Hoggin' the Road: Negative Externalities of Pork Slaughterhouses

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Abstract

Heavy industries have negative externalities such as truck traffic, and trucks cause automobile crashes. This paper estimates the effect of pork slaughterhouses on truck traffic and the resulting traffic crashes. To recover causal estimates using two stage least squares, we exploit historic hog population as quasi-random variation in current pork slaughterhouse location. We find an additional pork slaughterhouse increases truck traffic by 96% and fatal traffic crashes by 23%. These estimates are important for quantitatively assessing the optimal tax to address negative truck externalities resulting from slaughter and other industries.[1]

Keywords: truck traffic, road damage, pork slaughterhouses

JEL Classification: N52, Q10, R41, R42

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1 Introduction

Throughout the 19th century in the US, there was sustained economic growth which was correlated with rising trends in industrialization and urbanization (Kaldor, 1967). These trends also introduced negative externalities to cities, such as water pollution (Leon, 2008, pg. 5), air pollution (W. W. Hanlon, 2016), crime (United States President's Commission on Law Enforcement & Administration of Justice & Katzenbach, 1967, pg. 5, 17), and congestion (Glaeser, 2014, pg. 3). Modern industries, such as coal-powered energy generation, hydraulic fracturing, and agriculture also generate negative externalities. In response, at least one town in each major US shale formation (Bakken, Marcellus, Barnett) has attempted to ban heavy truck traffic from nearby fracking operations.[2] Similar to fracking, the hog slaughter industry is also associated with heavy truck traffic. The city of Great Falls, Montana attempted to prohibit the opening of a 3,000 acre meat processing facility near the city in 2019. Pollution, traffic, and road damage from trucks are among the major reasons residents cited as justifications to cancel the facility (Shinn, 2019).[3]

This paper quantifies how pork slaughterhouses affect truck traffic, road roughness, and fatal crashes. Given the additional planned subsidies to the pork industry (USDA, 2021), the negative consequences of trucks, and the concerns of residents, this is a highly relevant policy question. Furthermore, the negative externalities of heavy industry are a core concern for the economic literature.

An obstacle that complicates estimating the causal effects of pork slaughterhouses is that they do not locate randomly, instead choosing areas which minimize costs. The main approach addresses this challenge by appealing to variation in contemporary pork slaughterhouses which arises due to historic hog populations. The results show 1945 hog population predicts both contemporary hog population and pork slaughterhouses. This historic variation is then operationalized using a two-stage least squares (2SLS) approach. By conventional standards, 1945 hogs predicts contemporary slaughterhouses with adequate strength for minimally biased second stage estimates and the

[2]These concerns have been highlighted in popular media. Land owners in North Dakota were concerned about increased truck traffic from fracking wells (Associated Press, 2017); a Texas resident expressed concern about truck traffic from fracking, noting one of her friends was killed by a fracking truck (The Texas Tribune, 2014); Pennsylvania residents note the problems associated with the increased truck traffic due to fracking (The Allegheny Front, 2017).

[3]Residents are correct that trucks are used by the pork slaughter industry; trucks are the preferred mode of transportation for hogs (Food and Agriculture Organization of the United Nations, 2001) and Brodersen (2015) approximates that 2,000 trucks transport 1,000,000 hogs daily in the US.

weak-instrument efficient Anderson-Rubin confidence sets result in reassuringly similar inference (T. Anderson, Rubin, et al., 1949; Andrews, Stock, & Sun, 2019; Stock & Yogo, 2002).

The instrument, historic presence of production inputs, is closely related to previously used sources of variation. It is common to instrument for a contemporary endogenous variables using a historic source of variation such as planned interstate maps or historical mine sites (Duranton & Turner, 2011; Glaeser, Kerr, & Kerr, 2015; W. Hanlon & Heblich, 2021). In a different, clever approach, McArthur and McCord (2017) instruments for crop production using distance to fertilizer production. Our approach uses historic presence of agricultural inputs as a blended version of these distinct designs.

Contemporary pork slaughterhouses, instrumented for using 1945 hogs, are estimated to increase truck traffic by 96% This is driven by a reduced form that estimates for every 10,000 hog increase in 1945, contemporary truck traffic increases by 4.3% or approximately an additional 43 annual daily truck miles. Furthermore, OLS estimates similar positive associations between both pork slaughterhouses and truck traffic and pork slaughterhouses and car traffic in some specifications; the positive relationship between slaughterhouses and car traffic is inconsistent with the operations of slaughterhouses. With the instrumental variables strategy, we do not find a robust, statistically significant relationship between pork slaughterhouses and car traffic.

These results goes beyond prior anecdotal or descriptive evidence on the negative automobile externalities of the meat industry. The most closely related work only examines Kansas and does not invoke a strategy for separating the endogenous selection of slaughterhouse location from the causal effects of slaughterhouses (Bai et al., 2007); however, these results have an explicit causal strategy and use a national sample. Prior work has established that hog barns reduce house prices (Lawley, 2021) and these results expand the potential negative externalities of the meat industry to road-related outcomes.

Since slaughterhouses cause additional truck traffic, the next set of results investigates two negative downstream outcomes of trucks: automobile crashes and road roughness. Pork slaughterhouses also cause fatal crashes, but the parametric point estimates are unable find a significant association between slaughterhouses and road roughness. The estimates find that pork slaughterhouses increase fatal crashes by 23% and that 10,000 additional 1945 hogs increase contemporary fatal crashes by 7.8%.

These results extend the contribution beyond quantifying additional nuisance due to additional traffic. The additional truck traffic is also fatal for local residents which adds to the literature on how heavy vehicles lead to automobile crashes (M. L. Anderson & Auffhammer, 2014; Muehlenbachs, Staubli, & Chu, 2021; Xu & Xu, 2020). While Xu and Xu (2020) and Muehlenbachs et al. (2021) study trucking that originates due to hydraulic fracturing, these results show that their findings generalize to heavy trucking from an agricultural industry. Furthermore, our estimates provide percent changes in truck traffic and crashes which reveals the implied elasticity of fatal crashes with respect to truck traffic. If pork slaughterhouses were perfectly competitive markets, these negative externalities would imply that the industry should be taxed to reach the socially optimal output of pork.

Finally, we examine the distribution of slaughterhouses by top and bottom historic hog quartile to further understand the compliers. The most noticeable difference is that the bottom hogs quartile is 10 percentage points (pp) more likely to have no slaughterhouses. This suggests that our results are driven by areas without highly-concentrated industrial farm operations. This implies that rural areas are most vulnerable to adverse automobile outcomes that are driven by the pork slaughter industry.

Continuing the analysis, we find that Kolmgorov-Smirnov and Goldman and Kaplan (2018) tests for equality of distributions reject that distributions of truck miles and fatal crashes are equal for the top and bottom 1945 hog quartiles. The areas where the distributions diverge are within about 1 standard deviation of the mean of these outcomes, suggesting average places are particularly vulnerable. In contrast to the parametric regression results, the tests for equality of distributions also reject that the distributions of road roughness are equal.

Existent literature is limited to describing the association between trucks and road roughness (Bai et al., 2007) or is from outdated experimental evidence (Eschwege, 1979). It would be advantageous to obtain an updated causal effect of heavy truck traffic for policy and the literature. The exact causal effect of heavy industry truck traffic on road roughness is a widely-applicable and relevant policy parameter. For example, structural urban models on optimal truck taxation rely on the outdated experimental results for the parameters of how trucks damage roads (Parry, 2008). This runs the risk of using irrelevant information, since trucks and roads have changed since this experiment was run. Moreso, Parry (2008) calls for updating the parameters of the model as new information becomes available. Our results take a step towards updating the causal effect of trucks on road damage using a nation-wide observational sample and causal research design.

We begin by describing the multiple data sources and method for extracting historic hog populations from old maps in Section 2.[4] Section 3 provides a minimum working model of why slaughterhouse location is endogenous with respect to transportation outcomes and then describes how the research design addresses this concern. Section 4 presents results and Section 5 offers a brief conclusion.

2 Data

The research question is how a slaughterhouse affects road usage, crashes, and infrastructure. This requires data on slaughterhouse locations, truck miles traveled, fatal crashes, and road roughness. Ideally, slaughterhouses could be assigned randomly, yet this is cost prohibitive. To circumvent endogeneity and the cost of experimentally assigning slaughterhouses to locations, we also collect data on historic hog population from multiple sources in multiple points in time as quasi-random variation in contemporary pork slaughterhouse locations.

2.1 Road Outcomes

Road data on traffic and road quality comes from the Highway Performance Monitoring System (HPMS). HPMS data is published yearly by the Federal Highway Administration (FHWA), after the states submit data. The data are restricted to only two-way roads to focus on the most common roadway facility type in the HPMS and to reduce unnecessary variation in the outcome variables. Approximately 93% (N = 6,300,319) of the national HPMS universe of data is two-way roads.[5] The 2017 data include both the International Roughness Index (IRI) and Annual Average Daily Traffic (AADT) separately for cars and trucks.

