are considered as the optimal output (Figure 1). Table 1 shows the summary statistics of the variables used in the analysis. These variables and their sources are provided in Supplementary Information, Appendix A.

Table 1. Summary statistics of the data used in the estimation.

Variable	Mean	S.D.
Farm economic variables		
Hemp acres planted per farm (Acre)	27.03	78.66
Total capital investments per acre ($)	16,324.65	355,035.50
CBD biomass price per acre ($)	155.16	475.46
Plant-specific and agronomic variables		
Average THC level (%)	0.24	0.09
Land Capability Classification	4.26	1.00
Effect of climate variables on acreage		
Lagged GDD (°C)	707.84	15.64
Lagged SDD (°C)	178.34	46.10
Lagged Precipitation (mm)	100.34	15.13
Competing crop land percentages		
Share of wheat acres	0.12	0.25
Share of soybean acres	0.34	0.42
Share of corn acres	0.29	0.39
Share of tobacco acres	0.01	0.02
Share of alfalfa acres	0.01	0.01
Share of CRP acres	0.05	0.09
Labor market factors		
Labor force participation (%)	51.39	6.78
Unemployment rate (%)	4.87	1.30
Regional economic factors		
Population density (person/mile^2)	148.84	285.53
Median income ($/year)	48,553.90	11,507.48
Poverty rate (%)	17.42	5.86

Note: S.D. represents standard deviation. Land capability classification can have numbers from 1 to 8.

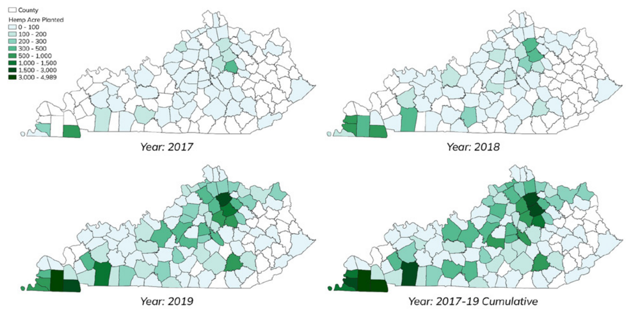

Figure 1. Hemp Planted Acres in Kentucky from 2017 to 2019.

Farm Economic Variables

The study includes two economic variables to capture farm finance: investment per acre and predicted CBD price per acre. We include county-level investment per acre as a proxy for hemp production cost.

An increase in crop output price subsequently increases crop-specific acreage when land from other crops is converted [24]. Because the use of crop prices to inform crop acreage decisions creates econometric problems such as endogeneity issues, existing literature suggests that futures and lagged received prices can be used interchangeably. Unfortunately, futures prices and received prices for Kentucky hemp do not exist for 2017–2019, so there is no future market for hemp. Hence, this study constructs a CBD biomass price variable using Jacobsen weekly price data (2020: 15th week; 2021: 32nd week). We construct an autoregressive model (Supplementary Information, Appendix B, equation (1)) and calculate predicted values and residuals. Since the residual of the first observation is missing, it is estimated by calculating the average of residuals for 52 weeks (1 year) from the 16th week of 2020 through the 15th week of 2021. Using the predicted residual, we determine the back-casted values by computing the reverse calculation (Appendix B). Since 88% of the sample consists of producers of floral materials, we use predicted CBD biomass prices to capture price impacts on hemp acreage. We use 7.5% CBD per pound according to Kentucky enterprise budgets for CBD production to construct the CBD biomass prices [25].

Price received per acre of CBD biomass materials is the weighted price for CBD biomass. CBD price may potentially be endogenous to acreage. Thus, omitting the endogeneity of price would cause an upward bias in OLS coefficient estimation on CBD price because price and acreage are positively correlated. We treat the CBD price as exogeneous to acreage by using predicted CBD biomass prices.

Plant-specific and Agronomic Variables

As mentioned, THC level is the main factor distinguishing industrial hemp from marijuana, making THC level a primary determinant in hemp production. The KDA database provided the THC levels of geolocated 2,000 hemp plots over three years (2017–2019). In addition, the inspector collected at least five plants that represented the plot composition, excluding plants close to the plot's perimeter. The collected sample was sent to a third-party chemistry lab determined by KDA, and the sampling process adhered to state regulations.

