Investigating the Effect of Highway Infrastructure Creation on Market Integration

Archive Edition

By Ansh Jhatakia
Department of Economics
University of Colorado Boulder

Defended on April 4th, 2022

Advisor:

Taylor Jaworski, Ph.D. – Department of Economics

Committee Members

Brian Cadena, Ph.D. – Department of Economics

Vanja Dukic, Ph.D. – Department of Applied Mathematics

Taylor Jaworski, Ph.D. – Department of Economics

Abstract:

The Interstate Highway System (IHS) is an integral aspect of modern-day transportation. The System changed the landscape of transportation in the United States by decreasing travel times dramatically and providing reliable roads that are now used by individuals and firms alike. This thesis seeks to answer the following question: *What is the effect of highway infrastructure creation on market integration?* The effect of the highway system is captured through county pair travel times between 1940 and 1992. Indicators used to measure market integration include pecuniary variables (differences in total farmland value and value per acre between counties) and non-pecuniary (differences in average farm sizes and the number of farms between counties) variables. Using linear models (fixed effects and interactions) and quadratic models, I analyze the effects of travel time on my various indicators for market integration. The analysis finds that increases in travel time led to slower decreases in market integration measured by pecuniary indicators and quicker decreases in market integration measured by non-pecuniary indicators. Furthermore, changes from the IHS exhibit diminishing returns, and the effect of travel time depends on whether counties specialized in the same crops before construction of the IHS began.

1 Introduction

The Federal Highway Act of 1956 proposed the creation of the Interstate Highway System (IHS) with the intent to build a more robust economy, facilitate national defense efforts, and increase interconnectedness between large cities.[1] The IHS, today which spans a total of 46,876 miles[2], has morphed into an integral part of modern transportation infrastructure for individuals and firms alike.

In theory, as two regions become more interconnected, there will be an increase in the number of customers in the market for a good or service provided by either region. The rationale behind this is straightforward: interconnectedness allows civilians and firms to access goods and services offered across a wider area. Similarly, interconnectedness may allow producers of goods or services to provide their goods or services to customers in a wider area. When this happens, goods and services are subject to the laws of supply and demand, meaning that price patterns for the good or service will start to follow similar price patterns in interconnected regions, so long as the market for the good or service is competitive. This concept is called *market integration.*

Interconnectedness may integrate certain markets or industries more than others. Particularly from the perspective of the agricultural industry, my research seeks to answer the following question: *What is the effect of highway infrastructure creation on market integration?* More specifically, my research sees how travel times, which have been reduced through the creation of the highway system, affect pecuniary indicators of market integration such as differences in total farmland values and values per acre between counties. Moreover, while differences in total farmland values and values per acre may be

[1] Smith, Jean Edward. *Eisenhower: In War and Peace*, Random House Trade Paperbacks, New York, 2013, p. 652.
[2] Highway History. (n.d.). Retrieved from https://www.fhwa.dot.gov/interstate/faq.cfm

pecuniary indicators of market integration, I will also focus on non-pecuniary indicators of integration such as differences in average farm sizes and the number of farms. For both pecuniary and non-pecuniary indicators, integration could be observed as convergence to zero, where markets would be considered to be perfectly integrated.

To answer my research, I will analyze two datasets. The first dataset includes GIS-generated decade-by-decade shortest travel times between American counties.[3] The second dataset includes data from the United States Agricultural Census.[4] This dataset includes county-by-county data related to agricultural inputs and outputs.

Currently, there exists closely related literature about the effect of reduced market barriers of entry on market integration. A 2020 study by Cremeño & Santiago-Caballero[5] analyzed the effect of roads on spatial market integration in Spanish wheat markets during the 18th century. Since the construction of the IHS began in a more modern era where geographical barriers did not limit market integration, my research focuses on national market integration rather than spatial market integration.

Another paper, by Zheng & Kahn[6] in 2013, studied changes in market integration levels from the creation of bullet trains connecting megacities to surrounding areas. Megacities represent regions with particularly high concentrations of resources whereas my research focuses on the United States as a whole, meaning that resources are, on average, less concentrated.

---

[3] Jaworski, T., & Kitchens, C. (2022). *Highways in the Twentieth Century (Working Paper).* Retrieved March 30, 2022.

[4] Haines, M., Fishback, P., & Rhode, P. (2018). United States Agriculture Data, 1840 - 2012. https://doi.org/https://doi.org/10.3886/ICPSR35206.v4

[5] Cermeño, A. L., & Santiago-Caballero, C. (2020, April 28). *All roads lead to market integration: Lessons from a spatial analysis.* Retrieved from https://ideas.repec.org/p/cte/whrepe/30247.html

[6] Zheng, S., & Kahn, M. E. (2013). Chinas bullet trains facilitate market integration and mitigate the cost of megacity growth. *Proceedings of the National Academy of Sciences,110*(14). doi:10.1073/pnas.1209247110

Measuring the magnitude of economic development and market integration is important for two main reasons. First, it allows us to retrospectively confirm whether or not the Federal Highway Act of 1956's goal of promoting future economic growth was met. Second, it allows economists and policymakers to prognosticate the economic impact of increased highway development. Aside from highway development, measuring economic development from the IHS may help provide insight through qualitative extrapolation into whether investment from the federal government in large-scale public works projects yields significant societal benefit.

2 Background

In 1919, the Transcontinental Motor Convoy, an army convoy made up of 81 vehicles and 297 individuals, traveled from Washington D.C to San Francisco using the Lincoln Highway. The Convoy's goal was clear: they wanted to gauge the feasibility of cross-country travel using road infrastructure available at the time.[7] Unfortunately, simple tasks don't always have simple solutions. Roads available at the time were maintained by individual states, meaning that the quality of roads was variable. In many cases, proper roads did not exist, meaning that the Convoy resorted to using unsafe travel routes. This led them to a slew of accidents. During the trip, the crew got into 230 accidents, many of which could have been prevented by the availability of well-built roads. In fact, the Convoy damaged (and repaired) a total of 88 bridges, some of which had deteriorated over time due to a lack of proper maintenance.[8] Traveling at an average speed of 6 miles an hour, it took the Convoy a total of 62 days to travel the 3,251 miles between

[7] Indot. (2021, July 15). *Indiana and the First Transcontinental Motor Convoy of 1919*. Indiana Department of Transportation. Retrieved March 28, 2022, from https://www.in.gov/indot/resources/indot-history/indiana-and-the-first-transcontinental-motor-convoy-of-1919/

[8] Greany, W. C. (1919). *Report of the First Transcontinental Army Motor Transport*. Eisenhower Presidential Library. Retrieved March 28, 2022, from https://www.eisenhowerfoundation.net/primary-source/item/report-first-transcontinental-army-motor-transport

Washington D.C and San Francisco. Today, a similar journey would take less than two days to complete – very likely with fewer accidents.

