Spatio-Temporal Distribution Patterns of Farm Wineries in the Mid-Atlantic US from 1975-2015

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by

Matthew Miyares
Bachelor of Arts
George Mason University, 2013

Director: Paul Houser, Professor
Department of Geography and Geoinformation Science

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George Mason University
Fairfax, VA

DEDICATION

This is dedicated to my Lord and Savior Jesus Christ, my loving parents Pete and Ada, and all the friends who gave me encouragement along the way.

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I would like to thank all those without whom I would not have been able to complete this thesis: my dad, who encouraged me to pick up and complete my graduate work; Professors Houser, Rice, and Yang for their invaluable assistance and advice throughout the process; and the hard-working vintners and winemakers throughout my home state of Virginia, whose work inspired me to understand it further.

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GIS .... Geographic Information Systems
USGS .... United States Geographic Survey
NCSS.. National Cooperative Soil Survey

ABSTRACT

SPATIO-TEMPORAL DISTRIBUTION PATTERNS OF FARM WINERIES IN THE MID-ATLANTIC US FROM 1975-2015

Matthew Miyares, M.S.

George Mason University, 2018

Thesis Director: Dr. Paul Houser

This thesis examines the changing spatial distribution of Farm Wineries in the Mid-Atlantic United States from 1975-2015. In order to determine the factors that influence the location of Farm Wineries in developing wine regions, I conduct four sets of statistical tests upon the datasets of Farm Winery locations in New York, Pennsylvania, New Jersey, Maryland, Virginia, and the total of all states within the Mid-Atlantic region (including Delaware). The four tests are temporal autocorrelation in the number of new wineries opened during each year of the study period, Nearest Neighbor Ratio of the wineries opened in each state, chi-squared test of the differences between the distribution of soil families in Farm Winery sites and the state/region, and clustering of elevation values of Farm Winery sites. Commonalities were detected in the volatility of year-to-year winery openings, indicating the influence of short-term economic factors upon the general pattern of wine region growth. Additionally, the common pattern of increased

clustering of Farm Wineries over time shows a general benefit to spatial clustering in developing wine regions. The lack of commonality between states in the patterns of elevation clustering and soil family distribution demonstrate that the potential effects of both factors in the success of Farm Wineries is best examined at the local level.

CHAPTER 1: INTRODUCTION

The past half-century has seen tremendous growth in new and existing wine regions around the world, driven by two major factors. The first is the rise in demand for wine, tied to an increase in affluence, knowledge, and curiosity within potential customers. The second is advances in technology and hybridization has expanded the viticultural potential of previously marginal and inconsistent land, as well as the potential quality of already existing vineyards. Increases of average affluence across the developing world, paired with the global spread of technology, seem set to drive this expansion in the wine industry for the foreseeable future.

This thesis presents a case study of the growth of viticulture and winemaking through the lens of spatio-temporal statistics. I am specifically focusing on Farm Wineries, which I define as farms where *vitis vinifera* grapes or their hybrids are cultivated for the purpose of on-site winemaking. I have selected this narrow definition to focus on the intersection of physical and economic geography in viticulture. Most such establishments sell to customers directly, as opposed to retail, thus making their location more relevant to their success as ventures. By examining where and when successful Farm Wineries were opened in the Mid-Atlantic United States, I intend to reveal general patterns in their distribution, and how said patterns change over time. These patterns can then be used to inform models of development and investment in other burgeoning wine regions.

Wine Regions of the US Mid-Atlantic

Geographic Overview

For the purposes of this study, I will be examining the growth and distribution of Farm Wineries in the Mid-Atlantic United States, defined as New York, Pennsylvania, New Jersey, Maryland, Delaware, and Virginia. Apart from coastal tidewater areas, the general climate of this region is continental, defined by a wide range of seasonal temperature shifts. This contrasts with the more maritime climates of California, Oregon, and Washington, which exhibit less variability. Overall, there is a great degree of climatic heterogeneity both between and within these six states, presenting a multitude of challenges and opportunities to potential viticulturalists and winemakers.

Latitude represents the prime differentiator in the environments between the states. The northern part of the region, characterized by colder temperatures and longer winters, threatens grapevines with short growing seasons and risks of winter damage. Southern areas bring opposite threats, with hot and wet summers increasing risks of pests and diseases. These seasonal extremes are balanced against a lower variance in Eastern diurnal temperatures, compared to the West Coast. This enables consistent mitigation of seasonal climate effects through judicious site selection and selecting grape varietals whose growing season corresponds to the local environment (Chien 2004).

The southernmost state in the selected study area, Virginia, is divided into three major regions with respect to viticultural suitability. From east to west, they are the tidewater plain up to the Piedmont foothills of the Blue Ridge mountains, the Blue Ridge Mountains and Shenandoah valley, and the Appalachian ranges west of the Blue Ridge. The easternmost region is primarily under maritime influence, mitigating risk of extreme cold temperatures damaging vines; however, most of the eastern plain is subject to very hot and humid summers, which negatively affect grape quality for the purposes of vinification and present risks of pests and diseases. By contrast, the westernmost region is primarily under continental influence, presenting the opposite risk of a too-short growing season and cold temperature vine damage. The middle region, subject to both influences, offers a balance between the two climates most suitable for viticulture. However, Mesoclimatic sub-regions within each may prove either more or less suitable for vineyard establishment, due to the state's highly heterogenous topography and climate patterns (Boyer 1998).

Due to their proximity and position to Virginia, Maryland and Delaware are subject to the same regional classification. As the smallest state in the study area, Delaware lies entirely within the maritime influences of the Tidewater area, sharing the same low elevations and flat topography. Maryland, in turn, spans from the Tidewater plains facing the Atlantic and Chesapeake, to the Blue Ridge and Shenandoah valley, to the western Appalachians, all of which exhibit the same climatic influences as the state's southern neighbor.

Further north, Pennsylvania exhibits a different distribution of regional characteristics. Having little Atlantic-facing coastline, maritime influences are felt only in the southeast and northwest corners, with Lake Erie providing the influence in the latter case. Due to its higher latitude, the Lake Erie region has greater potential for colder winters but exhibits less extremes than the mountainous center of the state. A pocket of extreme cold temperatures in the north-central portion of the state makes viticulture all but impossible, with the northwest and southeast flanking ridges suitable for certain cool-climate varietals (Chien 2005).

New Jersey is classed as having five distinct climate zones. The northwest is covered by the Appalachian highlands, presenting a continental climate subject to cold extremes. Separating the northern highlands from the rest of the state is a central belt of highly-urbanized land, all but useless for viticulture. South of this belt is a central zone of ‘pine barrens,’ a region of continental influence with the highest diurnal extremes of the region, though with less extreme cold temperatures than the northern highlands. To the west of these ‘barrens,’ the land comes under maritime influences from the Delaware Bay, mitigating extreme temperatures while remaining low-precipitation. To the east of the barrens is the Atlantic coast, where maritime influences mitigate extreme temperatures, but bring considerably more precipitation (Rutgers).

New York exhibits high heterogeneity in climate, due to the varied topography and large size of the state. In the southeast coastal corner and Long Island, maritime influences dominate, with temperature extremes mitigated and regular precipitation. North of New York city, and forming the north-south axis of the state, is the Hudson

River Valley. The southern half of this valley is continental, with hot summers and cold winters; the northern Hudson Valley has cooler summers and a shorter growing season. West of the valley runs a belt of continental highlands, interrupted by the valleys of the Finger Lakes, where the bodies of water exert mitigating effects on temperatures and the lower elevation allows for warmer summers. The westernmost region of the state shows a similar dynamic, due to the presence of Lake Erie (Cornell).

Farm Winery History and Legislation

Viticulture in the Eastern US has a long history, with the very first English Colony of Jamestown, Virginia, being the site of the first attempt to grow wine grapes. Environmental factors such as fungal pests prevented most early attempts at establishing vineyards, but by the latter half of the 19th century, both Virginia and New York had thriving wine industries focused around *vitis vinifera* and its hybrids. Unfortunately, the establishment of Prohibition in the early 20th century would wipe out most winemakers in the region. Only New York retained any functioning wineries post-repeal, and the quality of their output was not highly regarded (MacNeil, 2001).

What began the revitalization of viticulture in the Mid-Atlantic were the establishment of Farm Winery licenses, which allowed for the profitability of smaller-scale establishments by reducing fees and allowing direct sales. Pennsylvania was the first to offer these licenses after passing the Pennsylvania Limited Farm Winery Act of 1968, followed by New York in 1976 (Lake Eerie, 2018). Subsequent laws would be passed in Virginia in 1980 (Virginia State Law) and New Jersey in 1981 (New Jersey

State Law), allowing for new wineries to be established and existing wineries to be retroactively covered by their benefits. Following the passage of these laws, winemakers from California and Europe, as well as local enthusiasts, began to drive an increase in both the quality and quantity of wine produced (Janson, 1988).

Later changes in legislation would follow with the intention of further facilitating the growing industry. Both Virginia and Maryland would revise their Farm Winery license laws to ease the regulatory burden on licensees in 2006 (Virginia State Law, Maryland State Law). Delaware and Pennsylvania would also begin to allow mailing of wine to customers in 2015 and 2017, respectively (Delaware State Law, Pennsylvania State Law). Continued interest and support from local lawmakers demonstrates that the study of Farm Wineries is key to understanding viticulture in the Mid-Atlantic United States.

Literature Review

Terroir and Defining a Wine Region

Much of the literature that currently exists on the spatial distribution of viticulture is focused primarily on associated climate, soil conditions, and slope aspect. The combination of these factors into *terroir* in traditional wine-making countries such as France has formed the basis for spatial and geographic conceptions of viticulture, as outlined by Vadour's 2002 article in the *Journal of Wine Research*, "The Quality of Grapes and Wine in Relation to Geography: Notions of Terroir at various scales." In a later article, the author outlines the two different approaches usually adopted to delineating terroir: “The first approach is based largely on the geographic differentiation of wine, grape, or grapevine characteristics, while the second approach focuses on the geographical differentiation of land capability or vineyard suitability studies…” (Vadour & Shaw, 2005, pp 106). In this instance, the former could be classified as an empirical approach mapping the current status of viticulture, with the latter being normative and intended to guide future vineyard establishment.

The above two approaches are interrelated. One common approach, adopted by Tonietto & Carbonneau, was to use the climatic factors of night temperature, heliothermal index, and dryness index to define a scheme of regional classification, observe where existing vineyards reported high-quality yields for different varietals, and use those associations to map potential suitability of wine regions to grape varietal. Their approach was applied at a macroclimatic scale, mapping 97 regions in 29 countries (Tonietto & Carbonneau, 2004).

The multivariate approach is also applied predicting the success or failure of individual Farm Wineries to produce good grapes, at the meso and micro-climatic scales. Climate and terrain conditions such as drainage, slope, and aspect vary at the level of the individual vineyard, necessitating a need for advanced analysis techniques and data collection technology to conduct finer-scale studies (Jones, Duff, Hall, & Myers, 2010). Regions such as the Douro river valley of Portugal have been successfully zoned at a relatively fine (1 km) spatial resolution, providing a map to adjust vineyard practices and guide expansion in ways conducive to the local environment (Fraga et al. 2018).

However, there are methods of defining terroir that are not strictly based on the physical environment. Cultural and economic factors also shape what land areas will be suitable for viticulture. “There are very few examples of famous wine-growing areas developing in inhospitable and remote areas, far from centers of consumption” (Van Leeuwen & Seguin, 2006, pp 2). Historically, viticulture is established where it is economically feasible, and it is only over time that regions develop practices to ideally suit their terroir. When also considering the ability of modern technology to compensate for less-than-ideal harvests, merely taking account of the physical characteristics of the environment would not necessarily predict the location of profitable wineries.

Physical Influences on Winery Locations

A large vein of the current literature on the influence of physical environment upon viticulture are suitability studies, where factors of physical geography are mapped and analyzed to determine ideal locations for establishing viticulture. These are often conducted in new or expanding wine regions, to reduce the amount of trial and error that precedes a regional consensus on the match between terrain and grape varietal (Jones, 2004). The preferred methodology is the use of a GIS-based multivariate evaluation, as the use of remote-sensing in conjunction with GIS has been demonstrated to be the most effective means of predicting viticultural potential, when validated against data from an already developed wine region (Irimia et al. 2013).

The use of remote sensing in data gathering and Geographic Information Systems in data analysis has greatly aided researchers such as those in Poland (Symanowski et al.,

2007) and Romania (Irimia & Patriche, 2011) to map the *terroir* of potential vineyards in provinces they wished to develop as wine regions, and associate locations with suitable grape varietals. The ability to spatially associate vineyard terrain and resulting wine quality in a statistically robust manner enables the drawing of solid generalization, such as Irimia and Patriche identifying that the ideal terrain for good quality grapes was on land with a moderate (5-15%) slope, where the slope was southern-facing in its aspect.

Climate change has also made periodic studies of this kind useful in already-developed wine regions, as long-term change in local climate inevitably leads to change in the varietals suited to particular vineyards (G.V. Jones, 2005). The effects of climate change, particularly in regard to temperature range and averages, are more pronounced in continental rather than maritime regions (Sirnik 2013). These generally have more impact on the husbandry practices and varietal selection than vineyard location, however. As Jones states in an earlier article, "The average climate structure of an area has proven to determine to a large degree the defining wine style, with variations in in wine production being chiefly controlled by husbandry decisions and short-term climate variability." (Jones 2004, pp 168).

Supplementing the multivariate studies cited above, other researchers have sought to isolate certain environmental variables to determine their ordinate weight in an overall analysis. One study in the Rhone valley of France shows soil type and classification having little significant association with grape and wine quality (Coipel et al., 2006). This conclusion is supported in a modified form from evidence in a study of the Iberian viticultural regions, showing that the effect of soil type on vine vigor was dependent on local precipitation and temperature. In temperature humid conditions, soil type had little significant influence on vegetative growth, but under hot or cold-temperatures the differences in vigor associated with soil type grew more pronounced (Fraga et al. 2014).

Of greater impact is the factor of topography. One of the largest risks to the viticulturalist is the loss of crops to a spring frost, which is not only increased in areas of high elevation, but also paradoxically in low-elevation pockets or valley floors. This is due to the phenomena of inversion, where cold air flows downhill and collects at lower elevations, displacing warmer air. This can occur at the macro, meso, and micro-climatic scale, necessitating regard for local topography when selecting vineyard sites, particularly at higher latitudes (Webb et al., 2017). Even at warmer latitudes, the effect of topography can be observed upon grapevine vegetative and reproductive vigor, as demonstrated by Victorino et al. in their comparative study of four vineyards in the Lisbon region of Portugal. Their results not only demonstrated spatial variability, but a variability within each site between different varietals in their response to topographic variables, further emphasizing the impact and importance of topography (Victorino et al. 2017).

One factor of importance when considering locations of potential new vineyards is prior land use. Soil carbon and nutrient content are significantly affected by land use, with virgin forest and pasture lands typically having higher concentration than active or fallow farmland. Vineyards are typically found in lower-carbon environments; as other farmland, less organic matter is contributed to the soil, while exposure to the elements enhances decomposition (Bonfatti et al. 2016). As the potential for wine quality is related to the presence of moderate environmental stress (Coipel et al. 2006), the ideal conversion of land use is from previously cultivated terrain to vineyards, both increasing the harvest value while minimizing the environmental impact of industry expansion.

Economic Influences on Winery Locations

Less prevalent have been studies on the non-climatic factors governing a wine region's development. One significant study compared the Napa and Sonoma valleys of California, climatically similar environments, both of which are rated as equal in their potential to produce high-quality grapes and wine. However, Napa consistently ranks higher in all metrics: prestige, taster rankings, price, and market share. According to the authors, Napa valley's advantage in production was due to the socio-economic environment, as opposed to the physical geography. The local knowledge base is higher in Napa than Sonoma valley, as more world-class vintners are clustered there, allowing for greater knowledge sharing and competition. Additionally, with the local economy of Napa dominated by winemaking, further public and private investment in the industry attracts a greater quantity and quality of vintners. The source of this comparative advantage is traced mainly to historical accident, as the initial post-prohibition efforts to revive the practice and reputation of California wine were centered in Napa, rather than Sonoma (Hira and Swartz, 2014).

The importance of spatial differentiation in social capital in determining a wine region's success and prestige relative to its neighbors is not limited to California. A case study in El Priorat, a small wine region in eastern Spain, provides a striking example. The region was characterized by rough terrain that gave the potential to create wine of a unique character, but for most of the 20th century, there was not enough knowledge of the agricultural and marketing techniques to take advantage, leaving the region only known for low-quality wines and a poor, dwindling population of local vintners. It was only when four outside vintners moved in and began to integrate themselves within the community could the necessary knowledge be carried in and disseminated. The authors emphasize that the local ties that the newcomers developed was as important as their outside connections and expertise, since the region's current prosperity resulted from innovations being adopted as a whole, and not merely through select producers (Aldecua et al. 2017).

Other studies reveal strong economic factors governing the distribution of successful Farm Wineries, in addition to physical geography. West Coast wineries exhibit a strong tendency towards clustering in wine ratings and prices, suggesting that new vineyards benefit strongly by being close to a prestigious winery (Yang et al. 2012). This is likely due to the proximity effect of being associated with a nearby winery of renown, combined with a general consumer pattern of visiting multiple nearby Farm Wineries in one itinerary (Shor & Mansfeld, 2010). Further support for this premise is found in study of specific visitation patterns within two branded wine regions in southern Australia, where the predominating pattern was the combination of a highly prestigious winery with smaller and relatively more obscure operations (Alant & Bruwer 2010).

A North Carolina study also notes the phenomena of wine trails, spatially-linked Farm Wineries with complimentary services, and recommends local governments invest in transportation networks capable of facilitating development and growth of such wine trails (Xu, Leung, & Barbieri, 2015). In addition to local amenities, the natural beauty of the surrounding environs is also an important draw for visitors. A survey in southern Australia revealed that tourists will select wine regions to visit according to their impression of the landscape as much as the wine quality to be found there. Also, if a region has a draw independent of the wineries within it, there is an additional stream of impulse customers who enter a winery as one part of a larger planned trip (Bruwer et al. 2016).

Historical-Statistical Studies of Wine Regions

Of the approach I use in this thesis, a spatio-temporal analysis of the development of a wine region, I was able to find one example focusing on the Sangli District of Northern India (Gade, 2015). However, the data in that study was highly spatially aggregated, thus factors of micro-climate and the proximity of other wineries were obscured.

A higher-resolution study, set within my study area, was conducted in Boyer's 1998 "Geographic Analysis of Viticulture Potential in Virginia." One aspects of the overall site suitability study conducted for the state was a comparison of patterns of grape cultivation with the more mature industry of apple production. Over the course of their history in the state, apple orchards became considerably more clustered, restricted to the Blue Ridge and Shenandoah valleys. Boyer posits that the relative immaturity of grape production, and thus the dearth of local knowledge on ideal planting sites, accounts for the more dispersed pattern of vineyards throughout the state. However, he also acknowledges the economic incentives driving location choices according to market proximity, rather than pure site suitability. Given that Farm Wineries, which comprise most of the wine production in Virginia, depend on local access to customers for economic viability, one should expect to see a tension develop between the selection of physically suitable sites to economically suitable sites. This tension is shown in Boyer's conclusion, where he compares existing orchards and vineyards to his suitability model, finding that the average suitability of the orchard sites is greater than that of the vineyards, particularly in respect to elevation.

Methodology

Data Sources and Preparation

My initial data source for the list and location of Farm Wineries within each state will be from official state government GIS sites when possible, branching off into wine tourism directories if official GIS layers cannot be sourced. As the legal definition of what is licensed as a "Farm Winery" varies between states, often including cideries and meaderies, the data will have to undergo a cleaning process to make the comparison between states consistent. Locations of Farm Wineries will also be confirmed, or established if no official GIS layer exists, through Google Earth (Figure 1).

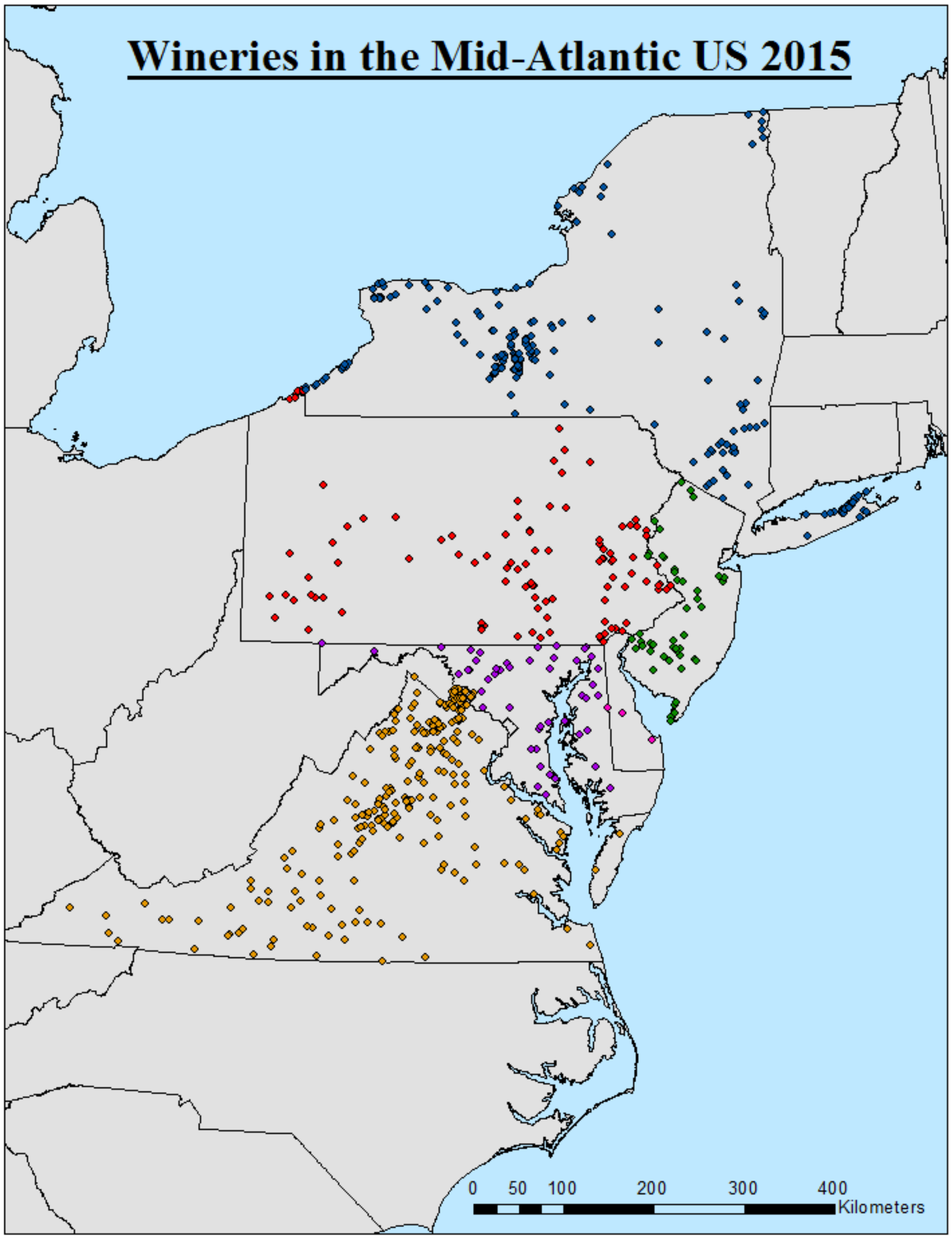

Figure 1 Wineries Data Set

Once a set of clean datasets is established, each Farm Winery "point" will be paired with a starting year. I count the starting year of a Farm Winery as the earliest available of the following: year of first vine planted, year of license granted, or year of officially opening for business. The dates will be sourced from the official web sites of each Winery if possible, or from ancillary sources such as newspaper articles or business registry sites if not. The final step in winery data preparation will be a re-projection into a Conic Equidistant map projection, as my analyses will rely upon accurately calculating Euclidian distance between the Farm Winery points.

To associate each winery data point with the soil type for its location, I sourced the soils data from the USDA web soil survey. Soil classification maps at 1km scale were retrieved for each state of the survey area. These maps were then re-projected into Conic Equidistant in ArcGIS, before spatially joining the Wineries datasets to them.

The elevation of each winery was determined using the National Digital Elevation Model, from the USGS Earth Resources Observation and Science Center. DEM rasters covering the entire study area were downloaded and mosaiced into one Elevation layer using ArcGIS, before point-sampling the elevation at each winery location point.

Analyses

This thesis will examine the changing patterns of Farm Wineries within the study area in four aspects over time from 1975-2015: the rate of new establishments, spatial clustering, soil type proportion, and elevation distribution.

Temporal Pattern Analysis

Purely temporal patterns in the number of wineries opened in a year will be detected with a time-series autocorrelation test, using a Poisson-distribution chi-squared statistic (Turchin, Lorio Jr., Taylor, & Billings, 1991). This test is used for determining the nature of changes over time within a population. Clusters of high-opening or low-opening years within a short time lag would indicate the effect of short-term external economic or legislative factors. These would then be considered when analyzing the associated changes in spatial distribution. Otherwise, clusters with a longer time lag, or no clusters at all, would indicate that relatively more constant factors of climate and terrain are predominant in the Farm Winery industry.

This analysis will first be run on the sets for each individual state, if state has enough data points to render a statistically significant result. The analysis will then be repeated for a combined dataset of all examined states, to detect factors that may be apparent at different spatial scales.

Spatial Clustering Analysis

Spatial clustering will be tested using Nearest Neighbor Distance test. NND tests the spatial clustering of a point dataset by calculating the ratio of the average distance between one point to its nearest neighbor (x) in a set of n points to a distance threshold equal to the expected average (x0) of the distance, assuming n points are distributed randomly within area y. This test is often used in other industries, particularly hospitality, to indicate whether business establishments tend to spatially cluster or disperse in attempting to maximize competitive benefits (Baum & Haveman, 1997).

The advantage of the Nearest Neighbor Distance test is that the distance threshold to test for clustering is adjusted dynamically for any increase in n; as more Farm Wineries open within a state, the distance between them must be lesser for the dataset to be considered clustered. Each dataset will be time-sliced by year, with each slice containing all the Farm Wineries open in that state that year, before being tested for clustering. This will give us a measure of whether the proximity of an existing winery is likely to facilitate the establishment of a new winery, and whether that probability will change over time. As with the first test, I will first run this test on the time-sliced datasets of individual states, and then upon a time-sliced dataset incorporating all states, to compare trends at different spatial scales.

Soil Type Proportions

The third method in my analysis will integrate soils data from USDA’s Web Soil Survey to analyze the change in spatial distribution of Farm Wineries over time with respect to a fixed environmental variable. Once a soil type is associated with each Farm Winery location, the proportions of soil types represented each year for each state are calculated. These yearly proportions are then compared to the soil type proportions of their respective state using the chi-square test to determine if there is any significant difference between them, and if this difference changes over time.

Elevation Distribution

The final test run will be to determine if there is a pattern in the distribution of winery elevations. Once each winery is associated with an elevation value, a two-step clustering test will be run on the datasets for each state for every year where the sample size is sufficient to yield statistically significant results. This will determine if there are clusters of elevation values where successful wineries have been established, how many clusters there are, and at what elevations are those clusters located. Running the tests for each year will also show whether the number and location of those clusters have changed over time.

Practical Implications of an Empirical Study of Farm Winery Regional Development

While previous studies have looked at the potential or current distribution of wineries within a wine region, few have tracked the change in distribution patterns over time. There is only one relevant study of this kind for the Mid-Atlantic United States, conducted only in Virginia a full 20 years ago (Boyer, 1998), and no datasets combining the location of individual operating Farm Wineries in these states with their year of establishment for that region. I propose to fill these gaps in the literature with my thesis research.

Farm Wineries represent a high-value proposition for investment in rural regions seeking to develop their local economy. This is because their economic impact is not limited to the production of wine. Farm Wineries have the potential to draw in tourists to the region as in addition to selling product, thus providing an influx of customers for local hospitality industry and other businesses (Bruwer, 2016).

