

# Economy, Industry and Sustainability: Spatial-Temporal Modeling of the Relationship between Individual Industry and the Economy using Panel Time Series Modeling

Angolla Praveen  
Marketing and Data Science  
Regis University  
Regis University , Denver, CO, USA  
pangolla@regis.edu

## EXECUTIVE SUMMARY

Aligning businesses with a sustainable future requires critical evaluation of the operations and the economics driving the business. A bi-directional perspective to the relationship between businesses and the economy accounts for the reality of both the businesses relying on the market and the market relying on businesses. This project considered the beer industry and utilizes three Panel Time Series Models (the Cross-lagged Panel Models (CLPM)) that evaluate both how the growth in the distribution of breweries affect the GDP and how the GDP as well affects the growth in the distribution of breweries. These models gained a spatial and temporal understanding of the bi-directional relationship between beer industry and the economy across the US (in order to derive relevant insights for beer in a sustainable future) given the inclusion of the income variable to account for the consumer purchasing power. The results from the Random Intercept Cross-lagged Panel Model (RI-CLPM) showed the existence of mutual effects between the distribution of breweries across the US and the GDP; with the brewery count having significant effect on the GDP and the GDP also having a significant effect on the brewery count. The Spatial Cross-lagged Panel Models (SCLPM) found only the temporal effects, in the form the lagged GDP as significant in predicting the GDP; the spatial effects were not found to be significant in predicting the GDP. The more robust model, Arellano-Bond Difference Generalized Method of Moments (GMM), found that none of the predictors were significant in predicting the GDP.

## I. PROBLEM STATEMENT AND MOTIVATION

### A. Background

The relationship between industries and the economy is a co-dependency relationship. From the point of view of the economy, the economy provides the foundation for the business environment in terms of the consumer purchasing power and access to capital (Karimi & Sugözü, 2025). On the other hand, industries contribute to the economy in terms of taxes, salaries and propagation of economic activities through purchases and sales (Karimi & Sugözü, 2025). The economy and industries are hence important in shaping the performance of each other.

As a present reality and an aspect for consideration into the future, sustainability forms a factor that can shape the future of the co-dependency relationship between industries and the economy. Sustainability has brought closer focus across all industries with the need to evaluate whether an industry is sustainable in terms of the United Nations Sustainability Goals. The beer industry faces sustainability questions that relate to economic, social and environmental sustainability (Fuentes et al., 2025; Ooyama et al., 2025). Given that the economics of an enterprise can be viewed from the social and environmental perspectives,

an evaluation of the beer industry from an economic point of view would provide critical insights into the sustainability of the future of the brewing industry in the United States.

### B. Problem Statement

Sustainability represents the future of the planet, hence making alignment, rather than opposition to sustainability, more reasonable. The industries therefore need to make adequate plans for a smooth transition to the sustainable future, that would allow for continued profitability (Joseph, 2025; Azizah & Haron, 2025). Analyzing the beer industry and the economy, as completed in Ravanal et al. (2024), would provide a picture of the past and present dynamics of the industry, with potential forecasting of the future. Although the effect of brewing on the economy can be evaluated for insights, the project considered a bi-directional relationship with the effect of the economy and beer industry on each other evaluated. The evaluation considered the perspective of time (to account for impact of sustainability overtime), location of industry (to account for the distribution in the growth of the beer industry across local markets in the US) and income (for consumer purchasing power across time and location).

## II. DATA COLLECTION AND PREPARATION METHODOLOGY

Data for the project was collected from the following sources; Open Brewery Database API, Kaggle (Brewery Profile and Rating Data), Bureau of Economic Analysis API and Federal Reserve Bank (FRED). Figure 1 below provides a visualization of the data collection process for the project.