Inadequacies in road infrastructure were acknowledged during this period, and governmental efforts were taken to aid the creation of a better system. One of the earliest efforts was the creation of the Federal Aid Road Act of 1916, which allocated 75 million dollars towards road development, portions of which could be provided as grants to states that agreed to assume 50% of road creation costs.[9] The Federal Highway Act of 1921 expanded upon the Federal Aid Road Act of 1916 and created the tentative framework for a modern and robust highway system. Finally, in 1956, Dwight D. Eisenhower, a member of the original 1919 Transcontinental Motor Convoy and POTUS at the time enacted the Federal Aid Highway Act of 1956. This act was the first *major* effort to construct the a national highway system. Instead of requiring state governments to bear 50% of the costs – a bearing that was not always desirable to states, the Federal Highway Act of 1956 placed 90% of the financial burden on the federal government.[10] This financial burden would be relieved through a fuel tax.[11] Relieving individual states of financial burdens associated with road creation proved to be an effective method of creating new infrastructure. After construction of the IHS began in 1956, it took 36 years (1956 - 1992), 48 metric tons of cement, 35 metric tons of asphalt, and 6 metric tons of steel[12] to build the 43,297-mile behemoth depicted in Figure 1.

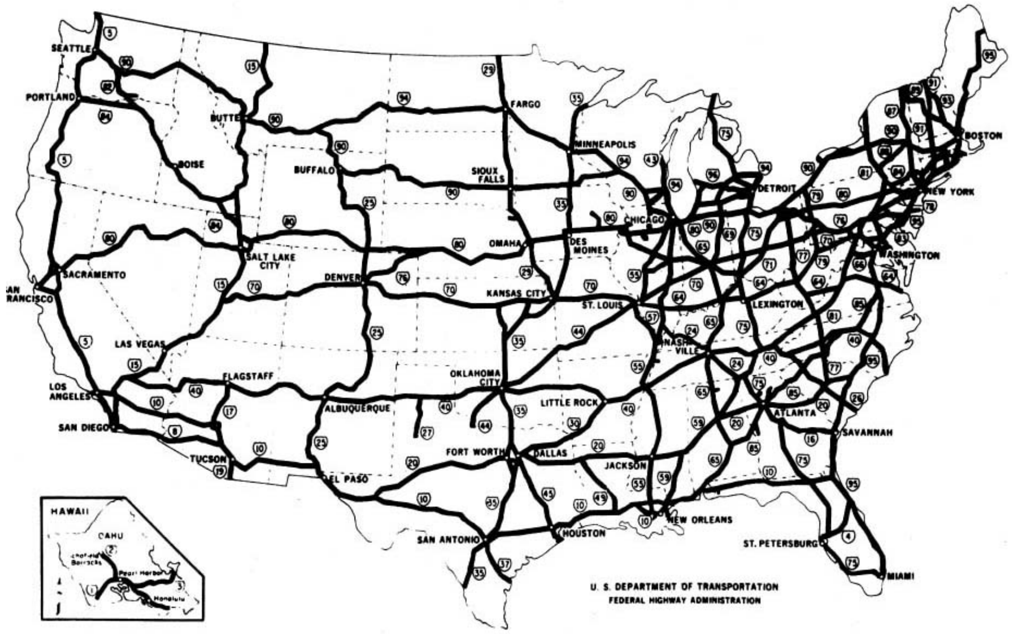
[9] Weingroff, R. F. (1996). *Federal aid road act of 1916: Building the foundation.* Retrieved March 29, 2022, from https://highways.dot.gov/public-roads/summer-1996/federal-aid-road-act-1916-building-foundation

[10] *Highway history.* U.S. Department of Transportation/Federal Highway Administration. (n.d.). Retrieved March 29, 2022, from https://www.fhwa.dot.gov/interstate/faq.cfm#question8

[11] National Archives and Records Administration. (n.d.). *National Interstate and Defense Highways Act (1956).* Retrieved March 29, 2022, from https://www.archives.gov/milestone-documents/national-interstate-and-defense-highways-act

[12] USGS. (2006). *Materials in use in U.S. Interstate Highways - USGS.* Retrieved March 30, 2022, from https://pubs.usgs.gov/fs/2006/3127/2006-3127.pdf

Figure 1: Proposed Interstate Highway System



Source: Federal Highway Administration

The IHS brought stark changes to interstate travel. The System led to about a 30% decrease in travel times between 1960 and 2010.[13] Today, 90% of Americans live within five miles of a highway.[14] From allowing for safe and convenient civilian travel to enabling highly efficient trade of everyday goods, the System continues to have a direct, large, and positive impact on many important facets of our lives.

3 Literature Review

The current literature related to this research question can be categorized into five different groups; these include the impact on economic activity from the IHS, rates of return over time from the IHS, changes in productivity from the IHS, labor market integration from the IHS, and international trends in market integration through road

[13] Jaworski, T., Kitchens, C. T., & Nigai, S. (2018). *The Interstate Highway System and the Development of the American Economy* ∗ | Semantic Scholar. Retrieved March 30, 2022.

[14] Slater, R. E. (1996). *The National Highway System: A Commitment to America's future.* Retrieved March 29, 2022, from https://highways.dot.gov/public-roads/spring-1996/national-highway-system-commitment-americas-future

development. From these categories, studies discussing international trends in market integration through road development are the most closely related to my research question.

First, some studies have investigated the impact on economic activity in the United States from the IHS. A study by Jaworski, Kitchens, & Nigai[12] from 2018 measured the counterfactual monetary impact of individual IHS segments. The monetary impact was determined by removing individual highway segments and measuring financial changes in decades between 1970 and 2010. Even after accounting for newly developed alternative routes, the removal of the ten most traveled highway segments yielded continuously increasing financial losses worth tens to hundreds of billions of dollars per segment.

In 2008, a study by Guy Michaels[15] took a different approach by investigating changes in economic activity in different industries from the creation of the IHS. The study found that retail sales and trucking activity increased by 7-10 percentage points, specifically in rural areas the highway crossed through compared to other rural areas where the highway did not cross through. While Michaels' study concluded that certain industries in rural areas did see increased economic activity, there was not necessarily a net increase in rural economic activity. A study by Chandra & Thompson from 2000 specifically focused on changes in economic activity from the creation of the IHS within rural counties. The study found that rural counties through which the IHS was built indeed saw increased economic activity. However, rural counties adjacent to these counties saw decreases in economic activity. This means that the net economic activity in rural

[15] Michaels, G. (2008). *The Effect of Trade on the Demand for Skill: Evidence from the Interstate Highway System*. Review of Economics and Statistics,90(4), 683-701. doi:10.1162/rest.90.4.683

regions remained roughly the same as before the construction of rural IHS segments, consistent with Michael's findings.

Second, some previous studies have discussed rates of return from the IHS over time. A 2006 study by Mamuneas & Nadiri[16] found that the rate of return from the IHS was an average of 34% between 1949 and 2000. However, the rate of return was only 14% between 1990 and 2000. This discrepancy indicates that the rate of return from the IHS decreased between 1949 and 2000.

Third, some studies have analyzed the impact of the IHS on national productivity. In a 1999 study, Fernald[17] investigated the effect of highway creation on productivity using data on 29 private economy sectors. He concluded that there is a positive correlation between public capital creation (in this case, highways infrastructure creation) and productivity. More specifically, industries that are heavily dependent on roads saw significant increases in productivity growth rates whereas industries that are not heavily dependent on roads saw decreases in productivity growth rates. For example, the trucking industry, which is heavily dependent on roads, benefitted from the decreased travel times between cities afforded by highway creation. Furthermore, Fernald found that the magnitude of productivity growth boosts decreased after 1973. This finding indicates that while the IHS did have a positive impact on productivity, there is a limit to how much productivity benefits can be reaped from highway creation.