Many regions across the globe have adopted viticultural tourism as an aspect to their rural economic development strategy. The growing markets of Poland and Eastern

Europe have sought to revive the private practice of viticulture following the collapse of centralized economic planning. Other parts of the developing world, such as Africa and India, are also seeking to develop wine regions of sufficient quality and renown to attract wine tourists (A.D. Gade, 2015). Even in developed countries, such as the United States, viticulture has been a growth industry for previously underdeveloped rural regions.

Studies have supported the optimism. The customers drawn to regions by wine tourism are affluent on average; what is more, they will not limit visits and spending to the well-known or largest establishments, instead incorporating nearby wineries into their itinerary (Alant & Bruwer, 2010). In addition to being wealthy and diffuse in spending, customers will often become repeat visitors, and recommend the destination to members of their social network (Shor & Mansfeld, 2010). Therefore, a successful wine region has the potential to bring in a significant, recurring source of wealth and growth stimulus to all living in the locality.

The lack of research into how a wine region changes over time is significant, given that the maturity level of an industry must be factored into investment decisions. In an industry like Farm Wineries, where said investments take the form of fixed capital (vineyards, winemaking facilities, and tasting rooms) that may take years to yield a return, the decision on where to place that investment would ideally be based on a sound prediction of where future success is likely to be, based on where it currently is. A general spatial model, if supported by the data, could provide a basis for that prediction. If readily-identifiable patterns emerge, then it will be possible to track the stages of Farm

Winery growth in a particular region and predict the likely locations of future establishments. This would allow for the intelligent prioritization of direct investment.

It is not just the location of investment to consider, but also what type of investment would give the most valuable returns. This is very largely dependent on the current state of development of the wine industry within the region. If it is young or undeveloped, priority should be given to measures increasing social and knowledge capital. This would include incentivizing outside vintners to immigrate and bring innovation and outside connection, as well as community initiatives to foster collaboration between local winemakers (Aldecua et al. 2017).

If in a relatively more developed state, the industry would be better served by infrastructure investments. Farm Wineries depend in large part upon direct customer sales, thus ensuring smooth transportation from population and travel hubs is critical. The impact on the local economy can also be enhanced by investment in hospitality ventures surrounding the wineries (Xu et al. 2015).

If in a mature state, attention should be paid to industries which would synergize well with viticulture. Biofuels in particular, as the agricultural practices of vineyards produce a considerable amount of organic waste which can be profitably sold (Zambon et al. 2018).

On the other hand, my research may reveal no common pattern between states, or across the region. In that case, future efforts to develop a general spatial model of Farm Wineries would be better spent in studies at a local level, to capture relevant factors and effects for each region to be considered. Either way, I am confident that my research will prove useful as a guide for further research, as well as practical policy and investment in prospective and developing wine regions.

CHAPTER 2: TEMPORAL AUTOCORRELATION ANALYSIS

This chapter will cover the methods, hypothesis, and results from my temporal autocorrelation analysis on the number of wineries opened each year in the Mid-Atlantic US. The purpose of this analysis is to determine the nature of the factors governing the decision to open a feasible Farm Winery. Correlation shown only between neighboring years would indicate the dominance of short-term economic incentives, while long-term correlations would indicate such factors as less important.

Methods and Hypothesis

This analysis was run using IBM SPSS 25.0's Autocorrelation function, on the datasets showing how many new Farm Wineries were opened each year in each state. For this thesis, I calculated both the ACF and Partial ACF. The ACF will measure the correlation between the values of two different years, considering the values of the years in between for longer time-lags. This will potentially capture longer-term factors that act over multiple years. Factors acting periodically are best captured by the Partial ACF, which calculates the correlations between two years independent from any values in between.

Equation 1: Autocorrelation Function

$$R(s,t) = \frac{\mathrm{E}[(X_t - \mu_t)(X_s - \mu_s)]}{\sigma_t \sigma_s},$$

Equation 2: Partial Autocorrelation Function

$$\alpha(k) = \text{Cor}(z_{t+k} - P_{t,k}(z_{t+k}),\ z_t - P_{t,k}(z_t)),\ \text{for } k \geq 2,$$

A positive value of ACF or PACF would indicate a direct correlation between the values of two years; a high number of winery openings in one year would predict a high number in the later year, and low values would predict low values. A negative value would indicate an inverse relationship between the two values, with high values predicting low values in the later year and vice versa.

This analysis was conducted twice, first on the raw data, and again after the datasets had been log-transformed. Because my datasets consisted of only 41 values that were often not normally distributed, I wanted to make sure that my analysis results would not be skewed by odd distributions within the data. Both sets of results will be recorded for comparison purposes.

Hypothesis

The literature indicates that winemaking operations only start in areas where the socioeconomic factors make them feasible, thus placing an emphasis on shorter-term economic factors rather than longer-term environmental ones (Van Leeuwen & Seguin, 2006). Empirical research supports this premise; a previous study focused on temporal patterns of Farm Winery openings in Virginia from 1976-2015 showed that PACF dropped off sharply following the increase in time lags from 1 year (Miyares, 2017). This would lead to the preliminary prediction that short-term economic factors would be predominate in the decision to open a Farm Winery in a new wine region.

A visual examination of the number of Farm Wineries opened each year in each state can also indicate the degree of volatility in the data. Virginia (Figure 2), appears to exhibit some degree of volatility, with an early period of spikes and dips in opening numbers followed by a steady lull through the 80's and early 90's, followed then by a sharp upturn in openings in the early 2000's leading to a greater series of spikes and dips. Maryland (Figure 3) and New Jersey (Figure 4) appear to be somewhat less volatile, with early years steadily showing either one or zero openings, followed by a spike in activity in the early 2000's. Pennsylvania (Figure 5) seems to show the most periodicity, consistently alternating between short periods of high and low openings. New York (Figure 6) shows the greatest degree of volatility of all the states in the early decades, though following 1995, there seems to be a steadier pattern of winery openings, through 2010, followed by a sharp alternating series to close out the study period. When looking at the total opening across the entire Mid-Atlantic (Figure 7), less volatility is apparent, leaving a relatively flat curve leading into a steady increase in openings around 1998, broken only by a spike in the late 2000's followed by a decline.

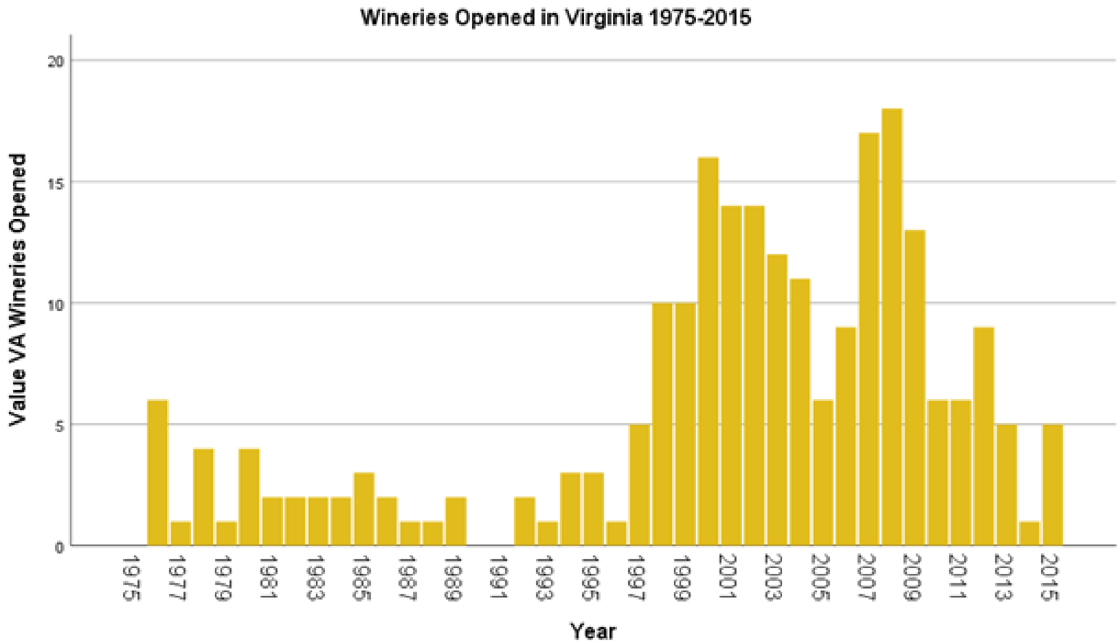

Figure 2: VA Winery Openings per Year

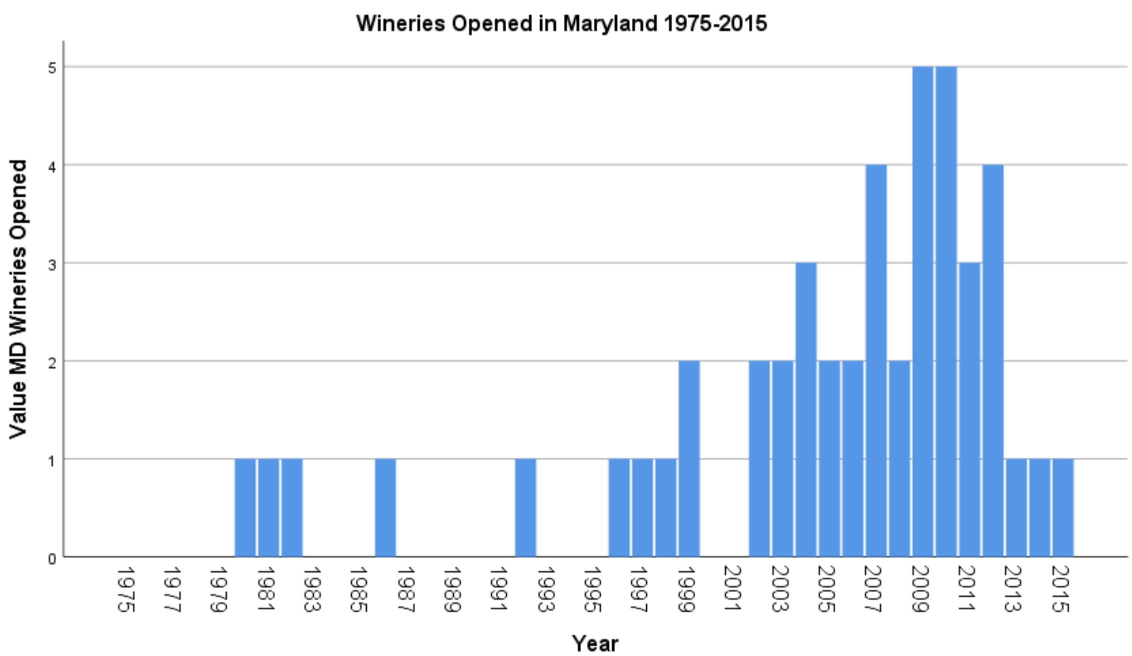

Figure 3: MD Winery Openings per Year

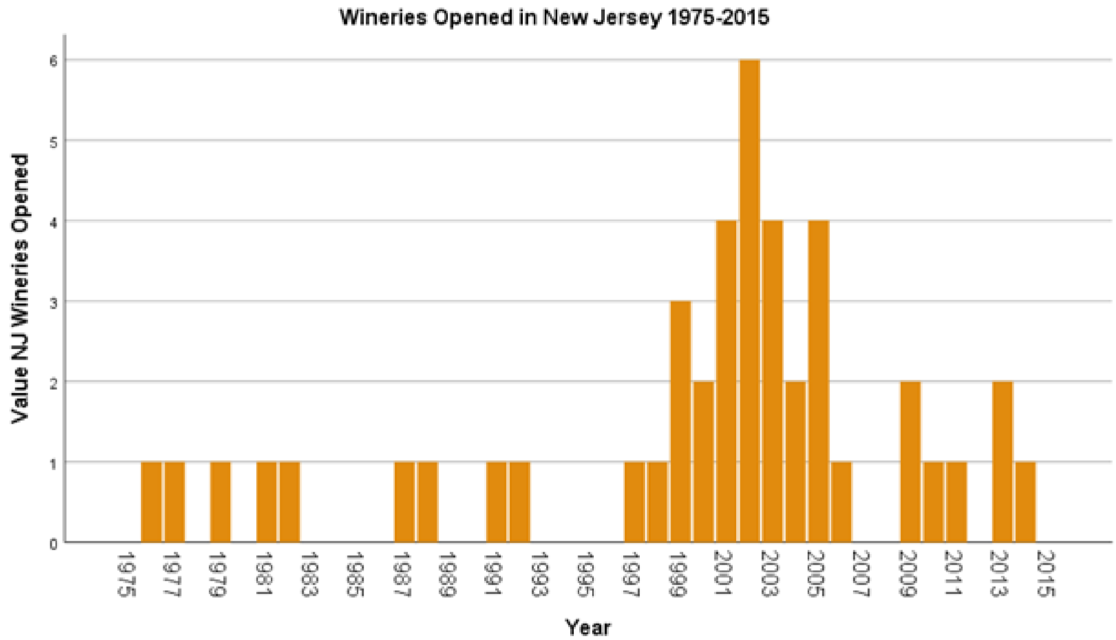

Figure 4: NJ Winery Openings per Year

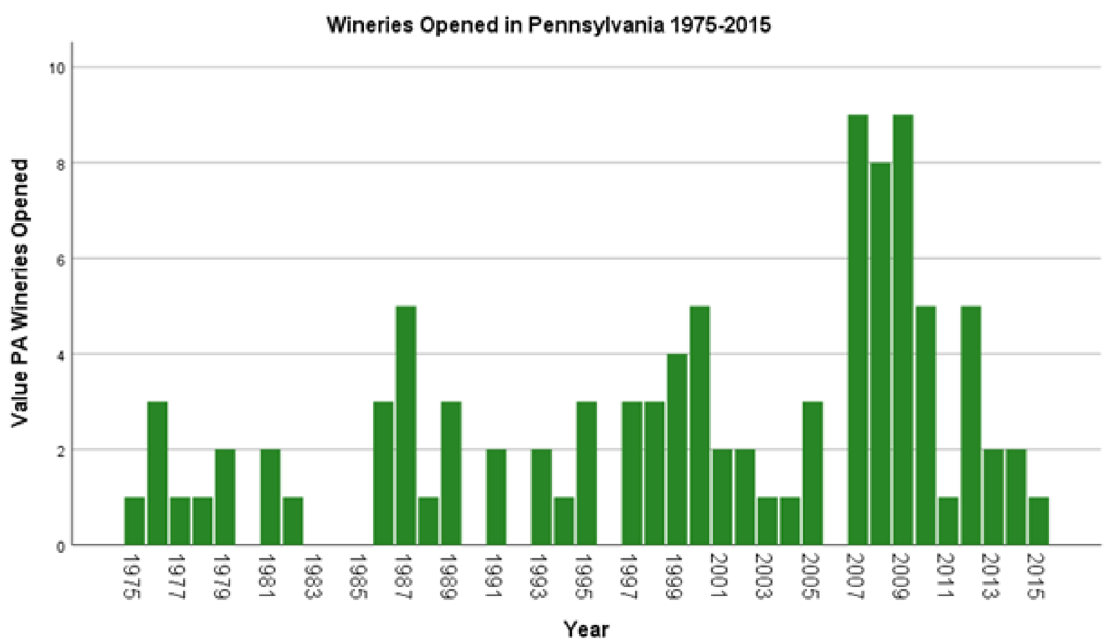

Figure 5: PA Winery Openings per Year

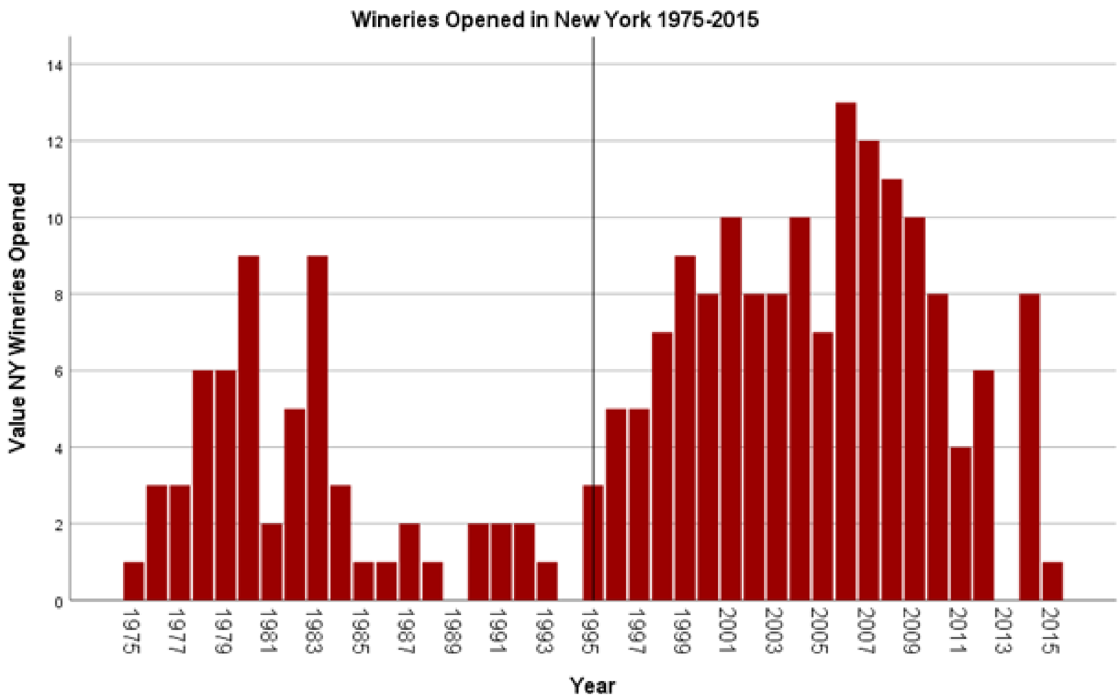

Figure 6: NY Winery Openings per Year

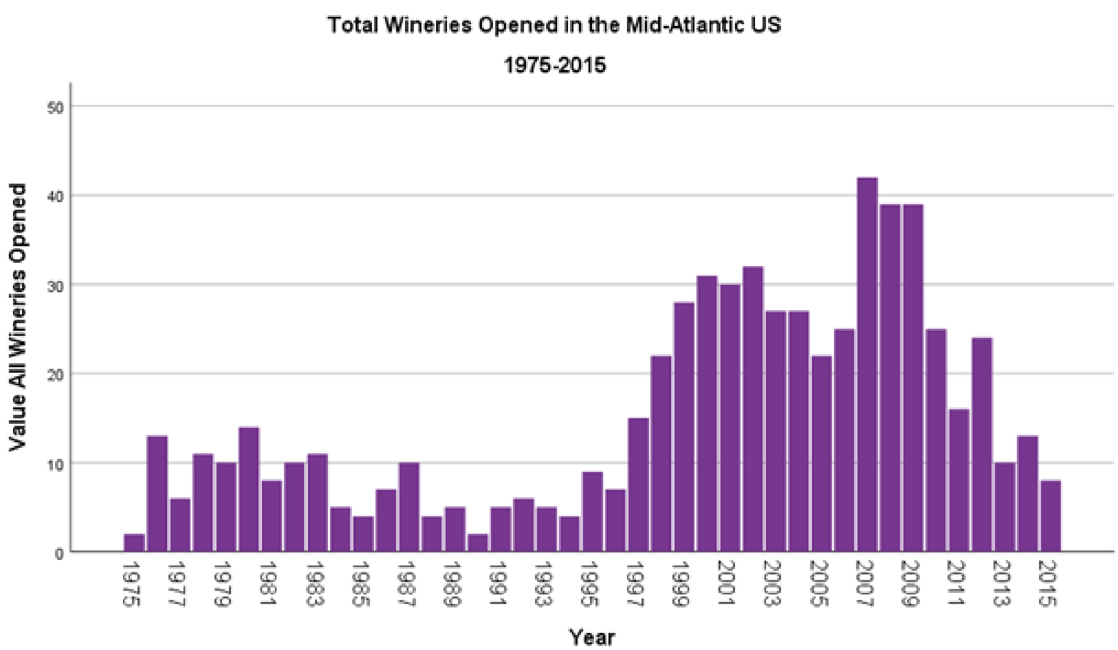

Figure 7: Winery Openings per Year Regional Total

Based upon previous research results on Virginia, combined with a comparison between all states within the region, I hypothesize the following:

In Virginia and New York, the ACF and Partial ACF will be significant and positive for time lags of one and two years. There will be no significant positive or negative ACF or Partial ACF for longer time-lags.

In Pennsylvania, the ACF and Partial ACF will be significant and Positive at a lag of one year, and significant and negative at a lag of two and three years. There will be no significant negative or positive ACF or Partial ACF at longer time lags.

In Maryland, New Jersey, and the Mid-Atlantic Region overall, the ACF and Partial ACF will be significant and positive for short time lags but will remain significant for longer time lags than Virginia. There will be no significant negative ACF or Partial ACF values at any time lag.

Results

The output of my analyses is a set of ACF and PACF coefficients for time lags of 1-16 years. I then graphed against the upper and lower confidence limit to show which of them were significant.

Virginia

From the untransformed dataset, the ACF (Figure 8) is positive and significant for lags of 1-6 years, with the highest coefficient being .787 at a lag of 1 year, declining gradually afterwards. At a lag of 10 years, an inversion occurs, and the ACF becomes negative, still trending downward until it passes the lower confidence limit at -.280 at a lag of 16 years.

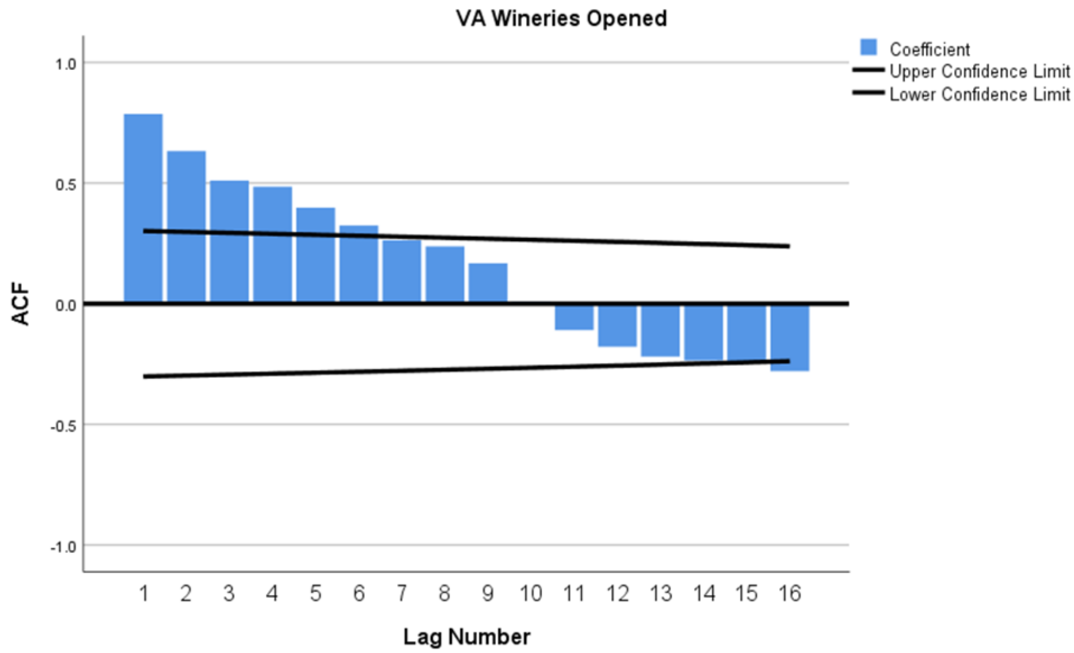

Figure 8: Untransformed ACF Results for VA

The PACF (Figure 9) shows one positive and significant coefficient at a lag of 1 year, which is expected, as the PACF and ACF will be equal at that lag. A significant and negative value of -.302 occurs at a lag of 10 years.

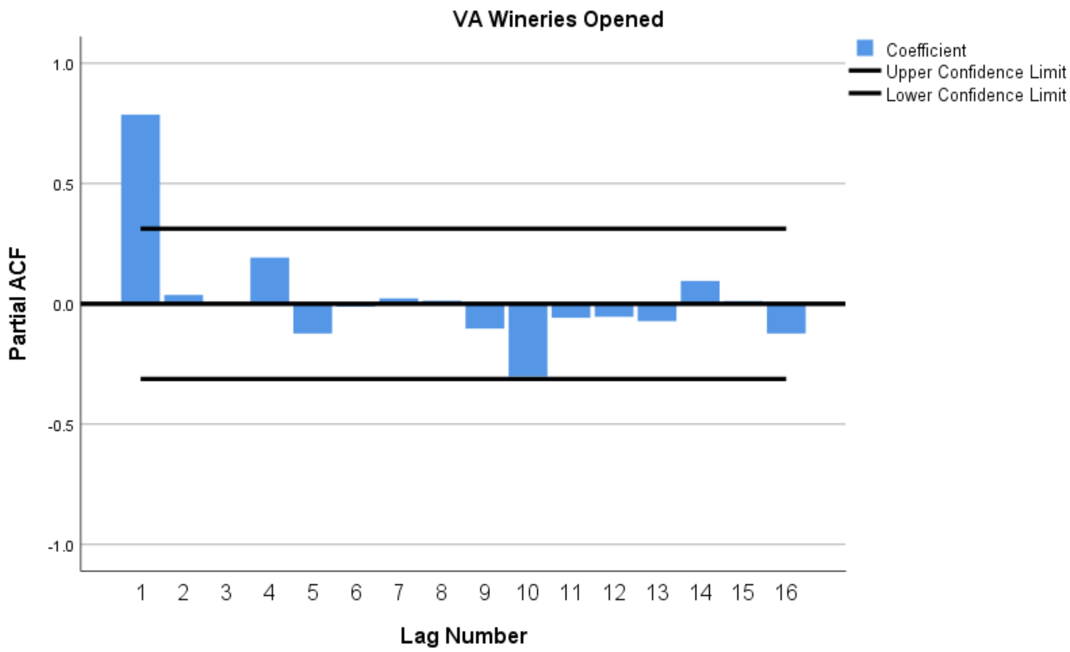

Figure 9: Untransformed PACF Results for VA

On the log-transformed dataset, the same general pattern is observed in the ACF (Figure 10). The coefficient values have been muted, with the 1-year lag having a coefficient of .630. The PACF (Figure 11) as well preserves the same general pattern, although the negative coefficient at year 10 is no longer considered significant.