Land quality in a county is likely to affect the planted crop in that county. Related models of land use suggested that land use patterns are associated with relative rents and land characteristics such as soil fertility [26]. Although hemp is considered a low-input crop, yields and quality suffer when plants are grown in poorly drained, low-fertile soils [8]. This study utilized soil classification classes in respective counties to control for soil characteristics; soil classification as the representative of soil quality is integrated into the estimation. County-level soil survey data from the Natural Resource Conservation Service (USDA NRCS) are used to access the non-irrigated Land Capability Classification (LLC), which shows the soil component with acres by county, implying the time-invariant variable. LLC is defined as a limitation of soils to field crops indicating how suitable the soils in a certain county are for crop growing and how big the operational costs would be to grow them on this kind of soil [27]. The soil classification is indexed from class 1 to class 8 in the ascending order. Class 1 indicates that soils are suitable for most field crops and class 8 indicates that soils have limited use for commercial field crops. To calculate county-level soil classification, this study employed weighted averages across agricultural sites, with the weight being the acreage of soil components over total arable acreage [28].

Effect of Climate Variables on Acreage

Recent studies have used county-specific weather data to examine the effects of temperature and precipitation on crop yields and acreage. Schlenker and Roberts (2009) projected that increased temperature could reduce crop yields in the United States by 30%–80%. In addition, climate has also been shown to affect crop acreage. For example, precipitation can influence planting dates, affecting crop choice and acreage [24]. The growing frequency of extreme weather events, the lack of crop insurance, and risk management may increase the risk of crop failures within regions [29].

However, the effects of increasing temperatures and precipitation on hemp are less well understood. 30 hemp cultivars are used to evaluate yield, agronomic performances, and disease resistance and CBD accumulation over the course of floral maturation under different temperatures (i.e., flowering times) [30]. Because high temperatures are thought to potentially increase THC levels in hemp, we include growing degree days (GDD) and stress degree days (SDD) in our econometric model. In the estimation of GDD, we use the range of optimal temperatures from 16°C to 27°C [7]. To compute GDD and SDD, we employ the temperature data from Parameter-elevation Regressions on Independent Slopes Model (PRISM) and utilize the formulae [27]. A growing body of literature uses nonlinear effects of temperature and precipitation to examine crop yield sensitivity and production [31–33]. These studies primarily examine the premise that increased exposure to extreme heats during the growing season can cause yield losses after certain temperature thresholds. Therefore, the models in this study include squared terms of GDD and SDD. Since the effect of precipitation is also a significant determinant of hemp production, we include growing period precipitation in our models, with a defined hemp growing period from April to October. Because the effect of precipitation depends on timing as well as intensity, we include nonlinear effects using the squared term of growing period precipitation. Depending on pre-planting weather information, farmers may adjust their planting acreage. Therefore, we include lagged weather variables.

Competing Crop Land Percentages

Agglomeration economies arise due to the interdependencies of other traditional crop industries. When similar industries share a geographic area (i.e., a county), the diffusion of production and marketing information and inputs, such as labor, are improved [34,35]. We control the impact of agglomeration economies by including the percentage of crop acres of major commercial crops in Kentucky, including alfalfa, corn, soybeans, tobacco, and wheat as well as Conservation Reservation Program (CRP) acres. In contrast, land availability is an important determinant of crop acreage. Competing crop acres can limit land availability for hemp production.

Labor Market Factors

The county-level total labor participation rate is included in the regression as a conditioning variable with an indeterminate coefficient sign. Labor-force participation is an important indicator for starting a business because it provides required experience and potential contacts useful for networking [36]. However, counties with high labor-force participation often have fewer farmers to start a new hemp business. Therefore, following the literature, this study included the county-level unemployment rate. Because the local unemployment rate reflects the ease or difficulty of finding employment in the local community, a positive coefficient estimate for this variable was expected, assuming that high unemployment would increase farming activities [36].