[16] Mamuneas, T. P., & Nadiri, M. I. (2006, August). *Production, Consumption and the Rates of Return to Highway Infrastructure Capital*. Retrieved from https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.352.8782&rep=rep1&type=pdf

[17] Fernald, J. G. (1999). *Roads to Prosperity? Assessing the Link Between Public Capital and Productivity.* American Economic Review,89(3), 619-638. doi:10.1257/aer.89.3.619

Next, some studies have investigated the effect of the IHS on employment. A 1987 study by Eagle & Stephanedes[18] found that areas with high levels of economic activity saw higher than typical rates of employment growth due to highway creation. Areas with less economic activity only saw this effect temporarily. Furthermore, Michaels'[15] 2008 study found that the highway system increased wage bills for high-skill workers in counties with abundant high-skilled workers compared to low-skill workers. The wage bill decreased in counties with a scarcity of low-skilled workers.

Economic activity, rates of return, national productivity, and employment trends may be useful when predicting market integration trends. Alas, their downfall is that they are affected by factors other than market integration, potentially making them unreliable predictors of market integration. Economic activity and national productivity could be affected by technological or efficiency improvements within the manufacturing process, which would increase demand for certain goods. Rates of return may be impacted by local economic patterns (creation and sale of new goods and services). Furthermore, employment trends may indicate labor integration, but do not provide clear insight when analyzing integration in the market for farmland since labor is a mobile factor of production while the land is not. Individuals in the labor force may move for several reasons aside from increased accessibility to other counties.

Finally, some studies have investigated the impact of transportation infrastructure on market integration in markets for agricultural goods and land. These studies include research closest to that of my own.

[18] Eagle, D., & Stephanedes, Y. (1987, January 01). *Dynamic Highway Impacts on Economic Development*: Semantic Scholar. Retrieved from https://www.semanticscholar.org/paper/DYNAMIC-HIGHWAY-IMPACTS-ON-ON-ECONOMIC-DEVELOPMENT-Eagle-Stephanedes/f77ceaf612b9f450572772df89247da2af2b7be0

A 2020 study by Cremeño & Santiago-Caballero[5] analyzed the effect of road development on market integration in Spanish wheat markets during the 18th century. Their model utilized cross-sectional data from a municipal level survey called the Cadastre de la Ensenada. Since Spain's geographical features could be deterministic in how simple trade was, the model controlled for factors such as altitude, terrain roughness, and distance to rivers. Trade activity was generally limited to a 50 km radius centered at a municipality, so their analysis was a measure of spatial integration rather than national integration.

My relative contribution to this literature stems from the differences between the United States between 1940-1990 and Spain during the 18th century. In Cremeño & Santiago-Caballero's analysis, they focused on spatial integration because geographical barriers to trade restricted national integration. This restriction was further solidified by Spain's lack of trains, cars, or airline systems during that time. Between 1940-1990 in the United States, however, the physical landscape was somewhat different. Moreover, even prior to highway construction, ownership of cars was somewhat commonplace amongst American families. Also, railroad and airline infrastructure were available which enabled nationwide shipping. These transportation abilities suggest that the United States had fewer barriers to creating nationally integrated markets and that new highway segments could potentially provide less marginal benefit in comparison to a road in 18th century Spain.

Another study, by Zheng & Kahn[6] in 2013, investigated the impact of increased transportation options on housing prices by analyzing housing price trends in Chinese megacities after the construction of bullet trains. For context, megacities are centers where the concentration of resources is far higher than in surrounding rural areas. As a result of a high resource concentration, residents of megacities often face higher housing prices. The model in this study, which controlled for levels of purchasing power in surrounding cities, highway improvements, and population, found that the construction of bullet trains lowered housing prices in megacities. Thus, there was an increase in market integration for the housing market.

While there is evidence for increased integration in the housing market, Zheng & Khan's conclusion may not apply to the United States. When the bullet trains were built, China already had highways that provided routes between cities and their surrounding areas. The United States did not already have these in 1940, meaning that the magnitude of change in market integration could be different in both countries. Furthermore, Zheng & Khan claim that it is unlikely that China's Ministry of Railway selected areas to be connected by bullet trains at random. It is possible that they chose areas that stood to benefit the most from the connection. Since the IHS was not intentionally built through specific rural communities that maximize the provided benefit, my research puts Zheng & Khan's conclusion to the test in environments where the IHS was not originally meant to benefit. Moreover, due to the economic diversity of the United States, my research focuses on a region where the average resource concentration is lower than that of a megacity.

4 Descriptive Analysis

Figure 2:

Figure 2 suggests that travel distance distributions remained relatively similar in their range between 1940 and 1992. This is somewhat expected. While the Interstate Highway System did provide a more expedited method of travel compared to inner-city/rural alternatives from before, there is a limit as to how much highways can change the physical distances between counties. However, the creation of expedited travel methods might have a more substantial impact on travel times.

Figure 3:

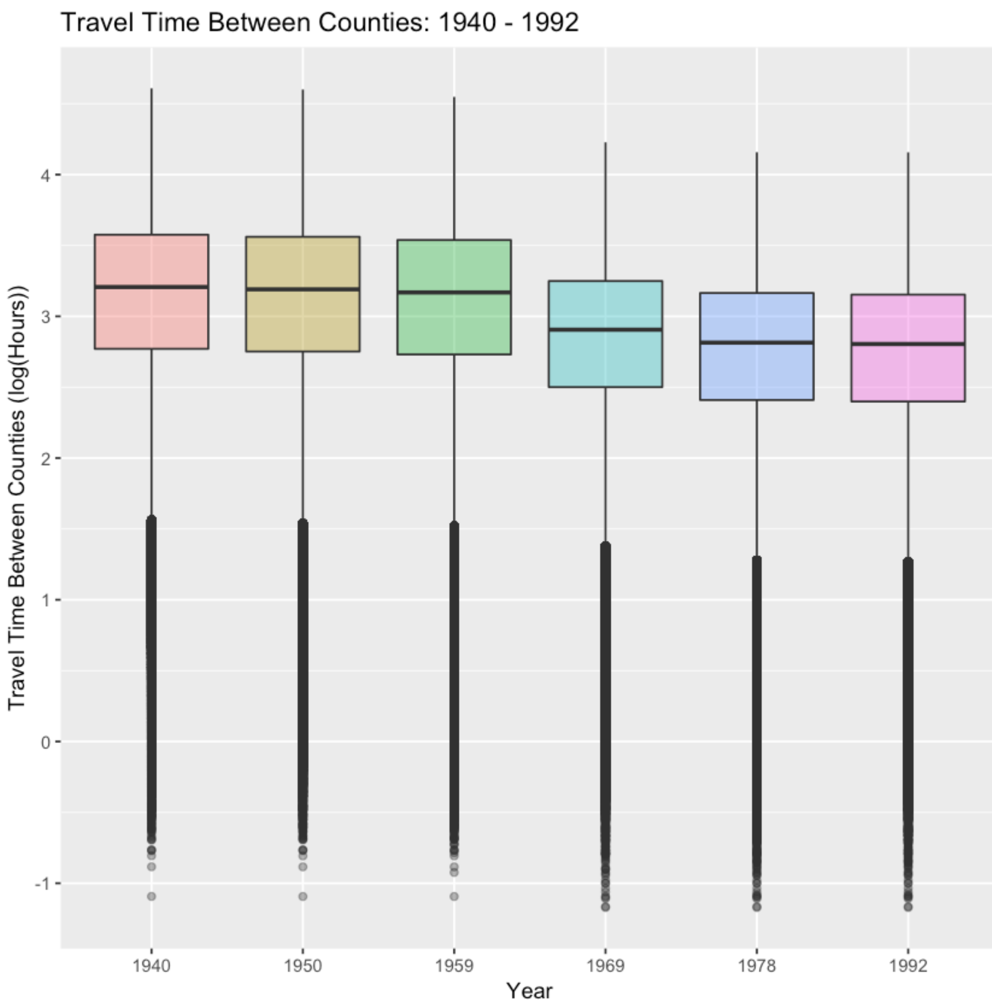
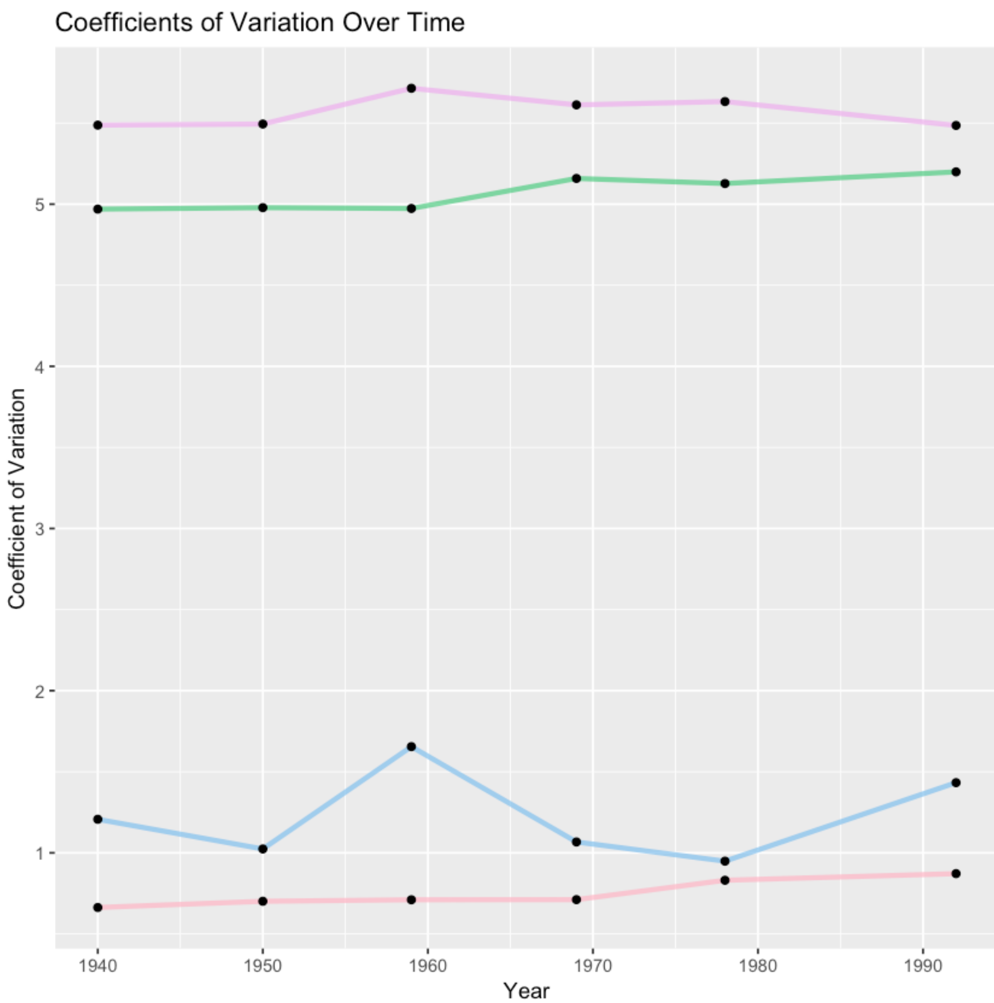


Figure 3 suggests that the distribution of travel times between 1940 and 1992 changed more notably compared to travel distances over the same period. The magnitude of change was most notable between 1959 and 1969, after which travel times continued to decrease at a slower rate. Note that in addition to good infrastructure, travel times are also affected by other factors. For example, the main motivator of the Emergency Highway Energy Conservation Act of 1974, which impacted national speed limits, was the high price of oil at the time. In this example, oil prices indirectly impacted travel time by altering speed limits. However, the act affected highways differently than it did non-highway roads; states were required to enforce a speed limit of 55 mph on highways whereas non-highway roads had the option of adopting speed limits less than 55 mph.[19] Based on this information, it can be deduced that highways, to a large extent, caused decreases in travel times.

Figure 4:



Purple: Total Farmland Value

Blue: Value Per Acre

Pink: Average Farm Size

Green: Number of Farms

[19] The New York Times. (1974, January 3). Nixon approves limit of 55 m.p.h. The New York Times. Retrieved March 28, 2022, from https://www.nytimes.com/1974/01/03/archives/nixon-approves-limit-of-55-mph-states-must-meet-standard-or-lose.html

Figure 4 highlights levels of variation over time in the total farmland value, value per acre, average farm size, and the number of farms observed in US counties. Total farmland value and number of farms see the most variation overall. This suggests that total farmland values and the number of farms are diverse across the United States. Values per acre and average farm sizes are less diverse overall. Over time, however, the coefficient of variation for values per acre tends to be less stable than the coefficients of variation for other variables. Finally, the number of farms and average farm sizes tend to become more varied over time whereas total farmland value and values per acre followed a more cyclic pattern.

Table 1: Mean Farmland Information for Counties

	Mean of Logged Value Per Acre ($)	**Mean of Logged Number of Farms**	**Mean of Logged Average Farm Size (Acres)**
1940	3.39	7.43	1.70
1950	4.17	7.30	1.74
1959	4.80	6.92	1.82
1969	5.42	6.59	1.89
1978	6.62	6.41	1.93
1992	6.86	6.23	1.96

Table 1 suggests that over time, average values per acre in counties are growing with the highest rates of growth occurring between 1940 and 1978. Moreover, in general, the average number of farms in a county is decreasing. However, this does not necessarily mean that the amount of agricultural product being produced is decreasing, especially since the average farm size shows growth over time.

5 Data and Methodology

5.1 Data

5.1.1 Datasets

United States Agricultural Data from 1840-1992 (ICPSR – Study 35206):

This data is collected from the United States Censuses of Agriculture taken between 1940 to 1992. It includes county-by-county agricultural panel data for each county in the United States. Some of the information provided in this dataset include types of crops grown, number of farms, farm sizes, farmland value, etc.

Geographic Information System (GIS) Data from 1940 to 2010 (Jaworski & Kitchens, 2022):

This data is sourced from shapefiles created by the U.S Department of Transportation. The dataset includes data from decades between 1940 and 2010 and contains variables such as travel time between all possible county pairs in the United States. Counties in a county pair may have multiple possible routes between each other, which can be a cause for concern. This dataset mitigates those concerns by using a graphing approach, whereby nodes (counties) are connected by branches (routes) and branch costs (travel times) are minimized by a shortest path algorithm (Dijkstra's algorithm). By using this approach, all travel times presented in the dataset are the shortest possible travel times using roads. Note that while the travel distances associated with the shortest travel time are not necessarily the shortest distance of any possible route, it is reasonable to believe that there is generally a positive correlation between travel time and travel distance.