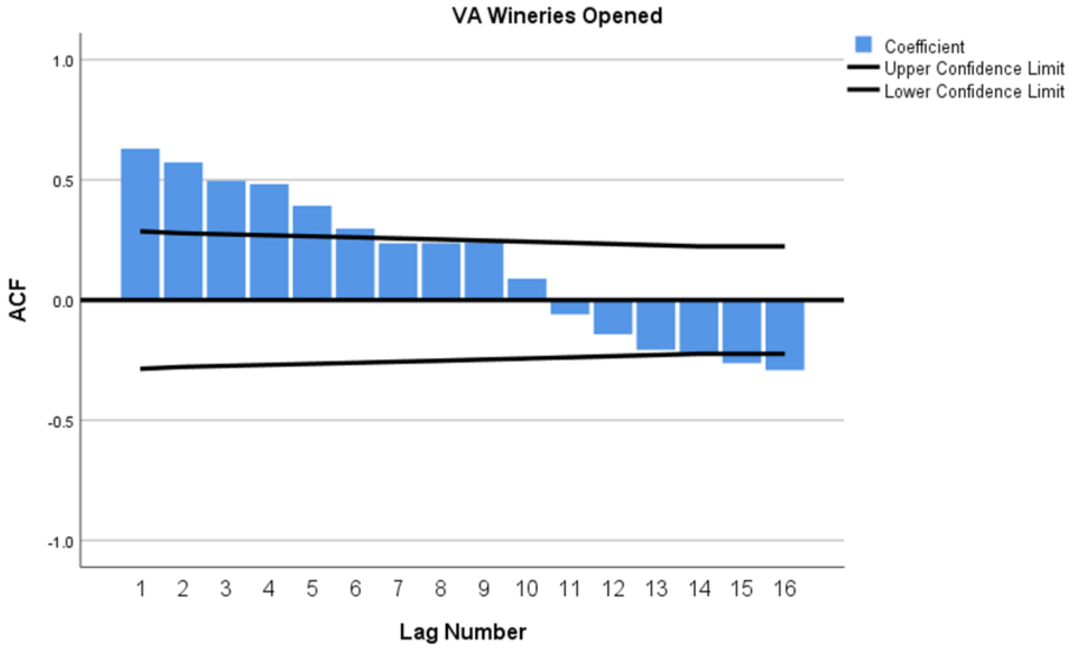

Figure 10: Log-Transformed ACF results for VA

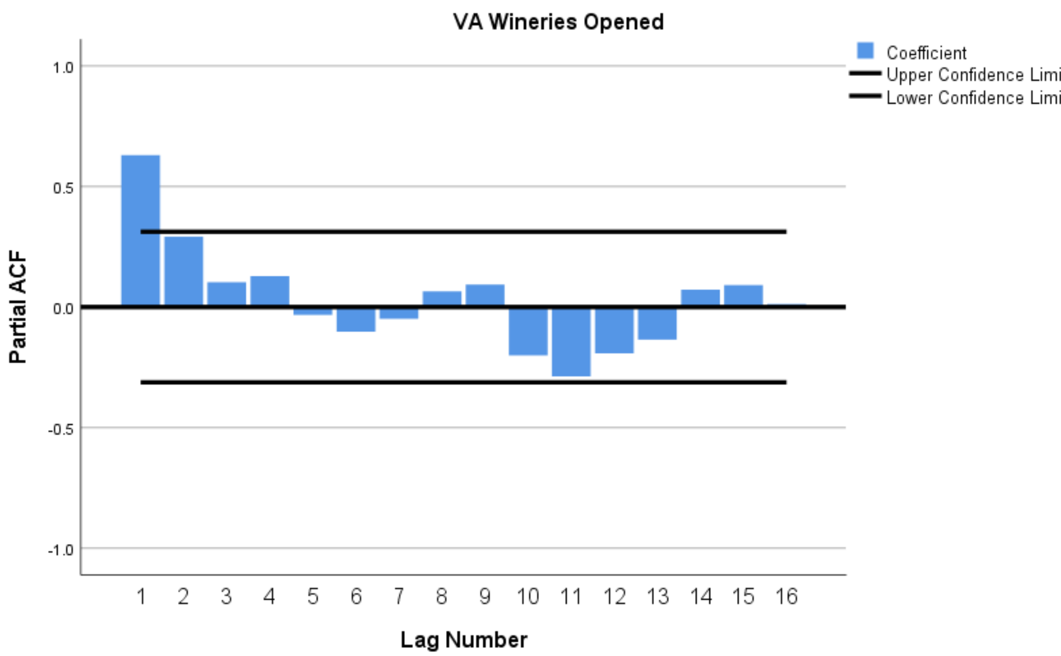

Figure 11: Log-Transformed PACF results for VA

New York

From the untransformed dataset, the ACF (Figure 12) is positive and significant for time lags of 1-4 years. Uniquely among the datasets, the coefficient actually increased from .612 to .623 when increasing the lag from 1 to 2 years. This increase is followed by a gradual decline as the time lag increases, becoming negative at 9 years, and significantly negative for lags of 12-16 years, with the lowest coefficient being -.364 at a lag of 14 years. The PACF (Figure 13) is significant and positive for time lags of 1 and 2 years, dropping off sharply at longer lags, with no other significant coefficients.

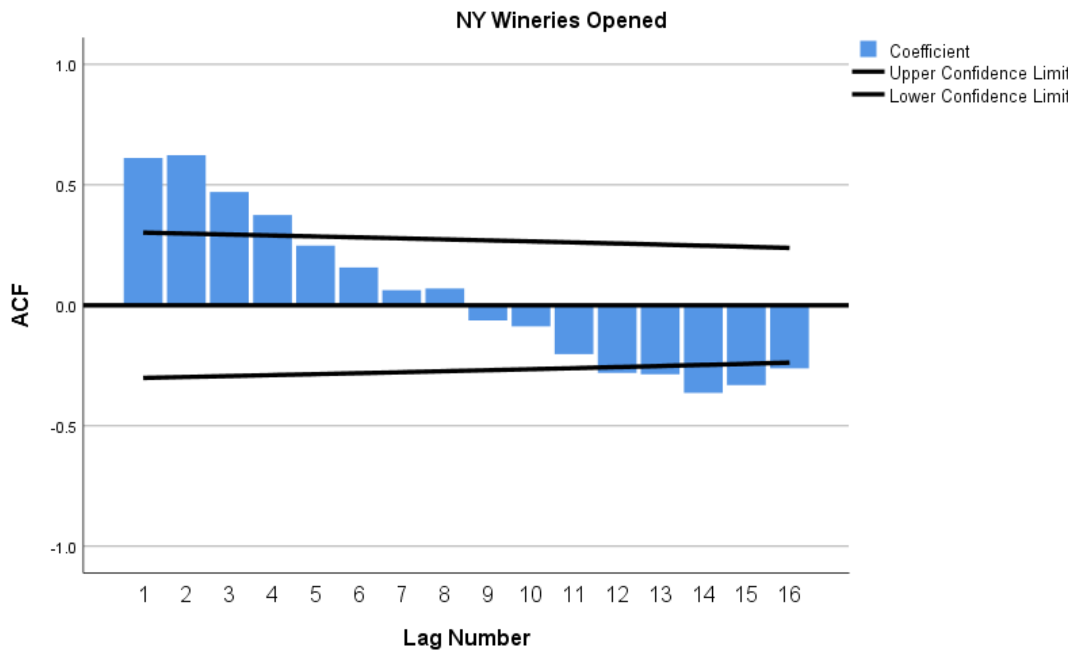

Figure 12: Untransformed ACF results for NY

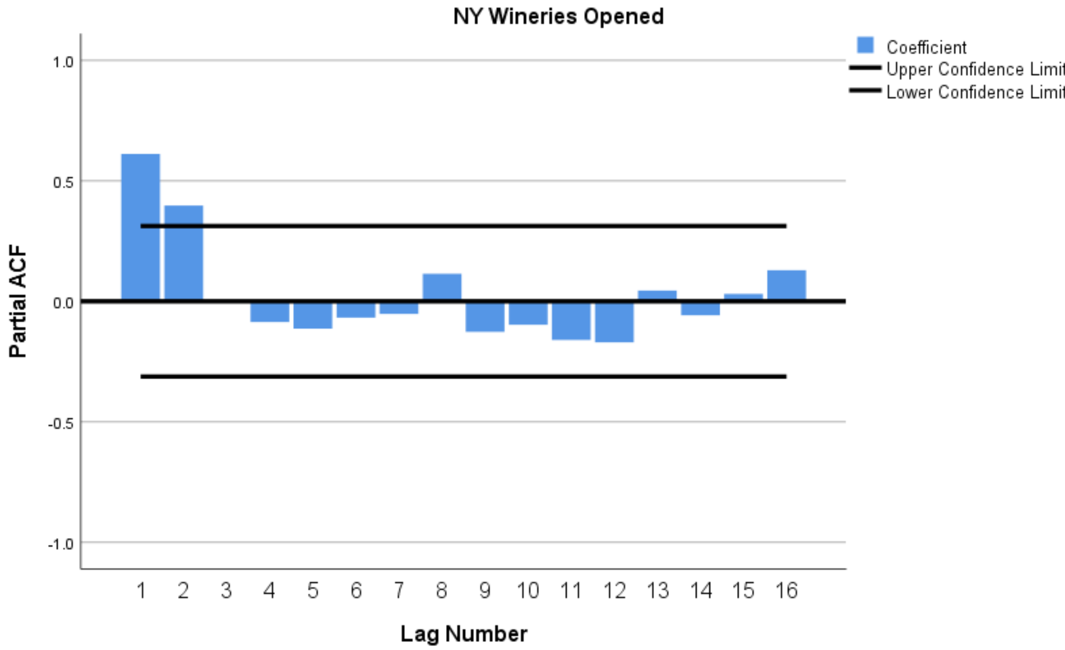

Figure 13: Untransformed PACF results for NY

On the log-transformed dataset, while the ACF (Figure 14) coefficients remain significant and positive for lags of 1-4 years, there is no longer an increase between lags of 1 and 2 years. Coefficients become negative at a lag of 8 years, but only significantly so for lags of 13-16 years. The general pattern of the PACF (Figure 15) remains unchanged, with positive and significant coefficients at time lags of 1-2 years, and no other significant values at any other lag.

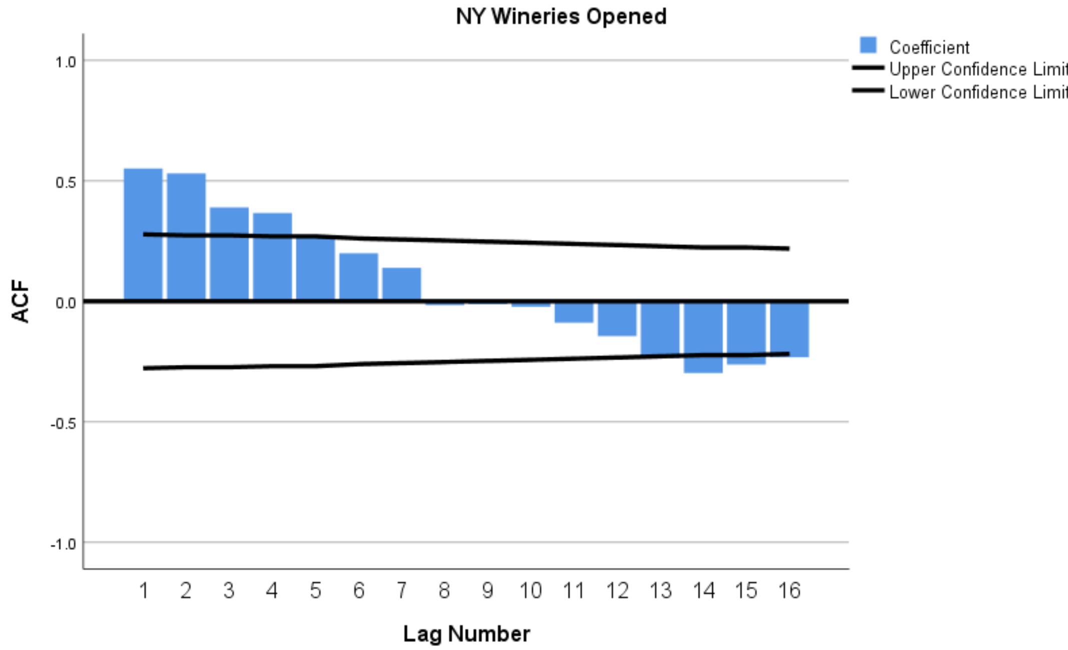

Figure 14: Log-transformed ACF results for NY

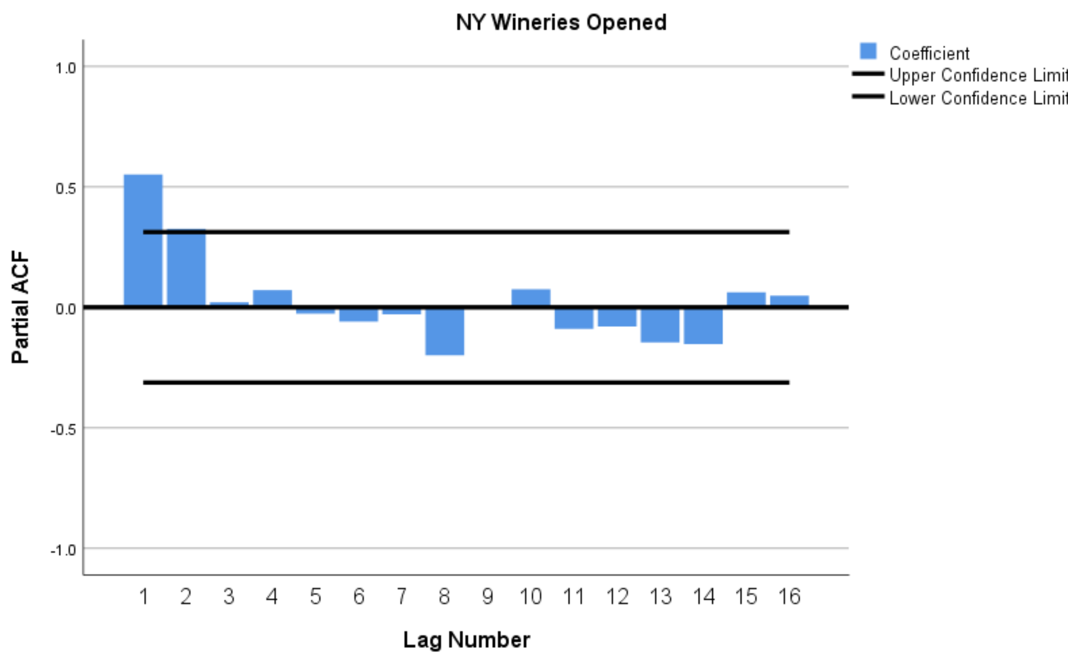

Figure 15: Log-transformed PACF results for NY

Pennsylvania

From the untransformed dataset, the ACF (Figure 16) is positive and significant for lags of 1-2 years, though the coefficient at lag 1 is the lowest of any state studied at .389. No other lags show significant coefficients, and the overall pattern oscillates between positive and negative. The PACF (Figure 17) also shows an oscillation between positive and negative, having two significant and positive coefficients at lags of 1 and 8 years.

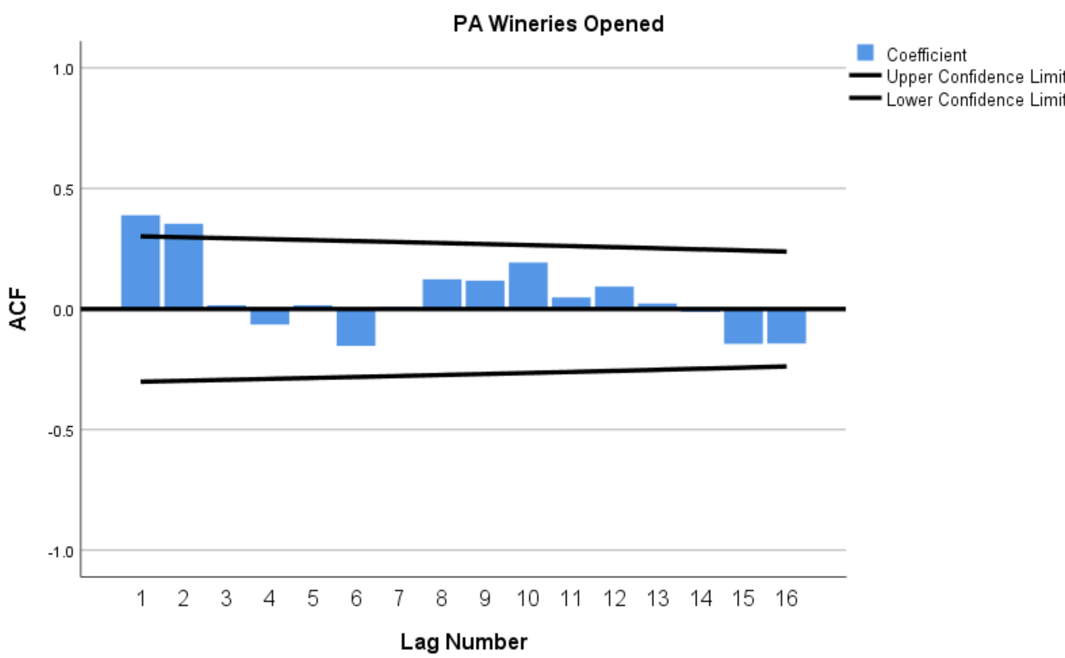

Figure 16: Untransformed ACF results for PA

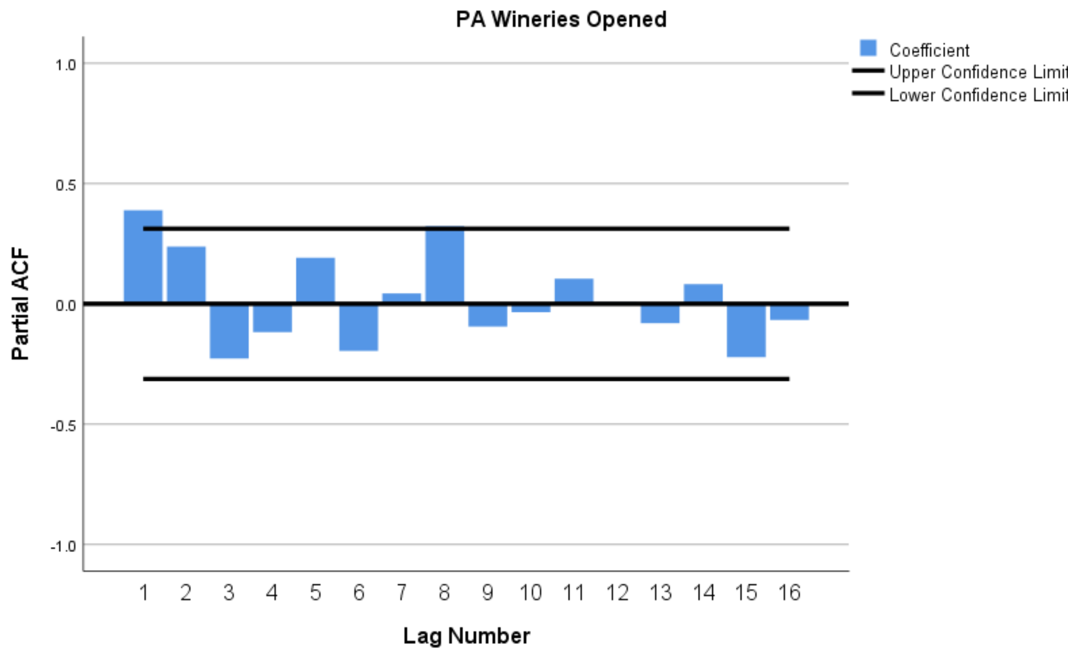

Figure 17: Untransformed PACF results for PA

On the log-transformed dataset, the oscillating pattern is preserved in the ACF (Figure 18). Three significant and positive coefficients are seen at lags of 1, 2, and 10 years. No significant PACF (Figure 19) coefficients were observed.

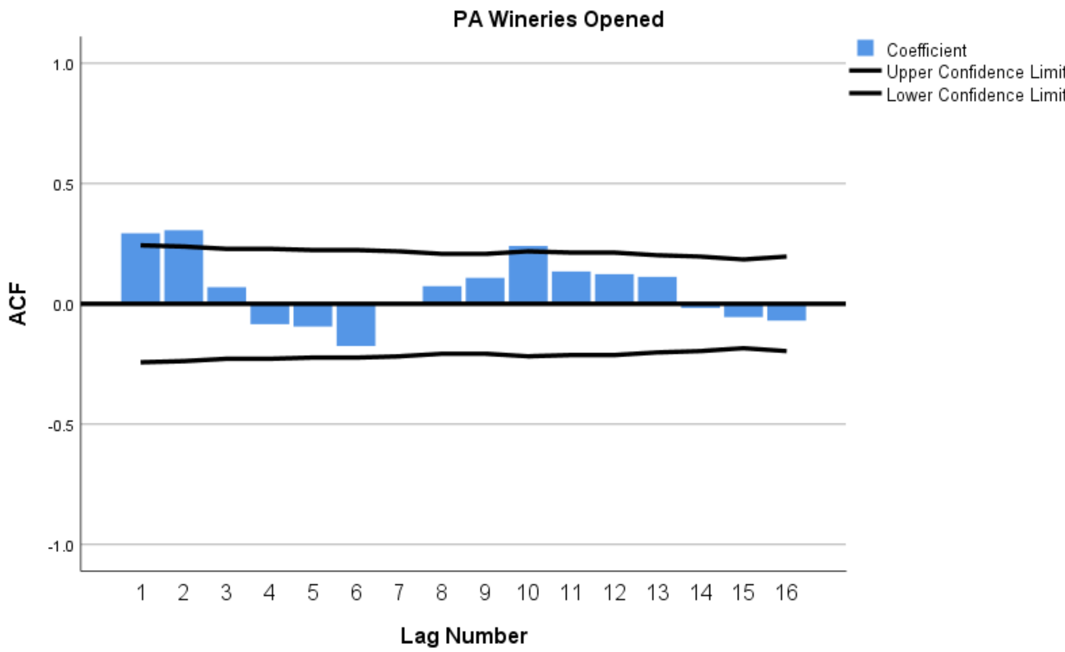

Figure 18: Log-transformed ACF results for PA

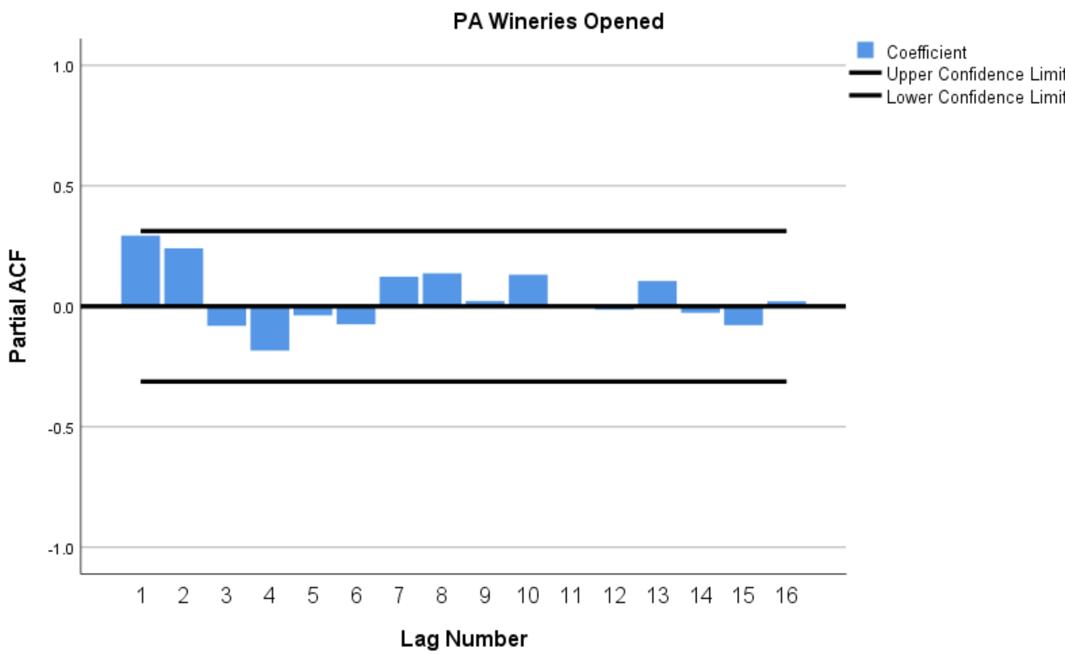

Figure 19: Log-transformed PACF results for PA

New Jersey

From the untransformed dataset, the ACF (Figure 20) is significant and positive for lags of 1-3 years, sharply dropping into negative but insignificant coefficients for lags of 5 years and greater. The PACF (Figure 21) is significant and positive for a lag of 1 year, and significant and negative for a lag of 5 years.

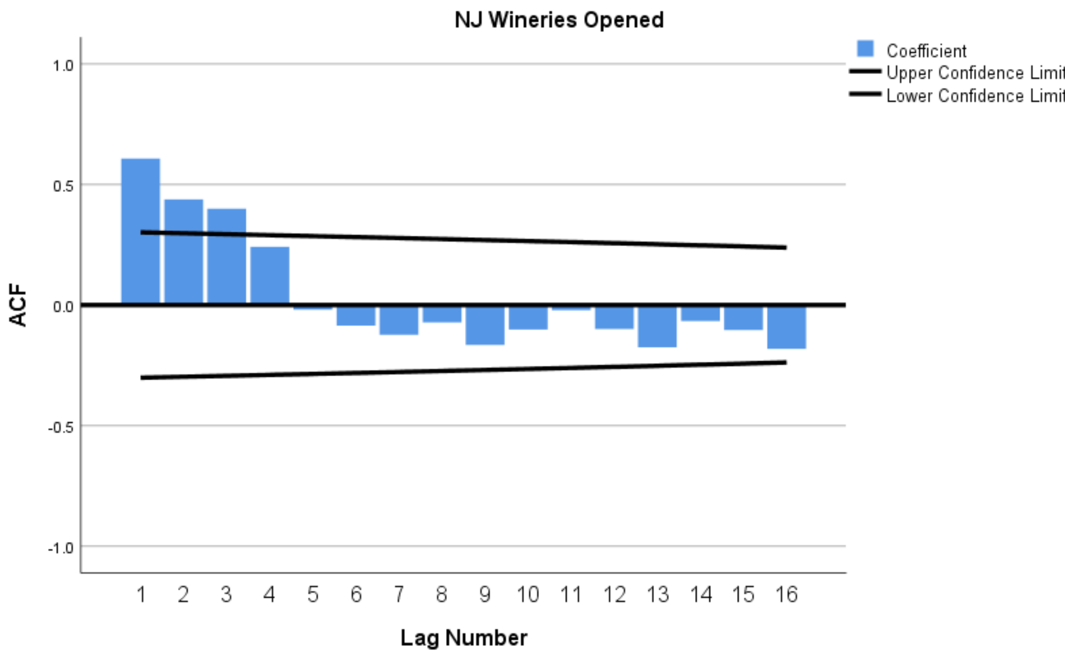

Figure 20: Untransformed ACF results for NJ

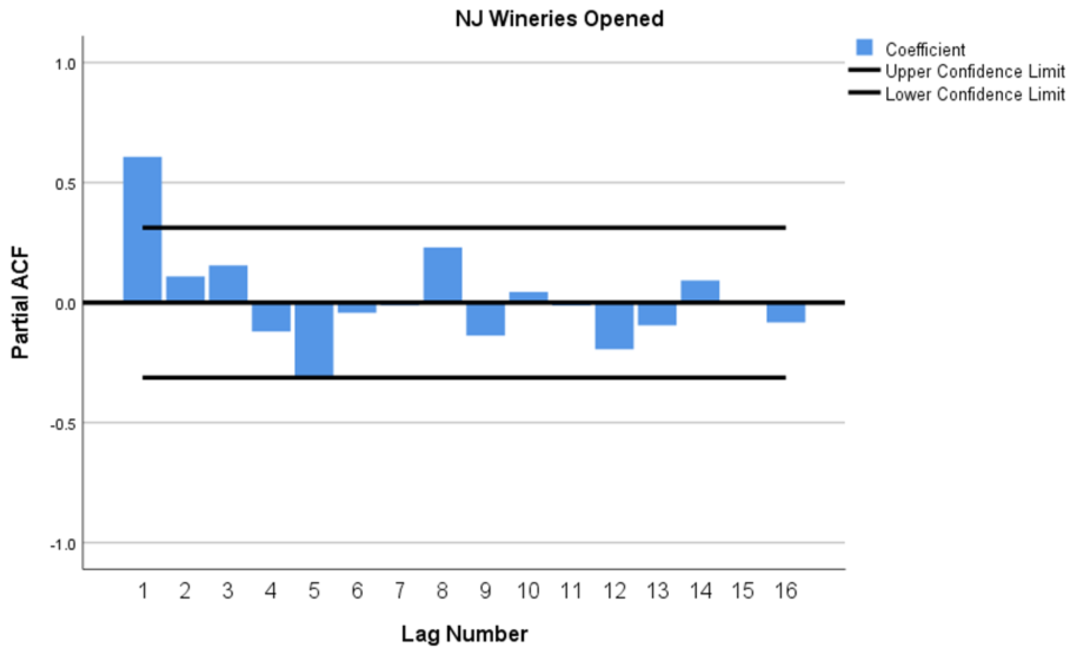

Figure 21: Untransformed PACF results for NJ

On the log-transformed dataset, the ACF (Figure 22) is significant and positive for lags of 1-4 years, only showing negative coefficients at lags of 7 years and greater. The PACF (Figure 23) shows a nearly identical pattern to that of the untransformed dataset.