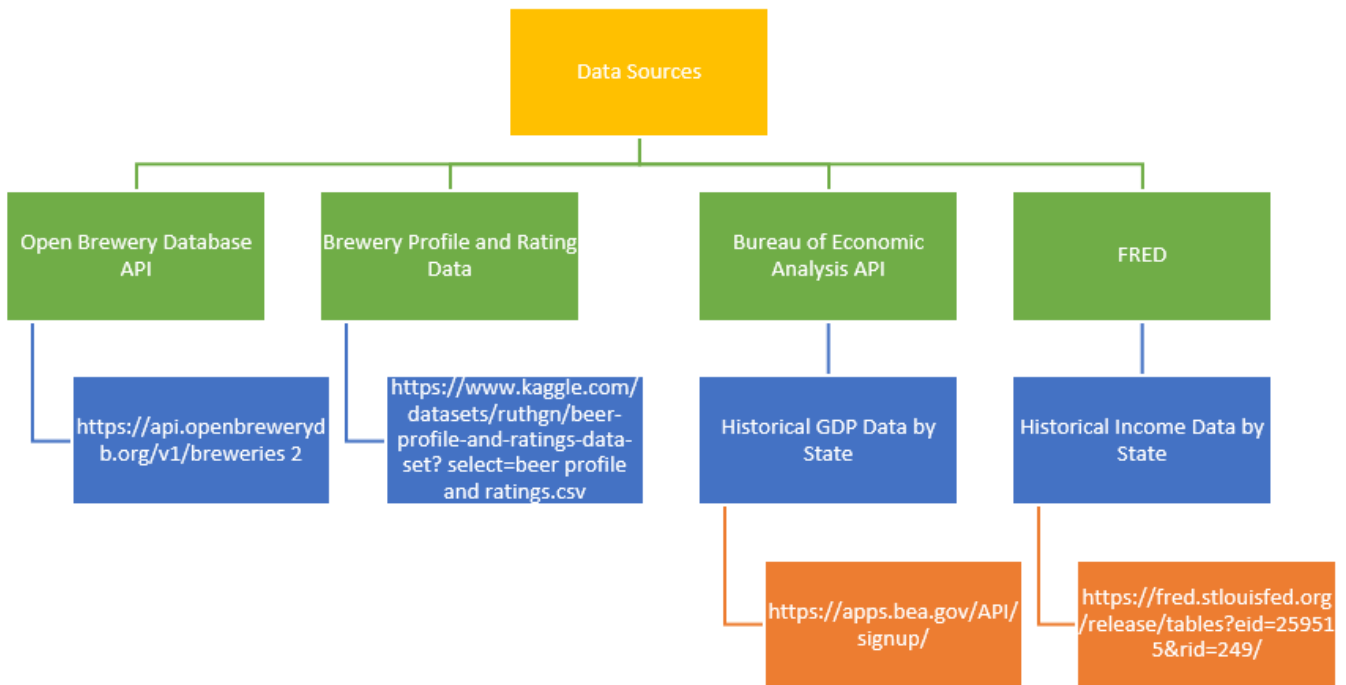


Figure 1

From the visualization of the data collection in Figure 1 above, the data was first collected through API access from Open Brewery Database API and Bureau of Economic Analysis API. The Open Brewery Database API provided access to data on the growth of the distribution of breweries across the states in the US. For the data from Bureau of Economic Analysis API, Historical Data for GDP by State data was extracted. Secondly, secondary data was also collected from Kaggle on the profile for breweries across the US. This dataset provided context for the data from Open Brewery Database API, with the two datasets merged to provide data on the beer industry. Thirdly, data was scraped from FRED on the

Household Income Data by State. Data preparation for the project involved the utilization of data cleaning approaches applied for data. Removal of variables with high number of missing entries was completed for the data on the beer industry. For the data from FRED, the data, as scraped from the FRED website, was in wide format with each year having a separate column for the household income of the respective states. Data cleaning for the income data hence involved the conversion of the data from wide format to long format; where there was a year column instead. After the cleaning of the data, data on the beer industry, Historical GDP and Historical Household Income were merged into the final dataset containing the following variables in Table 1 below.