5.1.2 Data Exclusions

While the United States Agricultural Data includes data between 1840-1992, this analysis will exclude any data before 1940. This exclusion is necessary because the IHS' construction began in 1956, meaning that data before 1940 adds little useful insight to the study. I chose to keep data from 1940 and 1950 because it provides some insight into how integrated the farmland market was directly before the beginning of IHS' construction. There have also been restrictions made to the GIS Data. Since the construction of the IHS primarily occurred between 1956 and 1992, I have excluded all data past 1990.

Unlike the GIS Data, the United States Agricultural Data is only collected on years when the agricultural census is conducted, which is not necessarily at the end of the decade. As a result of this, I have created the following pairings between the United States Agricultural Data years and GIS Data years.

Year from GIS Data	Closest Corresponding Year from Agricultural Data
1940	1940
1950	1950
1960	1959
1970	1969
1980	1978
1990	1992

To maximize accuracy in my results, I have matched the closest year where United States Agricultural Data was collected to each year from the GIS Data. Note that for the year 1989 in the GIS Data, the closest United States Agricultural Data data collections are from 1978 and 1982, both of which are equidistant from 1980. To main consistency with previous years, where the closest United States Agricultural Data year was slightly behind the corresponding GIS Data year, I have chosen to use United States Agricultural Data from 1978 instead of 1982.

5.2 Methodology

5.2.1 Variables

Predictor Variables:

My key predictor variable of interest is the shortest travel time between two counties in a county pair. Travel time is measured in hours. This predictor variable is generated using data from the GIS Dataset.

Fixed Effects Terms:

Fixed effects allow me to control for properties held by county pairs or years even if I do not have data specific about these properties. By controlling for these properties, I can reduce any skew that my county pairs or time might impose on my predictor variables. Below is an explanation of the fixed effect terms I will utilize.

a. **County-Pair Fixed Effects:**

   County pair fixed effects control for properties that are constant over time but differ across entities. Examples of these properties are the distance between the counties, the difference in climate between these counties, and the difference in land arability between these counties. These are all variables that could have an impact on levels of market integration.

b. **Time Fixed Effects:**

   Time fixed effects control for properties that are constant among county pairs but differ by period. An example of this property includes the national demand for different crops over time. With inventions such as polyester in the 1930s and high fructose corn syrup in the 1970s, it becomes clear that the demand for different crops changes over time and may affect land values and the scale of farms nationally. Other examples include national speed limit laws and gas prices, both of which affect the cost of travel for firms nationwide.

Response Variables:

Data to construct response variables can be found in the United States Agricultural Data Dataset. To measure levels of market integration, I will be using four different response variables. Response variables can be grouped into two categories: pecuniary and non-pecuniary. Pecuniary variables are variables that are related to money. Non-pecuniary variables are those that are not related to money. My response variables and their categorizations are shown below.

Note: For all response variables, i represents the origin county, j represents the destination county, and t represents the year.

Pecuniary:

a. Difference in Total Farmland Values ($):

$$DTFV_{ijt} = |ln(Total\ Farmland\ Value)_{jt} - ln(Total\ Farmland\ Value)_{it}|$$

b. Difference in Value Per Acre ($):

$$DVPA_{ijt} = |ln(Value\ Per\ Acre)_{jt} - ln(Value\ Per\ Acre)_{it}|$$

Non–Pecuniary:

c. Difference in Average Farmland Size (acres):

$$DAFS_{ijt} = |ln(Average\ Farmland\ Size)_{jt} - ln(Average\ Farmland\ Size)_{it}|$$

d. Difference in Number of Farms:

$$DNF_{ijt} = |ln(Number\ of\ Farms)_{jt} - ln(Number\ of\ Farms)_{it}|$$

5.2.2 Regression Specifications

Response variables will be calculated using linear regression and quadratic regression models. Linear regression models will be extended by interacting travel time with year and 1940 crop specialization. The general forms of these regression equations are shown below.

Note: For all regression models, i represents the origin county, j represents the destination county, t represents the year, α represents county pair fixed effects, μ represents time fixed effects, and ε represents error.

a. Linear Regression Models:

$$response_{ijt} = \beta_0 + \beta_1 \ln(Travel\ Time)_{ijt} + \alpha_{ij} + \mu_t + \varepsilon_{ijt}$$

Linear regression models allow me to see the effect of travel time on my response variables while assuming that the marginal effect of travel time is constant no matter how long or short the travel time is.

b. Quadratic Regression Models:

$$response_{ijt} = \beta_0 + \beta_1 \ln(Travel\ Time)_{ijt} + \beta_2 \ln(Travel\ Time)^2{}_{ijt} + \alpha_{ij} + \mu_t + \varepsilon_{ijt}$$

Quadratic regression models allow me to see the effect of time on my response variables while assuming that the marginal effect of travel time differs depending on how long or short the travel time is. From an economic perspective, this is an important consideration to make. Travel time can be thought of as a cost to an individual or a firm. The longer the travel time is, the more opportunity cost is associated with travel between counties. Eventually, the opportunity cost associated with travel time outweighs the benefits of traveling, and the levels of market integration begin to decrease. Therefore, it is within the realm of possibility that the marginal effect of travel time will change depending on how long or short it is.

c. ***Linear Regression Model with Year Fixed Effect Interaction:***

$$response_{ijt} = \beta_0 + \beta_1 \ln(Travel\ Time)_{ijt} + \sum_{k=2} \beta_k [\ln(Travel\ Time)_{ijt} * year] + \alpha_{ij} + \mu_t + \varepsilon_{ijt}$$

Construction of the highway system happened over the span of several decades. Because the developments to the system are different by decade, the marginal effect of travel time may be different by decade. By interacting travel time with the year, not only can I see the effect that a marginal increase in travel time has for each decade, but also whether the effect exhibits increasing, constant, or diminishing returns from the highway system.

d. ***Linear Regression Model with Crop Specialization Interaction:***

$$response_{ijt} = \beta_0 + \beta_1 \ln(Travel\ Time)_{ijt} + \sum_{k=2} \beta_k [\ln(Travel\ Time)_{ijt} * crop] + \alpha_{ij} + \mu_t + \varepsilon_{ijt}$$

- **<u>Note about *crop:*</u>** *crop* is a variable that may take the value $corn, cotton, or\ wheat$. $corn, cotton, and\ wheat$ are binary variables that take the value of 1 if both counties i and j had the same crop (either corn, cotton, or wheat) as their highest revenue producing crop in 1940 (before the construction of the IHS began). If both counties had different crops that produced the highest revenue in 1940, the value of *crop* will always be 0.

From the perspective of agriculture, changes in travel time may affect market integration depending on what farmland is used for. By interacting travel time with crop specialization, I can gather insight as to whether or not the marginal effect of travel time is universal regardless of what land is being used for.

General Interpretation:

The key predictor variable, travel time, can be interpreted as follows: a one percent increase in the travel time between counties i and j in year t is associated with a $\beta_1\%$ change in the response variable in question.

6 Results

6.1 Results for Linear Regression Models

Table 2: Linear Regression without County Pair FE

	Total Farmland Value Difference	Value Per Acre Difference	Average Farm Size Difference	Number of Farms Difference
Travel Time (hours)	0.09994*** (0.00052)	0.20269*** (0.00042)	0.41350*** (0.00056)	0.18456*** (0.00046)
Time FE	Y	Y	Y	Y
County Pair FE	N	N	N	N

Notes: All independent and dependent variables are logged. Values in parentheses are standard errors. Regressions based on 27,078,056 observations. * = p-value < 0.1; ** = p-value < 0.05; *** = p-value < 0.01;

According to Table 2, a one-percent increase in travel time leads to an increase in differences in total farmland value, per acre farmland value, average farm size, and the number of farms. The magnitude of the impact from a marginal increase in travel time was largest for the difference in average farm size, where a one-percent increase in travel time led to a 0.414% increase in the difference in farm size.