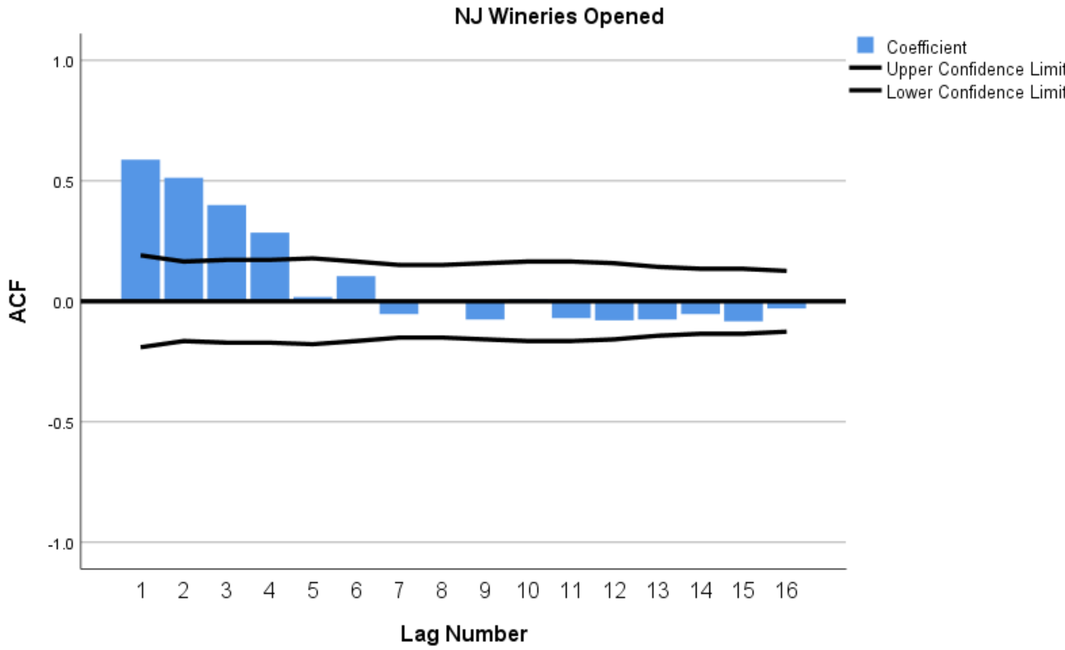

Figure 22: Log-transformed ACF results for NJ

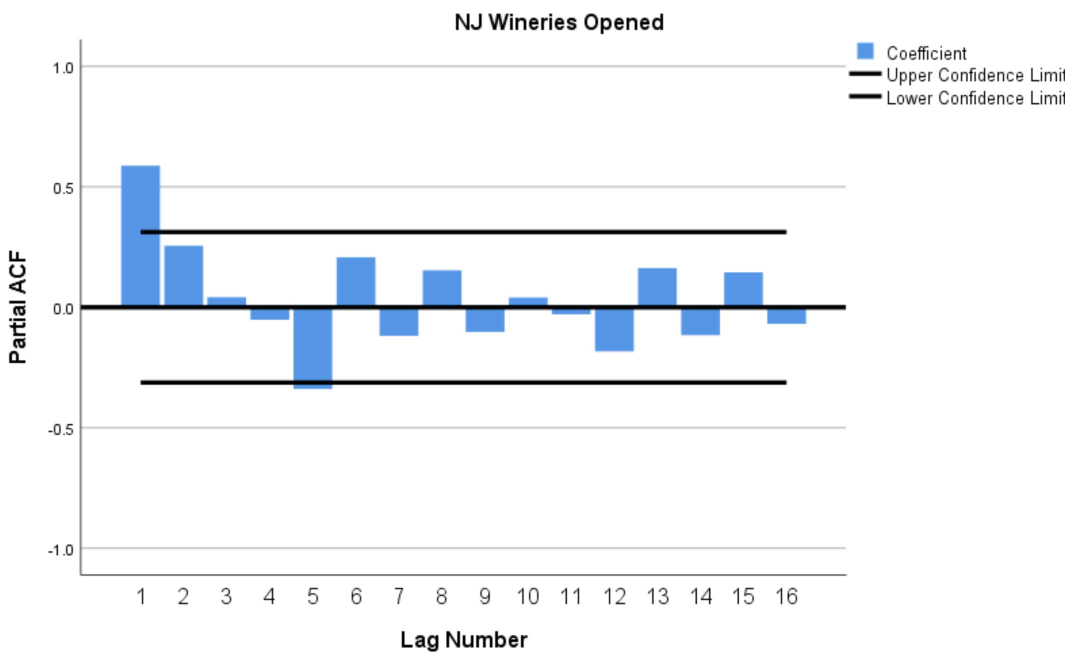

Figure 23: Log-transformed PACF results for NJ

Maryland

From the untransformed dataset, the ACF (Figure 24) is significant and positive for lags of 1-6 years, showing a general gentle downward trend with no other significant coefficients. The only exception to this pattern is the upward spike at a lag of 5 years. The PACF (Figure 25) is significant and positive only at a lag of 1 year, showing a pattern that oscillates between positive and negative.

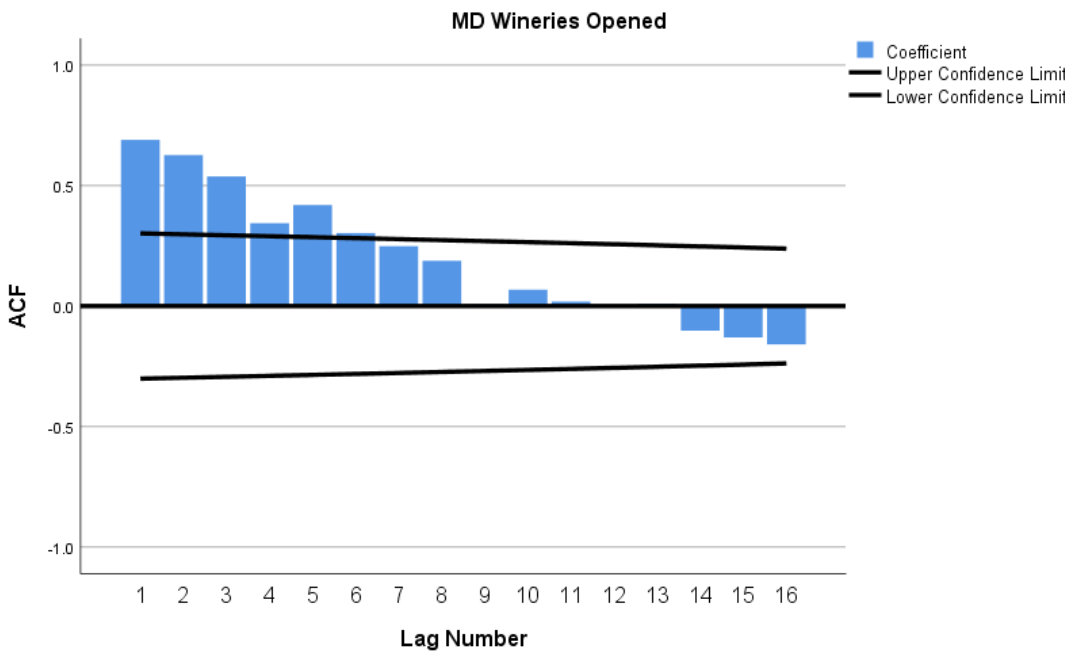

Figure 24: Untransformed ACF results for MD

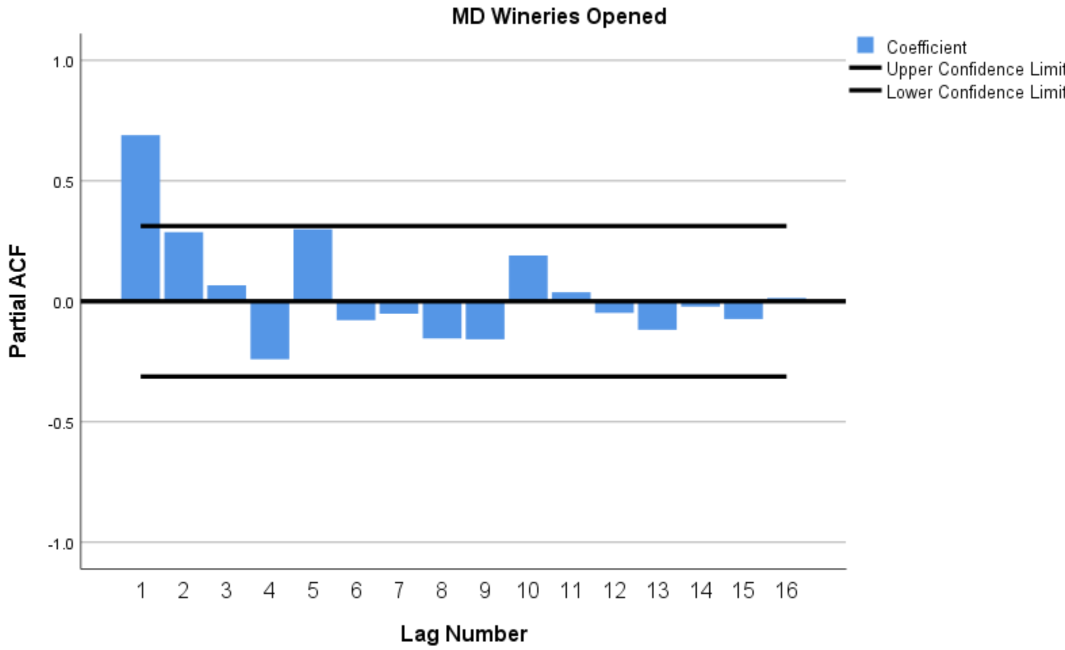

Figure 25: Untransformed PACF results for MD

On the log-transformed dataset, the ACF (Figure 26) and PACF (Figure 27) show nearly identical patterns to that of the untransformed dataset.

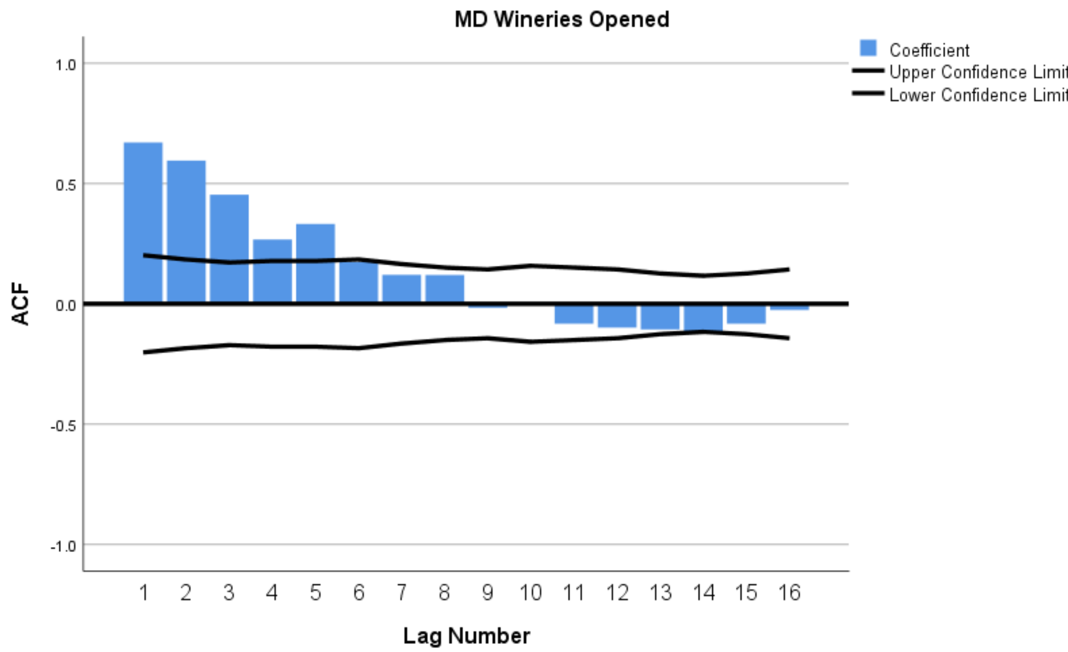

Figure 26: Log-transformed ACF results for MD

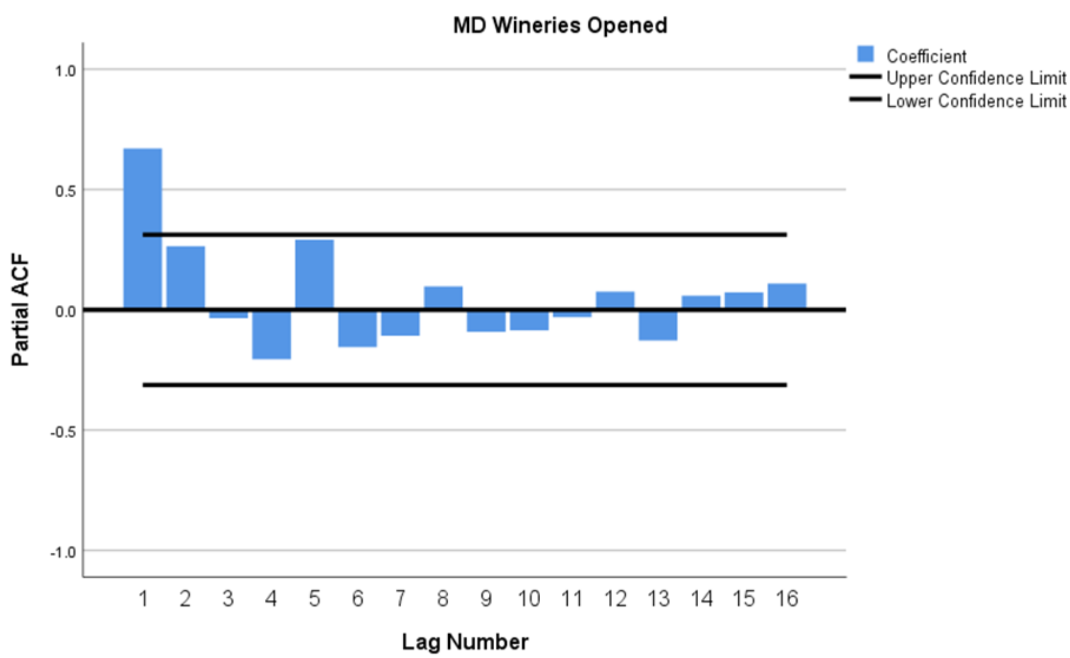

Figure 27: Log-transformed PACF results for MD

Total Mid-Atlantic Region

From the untransformed dataset, the ACF (Figure 28) is significant and positive for lags of 1-7 years, showing a gradual downward trend, becoming negative at lags of greater than 10 years, and significantly negative at lags of 13-16 years. The PACF (Figure 29) is only significant in a lag of 1-year, showing an oscillating pattern afterward.

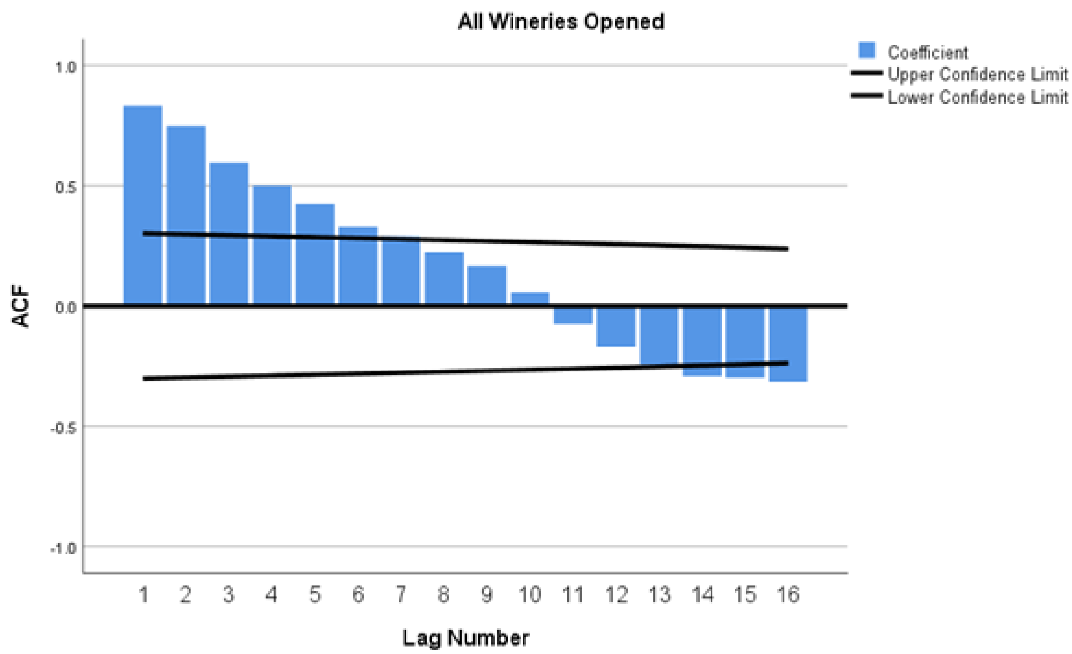

Figure 28: Untransformed ACF for the total Mid-Atlantic Region

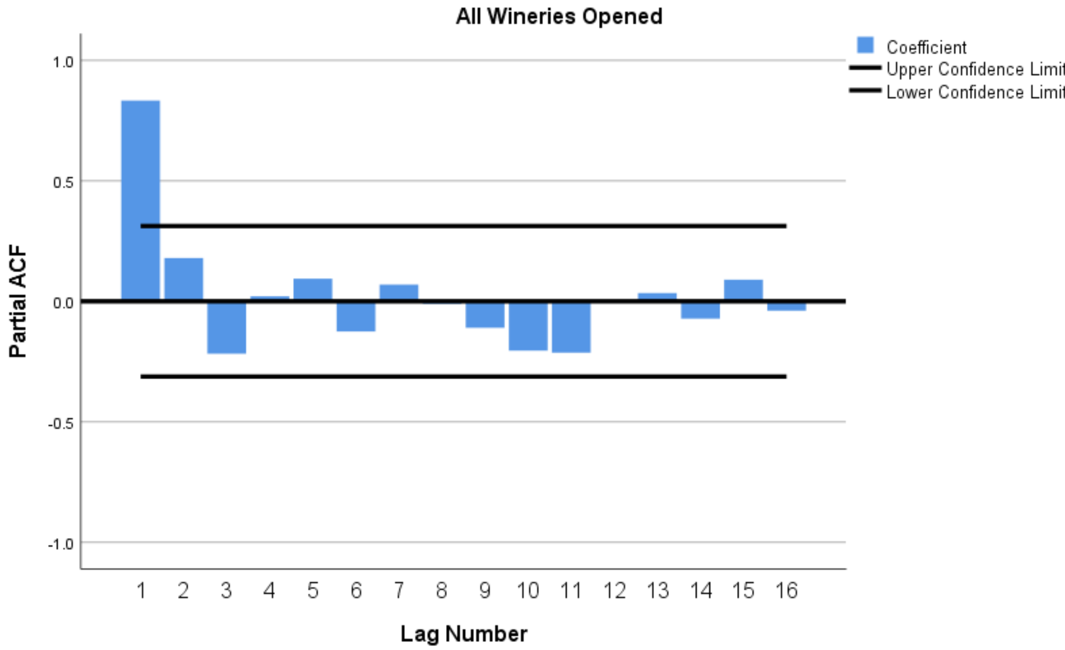

Figure 29: Untransformed PACF for the total Mid-Atlantic Region

On the log-transformed dataset, the ACF (Figure 30) exhibits a similar pattern, though the trend is less smooth. The only negative significant coefficients are at lags of 14 and 16 years. The PACF (Figure 31), while still showing an oscillating pattern, has positive and significant coefficients at lags of both 1 & 2 years.

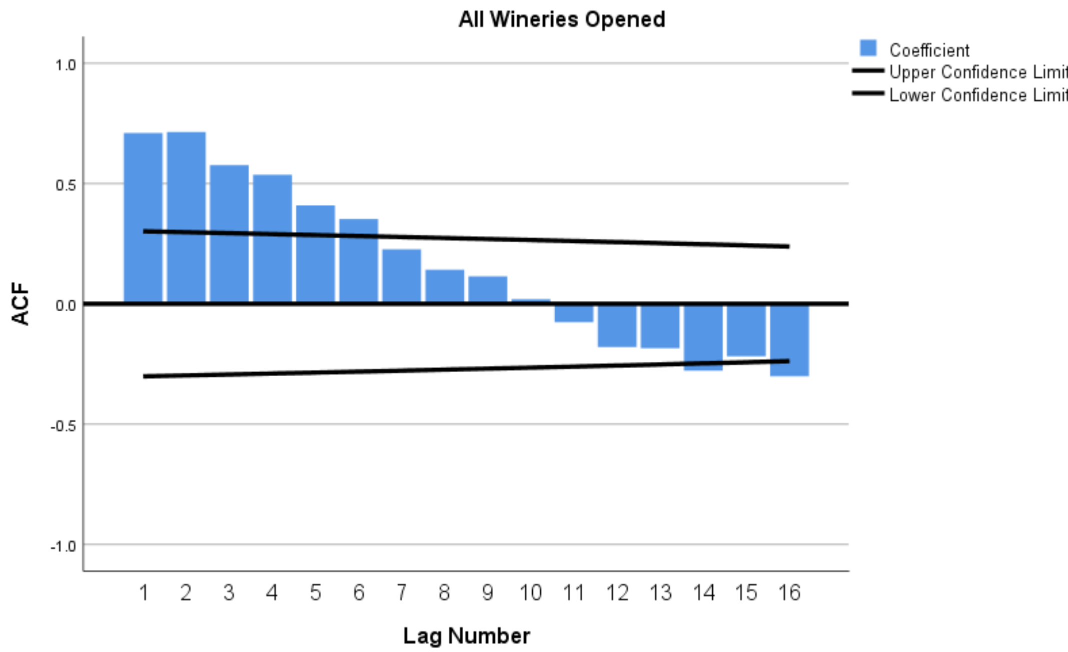

Figure 30: Log-transformed ACF for the total Mid-Atlantic Region

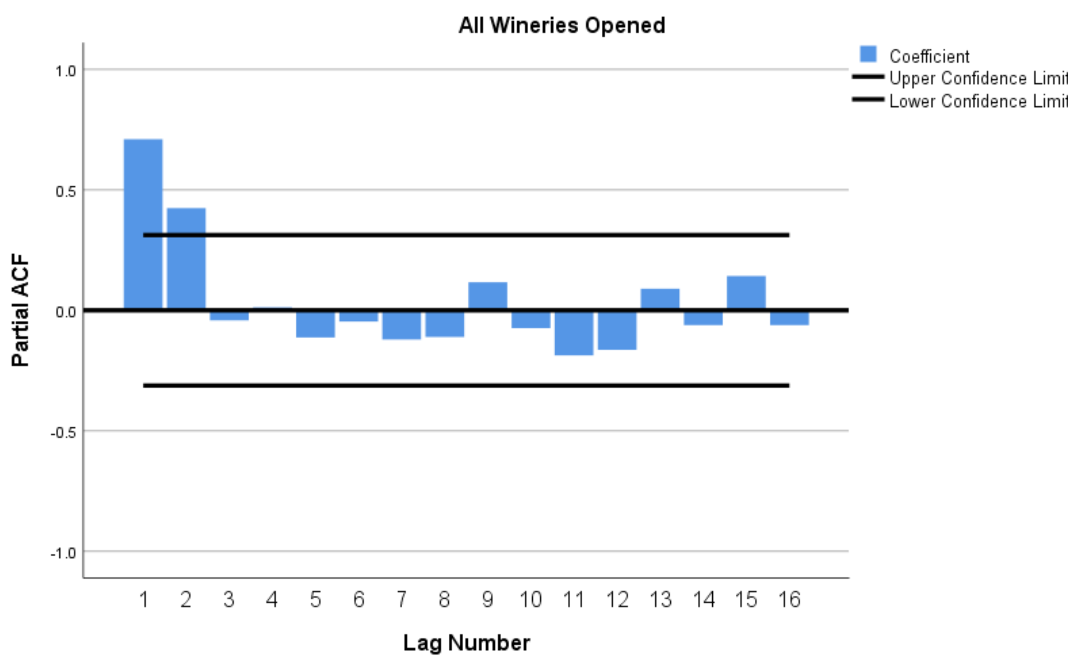

Figure 31: Log-transformed PACF for the total Mid-Atlantic Region

Conclusions

Overall, putting the datasets of wineries opened each year in each state. through log-transformation before Autocorrelation testing did not change the observed trends of the ACF or PACF coefficients, though the significance of individual coefficients close to the confidence limits was affected. The differences observed will not greatly affect the interpretation of results.

In Virginia, the ACF remained significant and positive for longer lags and at the longest lags became negative, contrary to my hypothesis of a sharp drop off after a lag of 2 years with no significant negative coefficients. The PACF showed a sharp drop off after 1 year but did have significant negative coefficients at longer lags.

The unexpected nature of these results could be attributed to the fact that my hypothesis was based on previous research (Miyares, 2017), which did not factor in the wineries opened in 1976 and emphasized the PACF over the ACF results. As a result, I underestimated the affect that a gradual, long-term upward trend in the data would have on the ACF. If such a trend exists, the degree to which a low or high value in one year will predict high or low value for years soon after is high but will gradually invert as the trend continues over time. Though less pronounced, this effect was also observed in the PACF.

My hypothesis for New York was the same as that for Virginia, based upon similar trends I saw in their data. The ACF results, while not matching my hypothesis, still closely resembled those of Virginia, exhibiting a long-term trend. The PACF results, however, matched my hypothesis more closely, with both the 1- and 2-year lags having significant and positive coefficients, and no significant negative coefficients. This may be accounted for by noting the greater volatility in the New York dataset, with some years having 0 wineries open between two years with a relatively high number of winery openings.

Pennsylvania had been singled out as the most volatile state in its pattern of winery openings, as the only state in which I hypothesized negative significant ACF and PACF coefficients. While none of the negative coefficients observed surpassed the confidence limit, a strong oscillating pattern was observed, with dips into the negative followed by positive spikes for 8-year lags for the PACF, and 10-year lags for the ACF. This would seem to indicate that Pennsylvania winery openings exhibit a more cyclical pattern over time, as opposed to the general upward trend evident in the other states, and the region overall.

In New Jersey, I had predicted a more gradual drop off of positive and significant ACF values, rather than a sharp drop after a lag of 1 or 2 years. While the trend was as gradual as predicted, it was less so than Virginia or New York, possibly due to the fact that the sudden growth of wineries in the early 2000's followed over 20 years of only one or no wineries opening, exhibiting more of a spike than a trend. The PACF showed an unexpected negative coefficient at a lag of 5 years, which may also be attributed to the early 2000's "spike."

Maryland's ACF results more closely reflected a general upward trend, similar to those of Virginia, though not as strongly, as there were no significant negative ACF or PACF coefficients at long lags.

Analyzing the total wineries opened each year across the entire study area, including the state of Delaware, also gave results strongly indicating that of a gradual, long-term upward trend. The ACF graph was nearly identical to those of Virginia and New York, though no significant negative PACF values were observed.

From these results, we see that the Mid-Atlantic region of the US showed a strong general upward trend in the number of wineries opened each year over time, though there was a significant spatial differentiation in the manifestation of this pattern over all the states within this region. One state, Pennsylvania, even exhibited a cyclical trend in contrast to the rest of the region.

The changes in rate of openings argue for the prevalence of economic factors in the decision to open a winery, and the differences in pattern between the entire region and each of the states argue for the prevalence of local economic factors, as opposed to regional or national ones being relevant. The spatial differentiation observed also argues against the possibility of a globally-generalized model of wine region growth.