Table 1

Variable	Variable Description	Measurement Scale
Year	Time series aspect providing data on the time the data was collected and measured in years. This presented the temporal characteristic for the data.	Interval Scale
State	Local market aspect providing the state in the US for which the data was collected. This presented the spatial characteristic for the data.	Nominal Scale
GDP	The Gross Domestic Product (GDP) that measures the economic performance of a state at a given time.	Ratio Scale
Brewery Count	The measure of the growth of the distribution of the beer industry measured as the number of breweries in the each of the states.	Ratio Scale
Income	The measure of the consumer purchasing power given as the household income of the each of the states.	Ratio Scale

### III. ANALYSIS METHODS AND IMPLEMENTATION DETAILS

The implementation of the analysis approach for the data involved the feature engineering for the data highlighted in the summary in Figure 2 below. The lagging of the data by the year variable allowed for the incorporation of the temporal aspect into the data. On the other hand, the computation of the spatial weights was conducted through contiguity, where the weights were assigned based on how the states bordered each other. Logarithm transformation of the data was mainly employed for the standardization of the variables in the data.

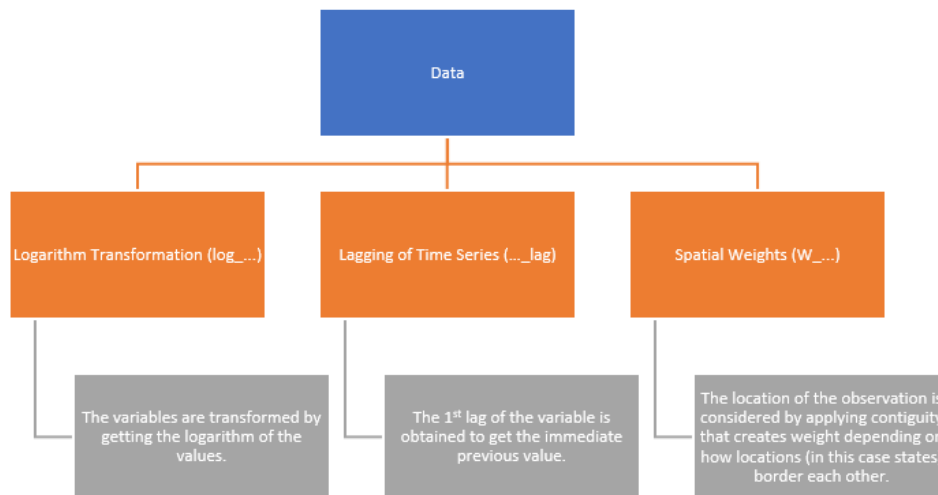


Figure 2

The approach to addressing the problem of the co-dependency of industry and economy for a sustainable future, employed data analytics. Both Rabbani et al. (2025) and Machmuddah et al. (2025) explain that

data analytics serve as a tool that can enable easier and faster alignment through anticipation and prediction of possible future scenarios in the transition towards complete sustainability. In the predictive analytics, the bi-directional relationship was evaluated using GDP for the economy and the number of established breweries per states for the growth in the distribution of the beer industry across the US. Spatial analysis, on the other hand, is explained in Fingleton (2023) to be the inclusion of locational aspects into the analysis on the attributes in a dataset. Spatial analysis was integrated into the evaluation of the bi-directional relationship through the inclusion of the state aspect for the different local markets for the beer industry. Among predictive analytics methods in data analysis is the panel time series modelling. As a form of the panel time series, the Cross-lagged Panel Models (CLPM) obtains the lag over time for data while ensuring the lagging considers the attribute of interest (Sorjonen & Melin, 2025). The CLPM represents an appropriate panel time series tool for the evaluation of the economics of the beer industry overtime and across local markets. Combined, the predictive analysis and the spatial analysis employed in the CLPM models constitute Spatial-Temporal Analysis (Fingleton, 2023). The utilization of the Spatial-Temporal Analysis for the project is summarized in Figure 3 below.