Table 3: Linear Regression with County Pair FE

	Total Farmland Value Difference	Value Per Acre Difference	Average Farm Size Difference	Number of Farms Difference
Travel Time (hours)	-0.20429***	-0.19354***	0.11831***	-0.01135***
	(0.00140)	(0.00115)	(0.00103)	(0.00126)
Time FE	Y	Y	Y	Y
County Pair FE	Y	Y	Y	Y

Notes: All independent and dependent variables are logged. Values in parentheses are standard errors. Regressions based on 27,078,056 observations. * = p-value < 0.1; ** = p-value < 0.05; *** = p-value < 0.01;

Table 3 highlights the large effect that adding county pair fixed effects have on the marginal impact on travel time. Additional travel time decreases the differences in total farmland value, value per acre, and the number of farms but, consistent with Table 1, increases differences in the number of farms.

The marginal effect of travel time is greatest for the difference in total farmland value, where a one-percent increase in travel time between two counties is associated with an average of 0.2043% decrease. The marginal effect of time is lowest on the difference in the number of farms, where a one-percent increase in travel time is associated with an average of 0.0114% decrease.

In summary, adding county pair fixed effects brought very substantial changes to the marginal impact of travel time. Whereas the model without county pair fixed effects associated larger travel times with larger differences, the county pair fixed effects model found the opposite for all response variables except for the difference in average farm size.

6.2 Results for Quadratic Regression Models

Table 4: Quadratic Regression

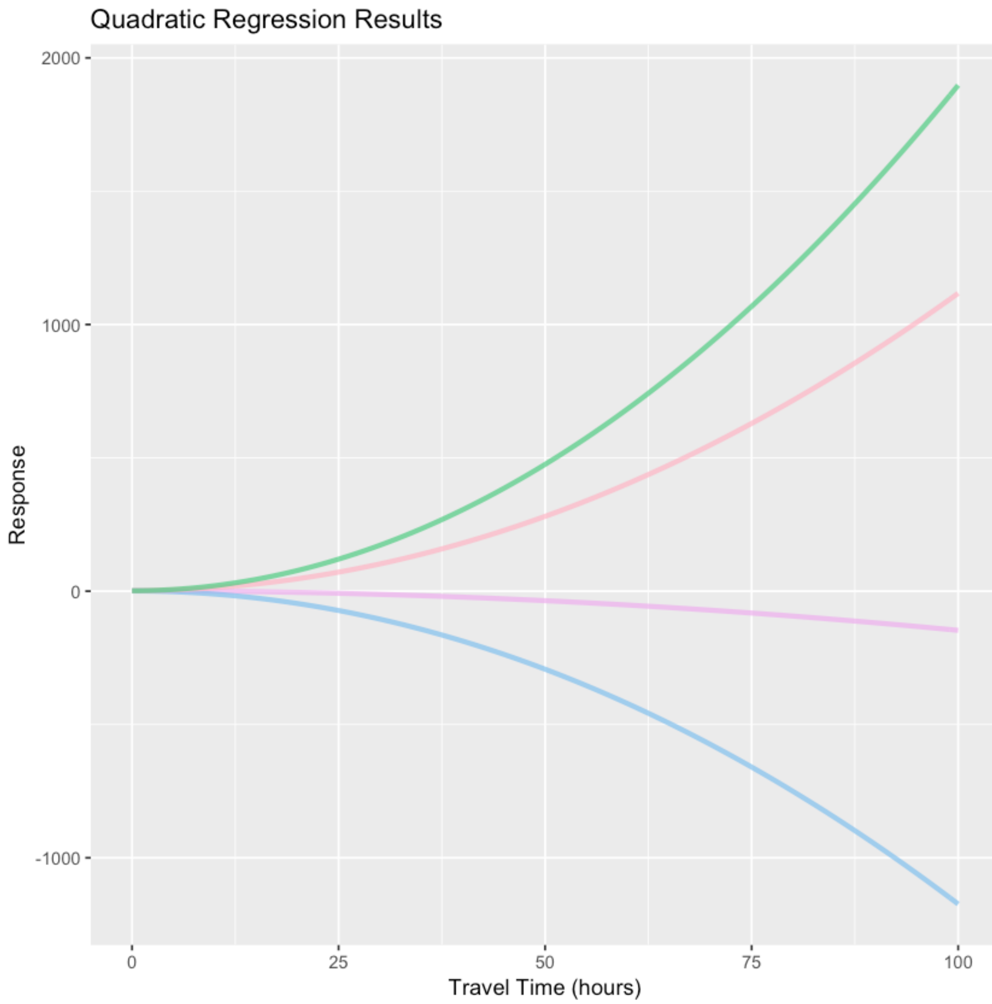
	Total Farmland Value Difference	Value Per Acre Difference	Average Farm Size Difference	Number of Farms Difference
Travel Time (hours)	-0.10529*** (0.00294)	0.59051*** (0.00241)	-0.86295*** (0.00215)	-1.27714*** (0.00264)
Travel Time Squared (hours*hours)	-0.01483*** (0.00039)	-0.11743*** (.00032)	0.11153*** (0.00028)	.18958*** (0.00035)
Time FE	Y	Y	Y	Y
County Pair FE	Y	Y	Y	Y

Notes: All independent and dependent variables are logged. Values in parentheses are standard errors. Regressions based on 27,078,056 observations. * = p-value < 0.1; ** = p-value < 0.05; *** = p-value < 0.01;

The quadratic models suggest that differences in total farmland value are consistently minimized as the travel time between two counties increases. Differences in value per acre follow a slightly different trend. For travel times between 0 and ~2.51 hours, values per acre become more different as travel time increases. However, for travel times greater than ~2.51 hours, per-acre farmland values become more similar as time increases.

Differences in average farm size and the number of farms follow the opposite pattern. Average farm sizes tend to become more similar for travel times between 0 and ~3.87 hours, after which they start to become less similar. Moreover, the number of farms tends to become more similar for travel times between 0 and ~3.37 hours, after which they start to become less similar.

Figure 5:



Purple: Total Farmland Value difference

Blue: Value Per Acre difference

Pink: Average Farm Size difference

Green: Number of Farms difference

As illustrated by the quadratic functions shown in Figure 5, the effect of shorter travel times is different than it is for longer travel times when measuring market integration through all variables. The effect of travel time on response variables is substantially less stable for differences in the number of farms, average farm size, and value per acre is than it is for differences in farmland value.