Regional Economic Factors

According to regional economics literature, input and output market access and demand for consumer products influence enterprise formation and business location [37,38]. This study includes median income, poverty rate, and county population density to capture these economic signals. The sign of per capita income is expected to be a positive impact, while the sign of poverty rate is expected to be negative. High per capita income may be due to off-farm employment, potentially reducing farming activities and preventing the initiation of new farming enterprises. Similarly, a high poverty rate may decrease the demand for hemp products, decreasing hemp acreage. The sign for population density is indeterminate. However, because high population density could increase the demand for outputs, it can also limit land availability for agricultural activities while increasing consumer access, business opportunities, knowledge, and information spillovers [36]. In addition, as the state legalizes industrial hemp, the local effect of hemp dispensaries on the population are important for understanding aggregate effects for policy implications to address the concerns of a particular county's residents. The residents may be open to legalization but "not in my backyard" attitude towards cannabis [39].

3. Results

This section describes the estimation results of the acreage regressions with three estimated alternative specifications. Table 2, which presents regression OLS results of the acreage model, shows that hemp acreage positively responds to an increase in CBD biomass price. This response is statistically significant at the 1% level, and the estimated acreage elasticity with respect to CBD biomass price is 0.1, which means a 10% increase in CBD biomass price would increase Kentucky hemp acreage by 1%. The coefficient of per-acre investment is negative and statistically significant, potentially indicating that an increased investment cost reduces the intensity of cultivation.

Results show that population density has a negative and a statistically significant effect on acreage, as is consistent with similar acreage studies. For example, a 10% increase in population density will decrease the total hemp acreage approximately by 1%. Model specification II, we run the model without weather information to test the acreage sensitivity to weather information. With a lack of weather information, farm-level average THC level is shown to have a negative and significant impact on hemp acreage. This may indicate that good weather conditions help to improve the THC content in hemp plants, but further research is needed to confirm the association between weather and THC content.

Our analysis indicates that increased hemp acreage could be tied to increased median income. The annual median income of a county impacts local economic conditions and demand for hemp products [40]. Surprisingly, there appears to be a correlation between an increase in poverty and a rise in hemp acreage. The results suggest that a 1% increase in poverty in Kentucky would approximately increase hemp acreage by 0.08%. These results are consistent with the literature [34]. This linkage suggests that economic benefits associated with hemp cultivation might be influencing regions experiencing low growth. This prompts the question: "Could lower-income or impoverished areas be less educated and falling prey to the allure of a get-rich-quick scheme?" This query introduces the possibility that socio-economic factors play a role in the decision-making processes within regions where hemp acreage is on the rise. The dynamics of socio-economic factors should be considered when examining decisions related to hemp cultivation. These factors may include economic desperation, limited educational opportunities, or a lack of diverse economic options, potentially leading individuals in lower-income areas to view hemp cultivation as an appealing venture. Despite the initial challenges posed by this endeavor, there is potential for hemp cultivation to offer a viable economic pathway, contributing positively to community development in impoverished areas.

We find that the coefficient of land capability classification is negative and statistically significant, indicating that, all else equal, additional acreage of infertile land decreases hemp acreage. We also find that growing season precipitation significantly negatively impacts hemp acreage. This is because hemp plants prefer moist but not saturated soils. In addition, damp foliage can cause diseases and reduced crop performance [41]. In addition, higher precipitation can increase weed pressure and seedling diseases [42]. A similar conclusion holds for previous corn acreage studies [24]. However, the quadratic term of precipitation is positive, indicating a U-shaped relationship between hemp acreage and precipitation meaning that the lack of water supply discourages growers to expand hemp acreage initially. But after a certain point (i.e., a threshold), growers will expand their hemp acreage when water supply is sufficient.

We use county's other crop acres as a proxy for agglomeration economies because other crop acres can affect internal scale economies of hemp production by acting as shift factors. For example, hemp production would improve by the alfalfa acres. Alfalfa acreage share can be sown in early spring (March/April) or late summer (August/September) and requires approximately one month to harvest crops meaning that hemp growers can cultivate alfalfa and hemp during the same year on the same plot. Another potential reason might be high labor intensity. Since alfalfa and hemp can both be labor intensive and access to labor for alfalfa production in Kentucky could also be a labor source for hemp. In addition, hemp and alfalfa can be used in crop rotation cycles due to complementary nature of both crops. Alfalfa can contribute to soil nitrogen fixation hemp can use the soil nitrogen the following year when used in crop rotation cycles.

Table 2. Estimated models for hemp acreage.