Annual Average Daily Traffic For truck AADT, the data is from the HPMS definition of "combination" trucks, which include trucks with four-or-less axles, single-trailer trucks through seven-

[4] Those who are interested in background on the hog industry can see Section B.

[5] HPMS data also include information on one-way roads, ramps, non-mainline, and planned roadway segments. These types of road facilities represent very different types of roadways that are not as commonly driven on.

or-more axles, and multi-trailer trucks.[6] This represents the most likely category for trucks used by industrial pork slaughter operations.

Earlier yearly iterations of HPMS data does not separate car AADT and truck AADT separately in every state. This makes it highly impractical to use HPMS data for a nationwide, panel analysis. Cross-sectional data does not limit the empirical strategy because it exploits a time-invariant source of variation (historic hog population in a specific year).

International Roughness Index Road roughness is measured using the International Roughness Index (IRI). The IRI is the number of inches the suspension of a typical car moves over one mile of road (Duranton, Nagpal, & Turner, 2020, pg. 6). A small IRI measure is associated with better overall pavement quality and a smoother ride compared to larger IRI measures, since a vehicle's suspension moves less over a road with a lower IRI.

Assigning Road Segments to a County The road segments in the HPMS data are assigned a county identifier based on the geographic location of each road segment using geographic information systems (GIS) software.[7] If a segment is within the geographic boundaries of a county, it is assigned that particular county identifier. This identifier is used in the calculation of a weighted amount of truck miles or road roughness and to merge to other data sources.

Weighting The road segments recorded in the HPMS are 0.08 miles long on average, but vary from 0.0000002 miles to 60 miles in length. Without appropriate weights, there is a risk that a short and a long road contribute equally to the recorded truck miles or IRI. This may not accurately measure the truck AADT or IRI in a county.

To more accurately represent the outcomes, weights are created for each road segment. The weights, w_{ij}, are based on the length of the road segment relative to the total length of road in a county:

$$w_{ij} = \frac{r_{ij}}{R_j}, \tag{1}$$

[6] See http://onlinemanuals.txdot.gov/txdotmanuals/tri/classifying_vehicles.htm for a visual representation.

[7] The short length of HPMS road segments (0.08 miles) means they are most often located within one county. If a segment crosses multiple counties, it is dropped before it is spatially joined to a county.

for road segment *i* in county *j*, *r* is the length of the segment *i* in county *j*, and *R* is the total length of county *j*'s road network.[8] The product of the weight and outcome (IRI, truck AADT) for each road segment are then summed within a county to create the outcome variables used,

$$Y_j = \sum_{i=1}^{i=I} (y_{ij} * w_{ij}), \tag{2}$$

in which y_{ij} is the truck AADT or IRI for each segment and Y_j is the (weighted) dependent variable by county used in the analysis.

Fatal Crashes Fatal crash data come from the Fatality Analysis Reporting System (FARS). We aggregate the number of fatal crashes in 2017 to the county level.

2.2 Historic Hog Location Data

Our identification strategy uses historic hog population locations to instrument for current hog population locations. Data on historical hog population locations come from two major sources. The United States Department of Agriculture (USDA) Agricultural Census provides publicly available data sets dating back to 1840.[9]

We use the 1945 Agricultural Census as the historical benchmark for several reasons. Because we are examining several outcomes that are related to roads, we wanted to choose a historical census that took place before the construction of the Interstate Highway System. Additionally, the vertical integration of the hog industry did not begin until the 1940s, so hog locations before the 1940s are less reflective of the current hog industry.[10] The year 1945 mitigates these two concerns.

2.2.1 Hog Populations Extracted from Maps

To provide a comparison to the USDA Agricultural Census, we also source data from a published map of hog locations in 1948. Figure A.1 illustrates this map. The map is from a series of livestock

[8] Intuitively, these weights sum to 1 within each county.
[9] See `https://www.nass.usda.gov/AgCensus/FAQ/2017/index.php`
[10] See Section B for more details.

and crop maps printed in a *World Geography* textbook (Bradley, 1948).[11] Since each point represents 5,000 hogs, the count of points from this map is representative of the historic hog population.

Figure A.2 shows the comparability of these data sets. In general, both sources of historical hog data follow similar distributions. The 1948 map distribution, however, includes fewer values in the tails of the distribution compared to the 1945 census.[12]

2.3 Contemporary USDA Data

The contemporary slaughterhouse data come from the United States Department of Agriculture (USDA) Food Safety and Inspection Service (FSIS) in 2019. The other contemporary data we use come from 2017. Even though the slaughterhouse data and the other contemporary data are from different years, we believe that this has little to no impact on the analysis. Between 2017 and 2019, only 5 out of 569, or 0.008%, of slaughterhouses in the US closed.[13] The 2019 data are restricted to only slaughterhouses that process and/or slaughter pork products. The slaughterhouses are geo-referenced by latitude and longitude.

Slaughter and processing volumes are discretely categorized in the data as 1-5, with 1 being the smallest slaughter volume and 5 being the largest. There are 569 total pork slaughterhouses and 449 of them are categorized as 1 or 2. In the main analysis, no distinction is made between slaughterhouses with larger or smaller slaughter volumes.We prefer to use the number of slaughterhouses as opposed to slaughter volume because it is more difficult to interpret the sum of discretely categorized slaughter volume.

Contemporary measures of the hog population by county come from the USDA's National Agricultural Statistical Service (NASS). The USDA Economic Research Service (ERS) provides Rural-Urban Continuum codes (RUCC) for each county. These data are based on population and commuting flows. The RUCC data are scaled from 1 to 9, with 1 being the most urban and 9 being the most rural.

[11] This book can be found in open-source format here: https://openlibrary.org/books/OL6028680M/World_geography

[12] Because the map data was sourced by aggregating the number of black pixels in the map, this could explain why the map data is under-counting the right tail of the distribution; several points on top of each other could have been counted as one point. The left tail of the distribution could be under-counting zeros due to fading, smudges, or folds of the physical map.

[13] We gather this information from https://www.pork.org/facts/stats/u-s-packing-sector/#uspackingplantclosing, but cannot precisely say which slaughterhouses closed.

2.4 Combining the Data

We aggregate all data to the county level. If a historic hog point, pork slaughterhouse, road segment, or fatal crash is within the geographic boundary of a particular county, then an identifier is attached for that county to the data. After the identifier is attached, it is straightforward to add up the number of hog points, slaughterhouses, and fatal crashes within a particular county.

We utilize cross-sectional, county-level data for a variety of reasons. There is little variation in pork slaughterhouse openings across time. Also, the HPMS data for the entire United States is only provided at the yearly level. Due to the amount of road maintenance and damage that could occur over the span of one year, using this data in a yearly-panel setting is less than ideal to examine road roughness over time. Additionally, earlier years of the HPMS data do not separate car and truck traffic, so looking at these types of traffic separately in a panel setting is impossible.

2.5 Conditional Correlations

Table 1 shows baseline OLS estimates for the relationship between contemporary pork slaughterhouses and contemporary traffic. Panel A summarizes the results for truck traffic, while Panel B summarizes the results for car traffic. Without any fixed effects included in the OLS model, column 1 shows there is a positive correlation between pork slaughterhouses and both truck and car traffic. However, this relationship hinges on the exclusion of state fixed effects and RUCC fixed effects. As shown in column 4, only truck traffic remains positive and statistically significant with the inclusion of state and RUCC fixed effects. Interacting these two fixed effects in column 5 eliminates this statistical significance. This non-significant result runs counter to intuition that pork slaughterhouses should be associated with more truck traffic.[14]

2.6 Descriptive Statistics

Table 2 displays the summary statistics for key variables at the county level. Panel A shows the full sample, while Panels B and C split the sample by the median 1945 hog count. Panels B and C illustrate counties with above the median hog points in 1945 have more contemporary slaughterhouses and more truck traffic than counties with fewer than the median hog counts. Additionally,

[14]This intuition is based on the nature of the slaughter industry discussed in Section B.

counties with more hog points in 1945 also have higher average IRI (rougher roads) and more fatal crashes in 2017.

Maps of Key Variables Figure 1 shows the relationships between county-level 1945 hog counts and both contemporary pork slaughterhouses and truck traffic. Figure 1a and Figure 1c highlight the spatial correlation between the location of 1945 hogs and contemporary pork slaughterhouses. Most counties with a large amount of 1945 hogs, as indicated by the dark blue color, also have a slaughterhouse within or nearby the county. This visual relationship indicates the potential for a strong first-stage relationship. Figure 1b and Figure 1d map the reduced form relationship between 1945 hog counts and contemporary truck traffic. Counties with both large levels of 1945 hogs and 2017 truck traffic are colored dark blue. In the Midwest, these dark blue counties appear to be counties that have pork slaughterhouses, lie along the road network, and/or are located around urban areas. In the South, these dark blue counties match more closely to just slaughterhouse locations.