6.3 Results for Year FE Interaction Regression Models

Table 5: Year FE Interaction Regression

	Total Farmland Value Difference	Value Per Acre Difference	Average Farm Size Difference	Number of Farms Difference
Travel Time (hours)	-0.22889***	-0.02469***	-0.36247***	-0.26909***
	(0.00152)	(0.00124)	(0.00110)	(0.00136)
Travel Time x 1950	0.00510***	-0.03295***	0.07174***	0.01344***
	(0.00042)	(0.00034)	(0.00030)	(0.00037)
Travel Time x 1959	0.02277***	-0.02739***	0.08024***	-0.32145***
	(0.00042)	(0.00034)	(0.00030)	(0.0007)
Travel Time x 1969	0.00393***	0.02212***	0.00098***	-0.10638***
	(0.00045)	(0.00036)	(0.00032)	(0.00040)
Travel Time x 1978	-0.01074***	0.01200***	-0.04098***	-0.14858***
	(0.00045)	(0.00037)	(0.00033)	(0.00040)
Travel Time x 1992	0.01094***	0.11901***	-0.09466***	-0.17649***
	(0.00045)	(0.00369)	(0.00033)	(0.00040)
Time FE	Y	Y	Y	Y
County Pair FE	Y	Y	Y	Y

Notes: All independent and dependent variables are logged. Values in parentheses are standard errors. Regressions based on 27,078,056 observations. * = p-value < 0.1; ** = p-value < 0.05; *** = p-value < 0.01;

According to Table 5, for all years except 1978, a marginal increase in the travel time between two counties decreased differences in total farmland value more slowly than in 1940. To exemplify this pattern numerically, in 1978, a one-percent increase in travel time between two counties decreased the difference in total farmland values by .011% more than in 1940. However, in 1992, a one-percent increase in travel time between two counties decreased the difference in total farmland values by 0.011% less than in 1940. When analyzing how much slower the decrease was, I found a cyclic pattern. To exemplify this pattern numerically, in 1950, a one-percent increase in travel time between two counties decreased the difference in total farmland values by 0.005% less than in 1940. About a decade later, in 1959, a one-percent increase in travel time between two counties decreased the difference in total farmland values by 0.023% less than in 1940, which is a substantially larger effect than in 1950. Finally, the magnitude of the effect decreased again in 1969, when a one-percent increase in travel time between two counties decreased the difference in total farmland values by 0.004% less than in 1940.

Differences in values per acre show a more consistent pattern. Between 1941 and 1959, a marginal increase in travel time resulted in a decrease in the difference in values per acre faster than in 1940. In the years after 1959, the difference decreased more slowly than in 1940. For example, in 1950, a one-percent increase in travel time between two counties decreased the difference in value per acre by an average of 0.033% more compared to 1940. However, by the end of the IHS' construction in 1992, a one-percent increase in travel time between two counties increased the difference in value per acre by an average of 0.119% less compared to 1940. Moreover, the difference in value per acre saw a notable spike in the marginal effect of travel time between 1959 and 1969. In 1959, a one-percent increase in travel time between two counties decreased the difference in value per acre by 0.027% more than in 1940. In 1969, a one-percent increase in travel time decreased the difference in value per acre between two counties by 0.022% less than in 1940. The effect's magnitude continues to grow in 1992, but it grows in the same direction.

Next, between 1950 and 1969, a marginal increase in travel time between two counties decreased the difference in average farm sizes more slowly compared to in 1940. After 1969, the difference decreased more quickly. Similar to the difference in value per acre, there exists a notable spike in the marginal effect of travel time, specifically between 1959 and 1969. In 1959, a one-percent increase in travel time decreased differences in average farm sizes by 0.080% less relative to 1940. A large change was seen in 1969, where a one-percent increase in travel time decreased differences in average farm sizes by just 0.001% less relative to 1940. After 1969, changes in the rate of difference minimization were observed, but no changes were as drastic.

Finally, from 1959 to 1992, a marginal increase in travel time decreased the difference in the number of farms faster compared to in 1940. In 1950, a one-percent increase in travel time between counties decreased the difference by an average of 0.013% less than in 1940 whereas, in 1992, a one-percent increase in travel time between counties decreased the difference by an average of 0.176% more than in 1940. Again, regarding the difference in the number of farms, there was a single year where a major spike in the marginal effect of travel time remains sustained in decades after. In this case, the spike occured between 1950 and 1959. In 1950, a one-percent increase in travel time decreased the difference in the number of farms by 0.013% less than in 1940. The effect switches in 1959, where a one-percent increase in travel time decreased the difference in the number of farms by 0.321% more than in 1940.

6.4 Results for Crop Specialization Interaction Regression Models

Table 6: Crop Specialization Interaction Regression

	Total Farmland Value Difference	Value Per Acre Difference	Average Farm Size Difference	Number of Farms Difference
Travel Time (hours)	-0.19631***	-0.42641***	0.08733***	0.25509***
	(0.00177)	(0.00146)	(0.00133)	(0.00162)
Travel Time X Corn Specialization	-0.09522***	0.28040***	-0.11360***	-0.48566***
	(0.00180)	(0.00148)	(0.00135)	(0.00164)
Travel Time X Cotton Specialization	-0.04624***	0.01922***	-0.09948***	-0.21074***
	(0.00244)	(0.00201)	(0.00183)	(0.00223)
Travel Time X Wheat Specialization	-0.07967***	0.18423***	-0.24659***	-0.27278***
	(0.00120)	(0.00099)	(0.00090)	(0.00109)
Time FE	Y	Y	Y	Y
County Pair FE	Y	Y	Y	Y

Notes: All independent and dependent variables are logged. Values in parentheses are standard errors. Regressions based on 17,264,941 observations. * = p-value $<$ 0.1; ** = p-value $<$ 0.05; *** = p-value $<$ 0.01;

According to Table 6, a marginal increase in travel time between two counties decreased the difference in total farmland value in county pairs where corn, cotton, or wheat were the highest revenue producing crops of 1940 faster compared to counties where the highest revenue producing crop was different. The magnitude is largest for county pairs when corn is the highest revenue producing crop, where a one-percent increase in the travel time between two counties decreased the difference by 0.095% more compared to counties where the highest revenue producing crops were different in 1940.

Next, a marginal increase in travel time decreased the difference in value per acre where corn, cotton, or wheat were the highest revenue producing crops in 1940 compared to counties where the highest revenue producing crops were different. Again, the magnitude is largest for county pairs when corn was the highest revenue producing crop, where a one-percent increase in the travel time decreased the difference by 0.280% less compared to county pairs where the most valuable crops were different in 1940.

Moreover, a marginal increase in travel time yielded an increased difference in average farm size more slowly for county pairs where corn, cotton, or wheat were the highest revenue producing crops in 1940 compared to counties where the highest revenue producing crop was different. The magnitude is highest for county pairs when wheat was the highest revenue producing crop in 1940, where a one-percent increase in the travel time increased the difference by 0.247% less compared to county pairs where the highest revenue producing crops were different.

Finally, the difference in the number of farms follows a very similar trend to the difference in the average farm size. A marginal increase in travel time increased the difference in the number of farms more slowly for county pairs where corn, cotton, or wheat were the highest revenue producing crops in 1940 compared to counties where the highest revenue producing crops were different. The magnitude is highest for county pairs when corn was the highest revenue producing crop, where a one-percent increase in the travel time increased the difference by 0.486% less compared to county pairs where the highest revenue producing crops were different in 1940.

7 Conclusion

My results suggest that when measuring integration through pecuniary response variables (differences in total farmland value and value per acre), an increase in travel time eventually led to a slower decrease in market integration compared to before the construction of the highway system. Conversely, when measuring integration through non-pecuniary response variables (differences in average farm sizes and the number of farms), increases in travel time resulted in a quicker decrease in market integration compared to before the construction of the highway system.

Furthermore, differences in value per acre, average farm size, and the number of farms saw substantial one-time changes, after which the effect of increased travel time was more minor. Economically, this suggests that the highway system, or any infrastructure designed to decrease travel time, may provide diminishing returns. The largest effect from the infrastructure will be seen quickly after implementation. This result is consistent with findings in Fernald's study from 1999, where productivity boosts from the IHS were found to decrease after 1973.