Variables	Total Planted Acres with Weather	Total Planted Acres without Weather
CBD biomass price	0.001***	0.001***
	(0.000)	(0.000)
Investment per acre	−0.000***	−0.000***
	(0.000)	(0.000)
GDD	−0.287	
	(0.391)	
SDD	−0.035	
	(0.022)	
Precipitation	−0.165***	
	(0.054)	
GDD_sq	0.000	
	(0.000)	
SDD_sq	0.000*	
	(0.000)	
Precipitation_sq	0.001***	
	(0.000)	
Population density	−0.001**	−0.000
	(0.000)	(0.000)
Unemployment rate	0.119	0.101
	(0.177)	(0.184)
Median income	0.000**	0.000
	(0.000)	(0.000)
Labor participation rate	0.229	−1.241
	(2.520)	(2.763)
Poverty rate	0.081**	0.090**
	(0.040)	(0.045)
THC percentage	−0.950	−2.095*
	(0.920)	(1.197)
Share of corn acres	0.009	0.008
	(0.013)	(0.010)
Share of alfalfa acres	0.246***	0.238***
	(0.083)	(0.082)
Share of soybean acres	−0.011	−0.004
	(0.011)	(0.009)
Share of tobacco acres	−0.025	−0.074*
	(0.053)	(0.042)
Share of wheat acres	0.006	−0.006
	(0.005)	(0.008)
Share of CRP acres	−0.015	0.006
	(0.012)	(0.015)
Land capability classification	−0.393***	−0.513***
	(0.129)	(0.156)
	(0.000)	(0.000)
Year Fixed Effects	Yes	Yes
County Fixed Effects	Yes	Yes
R^2	0.23	0.21
N	1044	1044

Note: ***, **, and * denote the 1%, 5%, and 10% significant levels, respectively.

This section presents the estimation of a quantile regression model presented in equation (3). Estimated parameters are given in Table 3 for selected quantiles q = (0.25, 0.50, 0.75). The standard errors of the parameters are evaluated using bootstrapping.

CBD biomass price is only significant for farmers with more than 6 acres per farm. Small-scale producers or hobbyists (i.e., growers with 2 or less hemp acres) are less sensitive to CBD pricing than commercial producers meaning farmers with less than 6 acres are not sensitive to CBD biomass prices. Weather variables such as SDD and precipitation often exhibit statistical significance, but their effects vary across quantiles. Such differences emphasize the importance of the quantile approach to acreage analysis. For example, county-level median income and poverty level is only significant at 0.5 and 0.75 quantiles. The magnitude of those variables is higher at 0.5 acreage quantile, proving that the contribution of regional economic factors has a greater impact on low quantiles compared to high quantiles for hemp production.

The effect of alfalfa acres is positive and significant across all quantiles, with increasing impact for high quantiles. Soybean acres have a negative and significant impact at 0.25 and 0.5 quantiles, respectively. For example, a soybean harvest in Kentucky could begin in September and overlap with the hemp harvest season from September to November, meaning that growers must decide which crop to cultivate at a plot. The impact of wheat acres is positive and only significant at the 1% level for 0.5 quantile. The coefficient of county-level CRP acres is negative and statistically significant at 0.5 quantile. These findings indicate that the effects of agglomeration economies on Kentucky hemp occur in the middle quantile of the acreage distribution. Finally, the effect of land capability classification is negative and statistically significant for all quantiles, but the magnitudes vary with the quantile. The negative impact of infertile soil is stronger with increased acreage.

Table 3. Quantile regression model for hemp acreage.