3 Methods

The relationship of interest is how changes in the amount of pork slaughter affects truck traffic. The association can be estimated using the following equation via OLS:

$$Truck\ AADT_c = \kappa + \beta Slaughterhouse_c\ + X_c\gamma +\ u_c. \tag{3}$$

Here, β is unlikely to represent a causal effect without strong assumptions.

3.1 Theory

To examine causal effects of pork slaughterhouses, this paper uses a natural experiment in the assignment of slaughterhouses. This quasi-random assignment arises by appealing to cost-minimizing producers who optimally avoid high transport costs (McArthur & McCord, 2017; Picard & Zeng, 2005) and the persistence of natural regional advantages for certain industries (Glaeser & Gottlieb, 2009; Glaeser et al., 2015). This theory is useful in understanding endogeneity concerns inherent in OLS and establishing plausible conditions under which causal effects of pork slaughterhouses can be recovered.

3.1.1 Endogenous Slaughterhouse Location

The objective of slaughterhouses is to minimize costs. Costs are a function of transporting hogs and other factors (such as labor and capital). The objective function is:

$$\min_{D,I} C(Distance\ to\ Hogs\ (D),\ Other\ Inputs\ (I)).$$

Firms are subject to a target output level, $\overline{Q}$, and a production function. Firms choose the optimal amount of distance from hogs and amounts of other inputs. Under a wide set of plausible assumptions, the optimal distance depends on the price of distance,

$$D^*(P_D, ...).$$

The price of distance is influenced by existing infrastructure, because businesses prefer transportation infrastructure with low transportation costs. Higher truck traffic are usually found in areas with a larger quantity of roads and/or better quality of roads, which means that the price of distance depends on available infrastructure. However, AADT is also the outcome variable of interest. Since available roadway is correlated with truck traffic, the price of distance and slaughterhouse location decisions are endogeneous with respect to truck traffic. Thus, where firms choose to optimally locate, D^*, is a function of the outcome variable, Y, leading to reverse causality and endogenous firm location with respect to the infrastructure outcomes being studied,

$$D^*(P_D(Y, ...), ...).$$

In the absence of strong assumptions, this endogenous location decision causes the OLS β from Equation 3 to be uninformative about the causal effect of pork slaughterhouses on road outcomes.

3.1.2 Historic Hog Population, Contemporary Hog Population, and Pork Slaughterhouses

To estimate causal effects of slaughterhouses on truck traffic and infrastructure outcomes, historic hog population is used as quasi-random variation in current pork slaughterhouse location. The hypothesis is that hog populations are persistent, specifically that,

$$Corr(hog\ population_{c,y=1945}, hog\ population_{c,y=2017}) > 0,$$

due to persistent natural regional advantage (Glaeser & Gottlieb, 2009). Table 2 shows that areas with above average 1945 hogs have 47,172.25 hogs in 2017 on average and areas with below average 1945 hogs have an average of 2,630.77 hogs in 2017. Furthermore, as shown by Figure 2, the same positive persistence can be found when using hog populations as far back as 1840.

By predicting contemporary hog population, historic hog population predicts contemporary areas with lower transport costs,

$$Corr(hog\ population_{y=1945}, P_{D,y=2017}) < 0.$$

Since pork slaughterhouses reach lower isocost lines with lower prices of distance,

$$Corr(hog\ population_{c,y=1945}, pork\ slaughterhouses_{c,y=2017}) > 0. \tag{4}$$

This underlying persistence of hogs, as shown by Equation 4, provides the variation that our identification relies upon.

3.2 Econometric

Our strategy to identify causal effects of pork slaughterhouses on road traffic is to rely upon variation in pork slaughterhouse that arises due to persistence in local hog populations. The first-stage relationship between historic hog population and contemporary pork slaughterhouses is specified:

$$Pork\ Slaughterhouses_{c,y=2019} = \phi_1 Hogs_{c,y=1948} + X_c\beta + \gamma_s + \lambda_r + \epsilon_c, \tag{5}$$

in which c stands for county, s stands for state, y stands for year, and r stands for rural-urban continuum code. The theoretical reasoning predicts $\phi_1 > 0$.

In the second stage, the relationship of interest is how do contemporary pork slaughterhouses affect contemporary automobile transportation? To do this, the quasi-random assignment from the first stage is leveraged in the following equation

$$(6) \qquad ln(Truck\ AADT)_{c,y=2017} = \beta_1 Pork\ \widehat{Slaughterhouses}_{c,y=2019} + X_c\beta + \gamma_s + \lambda_r + u_c,$$

in which the subscripts are the same and $Pork\ \widehat{Slaughterhouses}$ are predicted values from Equation 5. Truck AADT (truck average annual daily traffic) is log-transformed, because, as shown by Table 2, it exhibits a large positive skew.[15,16] Both regressions include state, μ_s, and urbanicity, λ_r, fixed effects. Since pork slaughterhouses use trucks, observing a $\beta_1 < 0$ would be unexpected.

3.3 Identification

For our estimates to be given an interpretation as causal estimands, the goal of this paper, several assumptions must be satisfied (Angrist, Imbens, & Rubin, 1996; Imbens & Angrist, 1994). First, hog population needs to be sufficiently persistent that historic hog population is able to predict contemporary slaughterhouse location with adequate strength. Historic hogs predicts contemporary slaughterhouse strongly enough by conventional standards that the estimates are minimally biased (Stock & Yogo, 2002). We also present Anderson-Rubin confidence sets, because this inference is efficient in the presence of potentially weak instruments (T. Anderson et al., 1949; Andrews et al., 2019).

The second key assumption is that historic hogs are independent of contemporary slaughterhouses. If this is so, then the reduced form regression of contemporary traffic on historic hogs can be interpreted as an intent-to-treat effect. This is likely satisfied due to historic hog population being realized 72 years before contemporary slaughterhouses. For example, the interstate system was not built until after our measure of historic hogs is realized. Next, we describe the conditioning

[15]The maximum value is 10 times the standard deviation and mean.

[16]This transformation leads to a loss of 9 counties which have 0 truck traffic.

strategy which weakens this assumption to independence, conditional on additional fixed effects and covariates.

3.3.1 Exclusion

Third, the exclusion restriction requires that historic hog population is not correlated with the error term in the second stage,

$$corr(Hogs_{c,y=1945}, u_{c,y=2017}) = 0. \tag{7}$$

In other words, historic hog population affects contemporary truck traffic only through its ability to predict contemporary pork slaughterhouse location. Instead of relying on this unnecessarily strong assumption, our estimates require the weaker conditional exclusion assumption.

This restriction attempts to include the variables in $u_{c,y=2017}$ that are also correlated with historic hog populations in the regression. This makes it so that the remaining variation in $u_{c,y=2017}$ is uncorrelated with historic hog population. The following conditional exclusion restriction,

$$corr(Hogs_{c,y=1945}, u_{c,y=2017} \mid \mathbf{S}, \mathbf{R}, \mathbf{X}_{c,y=2017}) = 0, \tag{8}$$

is the relevant assumption for our estimates to have a causal interpretation. This exclusion restriction allows historic hog population to be correlated with states, $\mathbf{S}$, urbanicity, $\mathbf{R}$, and other contemporary covariates, $\mathbf{X_{c,y=2017}}$ such as land area, railway infrastructure[17], and other agricultural activity without invalidating the causal interpretation of β_1.

State fixed effects are important for several reasons. First, states differ in their hog product outputs and fixed effects account for this across-state variation. Second, state fixed effects account for state-level agricultural policies. Third, the national HPMS roadway data is submitted by states and state fixed effects account for possible differences across states in how these are prepared.

In addition to variation across states, there is also likely to be significant variation in both truck traffic and slaughter activity that differs by how rural an area is. For example, interstate traffic tends to be positively correlated with urban areas and agricultural activity tends to occur in rural

[17] Geo-referenced railroad data come from Homeland Infrastructure Foundation-Level Data (HIFLD) using GIS. Rail miles strictly used for passenger travel are not included in the analysis.

areas. The regressions control for this using the Rural-Urban Continuum Code which classifies counties from most urban 1, to most rural, 9. This code is created from both population and commuting flows. Furthermore, sometimes individual state and RUCC fixed effects dropped in lieu of interacted state and RUCC fixed effects. The interacted fixed effects account for state-specific differences in rural and urban areas. The control variables include land area, miles of railroads, and related agricultural activity such as corn and soybeans.