CHAPTER 3: NEAREST NEIGHBOR RATIO ANALYSIS

This chapter will cover the methods, hypothesis, and results of my Nearest Neighbor Analysis of Farm Winery locations over time in each state. The purpose of this analysis is to determine if the general distribution of Farm Wineries within a state is clustered or dispersed, and if that pattern changes over time. Comparing the results across each state and to the entire region can then determine if there is a commonality between them all that can be applied generally.

Methods and Hypothesis

This analysis was conducted in ArcMap version 10.5. From the dataset for each state and the region, 41 layers were derived, each showing the Farm Wineries successfully operating each year from 1975-2015. The Nearest Neighbor Ratio was then calculated for each layer and graphed to display its change over time. Certain datasets could not produce valid results for every year, as a minimum of four data points are required for a meaningful output to the analysis tool. The confidence interval chosen for significance was 95%.

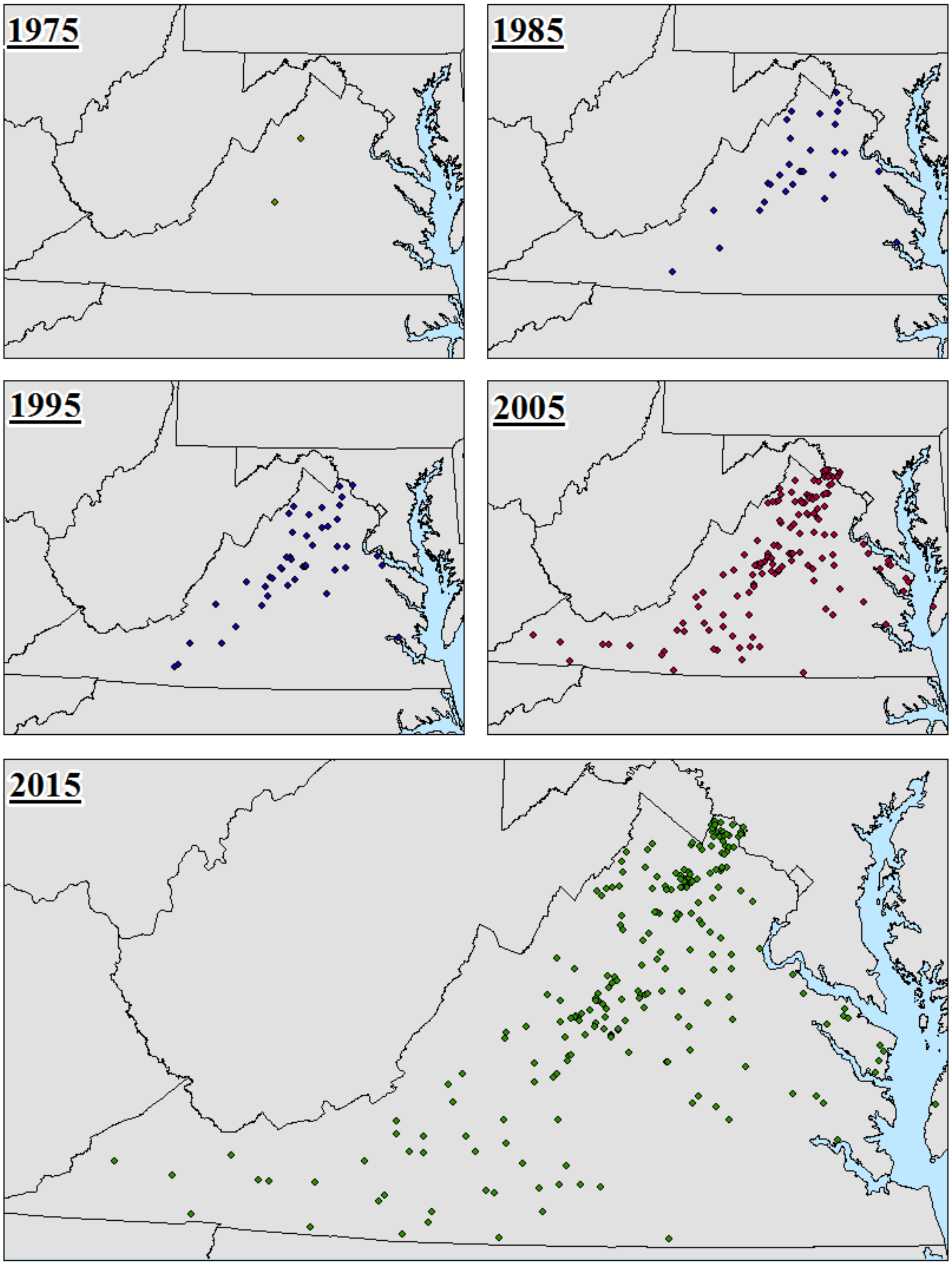

Figure 32: Farm Wineries in VA 1975-2015

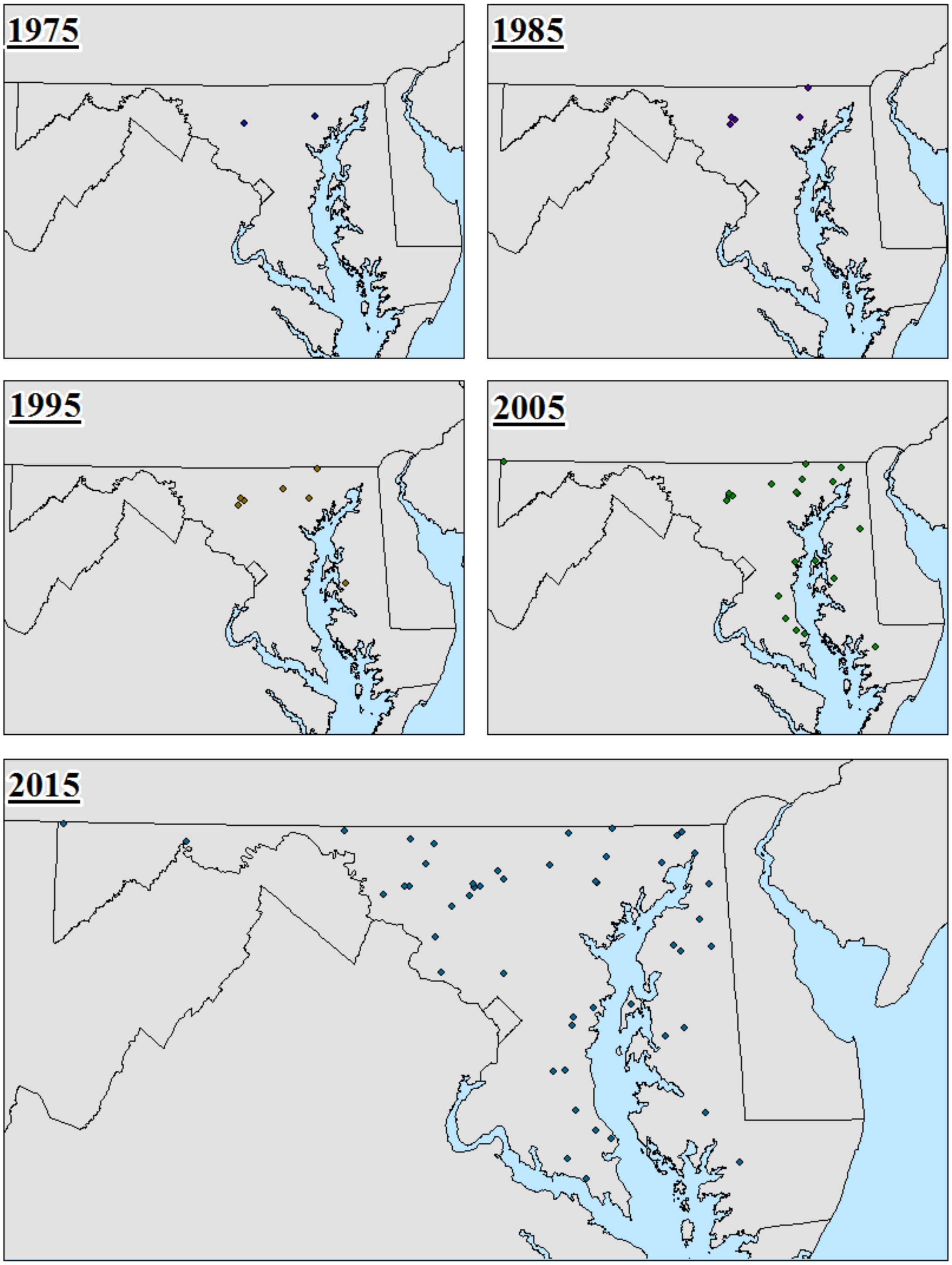

Figure 33: Farm Wineries in MD 1975-2015

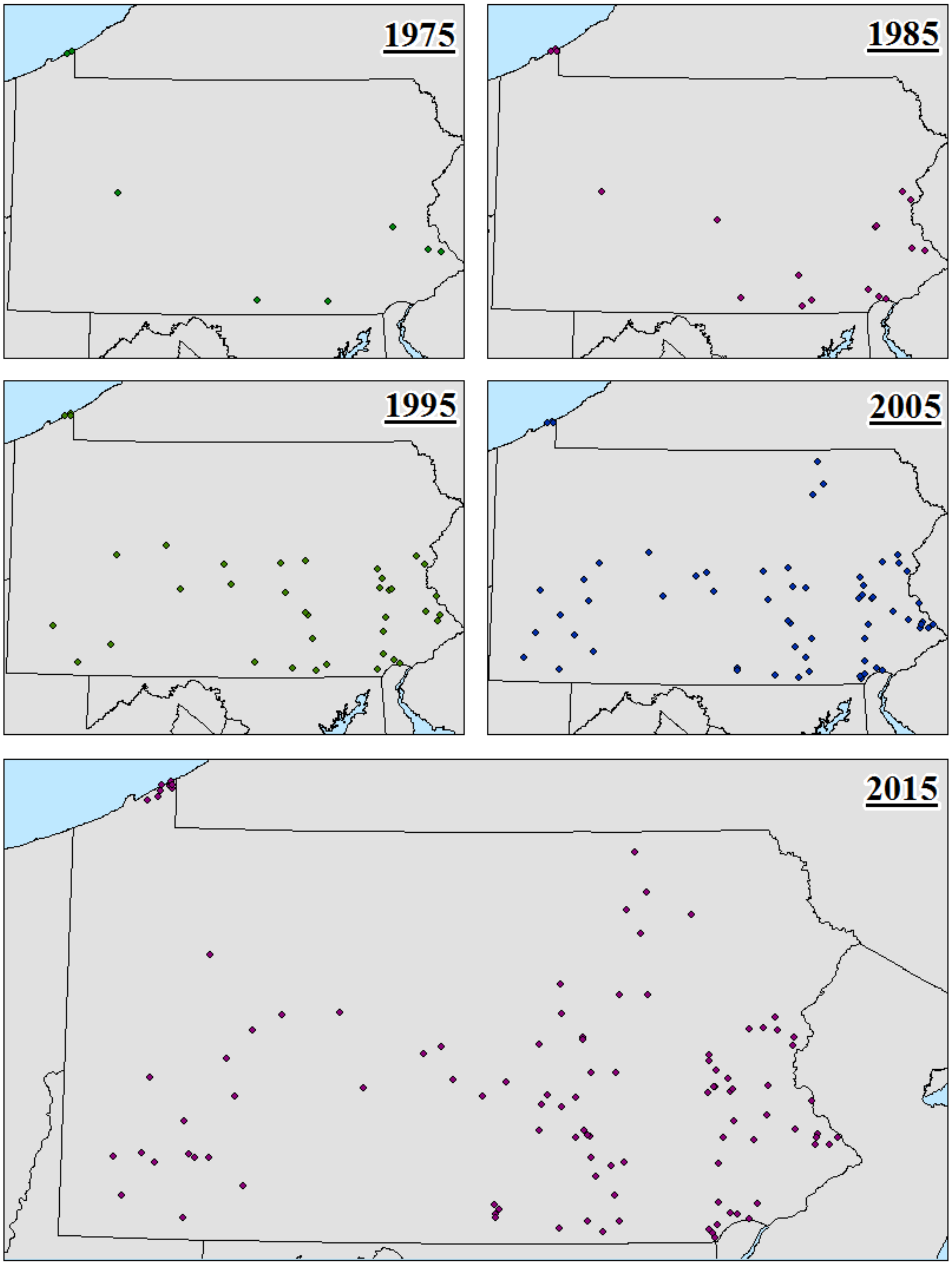

Figure 34: Farm Wineries in PA 1975-2015

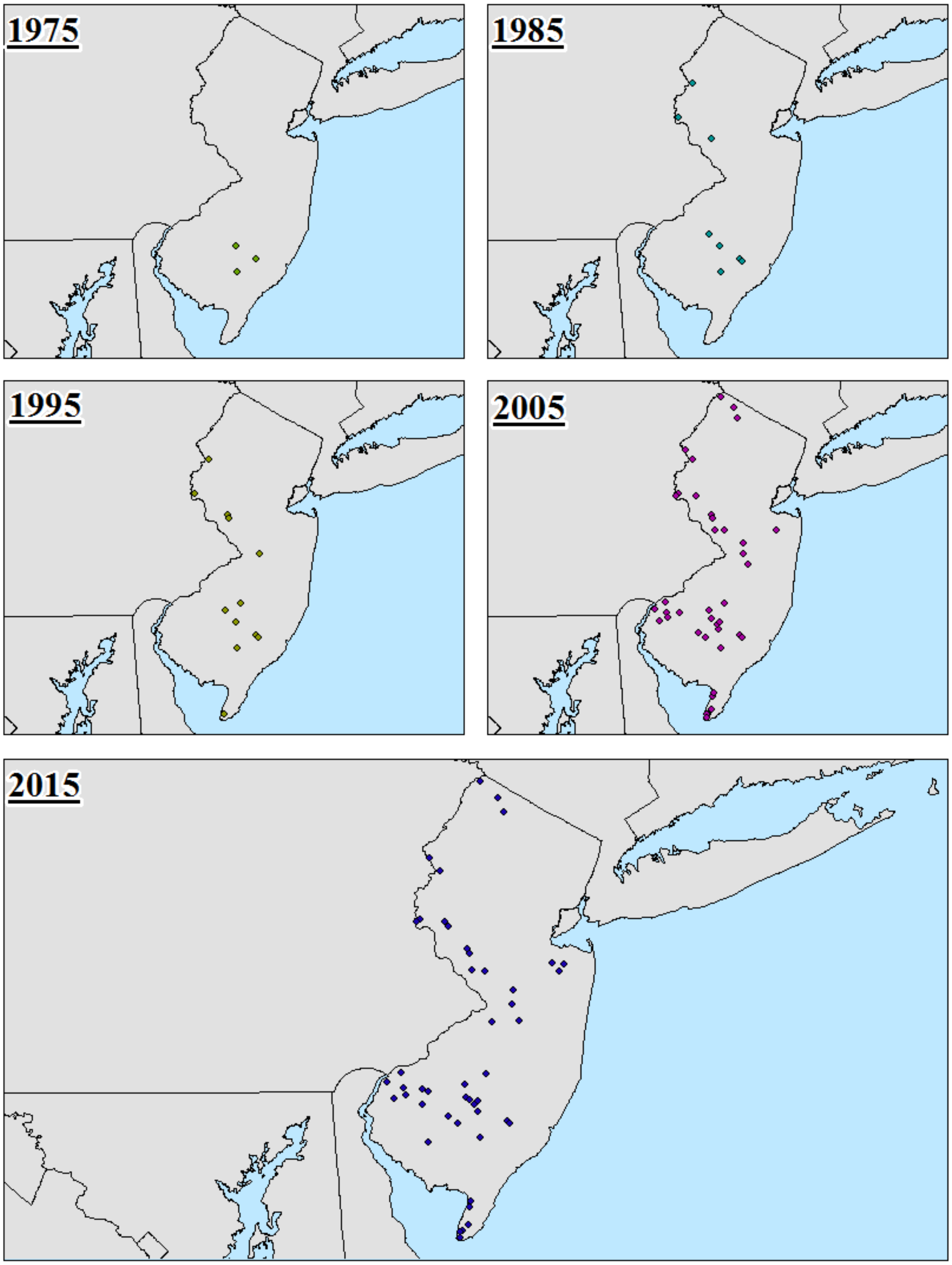

Figure 35: Farm Wineries in NJ 1975-2015

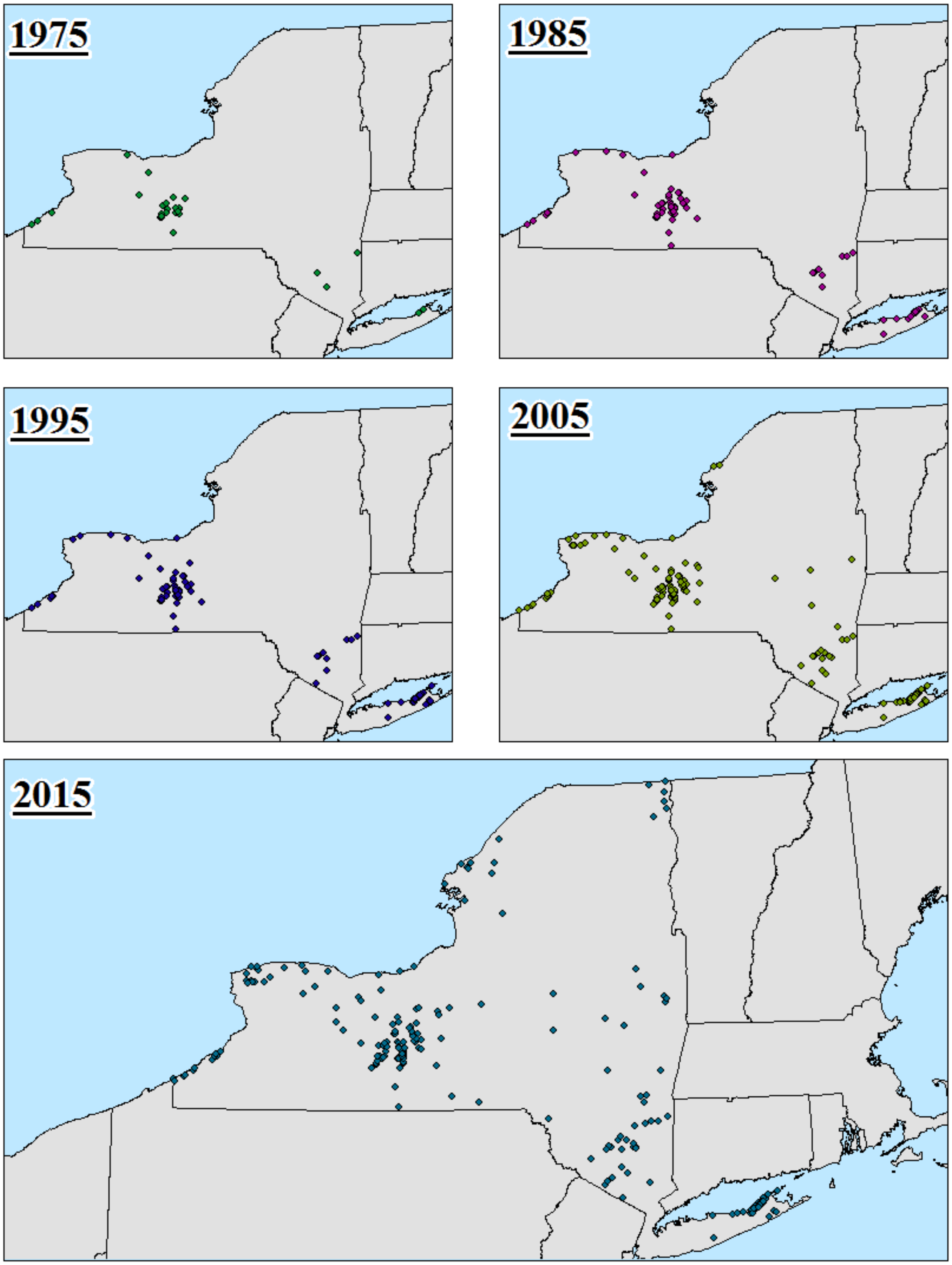

Figure 36: Farm Wineries in NY 1975-2015

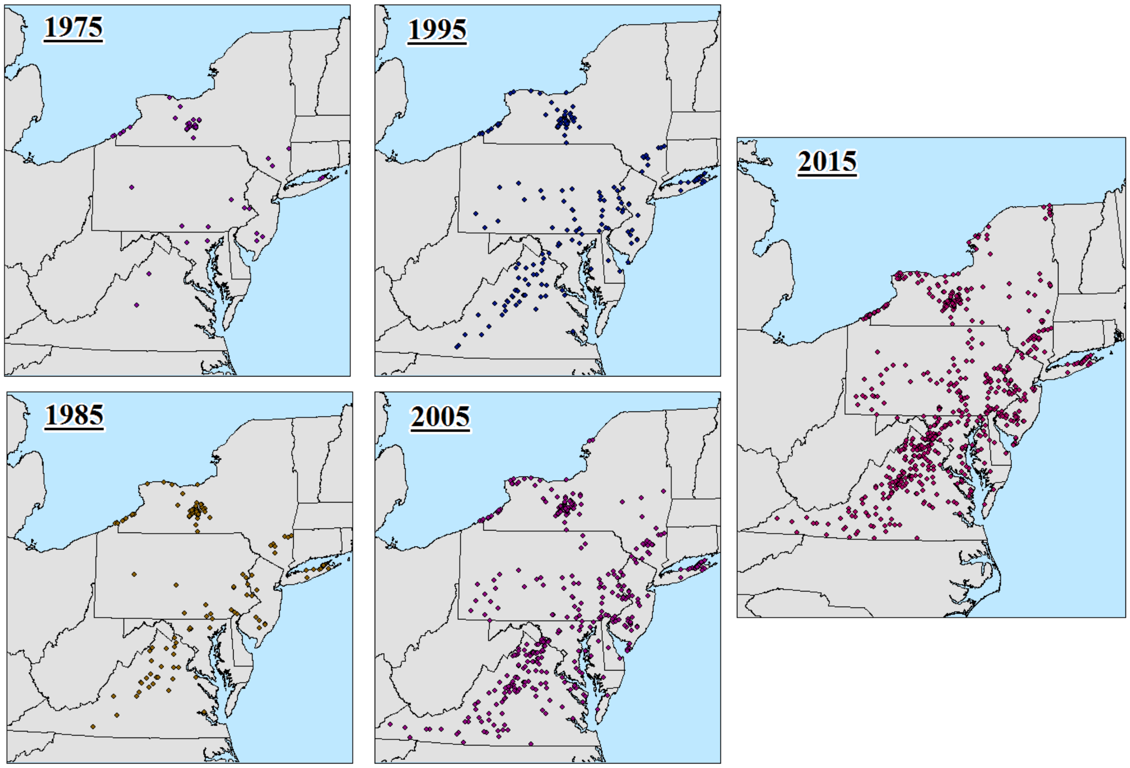

Figure 37: Farm Wineries in the Mid-Atlantic US 1975-2015

Hypothesis

From previous literature on the tendency of customers to visit multiple Farm Wineries in succession (Shor & Mansfield, 2010; Alant & Bruwer, 2010), it is reasonable to posit that Farm Wineries would spatially cluster to take advantage of consumer behavior. Empirical research into the formation of wine trails supports this (Xu et al., 2015). How this general tendency would manifest over time in a new wine region, where few previous establishments exist to cluster around, remains to be examined.

Previous research Farm Wineries in Virginia showed a distinct change in Farm Winery spatial distribution patterns over time. At the beginning of the study period, Farm

Wineries were in a statistically significant dispersed pattern, characteristic of a region where experimentation in discovering viable winery locations was taking place. Over time, the pattern would gradually and consistently become less dispersed and more clustered, as good and profitable locations were established, and new wineries were established in close proximity to successful ones (Miyares 2017).

I hypothesized that this pattern would apply generally across all states and the entire region. At the beginning of the study period, each state will have a Nearest Neighbor Ratio that is significantly greater than 1, indicating a dispersed pattern. Over time, this ratio trend downward at a gradual rate; and at the end of the study period, each state will have a Nearest Neighbor Ratio that is significantly less than 1, indicating a clustered pattern.

Results

The results of my analysis are displayed in column chart form. Columns are in blue if statistically significant and greater than 1, in orange if statistically significant and less than 1, and in purple if not significantly greater or less than 1.

Virginia

For Virginia (Figure 38), the first year where valid results could be derived from a Nearest Neighbor Ratio calculation was 1976, as 1975 had only two data points. The results are identical to previous research cited above, showing a gradual decrease from significantly dispersed between 1976-1980, to significantly clustered between 1993-2015, exactly as hypothesized.

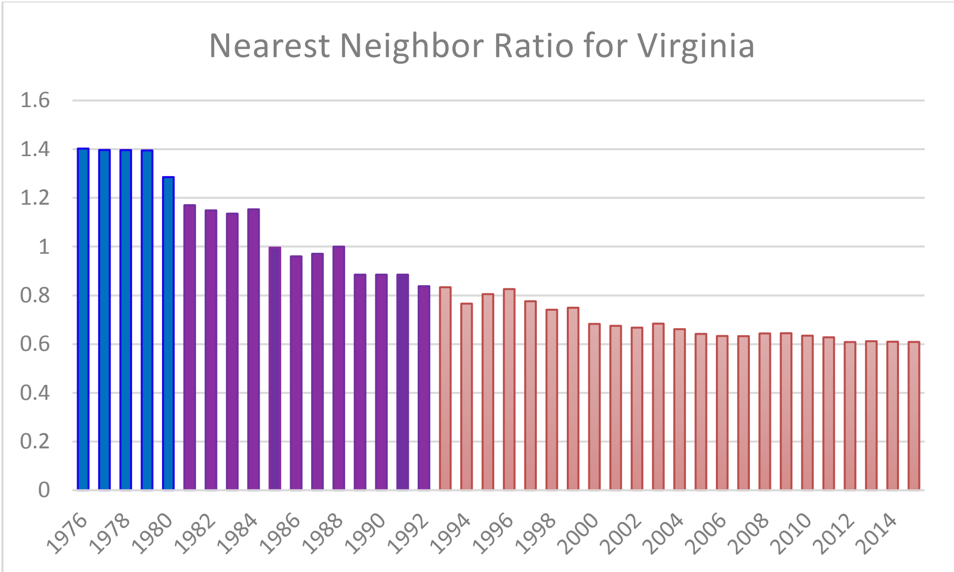

Figure 38: NNR Results for VA

New York

An entirely different pattern is displayed in the results for New York (Figure 39). Farm Wineries were significantly clustered throughout the entire study period. While there is greater clustering evident in 1975 than 2015, the general pattern remains relatively static, with brief instances of decreased clustering in 1980, 2000, and 2007. The degree of change is slight overall.

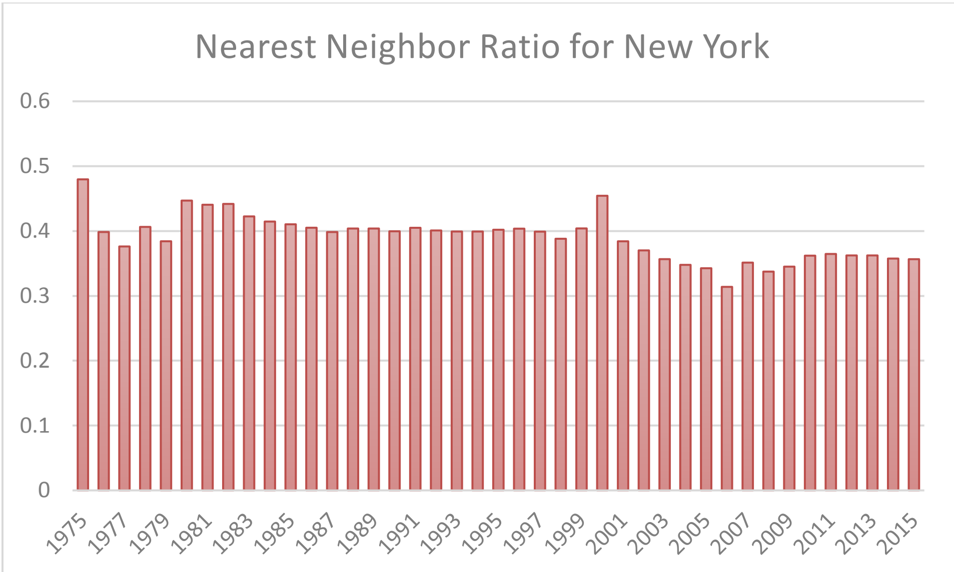

Figure 39: NNR Results for New York

Pennsylvania

Pennsylvania (Figure 40) exhibits a pattern closer to that of New York than Virginia. Farm Wineries begin as relatively, though not significantly, dispersed. There is a sharp drop in the Nearest Neighbor ratio between 1975 and 1978, which becomes significantly clustered in 1982. From that point, no long-term change in the degree of clustering in the state can be detected, though a temporary increase in dispersion occurred in 1998.