	Quantile q		
Variables	**0.25**	**0.50**	**0.75**
CBD biomass price	0.000	0.001***	0.001**
	(0.000)	(0.000)	(0.000)
Investment per acre	–0.000	–0.000	–0.000
	(0.000)	(0.000)	(0.000)
GDD	0.403	–0.107	–0.202
	(0.501)	(0.461)	(0.471)
SDD	–0.034**	–0.036***	–0.031***
	(0.015)	(0.010)	(0.012)
Precipitation	–0.215***	–0.167***	–0.141*
	(0.060)	(0.061)	(0.072)
GDD_sq	–0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)
SDD_sq	0.000**	0.000***	0.000***
	(0.000)	(0.000)	(0.000)
Precipitation_sq	0.001***	0.001***	0.001**
	(0.000)	(0.000)	(0.000)
Population density	–0.000	–0.000	–0.000
	(0.000)	(0.000)	(0.000)
Unemployment rate	-0.067	0.084	0.214
	(0.138)	(0.127)	(0.159)
Median income	0.000	0.000***	0.000*
	(0.000)	(0.000)	(0.000)
Labor participation rate	–0.404	0.119	2.147
	(2.124)	(2.197)	(2.633)
Poverty rate	0.079	0.132***	0.120**
	(0.051)	(0.043)	(0.048)
THC percentage	–0.983	–1.025	–0.491
	(0.952)	(0.934)	(0.891)
Share of corn acres	0.020*	0.013	0.005
	(0.011)	(0.011)	(0.015)
Share of alfalfa acres	0.215***	0.281***	0.294***
	(0.067)	(0.055)	(0.077)
Share of soybean acres	–0.022**	–0.019*	–0.014
	(0.009)	(0.010)	(0.014)
Share of tobacco acres	–0.024	0.060	–0.028
	(0.058)	(0.071)	(0.043)
Share of wheat acres	0.005	0.009*	0.006
	(0.006)	(0.005)	(0.008)
Share of CRP acres	–0.011	–0.030**	–0.005
	(0.014)	(0.014)	(0.020)
Land capability classification	–0.300**	–0.447***	–0.650***
	(0.131)	(0.112)	(0.134)
Intercept	–129.225	40.103	68.622
	(178.813)	(164.256)	(168.076)
Time trend	Yes	Yes	Yes
Observations	1,044	1,044	1,044

Note: ***, **, and * denote the 1%, 5%, and 10% significant levels, respectively.

4. Discussion

Hemp farmers differ systematically from traditional crop farmers in terms of production, processing, marketing [43], and opportunities (e.g., access to credit). Despite Kentucky's prior history of hemp production, this newly reintroduced crop requires formal economic assessments. Increased understanding of the current constraints for hemp production could beneficially impact production practice and the formulation of U.S. farm policy. Although potential increased income from hemp farming could encourage new entrants and the expansion of hemp production, factors such as pricing uncertainty, high production risk, and potential regulatory costs could hinder commercial hemp production.

The quantile regression estimates reported in Table 3 provide useful information regarding hemp acreage distribution in Kentucky and offer additional insights into the role of agronomic, farm-specific, and regional-specific economic factors on hemp acreage.

Small acreage of hemp production may not be commercially viable. The study shows that the effects of weather are asymmetric; although they have small significant negative impacts on the upper tail of acreage distribution, they have high impacts on the low tail of the distribution. The coefficient of land capability classification shows that infertile soils adversely impact hemp acres, and the impact magnitude increases on the upper tail. Regional economic factors only have a significant impact on higher levels of production. The quantile regression results state that the percentage of soybean acres has a negative and significant impact on the 25th and 50th percentiles confirming that soybean and hemp are competing crops for land.

As shown in Table 2, the quantile and pooled regression results are robust. However, we find that per-acre capital investment significantly reduces hemp production. Initial start-up investments for hemp include all phases of hemp production, from land preparation to seed purchase. Because hemp production requires irrigation systems, an additional production cost or increased capital investment can also be associated with decreased hemp acres. Study results show that county population density significantly deters hemp production. Consequently, county-level poverty rate and median income significantly impact hemp production because counties with low economic growth may initiate more hemp operations by providing preferential alterations [34]. The positive impact of median income on county-level hemp production may justify the high investment costs required for hemp start-ups. Study results also show that THC levels have an expected negative impact on hemp acres when the model is run without the weather variable (Table 2, column 2). THC levels greater than 0.3% may prompt the farmers to destroy the hemp field, resulting in investment losses. However, industrial hemp grows best on well-drained, fertile soils rich in organic matter. Since class 1 indicates fertile soil, increasing the soil class category may also negatively impact hemp production. Similarly, poor or infertile soil categories may also increase THC levels in hemp crop. Current study results do not reveal the relationship between soil fertility and THC level, but future research may consider the association between soil class and THC levels.

The current study contains several limitations. One limitation is the absence of reliable hemp price data specific to the state of Kentucky. Hemp prices and marketing data are currently unavailable for Kentucky hemp producers, meaning researchers must depend on self-reporting hemp production and marketing data. Further research is also needed to determine hemp pricing and market structures. In addition, the economics and profitability of hemp production is not yet well defined [8]. Local research is needed to provide specific economic data. Hemp farming is a capital-intensive activity, meaning credit availability and financing would help farmers recover their capital investments. Another limitation of this study is producer risk preferences since we do not measure producers' risk behavior. Future research may include risk preferences to gain insight on the determinants of county-level hemp acreage.