Additional Assumptions Furthermore, the estimated effects are valid for compliers. Compliers are counties that have slaughterhouses because they have historic hogs or don't have slaughterhouses due to absence of historic hogs. The assumption of weak monotonicity requires that contemporary slaughterhouses don't decrease with additional historic hogs. Finally, the stable unit value treatment assumption requires no spillovers across counties.

4 Results

In order to better understand the data upon which the upcoming regressions will be based, the results begin with binned scatter plots shown in Figure 3.As shown by Figure 3a and Figure 3b, the strong and weakly monotonic instrument requirements, described in Section 3.3, seem reasonably satisfied. Regardless of whether one uses the 1840 or the 1945 hog population, there is a noticeable, positive relationship between historic hogs and contemporary pork slaughterhouses. Given the positive persistence of hog population which is shown in Figure 2 and the price advantages of locating near inputs, this positive correlation is unsurprising.

Weak monotonicity seems reasonable for both 1840 hogs (Figure 3a) and 1945 hogs (Figure 3b), since increases in historic hogs do not lead to reductions in contemporary slaughterhouses. While weak monotonicity is reasonable for either historic year, there does seem to be differences in the shape of the relationship. The 1840 hogs first stage seems more linear while the 1945 hogs first stage is concave. With the concave relationship shown in Figure 3b, one might expect more error in the estimates when linear regressions are used; however, we stick closely to the conventional wisdom and use linear IV regressions (Lochner & Moretti, 2015).[18] Furthermore, after some low

[18]In unreported results, also logging the number of 1945 hogs did not noticeably reduce the concavity.

number of 1945 hogs ($\approx$ 10,000), almost all the points are above the linear regression fit, so the standard errors will be robust to heteroskedasticity and robust to arbitrary correlation within states.

The instrument seems to satisfy the strength and monotonicity requirements, so next the outcomes of interest are substituted for pork slaughterhouses on the y-axes. As shown by Figure 3c and Figure 3d, both contemporary truck traffic and fatal car crashes increase with hog population in 1945. The shape of these positive relationship is also concave, which suggests it is more than just the contemporary hog population that causes this. This concavity is seen in the historic hog-contemporary slaughterhouse relationship also, suggesting these are driven by slaughter activity. As shown by Figure 3e, there is also a positive relationship between historic hogs and road roughness, yet the linear regression line is less close to these points suggesting more error compared to the other binned scatter plots. All the conclusions are robust to including state and RUCC fixed effects using semi-parametric covariate adjustments (Cattaneo, Crump, Farrell, & Feng, 2019).

Next, the regression results are presented in Table 3. As shown by Panel A, 1945 hog population increases contemporary truck traffic and predicts contemporary pork slaughterhouses. In column 1, an increase of 10,000 hogs in 1945 increases 2017 truck traffic by 5.6%. An increase of 10,000 1945 hogs would be an increase equal to half the standard deviation or 2/3 of the mean of historic hogs which translates into about 56.39 additional annual daily truck miles.

An increase of 10,000 hogs in 1945 also predicts an additional 0.043 pork slaughterhouses. It is also another reasonably sized effect, since 0.043 is 22.6% of the mean number of pork slaughterhouses or 9.3% of a standard deviation. This estimate is also statistically significant above 99% confidence. As shown by the Kleibergen-Paap first stage F-statistic of 16.35 for historic hogs having no predictive power for contemporary slaughterhouses being beyond conventional instrument strength benchmarks, the instrument is strong enough to make the likelihood of biased two-stage estimates small.

The two-stage estimator, from Equation 6 and equivalent to the estimate in column 1 scaled by the estimate in column 2, is shown in column 3. This estimate implies that, holding state-specific urbanicity constant, an additional pork slaughterhouse increases truck traffic by 130.2% for compliers. This estimate is statistically significant above 99% confidence using the Wald tests or Anderson-Rubin confidence sets.

While state-specific urbanicity likely accounts for many concerning confounders, one could still be concerned with some specific factors through which it is possible that historic hogs affects contemporary truck traffic. As shown by Panel B and Panel C, adding land area or railway miles as controls does not alter the statistical significance or point estimates much. The most notable change is that when railway miles are included, the effect of historic hogs reduces from 0.057 to 0.043 and this reduces the effect of contemporary slaughterhouses to 1.05.

An additional concern is that contemporary agriculture production to support contemporary hogs is caused by historic hogs. To assess this possibility, Table A.1 shows the results with grain corn bushel production as a control. This reduces all the coefficients, particularly the reduced form effects in column 1 which is concerning. However, we do acknowledge that corn bushel production is measured with non-classical measurement error due to the suppression of production data for areas with 1 farmer which biases all the other coefficients.

4.1 Different Sources and Years of Historic Hogs

Since including agricultural production alters the estimated effects, it is possible agricultural production violates the assumptions required to interpret the coefficients as causal. Specifically, if historic hog population affects truck traffic through agricultural production, then it would violate the exclusion restriction. Parametrically controlling for agriculture altered the coefficients, so a different strategy may be required to identify causal effects.[19] A more plausible exclusion restriction might be that hogs from even further back in time are less likely to be correlated with contemporary agricultural production.[20] So our test of whether exclusion violations are causing the coefficient movements is to use hog populations from further back in time. If the coefficients move less when corn bushel controls are added, then it might be exclusion, but it is probably not as concerning for earlier iterations of hog populations.

The results of using different years of hogs are shown in Table A.2. As detailed in Section 2.2.1, these other years of hogs are extracted from old maps of hogs instead of from tabular documents.

[19]However, just because the coefficients changed does not necessarily mean that exclusion is violated. This coefficient movement could also be due to measurement error in corn bushels, specification error, or a different data-generating process, such as corn being a mediator between slaughterhouses and truck traffic.

[20]This logic is often appealed to in the historic instrument literature (Bleakley & Lin, 2012; Duranton & Turner, 2011; Glaeser et al., 2015).

As such, Panel A of Table A.2 redoes the results using the 1948 hogs. While both the reduced form and first stage estimates are slightly larger with the 1948 hogs from the map, the two stage estimates remain quite similar which is a reason to believe that data collected from the maps is useful.

Panel B of Table A.2 uses hog population from 1840 instead of hog population from 1945, because 1840 hog population is less likely to be correlated with 2017 agricultural production. The reduced form is about 3 times larger than 1945 hogs, but the first stage is comparably sized. The first stage estimate is statistically significant at 99% confidence, but also the first-stage F-statistic falls below the typical benchmark which is perhaps unsurprising given that hog population in 1840 is also less likely to be correlated with current slaughter activity. Nonetheless, the A-R 95% confidence set, that is robust to potentially weak instruments, for the second stage estimate does not include 0 and indicates that the structural estimates are significant above 99% confidence. Since the estimates using older hogs have the same signs and similar magnitudes, it is suggestive that the exclusion restriction is appropriate.

4.2 Additional Consequences of Truck Traffic

Given that the previous results show pork slaughterhouses having statistically and economically significant effects on truck traffic, the results in Table 4 focus on the negative consequences of truck traffic. These specifications use the inverse hyperbolic sine of fatal car crashes, because these are sometimes 0 and are skewed.

As shown by Panel A of Table 4, an additional 10,000 hogs in 1945 leads to a 7.8% increase in fatal automobile crashes (Bellemare & Wichman, 2020). This is remarkably close to the effect of 10,000 additional hogs on truck traffic. This further implies that pork slaughterhouses increase fatal car crashes by 23% for compliers. Panel B changes the dependent variable slightly to automobile crash fatalities and the results are almost exactly unchanged.[21,22] The next outcome that is examined is road roughness, because trucks have a disproportionate effect on road degradation (FHWA, 2000). There are no detectable effects of historic hogs or contemporary pork slaughterhouses on contemporary road roughness.

[21] Table A.3 shows that this finding also extends to the number of individuals involved fatal crashes.

[22] These results are also robust to using other transformations of the dependent variable such as the natural log.

4.3 Distributional Analysis

The second stage estimates are local average treatment effects for compliers which means they can, and do in this application, differ substantially from OLS estimates. To better understand this, the cumulative distribution functions of slaughterhouses and the outcomes by top and bottom 1945 hog quartile are plotted in Figure 4. As shown by Figure 4a, historic hogs leads to the most separation in the slaughterhouse distributions at 0 slaughterhouses. The likelihood of having 0 pork slaughterhouses is approximately 90% for bottom quartile hogs and approximately 80% for top quartile hogs. This difference compresses to being barely noticeable after 0 slaughterhouses.

This suggests that the 2SLS estimates are driven by areas that wouldn't have hog slaughter activity if it weren't for historic hog population. The most likely interpretation of the relatively large 2SLS estimates is that it is driven by rural areas which would have little activity in the absence of hog slaughter activity. Since hog slaughter makes up a large portion of the activity, this drives the estimates to be larger. Another plausible possibility is that there were select urban areas with historic hogs and that this caused these areas to have contemporary slaughterhouses; however, these areas already have lots of other industries.