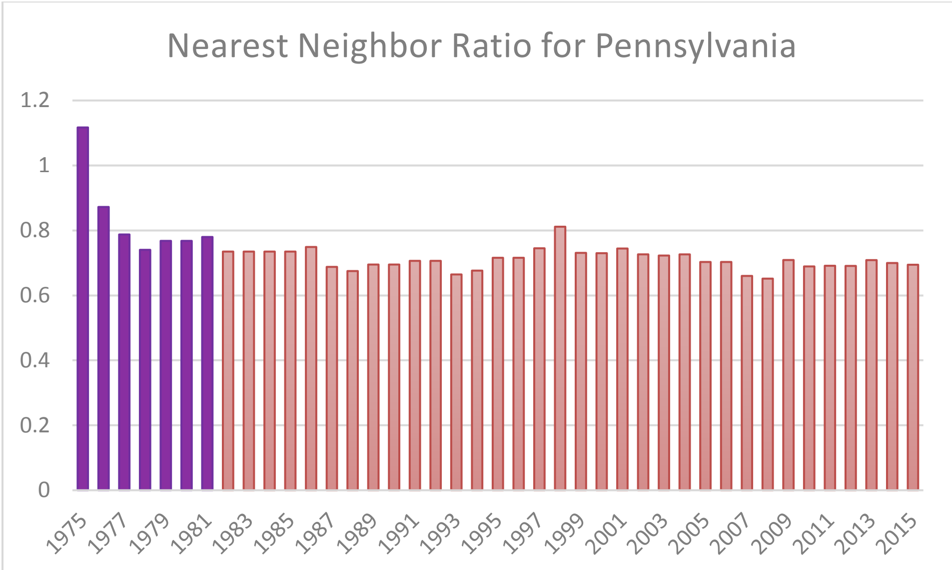

Figure 40: NNR Results for Pennsylvania

New Jersey

For New Jersey (Figure 41), the earliest year where valid results could be derived was 1976, as 1975 had only three data points. A trend towards clustering is more strongly apparent in in this dataset than those of New York or Pennsylvania, although the trend is not as constant as Virginia's. The most notable increases in dispersion can be seen in 1979 and 2001, after which the pattern becomes and remains significantly clustered, with no major changes.

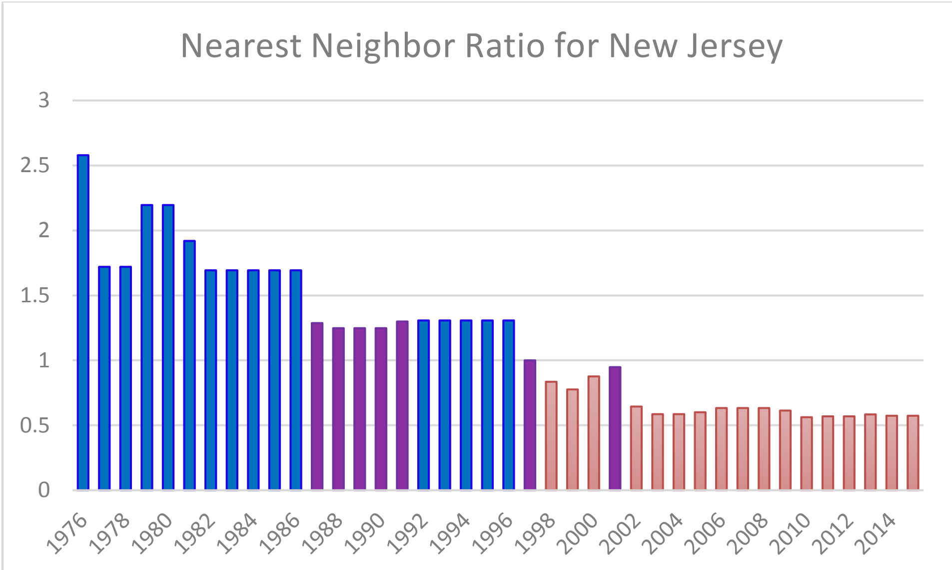

Figure 41: NNR Results for New Jersey

Maryland

For Maryland (Figure 42), the earliest year where valid results could be derived was 1981, as previous years had less than four data points. Maryland exhibits a pattern most similar to that of New Jersey, with a general trend towards clustering punctuated by reversals in 1986 and 1997.

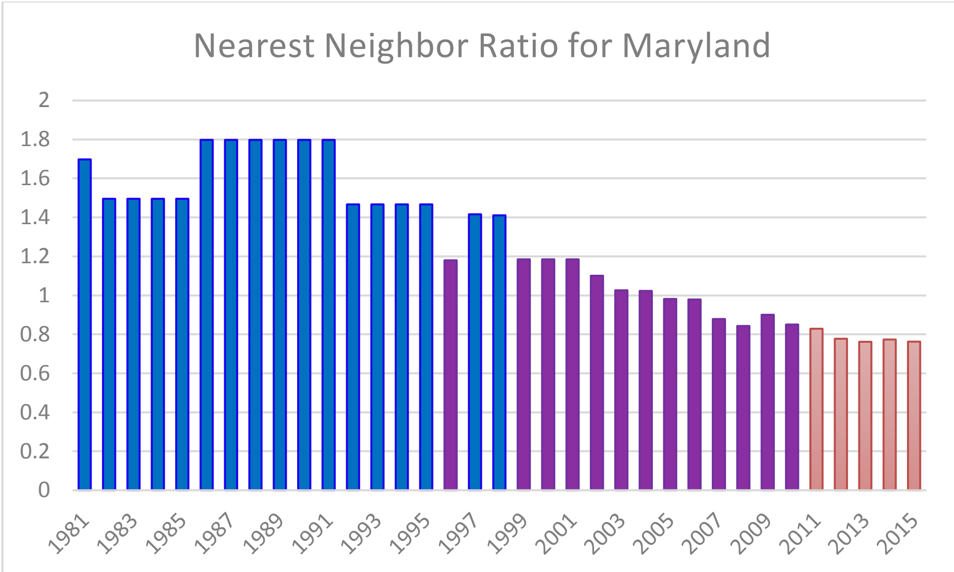

Figure 42: NNR Results for Maryland

Total Mid-Atlantic Region

When analyzing the Mid-Atlantic, the state of Delaware was included in the total, which could not be analyzed separately, as there were not more than four Farm Wineries in that state during the study period.

The NNR for the entire region (Figure 43) exhibits much the same pattern over time as New York, with a slight increase in clustering between 1975 and 2015, but no general trend evident.

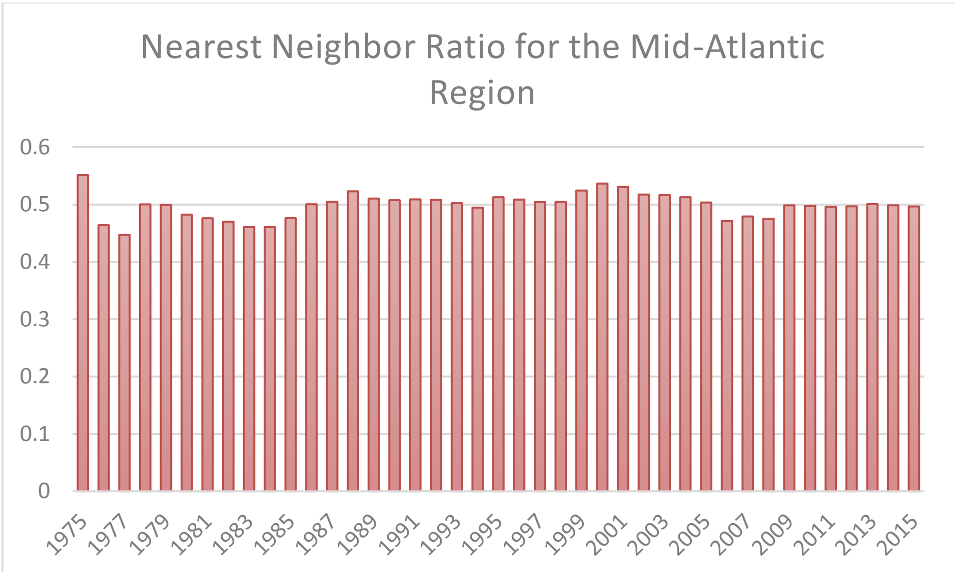

Figure 43: NNR Results for the Total Mid-Atlantic Region

Conclusions

The state I used to formulate my hypothesis, Virginia, seems to be exceptional rather than typical in how the distributions of Farm Wineries over time within it have changed. The gradual and steady pattern of increased clustering observed within that state is not replicated for any of the other states, nor for the region as a whole. The states which most closely fit my hypothesis were Maryland and New Jersey, which while exhibiting an overall trend towards clustering, also had several years where the distribution grew more dispersed instead. Pennsylvania only exhibited a trend towards clustering in the early years of the study period. The datasets for New York and the total Mid-Atlantic region seemed to show no trend, beginning and remaining clustered with little significant change in NNR.

Important factors from the state of the wine industry in each state may account for the observed differences. Of the five states analyzed, New York has the longest continuous history of Viticulture, by far having the largest number of wineries in the Mid-Atlantic in 1975. Pennsylvania, while not having so long a history, was the first among the states to license Farm Wineries, thus its wine industry would be relatively more mature than the other three states. Importantly, these were the only two states which had enough Farm Wineries in every year of the study period to run a Nearest Neighbor analysis upon, testifying to the greater maturity of their respective industries.

The differences between Virginia's pattern and those of New Jersey and Maryland is more difficult to account for. Growth in Farm Wineries came slower and later to both of the latter states than to Virginia, and both combined have fewer than half the number of wineries in Virginia today. However, this difference in the rate of industry expansion is probably a parallel effect, rather than a cause, of the difference in expansion patterns.

The Mid-Atlantic region as a whole mirrored New York in the degree of clustering shown in Farm Wineries over time. This is unsurprising in retrospect, as New York had the largest number of Farm Wineries consistently throughout the study period, and thus would have a highly-weighted effect on any region-wide analysis, particularly in the early years. There is also the issue of scale, as increasing the total area under analysis would increase the "expected distance" between a point and its nearest neighbor, assuming points were distributed randomly throughout the region.

While differences in clustering patterns over time are apparent in these results, most appear to be correlated to the relative maturity of the wine industry in each state. States with more developed wine industries prior to the beginning of my study period, New York and Pennsylvania, were more clustered in the early years of my study period than other states, and thus did not increase in the degree of Farm Winery clustering as much as states whose industries grew later in time. All states did become more clustered over time, though this pattern only occurs when analyzing at the state level. Given these results, I conclude that it is a general principle that Farm Wineries in growing regions begin as dispersed, but increasingly cluster over time as the region matures.

CHAPTER 4: SOIL CLASSIFICATION ANALYSIS

The purpose of this analysis is to test the significance and stability of soil family for Farm Winery locations. The results show whether distribution of soil families for winery locations differ significantly from to the total proportions of the state, and whether there was a change in the degree of difference over time. I also test the inter-decadal degree of difference between the soil family distributions of Farm Wineries to determine which periods saw the greatest and least change in their proportions.

Methods and Hypothesis

In the NCSS taxonomy, soil families are defined based on the specific physical and chemical properties of the soil, as opposed to soil orders, which are defined based on how the soil is formed and how mature it is. Family was isolated as the variable to be studied as the literature gave two conflicting conclusions on its importance for vineyard location. While soil family was not correlated with any difference in wine quality, soil family did affect subjective wine characteristics that would define specific regions. I wanted to determine whether that effect would result in preferences for distinct soil families within states.

In order to associate each winery location with a soil family, I sourced soil maps for each state within my study area from the USGS Web Soil Survey. Geospatial layers containing NCSS soil taxonomy data were then imported to ArcMap using the soil data viewer extension. After running a spatial join between my winery location and soil taxonomy layers, I extracted the data tables from the GIS layers, and consolidated the detailed taxonomic classification such that each winery was grouped according to soil family. Most of the soil taxonomic classification was classified by physical particle composition at the family level, but some soil polygons were not. In such cases, the most similar-level classification by mineral or other characteristics was selected. A full list of soil families within the Mid-Atlantic US and their defining characteristics is displayed below (Table 1).

Table 1: Soil Family Definitions (from "Soil Taxonomy" by Soil Survey Staff, USDA Second Edition 1999)

Soil Families	Classification	Definition
Clayey	Physical	>=35% Clay by weight, and are in a shallow family or in a Lithic, Arenic, or Grossarenic subgroup
Coarse-loamy	Physical	>=15% sand by weight, <18% clay by weight
Coarse-silty	Physical	<15% sand by weight, <18% clay by weight
Fine	Physical	<60% clay by weight in the fine-earth fraction
Fine-loamy	Physical	>=15% sand by weight, 18-35% clay by weight
Fine-silty	Physical	<15% sand by weight, 18-35% clay by weight
Loamy	Physical	Texture of loamy very fine sand, very fine sand, or finer, including <35% clay by weight in the fine earth fraction, in a shallow family or Lithic, Arenic, or Grossarenic subgroup
Loamy-skeletal	Physical	>=35% rock fragments by volume, <35% clay particles by weight

Loamy-skeletal over Clayey	Physical	Soil has intermixed characteristics of Loamy-skeletal and Clayey soils
Sandy	Physical	Texture predominantly sand, <50% very fine sand by weight
Sandy over Loamy	Physical	Soil has intermixed characteristics of Sandy and loamy soils
Sandy-skeletal	Physical	35% or more rock fragments by volume, < 50% (by weight) very fine sand
Very-fine	Physical	>=60% clay
Udorthents	Other	Shallow soils as a result of earth-moving activities
Euic	Mineral	Histosol and Histel Orders with >=4.5 pH
Dysic	Mineral	Histosol and Histel Orders with <4.5 pH
Mixed	Mineral	Soil has intermixed characteristics of mineralogical families
Saprists	Mineral	Histosols with highly decomposed organic matter
Sulfaquents	Mineral	Saturated soil with high amounts of surface sulfides

Once the process of association and classification was complete, I created subsets for each year from 1975-2015 of wineries open within each state and calculated the percentage of wineries in each year for each soil family. Using the statistics package within Microsoft Excel, I then ran the chi-squared distribution test for each year, with the total percentages of soil families within each state or the entire region as the ‘expected’ proportion of soil families.

Equation 3: Chi-Squared distribution

$$\chi_c^2 = \sum \frac{(O_i - E_i)^2}{E_i}$$

The chi-squared test was selected because the non-normal distribution of the data, combined with the lower sample sizes of earlier years necessitated a non-parametric test. If the p-value for the year was below the significance level of .05, I would reject the null hypothesis that there was no significant difference between soil family proportions represented by Farm Winery locations and the state or regional totals, and therefore conclude that a preference for particular soil families factored into Farm Winery location selection.

In addition to comparing the soil family proportions of winery locations to the state and regional totals, I also tested the proportions of years at 10-year intervals against each other, with the earlier year's proportions as the 'expected' values and the latter as the 'observed' values. If the p-value for that period was below the significance level of .05, then I would reject the null hypothesis that there had not been a significant change in the proportions of soil families for Farm Winery locations. This was to test whether there was stability or change in preferences for soil families in Farm Winery locations for each state within that decade.

Hypothesis

Based upon the literature (Coipel et al., 2006), I would hypothesize that soil family would not be considered an important factor for deciding where to open a Farm Winery until a wine region becomes known for having certain characteristics in its product. Soil preferences may also factor into location selection in the early establishment of a region, as outside vintners may select locations having similar soil profiles to their region of origin. Between these two periods, in the time when the wine region is exploring and expanding, soil type should be relatively unimportant in location selection.

This hypothesis would be reflected statistically in the p-values for the chi-squared test for each year. During the early years of the study period, the p-value should be low, signifying a significant difference between the soil families in Farm Wineries and the soil family distribution in the state or region as a whole. Over time, the p-value should increase as exploratory openings bring the proportions of soil families in Farm Wineries closer to a random sampling of soil families within each state. During the later years of the study period, the p-value should then start to decrease, as the marketable characteristics of the region become solidified within the minds of consumers, and wineries select locations to capitalize upon that.

If each state is moving from an early period when soil family is important for winery location through a middle period when it is less important to a latter period where its importance increases again, I hypothesize that there will be significant differences in the proportions of soil families within Farm Winery locations for the early decades

(1975-1985, 1985-1995, 1995-2005), statistically manifesting as low p-values for the chi-squared tests between the two ends of the decade, as the state will be transitioning through each of the hypothesized periods of development. A high p-value would then be the result for the last decade (2005-2015), as customer impressions and preferences would have solidified for the mature wine region.

Because the literature did not indicate a general preference for a particular soil family for quality wine, the differences in proportional representation for each soil type within different states should not affect the results. Therefore, I predict that all states within my study area, and the region as a whole, will follow this general pattern.

My null hypothesis in this instance is that there is no general or common pattern in the change or stability of soil families in Farm Winery sites over time in growing wine regions.

Results

Virginia

The results of the Chi-squared test on each year's soil family proportions at Farm Winery locations did not conform to my hypothesis, as seen in the trend line below (Figure 44). Results from 1975 are not included, as there were too few categories represented to give a valid result. Rather than the predicted arc where soil family proportions would begin as greatly different from the total distribution and become closer over time until the sites once again began to cluster in certain families disproportionately; Virginia has steadily seen the distribution of soil families among its Farm Winery locations approach the total state distribution, ceasing to be significantly different after 2012.

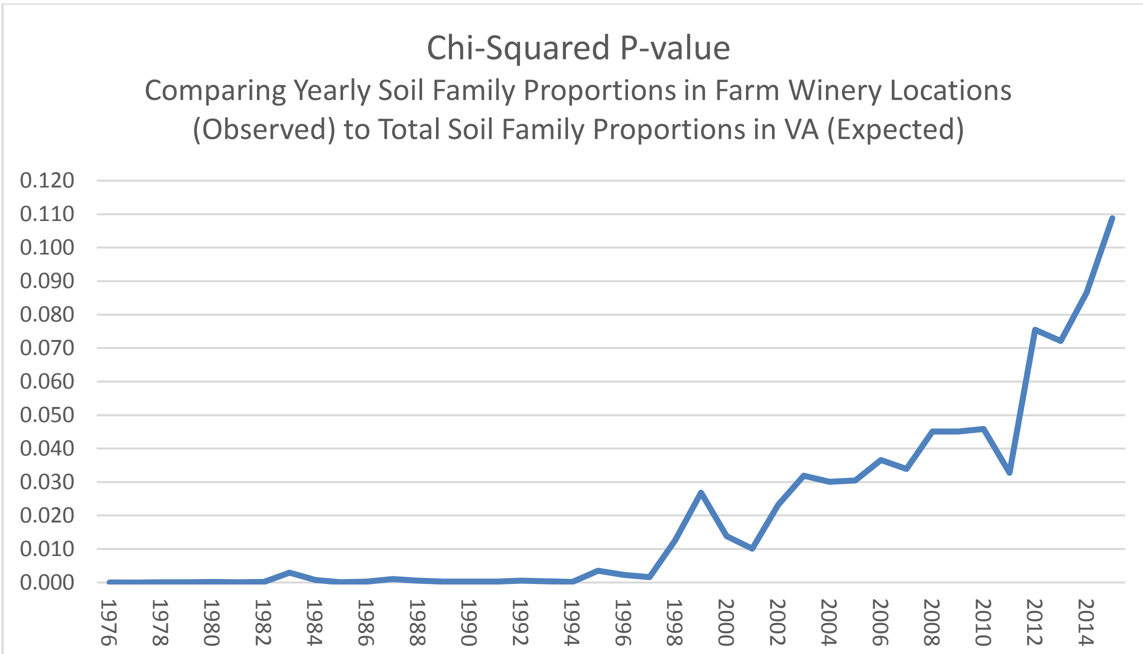

Figure 44: Chi-squared results for VA Soil Family Distribution among Farm Wineries

I noted one strong and two weaker pattern of individual soil family distributions among Virginia Farm Wineries. The strong pattern was that clayey soils were consistently overrepresented; approximately 45.1% of all soils in Virginia fall within this family, while the percentage of Farm Winery locations upon soils of this family never fell below 60% for the entire study period. The first weak pattern was that loamy-skeletal soils, comprising 18.9% of all soils in Virginia, were consistently under-represented, peaking at 14.3% of Farm Winery site soils in 2003, ending hovering at 13.3% for 2013-

2015. The second weak pattern was the consistent under-representation of fine-loamy soils, which comprise 18.2% of all soils in Virginia, but ranged between 10-15.6% of soils at Farm Winery locations, rising and falling throughout the study period.

The results of my second test, testing the end of a decade against the beginning to determine if there was a major change in soil family distribution among Farm Winery locations within that period, partially conformed to my hypothesis. Comparing the 1976 soil family distribution to the 1985 distribution yielded a p-value of .0028, well below my significance level of .05, signifying that there was significant changes in soil family preferences for Farm Winery sites in this 9-year period. Comparing 1985 to 1995, the p-value rose to .6165, signifying a stabilizing of soil family preferences. This value dropped slightly but not significantly to .4003 when comparing 1995 to 2005, before rising to .9889 in the comparison between 2005 and 2015, showing that the preferences for soil families among Farm Winery sites was now highly stabilized.

New York

The results of the Chi-squared test on each year's soil family proportions at Farm Winery locations did not conform to my hypothesis. Every year resulted in a p-value that was indistinguishable from 0, showing that there were strong preferences for certain soil families at Farm Winery locations throughout the study period.

Four differences in proportion between Farm Winery soil families and the total proportion of soil families in New York were consistently observed. The first is that coarse-loamy soils were significantly underrepresented; this family comprises approximately 51.1% of all soils in the state, yet no more than 37.1% of all Farm Wineries were on soils of that family at most in 1976, with the proportion falling to 21.3% in 2015. In contrast, fine-loamy soils were consistently over-represented; while only comprising 12.6% of all soils in New York, no less than 38% of all wineries operating in a year will be on soils of that family. Thirdly, Sandy-skeletal soils were not only over-represented, but increasingly so throughout the study period. Comprising 3.1% of all soils in New York, the percentage of Farm Wineries established on soils in that family rose from 9.3% in 1975 to 20.2% in 2015. Finally, Loamy-skeletal soils, comprising 10.7% of soils in New York, initially had a slight over-representation of 12.5% of soils on Farm Winery sites, but this proportions would decline throughout the study period, ending at only 4.1% in 2015.

When testing the proportions of soils within Farm Winery locations from decade to decade, there's a partial departure from my hypothesis. While comparing 1985 to 1975 resulted in a chi-squared p-value of .0000, showing a significant change in distribution of soil families, each of the following periods resulted in p-values >.9, signifying a sharply increased and consistent stability of soil family preferences in Farm Winery site locations.

Pennsylvania

In the case of Pennsylvania, the general pattern of results from the chi-squared tests between winery soil family proportions and the total state proportion partially conformed to my hypothesis. The trend line below (Figure 45) shows that the difference in distributions was significant, with a p-value <.05, from 1975-1997. After this period, the p-value rose to a peak of .906 in 2009, signifying that the proportions of soil families at Farm Winery sites was increasingly less differentiated from the total statewide soil family proportions. After 2009, a sharp decrease can be observed, down to .313 in 2011, rising slightly afterward. While the shape of this arc does conform to my hypothesized sequence of high difference followed by low difference, then increasing difference at the end of the study period, it is important to note that no difference in distribution is statistically significant after 1999.

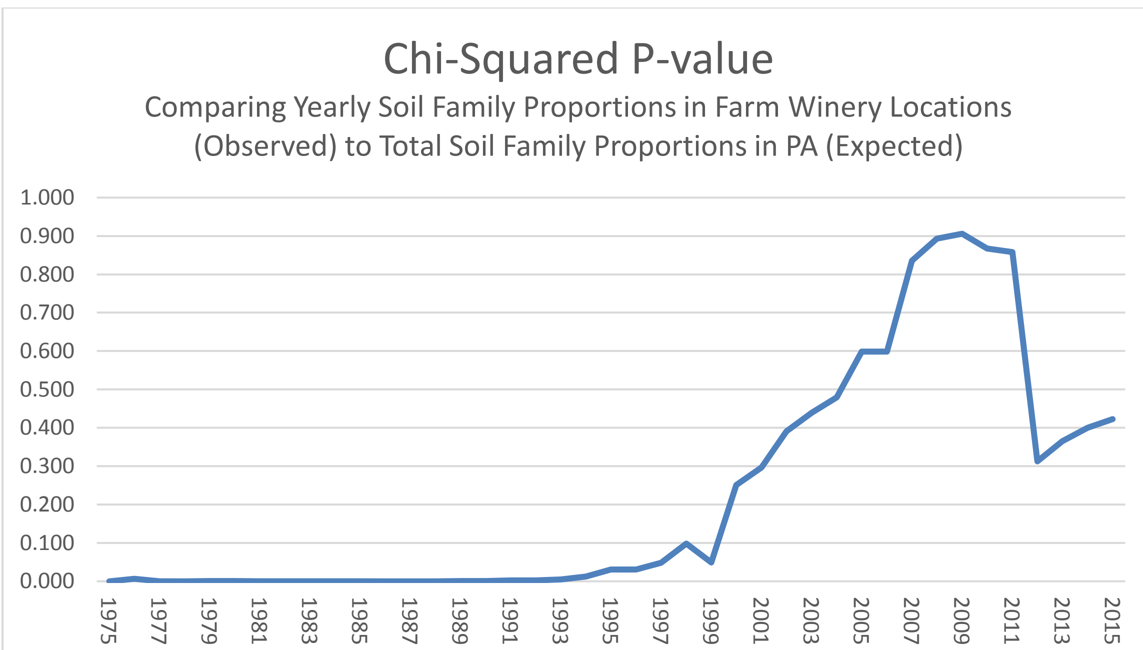

Figure 45: Chi-squared results for PA Soil Family Distribution among Farm Wineries

The consistent lack of any statistically significant difference between Farm Winery and total statewide soil family distributions after 1999 means that few soil families can be isolated as being consistently over or under-represented. The only exception in this case would be Fine soils, which comprise approximately 4.6% of soils in Pennsylvania. These are consistently over-represented among Farm Winery locations, but to a decreasing degree over time, from 16.7% in 1977 to 8.7% in 2015. All other soil families differed only by 1% between their statewide and Farm Winery location proportions in 2015.

The results of the chi-squared tests between Farm Winery soil family proportions in different decades also differed from my hypothesized pattern. 1975-1985 showed a p-value of .157, low but not statistically significant, in contrast to 1985-1995, with a p-value of .002, signifying a significant change of soil type preferences within this period. In contrast, 1995-2005's p-value of .395 and 2005-2015's p-value of .984 show an increased stability in soil family preferences within the latter decades of the study period.

New Jersey

In the case of New Jersey, the pattern of results from the chi-squared tests of Farm Winery soil families against the total state proportions closely match my hypothesis (). P-values remain <.01 from 1975 to 2004, subsequently rising to a peak of .033 in 2011, before dropping back to .005 in 2009. This sequence of high-decreasing-increasing difference is what I had hypothesized, though it is important to note that there was a statistically significant difference in soil family distributions for every single year of my study period in this state.