Moreover, the effect of travel time was different depending on crop specialization. A marginal increase in travel time always had a different effect for counties that specialized in the same crop in 1940. Specifically for non-pecuniary variables, a marginal increase in travel time leads to a slower decrease in market integration when crop specialty is the same compared to when it is different. This pattern that suggests farm sizes and the number of farms may be dependent on more than travel time; perhaps the scale needed to be profitable, or the scale needed to maximize productivity has an impact too.

While some insight can be extrapolated from my regression results, it must be noted that the key results of my regressions, which suggest that a marginal increase in travel time leads to an *increase* in market integration are theoretically inconsistent. In theory, the less the travel time between two counties, the more integrated the counties should be. This inconsistency could stem from omitted variable bias in my model. Some potential omitted variables that may cause bias include road congestion and highway maintenance spending amounts.

First, omitting road congestion may be a source of bias in my models. Since population grows faster than the highway changes, the amount of strain on highways may change over time. In theory, road congestion, which lowers access between counties, acts as a physical barrier to trade. For this reason, road congestion should be negatively correlated with market integration. Road congestion also has a positive covariance with travel time because high levels of road congestion lead to high travel times. Because of this, road congestion should have a negative bias on travel time.

Second, omitting highway maintenance spending amounts may be another source of bias in my models. Badly maintained roads may increase travel time by causing more accidents and reducing vehicle speed, which may make travel more costly. Because of this, maintenance spending is expected to be positively correlated with market integration. Moreover, maintenance spending has a negative covariance with travel time. Overall, maintenance spending is expected to have a negative bias on travel time.

Aside from bias from omitted variables, my analysis may be flawed in determining the impact of highway infrastructure on market integration because I focus solely on the agricultural industry. Different industries may have different highway usage patterns. Alternatively, they may only use highways scarcely in favor of air or rail travel. Even the agricultural industry, which makes heavy use of highway infrastructure, resorts to alternative forms of transportation for certain products.[20]

Finally, since market integration in large economies is very multi-faceted, it would be interesting to analyze the effect of farm consolidation on market integration within the agricultural industry. Farm consolidation refers to the decrease in the number of farms

[20] United States Department of Agriculture. (2020, December). *The Importance of Highways to U.S. Agriculture.* Retrieved March 31, 2022, from https://www.ams.usda.gov/sites/default/files/media/Main_Highway_Report.pdf

and the increase in average farm sizes between 1935 and the 1970s.[21] Over time, the amount of farmland in the United States has also slowly decreased[20], in part due to urban sprawl. Farm consolidation will certainly have an impact on differences in the number of farms and average farm sizes. It may also have an impact on total farmland value and value per acre due to the benefits in productivity and economies of scale that consolidation garners.

Highways have widespread impacts on the national economy of the United States. Much of their effect, for both individuals and firms, remains unexplored. However, infrastructure such as the Interstate Highway System with effects pervasive enough to revolutionize the American lifestyle is certainly worth exploring, and I hope that future research regarding the System continues to reveal wonders.

[21] USDA Economic Research Service. (2022, February 4). *Farming and farm income*. Retrieved March 31, 2022, from https://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/farming-and-farm-income/

8 Works Cited

- Cermeño, A. L., & Santiago-Caballero, C. (2020, April 28). *All roads lead to market integration: Lessons from a spatial analysis.* Retrieved from https://ideas.repec.org/p/cte/whrepe/30247.html
- Eagle, D., & Stephanedes, Y. (1987, January 01). *Dynamic Highway Impacts on Economic Development*: Semantic Scholar. Retrieved from https://www.semanticscholar.org/paper/DYNAMIC-HIGHWAY-IMPACTS-ON-ECONOMIC-DEVELOPMENT-Eagle-Stephanedes/f77ceaf612b9f450572772df89247da2af2b7be0
- Fernald, J. G. (1999). *Roads to Prosperity? Assessing the Link Between Public Capital and Productivity.* American Economic Review,89(3), 619-638. doi:10.1257/aer.89.3.619
- Greany, W. C. (1919). *Report of the First Transcontinental Army Motor Transport.* Eisenhower Presidential Library. Retrieved March 28, 2022, from https://www.eisenhowerfoundation.net/primary-source/item/report-first-transcontinental-army-motor-transport
- Haines, M., Fishback, P., & Rhode, P. (2018). United States Agriculture Data, 1840 - 2012. https://doi.org/https://doi.org/10.3886/ICPSR35206.v4
- Highway History. (n.d.). Retrieved from https://www.fhwa.dot.gov/interstate/faq.cfm
- *Highway history.* U.S. Department of Transportation/Federal Highway Administration. (n.d.). Retrieved March 29, 2022, from https://www.fhwa.dot.gov/interstate/faq.cfm#question8
- Indot. (2021, July 15). *Indiana and the First Transcontinental Motor Convoy of 1919.* Indiana Department of Transportation. Retrieved March 28, 2022, from https://www.in.gov/indot/resources/indot-history/indiana-and-the-first-transcontinental-motor-convoy-of-1919/

Interstate Highway System. Review of Economics and Statistics,90(4), 683-701. doi:10.1162/rest.90.4.683

- Jaworski, T., & Kitchens, C. (2022). *Highways in the Twentieth Century (Working Paper)*. Retrieved March 30, 2022.
- Jaworski, T., Kitchens, C. T., & Nigai, S. (2018). *The Interstate Highway System and the Development of the American Economy ∗* | Semantic Scholar. Retrieved March 30, 2022.
- Mamuneas, T. P., & Nadiri, M. I. (2006, August). *Production, Consumption and the Rates of Return to Highway Infrastructure Capital*. Retrieved from https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.352.8782&rep=rep1&type=pdf
- Michaels, G. (2008). *The Effect of Trade on the Demand for Skill: Evidence from the*
- National Archives and Records Administration. (n.d.). *National Interstate and Defense Highways Act (1956)*. Retrieved March 29, 2022, from https://www.archives.gov/milestone-documents/national-interstate-and-defense-highways-act
- Slater, R. E. (1996). *The National Highway System: A Commitment to America's future*. Retrieved March 29, 2022, from https://highways.dot.gov/public-roads/spring-1996/national-highway-system-commitment-americas-future
- Smith, Jean Edward. *Eisenhower: In War and Peace*, Random House Trade Paperbacks, New York, 2013, p. 652.
- United States Department of Agriculture. (2020, December). *The Importance of Highways to U.S. Agriculture*. Retrieved March 31, 2022, from https://www.ams.usda.gov/sites/default/files/media/Main_Highway_Report.pdf
- USDA Economic Research Service. (2022, February 4). *Farming and farm income*. Retrieved March 31, 2022, from https://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/farming-and-farm-income/
- USGS. (2006). *Materials in use in U.S. Interstate Highways - USGS*. Retrieved March 30, 2022, from https://pubs.usgs.gov/fs/2006/3127/2006-3127.pdf

- Weingroff, R. F. (1996). *Federal aid road act of 1916: Building the foundation.* Retrieved March 29, 2022, from https://highways.dot.gov/public-roads/summer-1996/federal-aid-road-act-1916-building-foundation
- Zheng, S., & Kahn, M. E. (2013). Chinas bullet trains facilitate market integration and mitigate the cost of megacity growth. *Proceedings of the National Academy of Sciences,110*(14). doi:10.1073/pnas.1209247110