As shown in Figure 4b, historic hogs also lead to differences in the lower parts of the truck traffic distribution. Specifically the difference in distributions is noticeable by around 5, about 1 standard deviation below the mean, and this gap persists until about 7 which is slightly less than 1 standard deviation above the mean. Furthermore, using the Kolmogorov–Smirnov and Goldman and Kaplan (2018) tests for equality of distributions reject that the distributions are the same with above 99% confidence. As shown in Figure 4d and Figure 4e, the results are essentially the same for both fatal crashes and fatal crash fatalities.

In contrast to the parametric regression results which found no effects of historic hogs on contemporary road roughness, Figure 4c shows suggestive evidence that historic hogs do matter for contemporary road roughness. Regardless of whether one uses the Kolmgorov-Smirnov test or the Goldman and Kaplan (2018) test of equality of distributions, the distribution of road roughness for counties in the top quartile of 1945 hogs is different than the distribution of road roughness for counties in the bottom quartile of 1945 hogs. A major noticeable difference between road roughness and the other outcomes is that the distributions only look different from about 1 standard deviation below the mean of IRI to the mean of IRI. As shown by Figure A.5, these conclusions are robust to using 1840 hogs in place of 1945 hogs.

5 Conclusion

This paper investigates the causal effect of pork slaughterhouses on truck traffic and truck traffic on other road outcomes including fatal crashes and road roughness. Naïve results indicate no effect of slaughterhouses on truck traffic, which is suspect given the necessity of trucks for slaughterhouse operation. To circumvent endogenous business location making OLS estimates uninformative, we appeal to a model where cost-minimizing slaughter firms prefer high population hog areas because these areas have lower transportation costs.

Historic hog population is strongly correlated with current pork slaughterhouses. Using two-stage least squares, we find that pork slaughterhouses cause an increase in truck AADT by 96%. With the addition of added controls for land area usage and railway miles, statistical significance and point estimates remain relatively consistent. Using historic hog population estimates from other data sources and earlier years compared to 1945, we support a valid exclusion assumption, suggesting causal interpretations are reasonable. To further the analysis, we uncover a 23% increase in fatal automobile crashes due to pork slaughterhouses, a potential byproduct of the increased truck traffic.

The first contribution of this paper is combining literatures on agricultural inputs (McArthur & McCord, 2017) and using historic measurements (Duranton & Turner, 2011) as a basis for quasi-random variation in contemporary agriculture business location. We document that by not using this design, the results are inconsistent with basic background on pork slaughterhouse operation. The extension of these two designs is important to uncover causal estimates consistent with industry background.

The second contribution of this paper is estimating the causal effect of additional pork slaughterhouses on truck traffic and fatal crashes. This is critical for policy-making related to pork slaughterhouses because estimates that do not address causal issues (like endogenous business location, omitted variables, etc.) suggest no negative truck externalities of pork slaughterhouses. If policy-making is based on these null results or other descriptive work, then it may lead to sub-optimal policies which harm individuals, such as those in Great Falls, Montana. This is especially relevant given the statistically significant results we find linking pork slaughterhouses to fatal automobile crashes. Further research could work to quantify the current extent to which the pork industry is currently internalizing its externalities.

Table 1: OLS Estimates of Pork Slaughterhouses on Truck and Car Traffic

Panel A: Truck AADT					
	(1)	(2)	(3)	(4)	(5)
Pork Slaughterhouses	0.14*	0.20***	-0.02	0.09*	0.07
	(0.08)	(0.05)	(0.08)	(0.05)	(0.06)
Observations	3038	3038	3037	3037	3037
State FEs	-	X	-	X	-
Rural-Urban (RUCC) FEs	-	-	X	X	-
State By RUCC FEs	-	-	-	-	X
Panel B: Car AADT					
	(1)	(2)	(3)	(4)	(5)
Pork Slaughterhouses	0.20***	0.16***	0.03	0.05	0.04
	(0.05)	(0.04)	(0.04)	(0.03)	(0.04)
Observations	3038	3038	3037	3037	3037
State FEs	-	X	-	X	-
Rural-Urban (RUCC) FEs	-	-	X	X	-
State By RUCC FEs	-	-	-	-	X

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Cluster-robust standard errors, by state (Panel B) in parentheses. All regressions estimated by OLS. The independent variable is the number of USDA-inspected pork slaughterhouses. In Panel A, the dependent variable is truck average annual daily traffic (AADT) and in Panel B, the dependent variable is car AADT. Column 1 includes no controls. Column 2 includes state fixed effects. Column 3 includes the 2013 (most recent) United States Department of Agriculture's (USDA) Rural-Urban Continuum Codes (RUCC) fixed effects, of which there are 9. Column 4 includes state and RUCC fixed effects separately. Column 5 includes interacted state and RUCC fixed effects.

Table 2: Descriptive Statistics, By 1945 Hog Count

Panel A: Aggregate

	Mean	Median	SD	Min	Max	Count
Pork Slaughterhouses	0.19	0.00	0.46	0.0	4.0	3046
Truck AADT	1007.06	525.42	1361.09	0.0	13928.7	3046
1945 Hog Population	15089.07	7863.00	20416.93	0.0	183329.0	2999
1948 Hog Population (Map)	11502.05	7800.00	12711.97	0.0	107800.0	3046
2017 Hog Population	26091.68	279.00	102770.81	3.0	1957364.0	2337
Fatal Crashes	11.15	5.00	26.74	0.0	709.0	3046
International Roughness Index (IRI)	103.35	99.33	29.43	0.6	287.9	3046
Car AADT	414.39	265.19	428.80	0.0	4394.4	3046
USDA Rural-Urban Continuum Code, 2013	4.95	6.00	2.70	1.0	9.0	3045

Panel B: 1945 Hogs > Median

	Mean	Median	SD	Min	Max	Count
Pork Slaughterhouses	0.23	0.00	0.52	0.0	4.0	1546
Truck AADT	1117.10	621.22	1399.78	0.0	13928.7	1546
1945 Hog Population	26665.81	17424.00	23696.11	7874.0	183329.0	1499
1948 Hog Population (Map)	18534.22	14950.00	13768.18	0.0	97800.0	1546
2017 Hog Population	47172.25	1104.00	134444.72	4.0	1957364.0	1231
Fatal Crashes	13.18	6.00	33.90	0.0	709.0	1546
International Roughness Index (IRI)	104.51	99.85	27.32	2.1	227.4	1546
Car AADT	430.05	278.02	436.26	0.0	4380.5	1546
USDA Rural-Urban Continuum Code, 2013	4.67	5.00	2.58	1.0	9.0	1545

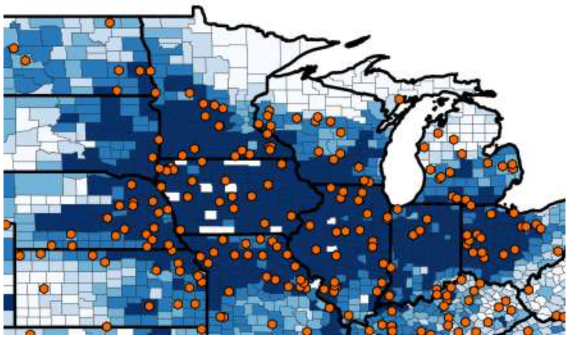
Panel C: 1945 Hogs < Median

	Mean	Median	SD	Min	Max	Count
Pork Slaughterhouses	0.14	0.00	0.39	0.0	3.0	1499
Truck AADT	893.79	429.66	1311.29	0.0	13859.3	1499
1945 Hog Population	3517.15	3294.00	2146.82	0.0	7836.0	1499
1948 Hog Population (Map)	4255.64	3450.00	5415.17	0.0	107800.0	1499
2017 Hog Population	2630.77	137.00	34100.96	3.0	1094877.0	1105
Fatal Crashes	9.04	4.00	16.10	0.0	208.0	1499
International Roughness Index (IRI)	102.17	98.78	31.41	0.6	287.9	1499
Car AADT	398.07	255.16	420.58	0.0	4394.4	1499
USDA Rural-Urban Continuum Code, 2013	5.23	6.00	2.78	1.0	9.0	1499

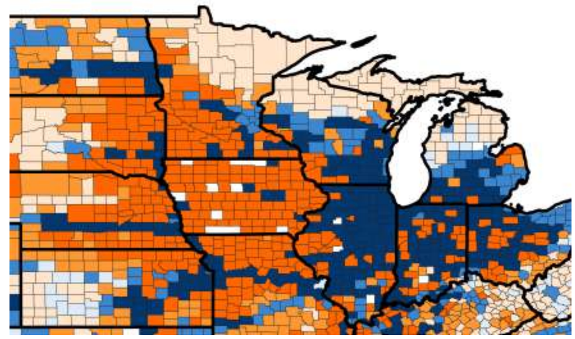
Note: Panel A reports summary statistics for all counties in 2017. Panel B reports summary statistics for those counties above average historical hogs population and Panel C reports summary statistics for those below historical hogs population. Pork slaughterhouses comes from the United States Department of Agriculture (USDA) Food Safety Inspection Service (FSIS). Truck and Car Average Annual Daily Traffic (AADT) and International Roughness Index (IRI) comes from the Federal Department of Transportation's (DOT) Highway Performance Monitoring System (HPMS). It is traffic on road segments, with road segments being weighted by their physical length. IRI is the amount of inches a vehicle's suspension moves over 1 mile. Hog population in 1945 comes from the USDA historic agriculture census. Hog population in 1948 comes from the hog point geographic extraction technique which is described in Section 2.2.1. Hog population in 2017 comes from the USDA's National Agriculture Statistical Service (NASS). Total fatal car crashes comes from the Fatal Accident Reports System (FARS).