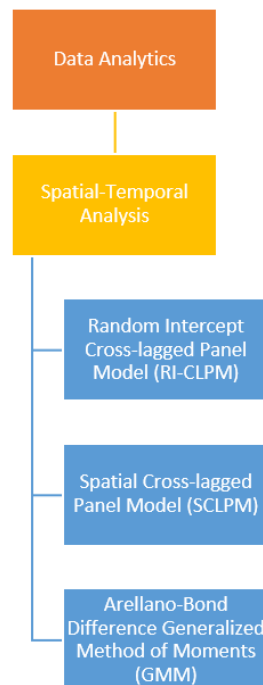


Figure 3

The utilization of the Spatial-Temporal Analysis presented above in Figure 3 shows that specifically, the Random Intercept Cross-lagged Panel Model (RI-CLPM), Spatial Cross-lagged Panel Models (SCLPM) and Arellano-Bond Difference Generalized Method of Moments (GMM) were utilized for the evaluation of the bi-directional relationship between the beer industry performance and the economy overtime and across local markets. The RI-CLPM is described in Sorjonen and Melin (2025) to employ cross lagging through re-ordering data by attribute of interest and time attribute, and lagging over time. Also, Sorjonen and Melin (2025) explain that the RI-CLPM allows for cross lagged effects to be observed for the two key variables which are being evaluated for mutual effects; on whether each of the two variables is significant in predicting the other. The model contained the following three groups of predictors for the GDP and Brewery Count; Random Intercepts, Cross-lagged Effects and Covariance between Residuals. The second model, the SCLPM applies a more direct approach to the spatial analysis. SCLPM applies cross lagging through the initial use of multi-index for the spatial attribute along with the time attribute – with the lagging of the data after setting of multi-index ensuring cross-lagging (Fingleton, 2023). Additionally, the SCLPM computes the spatial weights for the two variables being considered for mutual effects, to further

account for the spatial attribute in the data (Fingleton, 2023). The model contained the following three groups of predictors for the GDP; Log transformed variables, Spatial weighted and lagged variables and Brewery count. The final model, GMM, represented an improvement to the SCLPM model. The GMM represents a robust approach in handling dynamic panel data (Jula et al., 2026). The robustness of the GMM is the consistency that results from the differencing to remove spatial effects that are time-invariant or very specific; this makes the model very sensitive to the attributes included in the modeling (Jula et al., 2026). The model contained three groups of predictors for the GDP; Endogenous variables (the lag of the dependent variable since it is correlated with the dependent variable), Exogenous variables (external variables not correlated with the dependent variable) and Instruments (2nd lag of dependent variable for accounting for the effect of differencing increasing endogeneity).

#### IV. RESULTS

##### A. Exploratory Data Analysis (EDA) and Geospatial Analysis

The line charts in Figures 4 and 5 below show the trend in the GDP and the Household Income in the US (collectively for all states) respectively. For the trend in the GDP, we note that the GDP had a general rising trend between 2018 and 2023, with a slight deep in 2020. For the trend in the Household Income, we note that the Household Income had a series of jumps and falls between 2018 and 2023 and hence had year to year variation.