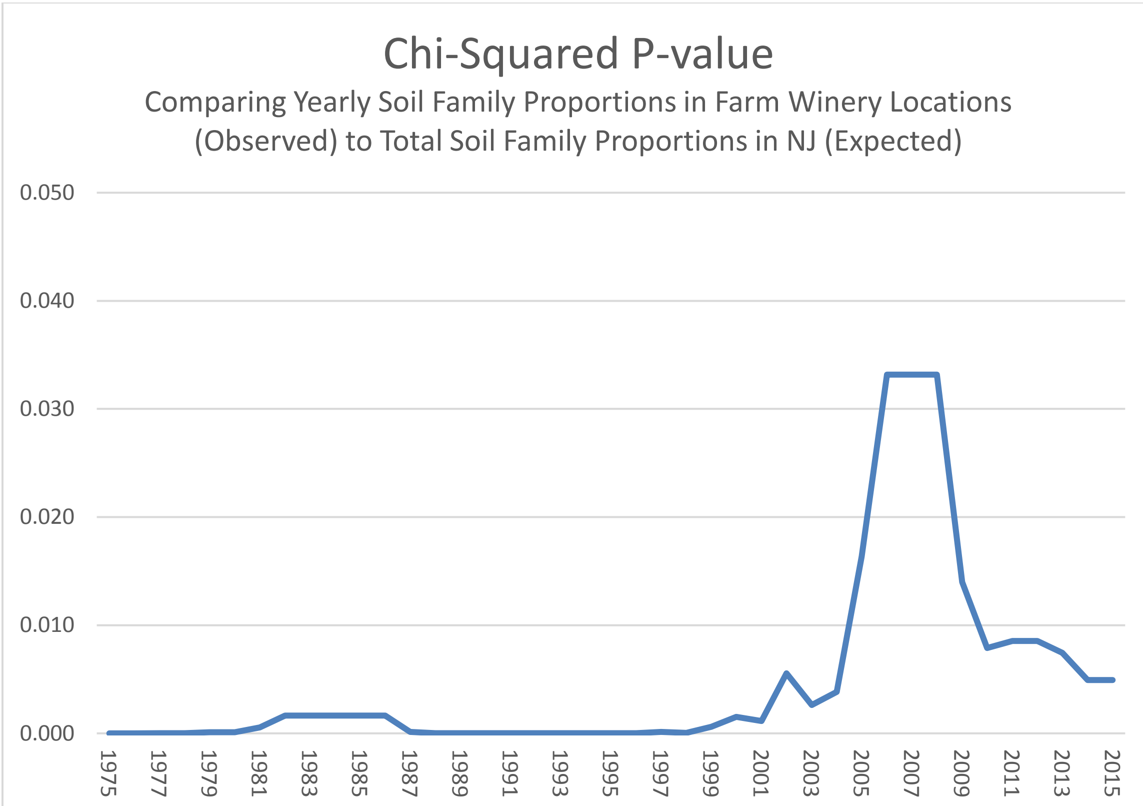

Figure 46: Chi-squared results for NJ Soil Family Distribution among Farm Wineries

Notable patterns for individual soil families were also observed. From 1975-2001, Sandy soils were over-represented among Farm Wineries, but after this period have been slightly under-represented; Sandy soils comprised 17.5% of all soils in New Jersey, 33.3% of soils at Farm Winery locations in 1996, declining to just 14.9% of Farm Winery soils in 2015. In contrast, coarse-loamy comprising 28.4% were increasingly over-represented after 1996, rising from 25% of Farm Winery soils to 38.3% in 2015. Fine-loamy soils were more consistently over-represented; comprising 24.7% of statewide soils, they rose from 28.6% of Farm Winery soils in 1981 to a peak of 50% of Farm Winery soils in 1988, falling to a still over-representative 38.3% in 2015.

The results of comparing inter-decadal Farm Winery soil family distributions with a chi-squared test also conformed to my hypothesis. The p-values from 1975-1985 [.000], 1985-1995 [.013], and 1995-2005 [.000] all showed significant changes in soil type preferences for Farm Winery locations within those decades, while the p-value from 2005-2015 [.971] showed that soil family preferences had stabilized for Farm Winery locations within New Jersey.

Maryland

In the case of Maryland, the chi-squared test of soil family distribution at Farm Winery locations against statewide soil family totals gives results similar to the pattern I had hypothesized, though examining the trendline below closely reveals that this is mainly due to the results for only one year in the study period (). Every year before and after the peak p-value of .043 in 2005 has a p-value of <.005, which I would interpret as showing 2005 as an outlier, rather than indicating a pattern of decreasing and increasing differences. Important to note is that even at the 2005 peak, all p-values are below the significance level of .05, indicating that every year in Maryland there was a significant difference between Farm Winery and statewide soil family distributions.

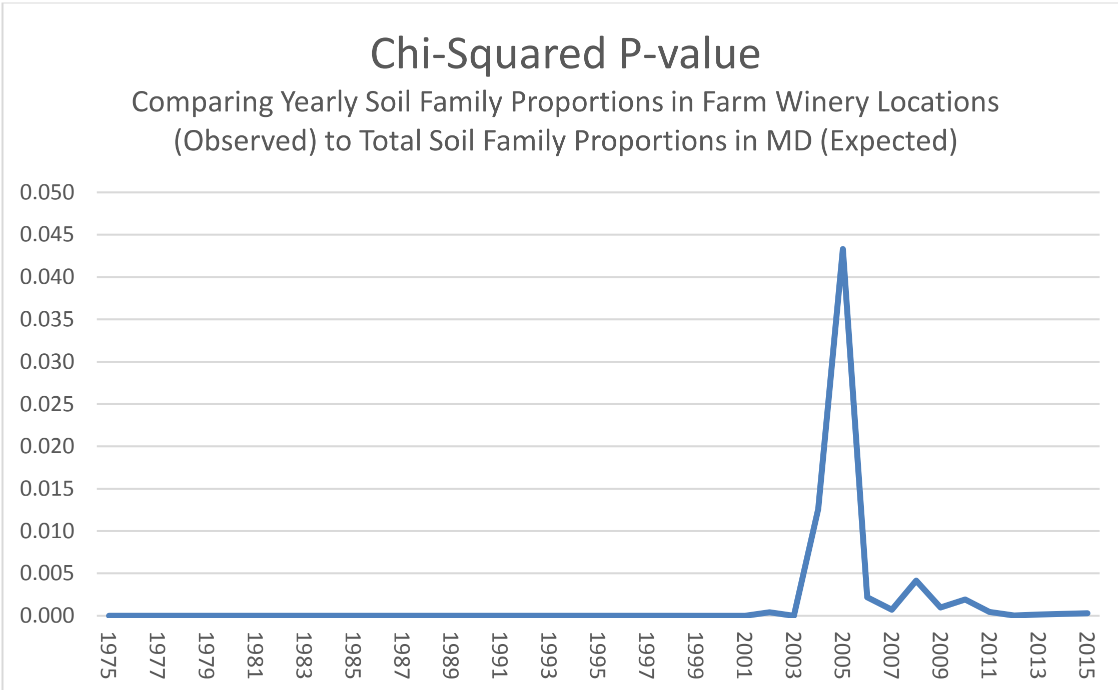

Figure 47: Chi-squared results for MD Soil Family Distribution among Farm Wineries

Four clear differences at the individual soil family level were observed. First was the decreasing over-representation of loamy-skeletal soils over the study period; they comprise 11.5% of the total soils in the state, yet from 1975-1991 at least 50% of all wineries within the state were located on soils of this family, with this percentage decreasing to only 16.3% in 2005. Second was the consistent over-representation of coarse-loamy soils, which comprise approximately 16.0% of Maryland soils; their representation among Farm Winery sites ranged between 20% to 32.4% from 1985-2009, before steadily decreasing to 24.5% in 2015. Third is the under-representation of fine-loamy soils, which is the most common family of the Maryland soils at 38.7%; while their representation among Maryland Farm Wineries rose from 14.3% in 1992 to a peak of 42.9% in 2002, it subsequently declined to 26.5% in 2015. The last pattern to emerge is the relative over-representation of clayey soils, which comprise only 2.4% of soils in Maryland; the first wineries on soils of this family did not open in Maryland until 2009, growing in 6 years to represent 8.2% of Farm Wineries in Maryland.

The inter-decadal chi-squared test does conform to my hypothesis, with the p-values of the comparisons between 1975-1985 [.000], 1985-1995 [.006], and 1995-2005 [.000] all falling below the significance level of .05, signifying that there were significant changes in soil family preference for Farm Winery locations within those periods. The result from comparing 2005-2015 [.156] is above the significance level; without a statistically significant difference observed between the soil family distributions within the last decade, I conclude that there is an increased stability in preference, though to a lesser degree than in other states.

Total Mid-Atlantic Region

The hypothesized arc of p-values for the yearly chi-squared tests of the soil families of all Farm Winery locations in the Mid-Atlantic region against the total soil family proportions of the region was not observed. All years exhibited a p-value of .000, with the exception of 1976's p-value of .002. In every year of the study period, the distribution of soil families among Farm Winery locations differed significantly from the total regional distribution, with no significant change in the degree of difference.

Five soil families present patterns of interest. Fine-loamy soils were consistently over-represented, comprising 27.0% of all soils in the region and never less than 31.1% of soils in Farm Winery locations. Another consistently over-represented family were the sandy-skeletal soils, which comprise only 1.1% of all soils in the Mid-Atlantic region, but grew from 5% of Farm Winery locations to a peak of 13.8% in 1983, before decreasing gradually to 7.7% in 2015. Clayey soils, comprising 12.3% of the regional total, were not consistently over-represented, being in only 4.2% of winery locations in 1976; this proportion would grow consistently over time to an over-representative proportion of 21.5% by 2015. Conversely, Coarse-loamy soils, comprising 22.5% of the regional total, represented 31.9% of Farm Winery soils in 1975, before steadily declining to an under-representative percentage of 15.8% in 1985, and ending 2015 at 13.7%. Finally, Loamy-skeletal soils, comprising 18.8% of total regional soils, were consistently under-represented, peaking at 16.7% of Farm Winery soils in 1976, declining to 12.7% in 2015.

When examining the results of chi-squared testing decadal changes in Farm Winery soil distribution, it is clear that most of the changes in distribution occurred between 1975-1985, as the p-value for that test was .000, while the subsequent tests all yielded p-values <.9, showing a great degree of regional stabilization of soil type preferences for Farm Winery sites.

Conclusions

No common pattern between states in the Mid-Atlantic region emerged when examining either the difference between soil family distributions at Farm Winery sites and the statewide totals over time, or the changes within the soil family distribution at Farm Winery sites between decades. The pattern which I predicted, that of starting at high degrees of difference between Farm Winery soils and statewide, becoming less different over time for a period, then increasing in differentiation over time, with the majority of change occurring in the first three decades of the study period, followed by a highly stable fourth decade, was only observed in New Jersey. Given this, do these results disprove the model upon which I based my hypothesis, and do they support the proposition that soil family is a significant factor for Farm Winery location selection?

For the sake of clarity, I will discuss these two questions under separate headings.

Rejecting or retaining the general model

To restate my premises, I made my predictions based upon the following propositions derived from the literature: soil type preferences would change over time as growing wine regions matured; pioneering vintners would establish Farm Wineries upon soils familiar to them from other regions, thus soil family distributions at Farm Wineries would begin as quite different from the states. As these regions grew and expanded, the distribution of soil types among Farm Wineries would more closely match the total state or regional distribution as more congenial possibilities were explored. Later as each region matured, their wines would gain reputation for certain characteristics that arise from growing grapevines on particular soil families, and later ventures would capitalize on this reputation by selecting sites accordingly.

Do the observed deviations from my predictions in each state justify rejecting this model? I will take each state in turn, beginning with New York. As the state within my study area with the longest history of viticulture, it is overall likely that my hypothesized changes in soil type preferences would have already occurred before the beginning of my study period. This explanation is supported both by the fact that the degree of difference between Farm Winery and statewide soil family distribution remained significantly different for every year of the study period, and that the distribution among Farm Wineries only significantly changed during the first decade of my study period and remained very stable for the remaining 30 years.

While my model may not be disproved in the case of New York, the results demonstrate that it does not apply to Virginia. Instead, the difference between soil family distribution in Farm Winery sites and the entire state steadily decreases until it is no longer statistically significant, yet at the same time, there is a sharp increase in stabilization of soil family distribution in Farm Winery sites. Preferences have therefore solidified, but not in such a way as to provide evidence of soil family being a significant factor in deciding upon a Farm Winery location.

While the pattern of results in Pennsylvania more closely matches my predicted arc, the deviations from my predictions are sufficient to cast doubt upon my model. The trend until 2011 is the same as Virginia, an increasing similarity between the soil family distributions of the state and Farm Winery sites within it. Even the sharp increase in difference between 2011 and 2012 does not increase the degree of difference between the two distributions to the level of statistical significance that I defined. Furthermore, the decade-to-decade pattern of stability and change in Farm Winery soil family distribution does not follow my predicted pattern; the only decade where there was statistically significant change in distribution was 1985-1995.

The results from Maryland may be construed as supporting evidence for my model, with the pattern of preference stabilization over time matching my prediction, and a visible, if brief, arc in the difference between Farm Winery and statewide soil family distribution over time. However, the short time span of the arc, from 2003-2007, casts doubt on my hypothesized mechanism of soil family preferences originating from customer recognition of wine characteristics imparted by soil family.

Therefore, given the difference of results between all the states in my study area, and the inability of my hypothesized mechanisms of preference driving to fully account for them, I must reject that the model I proposed for how soil family affects Farm Winery locations in a growing region can generally apply to new and growing wine regions.

Rejecting or retaining the significance of soil family preference

Given that my proposed model of soil family preference for Farm Winery location does not apply in the Mid-Atlantic region, the next relevant question is whether any preferences can be detected in the data. To answer this question, I will compare the significant patterns of over or under-representation of soil families in Farm Winery locations in relation to each of their respective states (Table 2).

Table 2: Farm Winery Soil Family Representation Patterns by State

Soil Family	Mid-Atlantic	Virginia	New York	Pennsylvania	New Jersey	Maryland
Clayey	**Over-represented (rising over time)**	**Over-represented (Consistent over time)**	No soils of this family in NY data	0 wineries on soils of this family; Family Comprises 0.7% of total PA soils	0 wineries on soils of this family; Family Comprises 1.2% of total NJ soils	**Over-represented (consistent)**

Coarse-loamy	**Under-represented (decline)**	No consistent under/over-representation; Family comprises 2.0% of total VA Soils	**Under-represented (Consistent)**	No consistent under/over-representation; Family comprises 11.1% of total PA Soils	**Over-represented (Consistent)**	**Over-represented (consistent)**
Fine	No consistent under/over-representation; Family comprises 5.7% of total Regional Soils	No consistent under/over-representation; Family comprises 10.1% of total VA Soils	No consistent under/over-representation; Family comprises 4.6% of total NY Soils	**Over-represented (Consistent)**	0 wineries on soils of this family; Family Comprises <.01% of total NJ soils	No consistent over/under representation; Family comprises 3.9% of MD Soils
Fine-loamy	**Over-Represented (Consistent)**	**Under-represented (consistent)**	**Over-represented (Consistent)**	No consistent under/over-representation; Family comprises 47.6% of total PA Soils	**Over-represented (Consistent)**	**Under-represented (Consistent)**
Loamy-skeletal	**Under-represented (consistent)**	**Under-represented (consistent)**	**Under-represented (decline)**	No consistent under/over-representation; Family comprises 32.2% of total PA Soils	No consistent under/over-representation; Family comprises 6.4% of total NJ Soils	**Over-represented (decline)**
Sandy	No consistent under/over-representation; Family comprises 2.9% of total Regional Soils	0 wineries on soils of this family; Family comprises 0.05% of total VA Soils	No consistent under/over-representation; Family comprises 4.7% of total NY Soils	No soils of this family in PA data	**Under-represented (decline)**	0 wineries on soils of this family; Family Comprises 2.9% of total MD soils
Sandy-skeletal	**Over-Represented (Consistent)**	No soils of this family in VA data	**Over-represented (Consistent)**	0 wineries on soils of this family; Family Comprises <.01% of total PA soils	0 wineries on soils of this family; Family Comprises 2.4% of total NJ soils	No soils of this family in MD data

While no soil family is consistently over or under-represented across all states, there are some patterns that arise from the comparison. Clayey soils are over-represented in the region overall, largely driven by Virginia and Maryland, as the other states have <2% soils in that family. Similarly, sandy-skeletal soils show as over-represented in the regional dataset, driven by New York; all other states have <2.5% of soils in that family. With soil families well represented in all states, under and over-representation tends to differ at the state level, with the regional representation driven mainly by the larger states. For example, coarse-loamy soils are under-represented in New York, and over-represented in Maryland and New Jersey, but as there are significantly more wineries in New York, it has more weight in the regional representation calculation.

With strong preferences evident at the state level, but not consistent at the regional level, I conclude that if soil family does operate as a deciding factor for Farm Winery locations, those decisions are motivated by reasons operating at a state or local level, not because any soil family is inherently conducive to the success of a Farm Winery. This is consistent with my conclusion from the literature, which assigned importance to soil family only in so far as it would affect subjective characteristics of the wine produced. Therefore, soil family is only a deciding factor in where a Farm Winery opens if or which of those subjective characteristics are of marketable importance, which is a factor that is difficult to generalize at a broad geographic scale.

CHAPTER 5: ELEVATION CLUSTERING ANALYSIS

The purpose of this analysis is to determine how the elevation distribution of Farm Wineries changed over time. The results show whether the elevation values for Farm Winery locations cluster in each year, what elevation values those clusters are centered on, how tight those clusters are, and how the distribution of clusters changed over time in each state. Clustering observed in early years and remaining constant throughout would indicate that elevation is a primary factor for the selection of Farm Winery sites, while inconsistent clustering would indicate that other factors take priority in the decision-making process.

Methods and Hypothesis

This analysis was conducted in IBM SPSS Statistics version 25.0, using the two-step clustering analysis function. This tool was selected in preference to methods such as k-means clustering, as the latter requires that the analyst specify the number of clusters ahead of time. As that was one of the questions I wished to answer through my analysis, I instead selected a method that could itself determine the number of clusters in each data set.

The first "step" in the two-step tool is pre-clustering, in which each data point is sequentially examined to determine if it fits within previously established clusters, or whether it is sufficiently distant in value to be categorized in a new cluster. Once a number of clusters is determined in this step, this number is then used as the input in a hierarchical clustering method as the second step. The validity of the clustering is determined by the software running multiple iterations of calculation, measuring the greatest distance between cluster centroids and the Baysiean Information Criterion, which is a measure of error variance in the model. The iteration which produces the greatest average distance between cluster centroids with the lowest BIC is selected as the "winner," giving the number of clusters, their centroid, and their standard deviation.

This model was run for each state and the region on each year's dataset that had >=6 values, as little could be determined from the distribution of a lesser number of elevation values. Given the overall low number of wineries in early years, I observed that outlier values could significantly affect the results of the clustering algorithm. However, given that in each case, these the elevations of these wineries were not outliers in the datasets of later years, I chose to not remove them from the analyses in order to preserve year-to-year comparability.

Hypothesis

The impact of elevation upon vineyard sites primarily relates to temperature and frost risk. In general, higher elevations will lead to lower average temperature, and thus shorter growing seasons and increased chances of crop-damaging frosts. However, the effects of temperature inversion, where cold air flowing downhill collects in valleys and clefts in local topography, can also make low-elevation sites undesirable for Farm Wineries.

Taking these factors into account, Boyer's 1998 analysis of viticultural potential in Virginia posited that the ideal elevation for vineyard sites was a thermal band, between the frost danger zones of high elevation and inversion sites. The ideal range was between approximately 800 and 1200 feet, or 243 and 365 meters. However, when examining the actual extent of grape cultivation in his study site, he determined that only 12.5% of total grape acreage fell within that ideal range, with the majority being distributed at significantly lower elevations (Boyer, 1998).

Given these results, I did not expect most of the Virginia sites to cluster at Boyer's posited ideal elevation range. However, his study was conducted in 1998, and mine extends to 2015; so supposing his own model of ideal elevation in Virginia is correct, I hypothesize the following:

- Early years will show little clustering in the dataset, as winery founders are still in the experimental phase of site selection.
- The earliest distinct cluster to emerge will be a low-elevation cluster, consisting of most of the dataset for those years
- After 1998, a second distinct cluster at a higher elevation, within the "ideal" range will emerge

For the other states in my study area, I do not have any corresponding analysis of state-wide viticultural suitability. However, the only difference between the effects of elevation in each should be relative latitude, as higher latitude environments be cooler in climate. Thus, cooler average temperatures will be found at lower elevations. Therefore, for wineries in Maryland, New Jersey, Pennsylvania, and New York, I hypothesize the following:

- The overall patterns of elevation distribution over time will be the same for each state (Early years have no distinct clustering; the first cluster to emerge being low-elevation; a second higher-elevation cluster emerging after 1998)
- The centroids of the elevation clusters in Maryland will be lower than those of Virginia.
- The centroids of the elevation clusters in Pennsylvania and New Jersey will be lower than Maryland, and relatively close to each other.
- The centroids of the elevation clusters in New York will be lower than all other states.

Finally, when analyzing the elevation values of Farm Wineries across the total Mid-Atlantic region, I hypothesize that multiple clusters at various elevations will emerge, as the study area ranges too widely in latitude for a general ideal range to be established for it.

Results

The results of my analysis are presented in table format. For each year, I list the number of clusters in that year's elevation values, with the third column consisting of the characteristics of each cluster in brackets. The first value in the brackets is the number of wineries in that cluster, the second value is the mean centroid elevation of that cluster given in meters, and the third value is the standard deviation of that cluster. Given that the clustering algorithm sorts all the values in a set into at least one cluster, if there was only one cluster found for that year, I recorded it as 1~0, as no significant clustering was found within that dataset.

Virginia

Table 3: Winery Elevation Clusters in Virginia

Year	# Of Clusters	Members, Means, & Standard Deviations
1976	1~0	[1, 222.974, 52.224]
1977	2	[5, 256.798, 30.325] [4, 168.609, 8.07]
1978	2	[12, 195.507, 80.648] [1, 1049.157,]
1979	2	[13, 194.707, 77.268] [1, 1049.158,]
1980	2	[17, 187.871, 74.494] [1, 1049.158,]
1981	2	[19, 182.213, 72.931] [1, 1049,]
1982	2	[21, 186.052, 72.055] [1, 1049.158,]
1983	2	[23, 181.392, 70.872] [1, 1049.158,]
1984	2	[25, 193.985, 81.705] [1, 1049.158,]
1985	2	[28, 188.742, 84.664] [1, 1049.158,]
1986	2	[30, 182.655, 86.806] [1, 1049.158,]
1987	2	[31, 179.791, 86.823] [1, 1049.158,]

1988	2	[31, 179.791, 86.823] [2, 814.970, 331.191]
1989	2	[32, 176.854, 87.012] [3, 856.547, 245.010]
1990	2	[32, 176.854, 87.012] [3, 856.547, 245.010]
1991	2	[32, 176.854, 87.012] [3, 856.547, 245.010]
1992	2	[34, 179.715, 85.146] [3, 856.547, 245.010]
1993	2	[35, 182.324, 85.293] [3, 856.547, 245.010]
1994	2	[38, 183.907, 83.908] [3, 856.547, 245.010]
1995	2	[39, 185.394, 83.316] [5, 784.214, 217.075]
1996	2	[40, 182.460, 84.309] [5, 784.214, 217.075]
1997	2	[44, 187.012, 84.815] [6, 782.384, 194.210]
1998	2	[53, 189.319, 88.335] [7, 751.240,]
1999	2	[62, 195.506, 96.131] [8, 753.299, 181.093]
2000	3	[37, 292.988, 72.349] [8, 776.415, 163.056] [41, 127.567, 56.975]
2001	2	[18, 591.887, 209.583] [82, 183.689, 83.936]
2002	3	[45, 283.342, 59.652] [12, 705.870, 167.188] [56, 122.693, 56.518]
2003	3	[51, 281.044, 58.738] [14, 692.383, 158.299] [60, 121.378, 57.235]
2004	3	[53, 281.905, 56.996] [15, 699.853, 155.260] [68, 124.623, 60.023]

2005	3	[56, 282.586, 57.482] [15, 699.853, 155.260] [71, 122.885, 59.913]
2006	3	[56, 282.586, 57.482] [15, 699.853, 155.260] [80, 125.247, 59.045]
2007	3	[60, 287.721, 60.665] [16, 695.315, 151.090] [92, 130.254, 58.682]
2008	3	[62, 291.100, 61.649] [18, 709.178, 147.622] [106, 131.511, 58.187]
2009	2	[179, 188.200, 93.979] [20, 684.230, 159.395]
2010	3	[70, 289.718, 64.040] [18, 709.178, 147.622] [117, 131.386, 55.744]
2011	2	[192, 186.864, 92.588] [20, 684.230, 159.395]
2012	2	[199, 185.463, 92.314] [21, 682.728, 155.511]
2013	2	[204, 185.167, 91.788] [21, 682.728, 155.511]
2014	2	[205, 184.980, 91.602] [21, 682.728, 155.511]
2015	2	[31, 590.437, 186.181] [199, 175.078, 81.018]

The patterns of winery elevation distribution in Virginia (Table 3) only partially conform to my hypothesis. Prior to 1998, the results conform to expectations, showing a loose clustering around an elevation centroid lower than Boyer's predicted threshold of 234m-365m, ranging from 179m-195m, with some high-elevation outliers. After this period, we do see the predicted emergence of two tighter elevation clusters between 2000 and 2010 one below the “ideal” threshold, ranging between 147m-167m, and one within Boyer’s ideal band, ranging between 282m-292m, again with the addition of high-elevation outliers.

However, starting from 2011, there is a reversion to the pre-1998 pattern, showing a somewhat loose cluster with a centroid below Boyer’s threshold, with an even looser cluster of high-elevation outliers with a centroid above Boyer’s threshold.