Figure 1: 1945 Hog Population, 2019 Pork Slaughterhouses, and 2017 Truck AADT

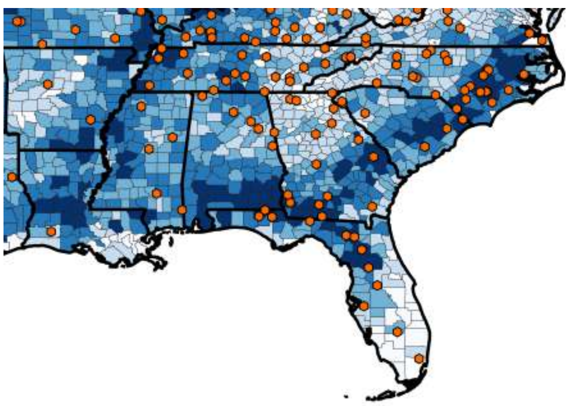
(a): Midwest North, First Stage



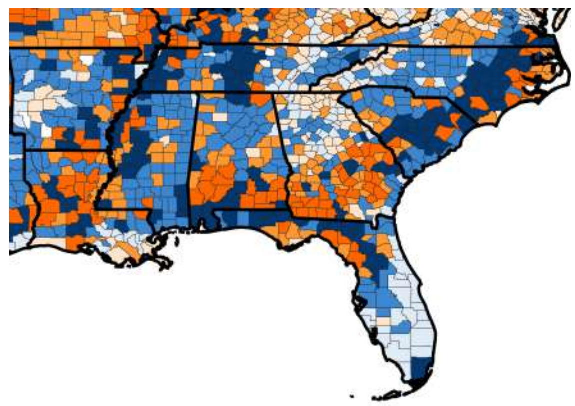
(b): Midwest North, Reduced Form



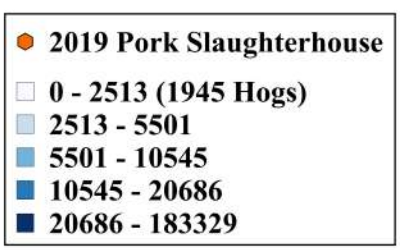
(c): East South, First Stage



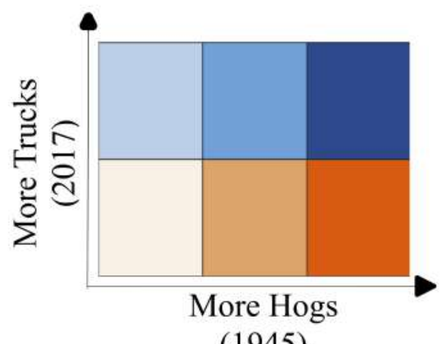
(d): East South, Reduced Form



(e): First Stage Legend



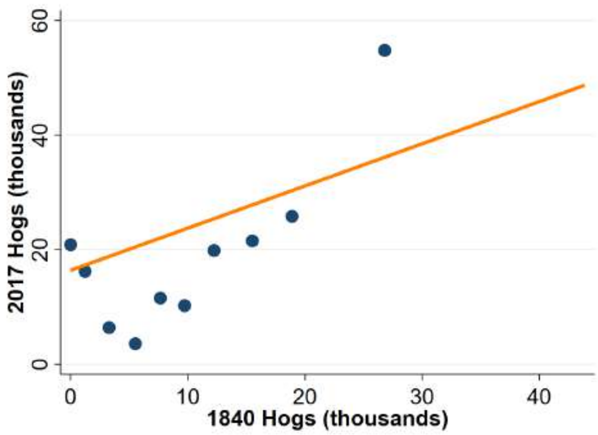
(f): Reduced Form Legend



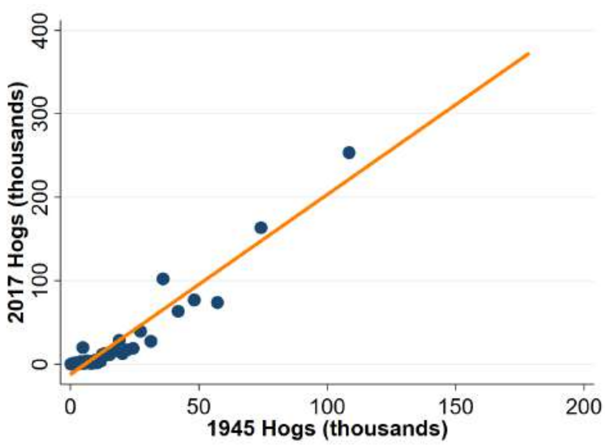
Note: Figure visually shows the first stage relationship between 1945 hogs and 2019 pork slaughterhouses at the county level in the left column and the reduced form relationship between 1945 hogs and 2017 truck AADT in the right column. An orange point represents one pork slaughterhouse in 2019. Darker shades of blue in the left column are associated with more hogs in the 1945 agricultural census. Cutoffs for the first stage legend split the hog data into equal quintiles. For the reduced form legend, hog groups: $0 < 4299$; $4299 \leq 13021$; > 13021; truck groups: $0 < 525$; ≥ 525.

Figure 2: The Persistence of Hog Population

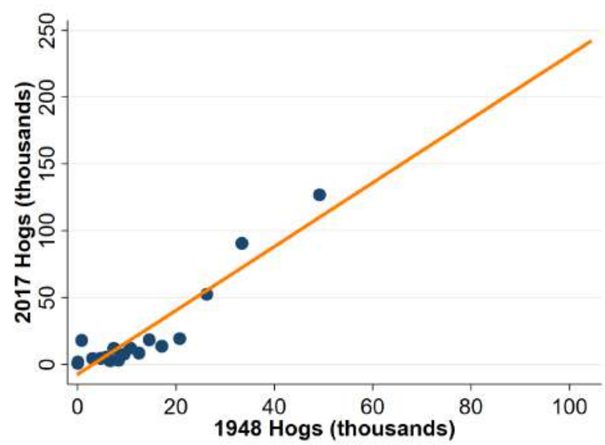
(a): 1840 Hogs



(b): 1945 Hogs



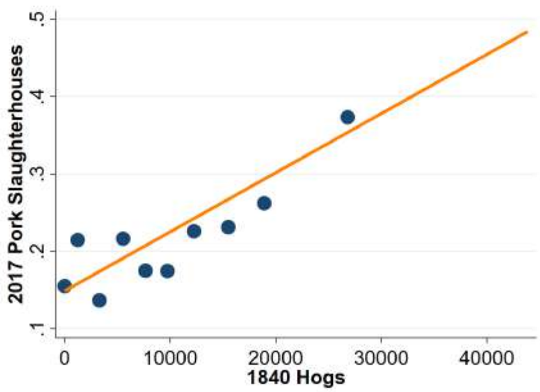
(c): 1948 Hogs



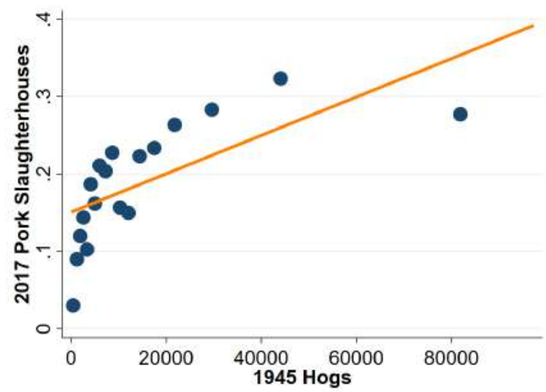
Note: Scales differ. All hogs are in thousands. (a) shows average 2017 hogs, conditional on 1840 hogs. (b) shows average 2017 hogs, conditional on 1945 hogs. (c) shows average 2017 hogs, conditional on 1948 hogs. Equal number of observations in each bin. Number of bins chosen as either the optimal number, in terms of bias-variance tradeoff (Cattaneo et al., 2019), or 10. Procedure selects number of bins to optimize a bias-variance tradeoff in the asymptotic integrated mean square error (IMSE) (Cattaneo et al., 2019).