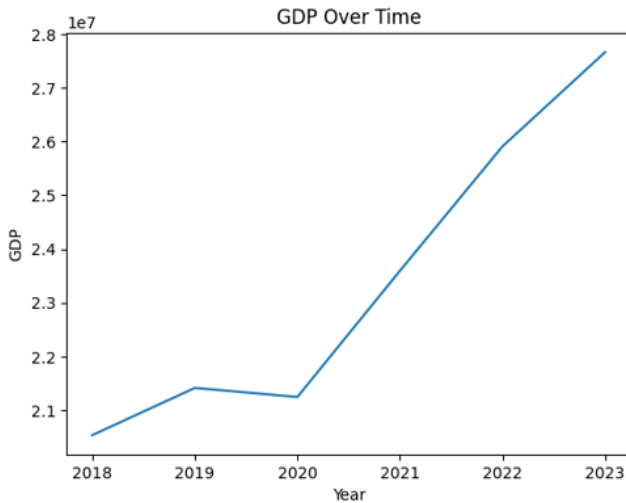


Figure 4

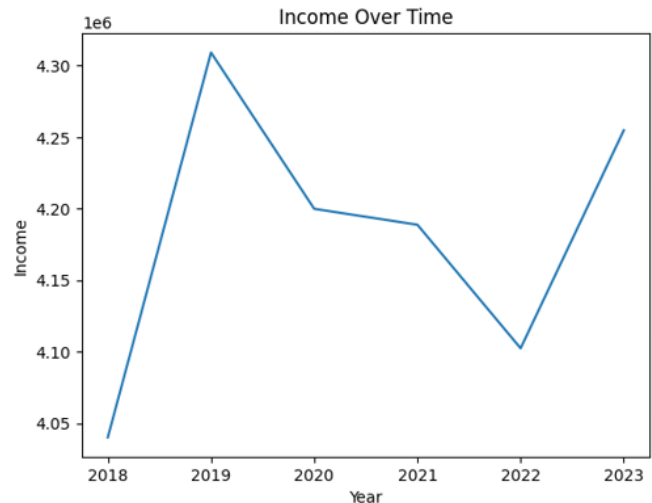


Figure 5

The geospatial mapping of the distribution of the growth in the number of breweries across the US is presented in Figure 6 below. We observed that breweries are predominately located on the East Coast, West Coast and in the states about the Great Lakes. We also note Washington State, California and Colorado lead in the number of breweries.



Table 2

	review_aroma	review_appearance	review_palate	review_taste	review_overall
count	3197.000000	3197.000000	3197.000000	3197.000000	3197.000000
mean	3.638789	3.754393	3.660428	3.702496	3.747522
std	0.503209	0.403416	0.449937	0.510361	0.444288
min	1.509615	1.571429	1.285714	1.214286	1.136364
25%	3.422559	3.604651	3.470021	3.500000	3.566667
50%	3.720183	3.833333	3.741667	3.791667	3.830239
75%	3.978000	4.000000	3.965587	4.033333	4.032847
max	5.000000	4.666667	5.000000	5.000000	5.000000

The histogram plots in Figures 8 below shows the distribution of the consumer ratings for aroma, appearance, palate and taste, and the overall rating. We that note the distributions for the ratings are negatively skewed; implying that majority of the ratings were high.

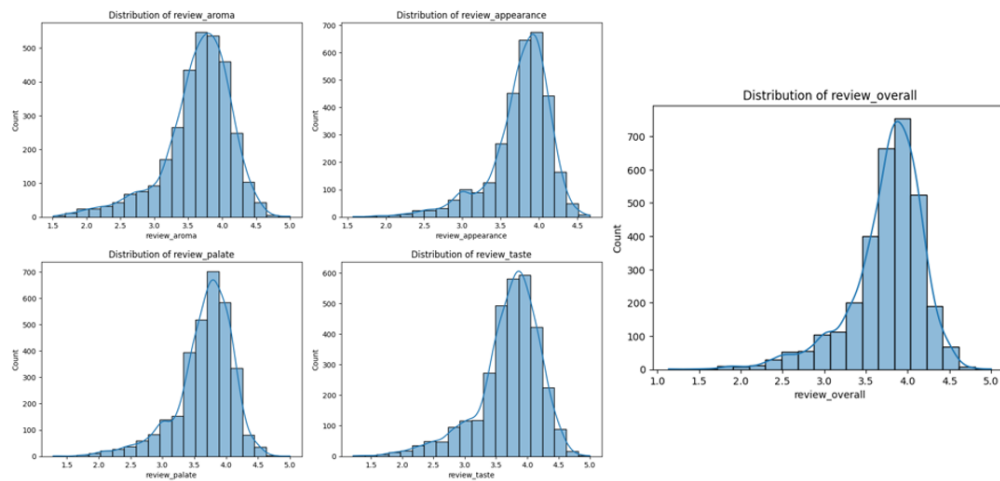


Figure 8

The bar chart in Figure 9 below shows the comparison of the average overall consumer ratings across different brewing styles for beer. From the plot, beers produced using the IPA – New England style, Wild Ale style and Stout – American Imperial Style had the highest average ratings by the consumers among the top 15 most used brewing styles for breweries.