5. Conclusions

This article investigates the determinants of hemp acreage at a county-level scale in Kentucky for 2017–2019. Even without establishing causation, knowledge of correlations between Kentucky hemp acreage and other influencing factors can still be valuable for informing decision-making process. The reduced form empirical framework developed in this study is based on the premise that county-level hemp acreage is influenced not only by farm economic factors but also by climate factors, regional economic factors, and land allocation decisions of farmers. Compared to previous studies, this study includes a more comprehensive set of climate, agronomic, and regional-specific factors that control for omitted variable bias.

We find statistically significant elasticities of hemp acreage with respect to predicted CBD biomass prices. Our analysis implies that the hemp acreage response is due to changes in farm-specific, plant-specific, and county-specific factors. Like similar studies, we also find that climate change significantly impacts acreage. The omission of weather variables while estimating hemp acreage leads to an assessment of the adverse impact of THC content, which is approximately a 2% reduction in acreage. However, factors impacting THC levels in hemp plants require further research.

The quantile regression approach provides a flexible representation of how the determinants mentioned above affect hemp acreage distribution. It shows how different production systems differ depending on the hemp farm's size. Although most of the results are robust to our main model, additional factors such as county-level soybean acreage and land devoted to CRP significantly impact average hemp farm size in Kentucky, consequently providing valuable insights to acreage distribution.

The article focuses on the acreage effects of farm-specific, plant-specific, and regional economic factors. Future research should decompose aggregate acreage effects and identify causal effects of specific factors to determine the effects on acreage. Nevertheless, our analysis confirms the important determinants of Kentucky hemp acreage. Although our empirical findings are specific to Kentucky hemp production, this analysis could be extended to various production regions.

Additionally, these results provide some important insight for hemp producers and hemp policymakers. While investment cost is a significant determinant of hemp acreage, market development and economic returns are equally crucial for a sustainable hemp industry. Hemp farmers are less likely to continue hemp production if more profitable options exist. Therefore, market information availability, especially a platform for CBD biomass price reporting and a friendly regulatory environment are critical for producers seeking to plan their hemp production. In addition, inconsistencies in state regulations and reporting standards may create additional challenges for hemp production. Thus, additional support through university extension programs and other statewide support services may help hem producers to expand their production. Even though we do not control for state government support, such support programs in terms of increased credit access and funding may also help hemp production and expansion.

In the realm of hemp cultivation, the absence of reliable pricing data presents a significant challenge for stakeholders seeking to understand market dynamics and make informed decisions. The lack of standardized pricing mechanisms for hemp products complicates efforts to accurately assess the economic landscape of the industry. Without clear and consistent pricing data, growers, investors, and policymakers face uncertainty in determining the profitability and viability of hemp cultivation. In light of this data constraint, we opt for correlation analysis rather than causation to identify factors influencing hemp acreage. While correlation analysis can reveal associations between variables such as environmental conditions, regulatory policies, and market trends, it falls short of establishing causal relationships. This reliance on correlation analysis underscores the pragmatic approach taken in the absence of comprehensive pricing data. By examining correlations among various factors and hemp acreage, analysts can glean insights into potential drivers of cultivation decisions without fully elucidating the underlying causal mechanisms. As the hemp industry continues to evolve and regulatory frameworks mature, addressing the absence of reliable pricing information will be essential for fostering a more nuanced understanding of market dynamics and facilitating evidence-based decision-making. The significant correlations identified in this study hold promise for future research to develop longitudinal studies aimed at establishing causation among influential factors.

Author Contributions

Buddhika Patalee, Hoyeon Jeong and Tyler Mark conceived of the presented idea. Buddhika Patalee developed the theory and Buddhika Patalee and Hoyeon Jeong performed the computations. Tyler Mark verified the analytical methods. Tyler Mark supervised the findings of this work. All authors discussed the results and contributed to the final manuscript.

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Data Availability

The data set used in this analysis is confidential.

Conflicts of Interest

The authors disclosed no conflict of interest.

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