Figure 3: First Stages and Reduced Forms

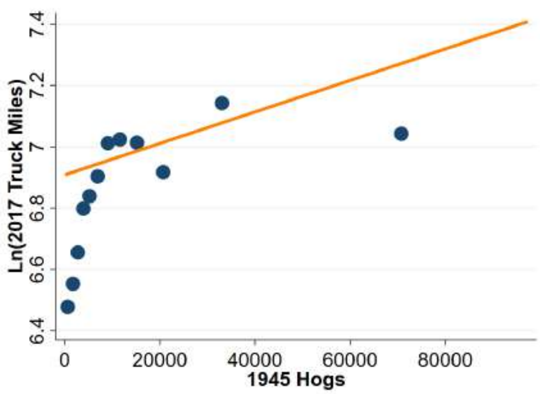
(a): 1840 Hogs First Stage



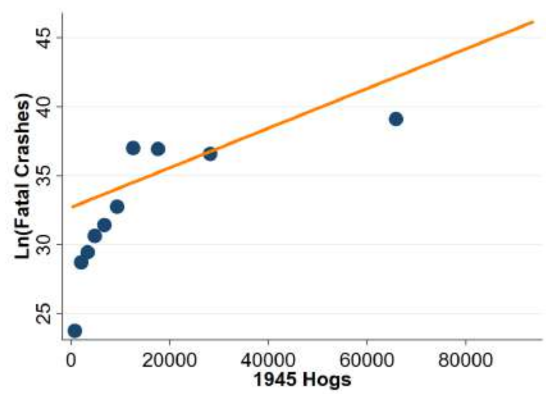
(b): 1945 Hogs First Stage



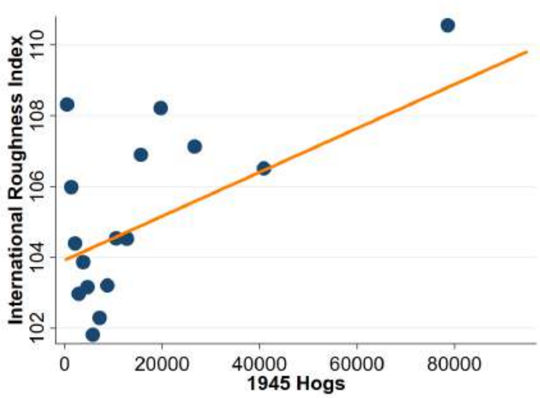
(c): Truck Miles Reduced Form



(d): Fatal Crashes Reduced Form



(e): Road Roughness Reduced Form



Note: Scales differ. All hogs are in thousands. (a) shows average 2017 pork slaughterhouses, conditional on 1840 hogs. (b) shows average 2017 pork slaughterhouses, conditional on 1945 hogs. (c) shows average 2017 truck average annual daily traffic (AADT), conditional on 1945 hogs. (d) shows average 2017 fatal automobile crashes, conditional on 1945 hogs. (e) shows average road international roughness index, conditional on 1945 hogs. Equal number of observations in each bin. Number of bins chosen as either the optimal number, in terms of bias-variance tradeoff (Cattaneo et al., 2019), or 10 if the optimal number was less than 10. Procedure selects number of bins to optimize a bias-variance tradeoff in the asymptotic integrated mean square error (IMSE) (Cattaneo et al., 2019).

Table 3: Estimates of Historic Hogs and Contemporary Slaughterhouses on Contemporary Average Daily Truck Miles

Dependent Variable:	(1) Reduced Form Ln(Truck AADT)	(2) First Stage Slaughterhouses	(3) Second Stage Ln(Truck AADT)
Panel A: State By RUCC FEs			
1945 Hogs (10,000's)	0.056**	0.043***	
	(0.023)	(0.011)	
Pork Slaughterhouses			1.302***
			(0.480)
Observations	2991	2991	2991
Kleibergen-Paap F			16.35
A-R 95% Confidence Set			[.485452, 2.76395]
A-R P-Value			0.00446
Panel B: Include Land Area			
1945 Hogs (10,000's)	0.057**	0.042***	
	(0.023)	(0.011)	
Pork Slaughterhouses			1.349***
			(0.486)
Observations	2991	2991	2991
Kleibergen-Paap F			16.04
A-R 95% Confidence Set			[.522274, 2.86886]
A-R P-Value			0.00353
Panel C: Include Rail Miles			
1945 Hogs (10,000's)	0.043**	0.041***	
	(0.021)	(0.010)	
Pork Slaughterhouses			1.050**
			(0.466)
Observations	2991	2991	2991
Kleibergen-Paap F			15.36
A-R 95% Confidence Set			[.183254, 2.47107]
A-R P-Value			0.0216

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Cluster-robust standard errors, by state, in parentheses. The table displays 2SLS regressions of contemporary truck traffic on pork slaughterhouses, using historic hog population as an instrument. Columns 1, 2, and 3 display the reduced form, first stage, and second stage respectively. Panel A includes state X urbanicity fixed effects. Panel B adds land area as a control variable. Panel C adds miles of railway infrastructure as a control variable. All panels show the Kleibergen-Paap first stage F-statistic for historic hogs. All panels show the corresponding Anderson-Rubin 95% confidence sets for the IV estimate, which are efficient for potentially weak instruments, as suggested by Andrews et al. (2019) for just-identified structural equations.

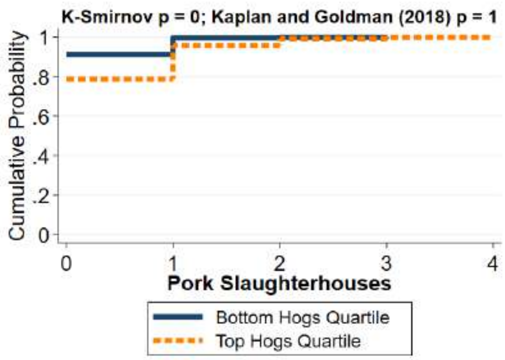
Table 4: Estimates of Historic Hogs and Contemporary Slaughterhouses on Contemporary Fatal Accidents and Road Roughness

Panel A: Crashes Dependent Variable:	IHS(Crashes) (1)	Slaughterhouses (2)	IHS(Crashes) (3)
1945 Hogs (10,000's)	0.052** (0.019)	0.042*** (0.011)	
Pork Slaughterhouses			1.230*** (0.398)
Observations	2999	2999	2999
Kleibergen-Paap F			15.91
A-R 95% Confidence Set			[.520667, 2.41346]
A-R P-Value			0.00303
Semi-Elasticity	0.078*** (0.030)		0.230*** (0.075)
Panel B: Fatalities **Dependent Variable:**	**IHS(Fatalities)** **(1)**	**Slaughterhouses** **(2)**	**IHS(Fatalities)** **(3)**
1945 Hogs (10,000's)	0.051** (0.019)	0.042*** (0.011)	
Pork Slaughterhouses			1.216*** (0.392)
Observations	2999	2999	2999
Kleibergen-Paap F			15.91
A-R 95% Confidence Set			[.517208, 2.41148]
A-R P-Value			0.00271
Semi-Elasticity	0.077*** (0.029)		0.228*** (0.073)
Panel C: Roughness Index **Dependent Variable:**	**Roughness Index** **(1)**	**Slaughterhouses** **(2)**	**Roughness Index** **(3)**
1945 Hogs (10,000's)	0.118 (0.474)	0.042*** (0.011)	
Pork Slaughterhouses			2.799 (10.496)
Observations	2999	2999	2999
Kleibergen-Paap F			15.91
A-R 95% Confidence Set			[-18.3955, 29.811]
A-R P-Value			0.788

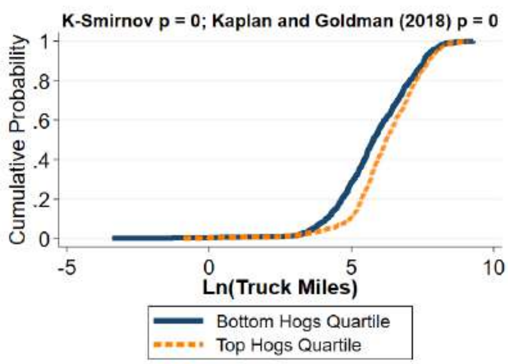
Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Cluster-robust standard errors, by state, in parentheses. The table displays 2SLS regressions of the effects of pork slaughterhouses on fatal automobile accidents and road roughness, using historic hog population as an instrument. Columns 1, 2, and 3 display the reduced form, first stage, and second stage respectively. All regressions include state by urbanicity fixed effects and land area as controls. Panel A uses the inverse hyperbolic sine of fatal automobile accidents as the dependent variable. Panel B uses the inverse hyperbolic sine of fatal automobile accident fatalities as the dependent variable. Both panels report the calculated semi-elasticity (Bellemare & Wichman, 2020). Panel C uses the international roughness index (IRI) as the dependent variable. All panels show the Kleibergen-Paap first stage F-statistic for historic hogs. All panels show the corresponding Anderson-Rubin 95% confidence sets for the IV estimate, which are efficient for potentially weak instruments, as suggested by Andrews et al. (2019) for just-identified structural equations.