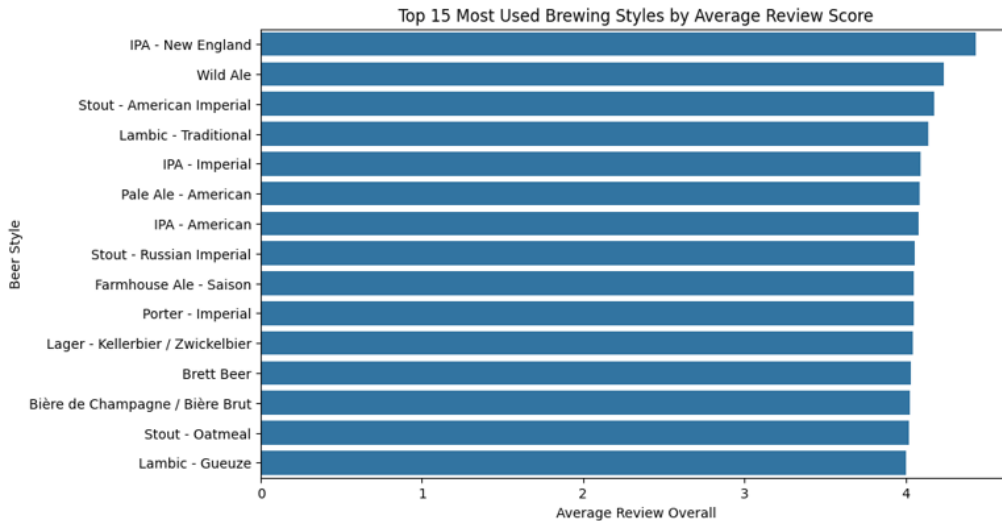


Figure 9

### B. Random Intercept Cross-lagged Panel Model (RI-CLPM)

Table 3 below shows the summary of the estimates of the coefficients for the RI-CLPM model for the predictions of the GDP and the brewery count. The results showed that for the estimated cross-lagged effects for the GDP, at a 5% level of significance, the increase in the:

- Brewery Count had an estimated 14.27 significant effect on the GDP.
- Lagged GDP(GDP\_lag) had an estimated 1.064 significant effect on the GDP.
- Household Income had an estimated -0.1846 effect on the GDP.

Also, the estimated cross-lagged effects for the Brewery Count, the increase in the:

- GDP had an estimated -0.000025 significant effect on the Brewery Count.
- Lagged GDP (GDP\_lag) had an estimated 0.000076 significant effect on the Brewery Count.
- Household Income had an estimated 0.00032 significant effect on the Brewery Count.

Table 3

	lval	op	rval	Estimate	Std. Err
0		GDP ~	RI_GDP	1.000000e+00	-
1	brewery_count	~	RI_brewery_count	1.000000e+00	-
2		GDP ~	brewery_count	1.426594e+01	0.000721
3		GDP ~	GDP_lag	1.063477e+00	0.047428
4		GDP ~	Household_Income	-1.845893e-01	1.954302
5	brewery_count	~	GDP	-2.449459e-05	0.000003
6	brewery_count	~	GDP_lag	7.545488e-05	0.000004
7	brewery_count	~	Household_Income	3.212835e-04	0.000007
8		GDP ~	brewery_count	9.298159e-08	0.000001
9		GDP ~	GDP	1.836277e+11	0.0
10		RI_GDP ~	RI_GDP	4.999804e-02	0.0
11		RI_GDP ~	RI_brewery_count	9.298159e-08	0.000001
12	RI_brewery_count	~	RI_brewery_count	3.568833e-03	16.234471
13	brewery_count	~	brewery_count	3.666223e+02	16.234471

	z-value	p-value
0	-	-
1	-	-
2	19788.104223	0.0
3	22.42308	0.0
4	-0.094453	0.924749
5	-8.750762	0.0
6	20.640231	0.0
7	3.679145	0.000234
8	0.100541	0.919915
9	182518614544960077168640.0	0.0
10	49696055233.757072	0.0
11	0.100541	0.919915
12	0.00022	0.999825
13	22.582951	0.0