New York

Table 4: Winery elevation Clusters in New York

Year	# Of Clusters	Members, Means, & Standard Deviations
1975	2	[21, 192.636, 80.478] [11, 356.665, 25.996]
1976	3	[6, 80.163, 59.225] [18, 230.954, 32.034] [11, 356.665, 25.669]
1977	3	[7, 70.409, 59.908] [19, 228.077, 33.564] [12, 366.057, 40.900]
1978	2	[15, 104.332, 66.734] [29, 291.164, 71.016]
1979	2	[18, 101.688, 67.276] [32, 287.717, 68.632]
1980	2	[24, 80.365, 67.938] [35, 282.650, 68.250]
1981	2	[25, 77.904, 67.637] [36, 281.440, 67.659]
1982	2	[28, 80.494, 66.778] [38, 279.743, 66.210]
1983	2	[34, 74.357, 65.264] [41, 277.171, 65.633]
1984	2	[38, 85.163, 69.516] [40, 281.055, 63.331]
1985	2	[35, 76.554, 65.506] [44, 274.234, 65.051]
1986	2	[36, 74.572, 65.650] [44, 274.234, 65.051]
1987	2	[36, 65.358, 62.232] [46, 269.961, 66.739]
1988	2	[36, 65.358, 62.232] [47, 269.809, 66.018]
1989	2	[36, 65.358, 62.232] [47, 269.809, 66.018]
1990	2	[37, 63.781, 62.107] [48, 269.997, 65.325]

1991	2	[39, 60.930, 61.726] [48, 269.997, 65.325]
1992	2	[40, 61.885, 61.228] [49, 268.936, 65.067]
1993	2	[40, 61.885, 61.228] [50, 268.419, 64.503]
1994	2	[40, 61.885, 61.228] [50, 268.419, 64.503]
1995	2	[43, 61.935, 61.498] [50, 268.419, 64.503]
1996	2	[47, 57.363, 60.702] [51, 266.898, 64.772]
1997	2	[53, 64.831, 63.782] [50, 269.532, 63.149]
1998	2	[57, 62.878, 63.430] [53, 269.675, 61.318]
1999	3	[34, 13.703, 16.334] [39, 159.772, 41.512] [46, 284.426, 55.239]
2000	2	[55, 51.756, 55.360] [72, 258.183, 64.888]
2001	2	[55, 45.905, 48.848] [82, 254.717, 69.688]
2002	2	[61, 44.378, 47.333] [84, 258.017, 79.536]
2003	2	[67, 43.643, 46.500] [86, 258.209, 78.644]
2004	4	[48, 14.166, 14.010] [40, 133.609, 32.729] [18, 378.362, 73.867] [57, 241.945, 27.899]
2005	4	[48, 14.166, 14.010] [46, 138.642, 33.569] [18, 378.362, 73.867] [58, 242.455, 26.883]
2006	4	[50, 15.905, 16.360] [52, 134.967, 32.867] [18, 382.892, 71.586] [63, 243.778, 28.387]
2007	4	[51, 15.856, 16.199] [55, 134.718, 33.039] [21, 389.451, 71.961] [68, 244.038, 28.807]

2008	4	[53, 17.289, 17.395] [61, 130.698, 31.771] [22, 390.697, 70.470] [70, 242.407, 29.961]
2009	4	[53, 16.977, 16.577] [67, 128.731, 31.881] [22, 390.697, 70.470] [74, 240.429, 30.449]
2010	4	[54, 16.769, 16.491] [70, 128.251, 31.970] [24, 390.482, 67.341] [76, 239.849, 30.633]
2011	4	[55, 16.679, 16.351] [73, 128.255, 32.285] [24, 390.482, 67.341] [76, 239.849, 30.633]
2012	4	[55, 16.679, 16.351] [76, 127.935, 32.340] [25, 387.130, 68.020] [78, 239.557, 30.238]
2013	4	[55, 16.679, 16.351] [76, 127.935, 32.340] [25, 387.130, 68.020] [78, 239.557, 30.238]
2014	4	[56, 17.615, 17.651] [80, 130.749, 32.142] [26, 385.233, 67.343] [80, 239.288, 30.241]
2015	4	[56, 17.615, 17.651] [81, 130.542, 31.995] [26, 385.233, 67.343] [80, 239.288, 30.241]

For New York (Table 4), 1975 shows that 1/3 of Farm Wineries were a tight cluster at a relatively high elevation [356m], while the rest were more dispersed at lower elevations. This pattern would hold through 2003, with a few exceptions in 1976, 1977, and 1999 where the lower-elevation dispersed cluster would split into two tighter clusters, making three total clusters. One consistent pattern observed through this period of time is that the centroid of the higher-elevation cluster would become lower over time, from 356, in 1975 to 258m in 2003.

Following this long streak of two-cluster years, each of the two clusters split into four total clusters, each with a tighter standard distribution. From this point, the pattern remains relatively stable until the end of the study period in 2015. The lowest elevation cluster, consistently having a centroid between 14-18m in elevation, is also the tightest, with a standard deviation also ranging between 14-18m. The two largest clusters are the middle strata, with elevation centroids ranging between 127-138m and 234-244m respectively, with comparable standard deviations between 28-33m. The highest elevation cluster is also the least populated and most dispersed, with a centroid ranging between 378-390m, and a standard deviation ranging between 67-73m.

Pennsylvania

Table 5: Winery elevation clusters in Pennsylvania

Year	# Of Clusters	Members, Means, & Standard Deviations
1975	1~0	[8, 216.490, 106.731]
1976	2	[10, 182.902, 45.768] [1, 457.121, ~]
1977	2	[11, 174.955, 50.793] [1, 457.121, ~]
1978	1~0	[13, 205.325, 94.038]
1979	2	[14, 175.076, 58.602] [1, 457.121,]
1980	2	[14, 175.076, 58.602] [1, 457.121,]
1981	2	[16, 179.705, 56.392] [1, 457.121,]
1982	2	[17, 175.940, 56.765] [1, 457.121,]
1983	2	[17, 175.940, 56.765] [1, 457.121,]
1984	2	[17, 175.940, 56.765] [1, 457.121,]
1985	2	[17, 175.940, 56.765] [1, 457.121,]
1986	2	[19, 174.669, 58.396] [2, 537.999, 114.378]
1987	2	[22, 174.531, 63.702] [4, 462.237, 115.762]
1988	2	[23, 175.216, 62.324] [4, 462.237, 115.762]
1989	2	[26, 176.046, 62.312] [4, 462.237, 115.762]

1990	2	[26, 176.046, 62.312] [4, 462.237, 115.762]
1991	2	[28, 172.346, 63.148] [4, 462.237, 115.761]
1992	2	[28, 172.346, 63.148] [4, 462.237, 115.761]
1993	2	[30, 173.593, 62.174] [4, 462.237, 115.762]
1994	2	[30, 173.593, 62.174] [5, 454.442, 101.757]
1995	2	[29, 165.482, 54.902] [9, 423.251, 139.250]
1996	2	[29, 165.482, 54.902] [9, 423.251, 139.250]
1997	2	[32, 169.202, 54.236] [9, 423.251, 139.250]
1998	2	[33, 170.076, 53.617] [11, 412.621, 128.944]
1999	2	[35, 170.234, 54.217] [13, 404.143, 119.982]
2000	2	[37, 164.368, 58.421] [16, 399.054, 110.803]
2001	2	[38, 162.398, 58.892] [17, 391.856, 111.314]
2002	2	[38, 157.931, 57.123] [19, 383.689, 108.887]
2003	2	[41, 165.976, 62.147] [17, 396.823, 107.678]
2004	2	[42, 165.054, 61.675] [17, 396.823, 107.678]
2005	2	[42, 161.067, 57.230] [20, 381.151, 106.589]
2006	2	[42, 161.067, 57.230] [20, 381.151, 106.589]
2007	2	[52, 171.839, 62.306] [19, 395.212, 99.956]
2008	2	[52, 164.136, 56.878] [27, 381.457, 108.908]
2009	2	[56, 160.809, 53.580] [32, 374.539, 106.344]

2010	2	[67, 172.563, 62.312] [26, 398.685, 104.102]
2011	2	[68, 173.839, 62.733] [26, 398.685, 104.402]
2012	2	[69, 170.530, 57.983] [30, 383.396, 104.483]
2013	2	[71, 171.839, 57.985] [30, 383.396, 104.484]
2014	2	[72, 173.052, 58.487] [31, 381.343, 103.362]
2015	2	[72, 173.052, 58.487] [32, 380.270, 101.862]

In Pennsylvania (Table 5), the pattern is considerably closer to my hypothesis. From 1975-1985, the elevations of the wineries are relatively dispersed with no significant clustering, apart from one high-altitude [457m] outlier. From 1986-2015, the dataset is split into two clusters, a very dispersed cluster at higher elevations, and a relatively tighter cluster at lower elevations.

The high-elevation cluster is consistently smaller than the lower-elevation cluster, never having more than half the members of its counterpart. As it becomes more populated, its centroid lowers in elevation from 538m in 1986 to 380m in 2015. The standard deviation trends up and down through this period, but consistently remains above 100m. The lower-elevation cluster also trends up and down from 1986-2015, both in elevation centroid [157-176m] and standard deviation [53-63m].

New Jersey

Table 6: Winery Elevation Clusters in New Jersey

Year	# Of Clusters	Members, Means, & Standard Deviations
1979	1~0	[6, 33.788, 20.941]
1980	1~0	[6, 33.788, 20.941]
1981	1~0	[7, 46.744, 39.249]
1982	1~0	[8, 47.558, 36.410]
1983	1~0	[8, 47.558, 36.410]
1984	1~0	[8, 47.558, 36.410]
1985	1~0	[8, 47.558, 36.410]
1986	1~0	[8, 47.558, 36.410]
1987	1~0	[9, 49.175, 34.402]
1988	1~0	[10, 47.551, 32.838]
1989	1~0	[10, 47.551, 32.838]
1990	1~0	[10, 47.551, 32.838]
1991	1~0	[11, 45.385, 31.971]
1992	1~0	[12, 41.769, 32.956]
1993	1~0	[12, 41.769, 32.956]
1994	1~0	[12, 41.769, 32.956]
1995	1~0	[12, 41.769, 32.956]
1996	1~0	[12, 41.769, 32.956]
1997	2	[5, 71.603, 30.004] [8, 18.660, 11.326]
1998	1~0	[14, 39.571, 31.839]
1999	2	[7, 63.767, 27.953] [10, 19.005, 12.364]
2000	2	[2, 151.525, 38.245] [17, 31.397, 19.940]
2001	2	[2, 151.525, 38.245] [21, 31.986, 20.019]
2002	2	[4, 150.051, 38.082] [25, 30.941, 19.131]
2003	2	[4, 150.051, 38.082] [29, 31.167, 19.793]

2004	2	[4, 150.051, 38.082] [31, 30.097, 19.717]
2005	2	[6, 155.158, 30.633] [33, 29.657, 19.628]
2006	2	[6, 155.158, 30.633] [34, 29.586, 19.333]
2007	2	[6, 155.158, 30.633] [34, 29.586, 19.333]
2008	2	[6, 155.158, 30.633] [34, 29.586, 19.333]
2009	2	[7, 155.911, 28.035] [35, 29.906, 19.141]
2010	2	[7, 155.911, 28.035] [36, 30.306, 19.018]
2011	2	[7, 155.911, 28.035] [37, 30.225, 18.758]
2012	2	[7, 155.911, 28.035] [37, 30.225, 18.758]
2013	2	[7, 155.911, 28.035] [39, 29.910, 18.421]
2014	2	[7, 155.911, 28.035] [40, 30.279, 18.333]
2015	2	[7, 155.911, 28.035] [40, 30.279, 18.333]

The elevation cluster distribution in New Jersey (Table 6) also conforms to my hypothesis. From 1979 to 1996, there is little significant clustering observed in the dataset. Between 1997-1999, the clustering pattern is in flux, stabilizing in 2000 into a 2-cluster pattern which remains stable and consistent through 2015.

Similar to previous results, the high-elevation cluster is less populated and less tight than its lower-elevation counterpart, though it does become tighter over time, from a 38m standard deviation in 2000 to a 28m standard deviation in 2015; the centroid remaining stable between 150m-155m above sea level. The low-elevation cluster also remains stable over time, with a centroid ranging 29-31m above sea level, with a standard deviation between 18-20m.

Maryland

Table 7: Winery Elevation Clusters for Maryland

Year	# Of Clusters	Members, Means, & Standard Deviations
1986	1~0	[6, 163.031, 39.547]
1987	1~0	[6, 163.031, 39.547]
1988	1~0	[6, 163.031, 39.547]
1989	1~0	[6, 163.031, 39.547]
1990	1~0	[6, 163.031, 39.547]
1991	1~0	[6, 163.031, 39.547]
1992	1~0	[7, 140.339, 70.055]
1993	1~0	[7, 140.339, 70.055]
1994	1~0	[7, 140.339, 70.055]
1995	1~0	[7, 140.339, 70.055]
1996	1~0	[8, 135.106, 66.526]
1997	2	[8, 135.106, 66.526] [1, 631.380,]
1998	2	[9, 134.049, 62.310] [1, 631.380,]
1999	2	[11, 110.806, 76.039] [1, 631.380,]
2000	2	[11, 110.806, 76.039] [1, 631.380,]
2001	2	[11, 110.806, 76.039] [1, 631.380,]
2002	2	[1, 631.380,] [13, 98.750, 75.419]
2003	2	[15, 108.226, 74.201] [1, 631.380,]
2004	2	[18, 99.684, 72.737] [1, 631.380,]
2005	2	[20, 91.248, 73.660] [1, 631.380,]
2006	2	[22, 91.545, 71.229] [1, 631.380,]

2007	2	[26, 87.877, 75.097] [1, 631.380,]
2008	2	[28, 82.205, 75.221] [1, 631.380,]
2009	3	[16, 17.715, 16.882] [17, 160.309, 37.474] [1, 631.380,]
2010	3	[2, 549.021, 116.474] [19, 18.702, 16.916] [18, 159.511, 36.513]
2011	3	[2, 549.021, 116.474] [19, 18.702, 16.916] [21, 165.234, 39.100]
2012	3	[2, 549.021, 116.474] [20, 21.682, 21.181] [24, 169.054, 40.281]
2013	3	[2, 549.021, 116.474] [20, 21.682, 21.181] [25, 166.681, 41.180]
2014	3	[2, 549.021, 116.474] [21, 21.408, 20.683] [25, 166.681, 41.180]
2015	3	[2, 549.021, 116.474] [22, 21.443, 20.185] [25, 166.681, 41.180]

The pattern for Maryland (Table 7) somewhat deviates from my hypothesis. As predicted, from 1986-1996, the winery elevations do not display significant clustering. Except for one high-elevation outlier [631m], this pattern continues from 1997-2008. In 2009, two clusters then develop separate from the outlier, which then gains a member of its own cluster in 2010. This clustering pattern then remains consistent through 2015

As with all previous results, the lowest-elevation cluster is the tightest on average, ranging between 16-20m of standard deviation around a centroid that trends from 17m to 21m above sea level. By 2015, the center cluster is the highest populated, with a relatively stable centroid ranging between 160-166m above sea level, though it has become less tight over time, trending from 37m to 41m in standard deviation. The highest elevation cluster, consisting of only two members, may be classified as outliers, having only two members an average elevation [549m] over 3 times higher than the center cluster, and a very high standard deviation of 166m.

Total Mid-Atlantic Region

Table 8: Winery Elevation Clusters for the Total Mid-Atlantic Region

Year	# Of Clusters	Members, Means, & Standard Deviations
1975	3	[9, 49.951, 41.360] [25, 217.281, 36.368] [13, 359.453, 41.705]
1976	2	[27, 127.372, 66.593] [33, 290.067, 63.796]
1977	3	[13, 48.569, 38.761] [39, 209.905, 40.983] [14, 367.304, 49.683]
1978	3	[37, 113.377, 66.753] [39, 287.949, 69.160] [1, 1049.158,]
1979	4	[26, 68.164, 47.452] [47, 219.582, 39.730] [13, 373.062, 46.598] [1, 1049.158,]
1980	3	[51, 99.225, 66.260] [49, 276.421, 66.788] [1, 1049.158,]
1981	3	[56, 101.069, 65.851] [52, 273.229, 66.259] [1, 1049.158,]
1982	3	[63, 102.648, 64.553] [55, 272.357, 64.553] [1, 1049.158,]
1983	3	[72, 99.949, 65.256] [57, 272.335, 63.706] [1, 1049.158,]
1984	3	[74, 101.725, 65.244] [60, 274.261, 63.821] [1, 1049.158,]

1985	3	[76, 101.612, 65.736] [62, 273.600, 62.920] [1, 1049.158,]
1986	3	[76, 101.612, 65.736] [62, 273.600, 62.920] [1, 1049.158,]
1987	5	[32, 20.711, 19.262] [57, 142.402, 35.342] [49, 246.057, 26.084] [17, 389.756, 73.480] [1, 1049.158,]
1988	2	[93, 101.025, 67.259] [67, 301.238, 124.218]
1989	5	[33, 21.081, 19.078] [61, 142.178, 35.612] [51, 246.805, 25.833] [18, 400.369, 84.315] [2, 994.429, 77.398]
1990	5	[34, 20.667, 18.941] [61, 142.178, 35.612] [52, 247.421, 25.961] [18, 400.369, 84.315] [2, 994.429, 77.398]
1991	3	[100, 96.641, 66.578] [68, 277.542, 62.949] [4, 797.129, 232.684]
1992	5	[40, 20.506, 19.871] [63, 142.051, 35.735] [55, 246.088, 25.890] [18, 400.369, 84.315] [2, 994.429, 77.398]
1993	5	[41, 20.457, 19.624] [64, 142.137, 35.457] [58, 246.267, 25.463] [18, 400.369, 84.315] [2, 994.429, 77.398]
1994	5	[41, 20.457, 19.624] [65, 141.697, 35.357] [60, 246.284, 25.100] [19, 401.574, 82.107] [2, 994.429, 77.398]
1995	3	[104, 89.081, 64.484] [85, 269.273, 63.926] [7, 743.095, 191.047]
1996	3	[109, 85.113, 64.109] [87, 267.420, 64.337] [7, 743.095, 191.047]
1997	3	[117, 86.994, 64.467] [92, 266.533, 63.871] [9, 734.031, 170.163]
1998	3	[127, 85.897, 63.689] [103, 268.542, 64.400] [10, 717.066, 169.164]
1999	3	[138, 84.353, 63.731] [119, 269.541, 65.451] [11, 721.670, 161.207]

2000	3	[153, 86.926, 64.716] [134, 275.525, 67.008] [12, 723.184, 153.795]
2001	5	[74, 22.543, 20.757] [104, 141.407, 34.710] [36, 378.250, 42.689] [101, 247.460, 29.351] [14, 701.977, 151.779]
2002	3	[194, 85.425, 63.560] [149, 275.467, 66.007] [17, 674.242, 152.190]
2003	3	[208, 83.159, 63.184] [160, 273.712, 65.185] [19, 667.633, 145.422]
2004	3	[226, 83.952, 63.750] [168, 272.263, 64.489] [20, 674.473, 144.811]
2005	5	[112, 23.203, 20.082] [141, 144.224, 33.974] [40, 376.032, 41.474] [124, 248.087, 29.765] [19, 685.268, 140.268]
2006	4	[179, 52.735, 43.749] [59, 352.576, 49.850] [204, 206.574, 41.180] [19, 685.268, 140.268]
2007	3	[282, 90.426, 64.339] [199, 274.161, 65.393] [22, 664.968, 142.242]
2008	5	[129, 25.061, 21.129] [186, 142.081, 33.143] [52, 382.087, 44.509] [152, 246.606, 31.598] [23, 692.387, 134.057]
2009	5	[134, 26.033, 22.035] [198, 243.638, 33.543] [171, 385.595, 46.294] [55, 385.595, 46.294] [23, 692.387, 134.057]
2010	5	[155, 32.079, 27.516] [193, 144.357, 28.134] [176, 243.394, 33.318] [59, 385.880, 46.816] [23, 692.387, 134.057]
2011	5	[142, 25.447, 21.093] [217, 139.445, 31.610] [70, 370.584, 49.558] [170, 238.572, 29.278] [24, 684.895, 136.151]
2012	4	[146, 26.904, 22.552] [277, 151.636, 38.087] [198, 294.637, 65.846] [25, 683.607, 133.440]
2013	3	[287, 71.333, 51.014] [337, 243.383, 69.255] [32, 635.176, 149.818]
2014	4	[230, 53.299, 41.174] [287, 188.621, 37.359] [127, 328.527, 60.485] [25, 683.607, 133.440]

2015	3	[401, 98.679, 62.980] [248, 278.125, 66.277] [27, 667.772, 140.326]

In the results for the total Mid-Atlantic region (Table 8), a consistent pattern does not ultimately emerge. There are periods where the pattern I predicted, multiple tight clusters at different elevation levels corresponding to the different latitude bands of the states in the region, does emerge. From 1987-1994 and 2008-2011, up to five distinct clusters were detected.

However, the prevailing pattern through most of the period consists of three clusters: the lower elevation cluster with a centroid ranging 42m-101m, a mid-tier elevation cluster with a centroid ranging 209-278m, and a looser third cluster of high-elevation outliers.

Conclusions

The results of this analysis are neither sufficient to reject the null of my hypothesis, nor do they reveal any general patterns of Farm Winery elevations observable at the state level. Virginia and New York represent the most significant refutations of my predictions; the former had no clustering within the elevation band that I predicted based on Boyer's posited ideal elevation, and the latter had double the number of expected clusters develop at the latter end of the study period. The significance of these deviations from expectation are enhanced by the fact that these two states have the top number of Farm Wineries within them by a large margin, therefore arguably representing the characteristics of the most mature and prosperous wine regions.

Maryland and New Jersey had results more in line with my predictions, showing two relatively tight clusters at two distinct elevation tiers. However, these two states had the least number of Farm Wineries within them, so less weight can be given to them. While Pennsylvania exhibited the same clustering pattern, the clusters in that state were looser, having a larger average standard deviation. Overall, I cannot say definitively that there was any consistent pattern of elevation clustering that could be attributed across all the states within this one region.

Not only did the patterns not emerge as predicted, but the elevation centroids did not entirely correspond to latitude, either. Compare the centroid of the most-populated cluster in each state in 2015, listed in order of increasing latitude: Virginia at 175m, Maryland at 166m, New Jersey at 30m, Pennsylvania at 173m, and New York at 130m. I had predicted a consistent pattern of cluster elevation becoming closer to sea level as latitude increased, but this pattern did not seem to emerge either.

Altogether, these results would support the conclusion that absolute elevation does not represent a significant factor in Farm Winery site selection. Rather, the risk of frost is best mitigated by selecting sites based on relative elevation, which emphasizes topography at a local scale. Thus, a generally applicable pattern of wine region development cannot be derived from examining the elevations of successful Farm Winery sites.

CHAPTER 6: SUMMARY AND CONCLUSION

In this thesis, I have hypothesized four factors that affect the successful establishment of a Farm Winery: time of opening, location with respect to other Farm Wineries, soil family at site, and elevation at site. By conducting an empirical study of Farm Wineries in the Mid-Atlantic United States from 1975-2015, I have separated which factors show generally applicable patterns that can be integrated into a model for global wine region development, and which should be analyzed separately at the local level.

Results Summary

In the first factor examined, the year in which Farm Wineries were established in each state, I used temporal autocorrelation analysis to determine how volatile the factors governing the initial decision to open a Farm Winery were in each state, and whether these factors commonly occurred across the Mid-Atlantic region. Each state demonstrated significant degrees of volatility, indicating factors operating at shorter time scales affected the decision to open a Farm Winery in any particular year; the lack of commonality between the autocorrelation results between states and the Mid-Atlantic region indicate these factors operate at local levels.

The factor of location with respect to other wineries was tested by means of the Nearest Neighbor Ratio, taking the average distance of a Farm Winery to its nearest neighbor and determining whether it was greater or lesser than the expected average assuming random spatial distribution. For all states, this degree of clustering was strongly associated with the maturity of the wine region in each state. As each state did not mature at the same time, this pattern was not apparent when analyzing the entire Mid-Atlantic region.

The third factor of soil family at Farm Winery sites was tested by comparing the percentage distribution of soil families at Farm Wineries to the statewide and regional percentage distribution of soil families using the chi-squared distribution. I found that each state differed in whether these distributions became more or less differentiated over time. Also, when comparing the inter-decade distribution of Farm Winery soil families within each state, I did not find any common pattern of when periods of stability or change occurred. Isolating individual soil families and comparing patterns of over or under-representation revealed both common and conflicting patterns.

I examined the last factor elevation value by taking the elevation of each Farm Winery site above sea level and performing a two-step clustering analysis on all Farm Wineries in each state for each year, looking for emerging patterns of where and when clusters emerged. No common patterns emerged between states in either the pattern of clusters that developed, nor the timing of their emergence overall. Even my prediction that the centers of clusters for each state would decrease as latitude increased was not wholly supported by the data.

Conclusions on the Empirical Model

Of the four factors analyzed, the strongest commonality between states in my study area was observed in the degree of clustering over time. This suggests a common principle for Farm Wineries that proximity to other Farm Wineries provides significant economic benefit, thus increasing the chances that the winery will be successful.

A second commonality was observed in the temporal autocorrelation analysis; all states exhibited a degree of volatility in the rate in which Farm Wineries were opened within them. As volatile patterns more likely indicate economic rather than environmental causes, the second common principle suggested is that growth in a wine region is significantly more dependent upon the effective demand for the product, rather than the environmental suitability of the region for wine grape production.

The remainder of my results highlight factors which exhibit spatially differentiated patterns. The exact degree of volatility in the rate of winery openings within each state was not common, and even exhibited a cyclical pattern in the case of Pennsylvania. Studying the history of economic demand in one wine region will not necessarily provide a basis for predicting the pattern which will manifest in another. However, the differences observed do not de-emphasize the general importance of economic demand for the establishment of Farm Wineries.

In contrast, the lack of common clustering patterns in the absolute elevation of Farm Wineries does de-emphasize the importance of that factor. The number of meters above sea level that a Farm Winery is established is less important overall than the frost risk the site is exposed to, which has less to do with absolute elevation than the relative elevation of the site to the local topography.

The final factor, soil families at Farm Winery sites, has spatially differentiated patterns; these differences seem to suggest that the importance of this factor is itself spatially differentiated. Certain states, such as New York, exhibit strong and consistent patterns of preference in soil families, while other states, such as Virginia and Pennsylvania, are either less consistent or less preferential. As well, which soil families are over or under-represented among Farm Wineries also differs at the state level. This is consistent with my hypothesized mechanism of consumers preferring subjective characteristics associated with wine regions as a brand, independent of the product's quality. The degree to which this preference is evident or cultivated is different between wine regions and will determine the importance of this factor in predicting the sites of successful Farm Wineries.

Practical Implications

The first practical implication for policymakers and investors seeking to foster the growth of a new wine region is to evaluate demand before making major investments. If there are no local centers of population whose demographics match those of wine consumers and wine tourists, nor any pre-existing traffic of non-local visitors within that demographic, successful Farm Wineries will not have a sustainable economic base. Urban-to-rural transportation infrastructure investment, or parallel development of other tourist attractions would be good methods of increasing effective local wine demand.

Second, once wineries have been established within a region, local policymakers and investors should foster connectivity between them, both physically and socially. Successful wineries develop in clusters where both ideas and customers can be shared to the benefit of all within. These can be formalized into special regional denominations, but informal “wine trails” that facilitate customer travel from one winery to another are also effective in solidifying a region’s growth.

Two other implications apply mostly to prospective vintners in growing regions. First is that environmental risks to production, especially frost risk, is best evaluated at a local level. Examining regional or global statistics on the best elevation to open a Farm Winery will not be helpful in site selection. Finally, in cases where environmental factors affect subjective characteristics rather than wine quality, examining patterns of consumer perception of what wine from a region “should” be like is a helpful guide.

Limits and Areas of Future Research

The first major limitation of my research is its geographic scope. The Mid-Atlantic United States, while exhibiting some degree of diversity in its climatic and economic influences, is still a relatively coherent single geographic region. While differences between states within it can effectively negate general hypotheses, observed commonalities within it may not apply to other regions of North America or different continents altogether. Additionally, having only five distinct units within my study area makes it difficult to separate trends from outliers when comparing between them. An opportunity for future research would be to expand the scope of the comparison to widely distant regions of the same relative size, in order to confirm if the common patterns I discovered apply globally, or if differences I observed were due to outlier circumstances.

The second limitation of my research was the focus on one soil characteristic. While classification by particle composition is a significant aspect of soil, it is not the only factor which can significantly affect the cultivation of grapes. Another avenue for further research would be to expand the soil characteristics of Farm Winery sites to be studied, such as drainage, pH, or topsoil maturity.

Another limitation of this thesis was related to its study of topography. One element, that of absolute elevation, was examined, but there are other factors which have been indicated as important by the literature. Aspect in particular would merit future research, given the importance of insolation periods to the cultivation of grapes.

The final limitation of my research is that I examined and compared the degree of spatial clustering in Farm Winery sites, I did not examine the specific number or location of clusters within each state. The use of a method such as local Moran's *I* would enable a researcher to study where clusters of wineries were located with respect to factors such as population density, in order to determine if they were also factors influencing winery locations. Adding this method to the comparison between states would deepen the level of insight when examining the patterns of Farm Winery spatial distribution.

While many avenues of future expansion remain, the methodological framework presented in this thesis can serve as a firm foundation for future research into wine region development. By conducting comparative studies of Farm Winery and vineyard location over time and between distinct regions, it is possible to determine which factors are of importance in determining the success of a winery, and at what geographic scale these factors should be analyzed. These results can then be used to develop and refine models for regions seeking to grow an economically stable wine industry within them.

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BIOGRAPHY

Matthew Miyares graduated from Fairfax High School, Fairfax, Virginia, in 1983. She received her Bachelor of Arts from George Mason University in 1987. She was employed as a teacher in Fairfax County for two years and received her Master of Arts in English from George Mason University in 1987.