### C. Spatial Cross-lagged Panel Model (SCLPM)

Presented in Table 4 below is the summary of the estimates of the coefficients for the SCLPM model for the predictions of the GDP. The results in the table showed that at a 5% level of significance, the increase in the:

- Lagged GDP (log\_GDP\_lag) had a 0.99 significant effect on the GDP.
- Lagged Household Income (log\_Income\_lag) had a -0.016 effect on the GDP.
- Lagged Spatial Weighted GDP (W\_GDP\_lag) had a 0.005 effect on the GDP.
- Spatial Weighted Brewery Count (W\_brewery\_count) had a -0.011 effect on the GDP.
- Brewery Count (log\_brewery\_count) had an 0.012 effect on the GDP.

Table 4

	lval	op	rval	Estimate	Std. Err	z-value	p-value
0	log_GDP	~	log_GDP_lag	0.988748	0.007791	126.903443	0.000000
1	log_GDP	~	log_income_lag	-0.015848	0.033873	-0.467862	0.639883
2	log_GDP	~	W_GDP_lag	0.004552	0.005642	0.806808	0.419777
3	log_GDP	~	W_brewery_count	-0.011001	0.018247	-0.602891	0.546582
4	log_GDP	~	log_brewery_count	0.011598	0.008867	1.308024	0.190865
5	log_GDP	~~	log_GDP	0.006471	0.000573	11.291590	0.000000

*D. Arellano-Bond Difference Generalized Method of Moments (GMM)*

Table 5 below shows the summary of the estimates of the coefficients for the GMM model for the predictions of the GDP. The results in the table showed that at a 5% level of significance, the increase in the:

- Lagged GDP (log\_GDP\_lag) had a 21.531 effect on the GDP.
- Household Income (log\_Income) had a -0.6635 effect on the GDP.
- Lagged Weighted GDP (W\_GDP\_lag) had a -20.492 effect on the GDP.

Table 5

Parameter Estimates						
	Parameter	Std. Err.	T-stat	P-value	Lower CI	Upper CI
log_income	-0.6635	0.7838	-0.8466	0.3972	-2.1997	0.8726
W_GDP_lag	-20.492	23.163	-0.8847	0.3763	-65.891	24.906
log_GDP_lag	21.531	23.439	0.9186	0.3583	-24.408	67.470

Endogenous: log\_GDP\_lag  
 Instruments: log\_GDP\_lag2  
 GMM Covariance  
 Debiased: False  
 Robust (Heteroskedastic)

V. CONCLUSION

The results from the analysis showed that the trends between 2018 and 2023 in the GDP and income were such that there was a general increasing trend for the former and relative year to year variation for the latter. The brewing industry overview, from the geospatial mapping, showed that although California and Colorado led in the number of breweries, the West Coast, East Coast and the states about the Great Lakes formed the concentration areas for the breweries. The analysis of the distribution of the type of breweries showed that majority of the states had micro-breweries with the large breweries located in states with the highest number of breweries.

Results from the RI-CLPM showed that the brewery count and GDP had a bi-directional relationship where brewery count was a significant predictor of GDP and GDP was as well a significant predictor of brewery count. Although the SCLPM showed that the spatial effects were 0.005 for lagged GDP (W\_GDP\_lag) and -0.011 for lagged Brewery Count (W\_brewery\_count), neither were significant. Only the temporal effect, lagged GDP (log\_GDP\_lag), was significant in predicting the GDP. A more robust approach in the form of the GMM, included spatial-temporal attributes and found that none of the effects were significant in predicting the GDP. Extending the research to other industries within Food and Beverage sector would provide findings that can be generalized for the Food and Beverage sector.

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