Figure 4: Cumulative Distribution Functions by 1945 Hog Quartile

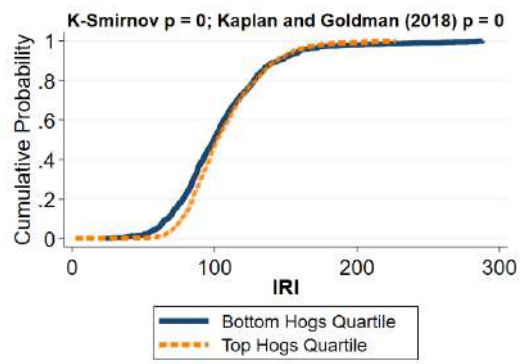
(a): First Stage: Pork Slaughterhouses



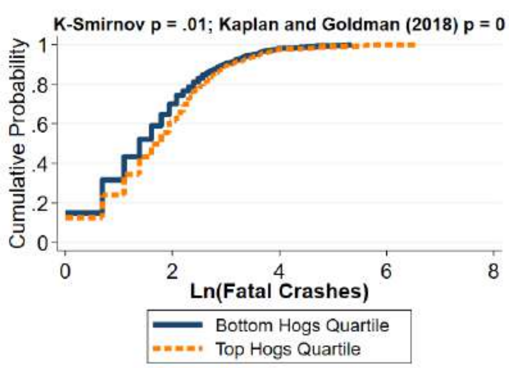
(b): Reduced Form: Ln(Truck AADT)



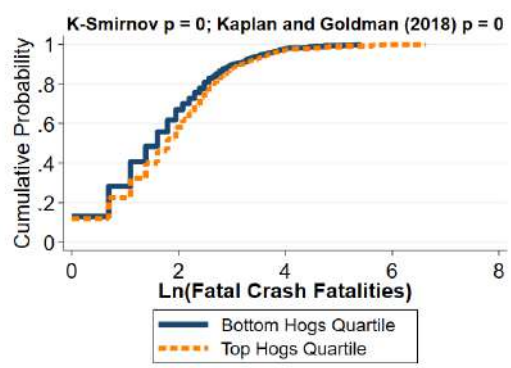
(c): Reduced Form: Road Roughness



(d): Reduced Form: Fatal Car Crashes



(e): Reduced Form: Fatal Car Fatalities



Note: Figures show the cumulative distributions of the dependent variables by 1945 hogs quartile. Above the graphs are p-values from two-tests for equality of distributions. The first is from the two-sample Kolmogorov–Smirnov test. The second test is also a test for equality of distributions from Goldman and Kaplan (2018).

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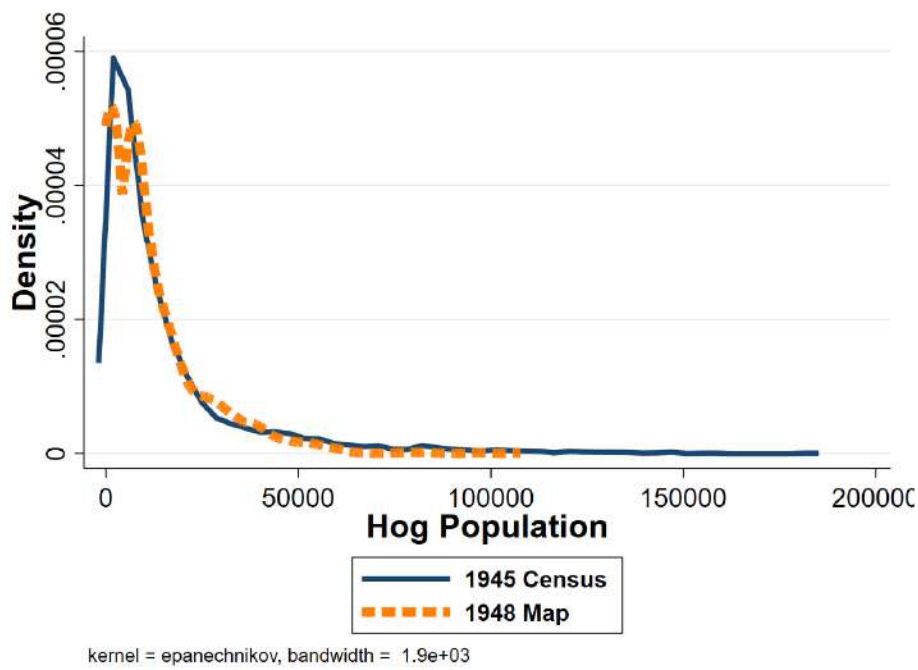
Online Appendix

A Additional Tables and Figures

Figure A.1: Hog Population in 1948

Note: Figure shows hog population in 1948. The map comes from the 1948 textbook *World Geography*.

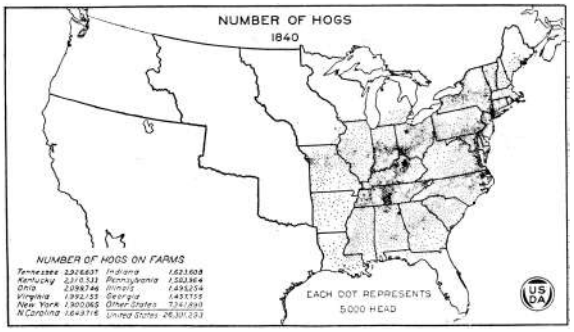
Figure A.2: Distributions of Hogs in 1945 (Census) and 1948 (Map)



Note: Figure compares the distributions of hog population counts from the 1945 USDA Agricultural Census and the 1948 *World Geography* textbook map. For details of how the hogs data was extracted from Figure A.1, see Section 2.2.1.

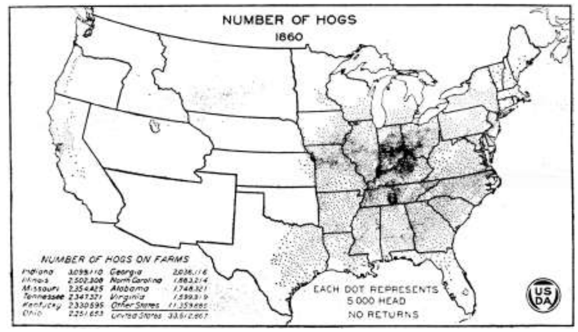
Figure A.3: Hog Population: 1840-1920

(a): 1840 Hog Points



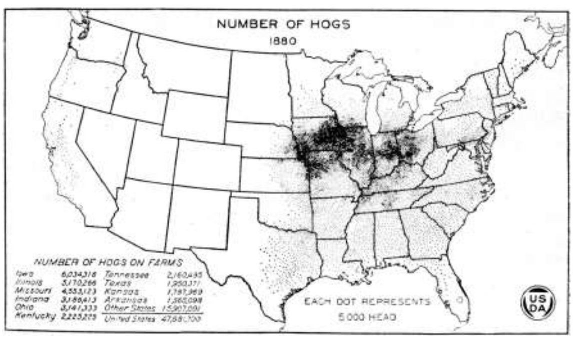
United States Production of Hogs, 1840
United States Department of Agriculture Yearbook 1922, Washington D.C.: Government Printing Office, 1922
Downloaded from *Maps ETC*, on the web at http://etc.usf.edu/maps [map #00157]

(b): 1860 Hog Points



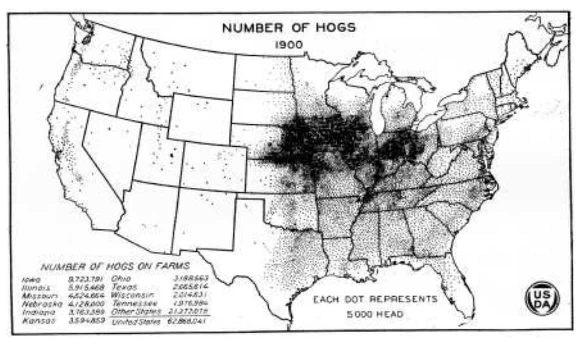
United States Production of Hogs, 1860
United States Department of Agriculture Yearbook 1922, Washington D.C.: Government Printing Office, 1922
Downloaded from *Maps ETC*, on the web at http://etc.usf.edu/maps [map #00158]

(c): 1880 Hog Points



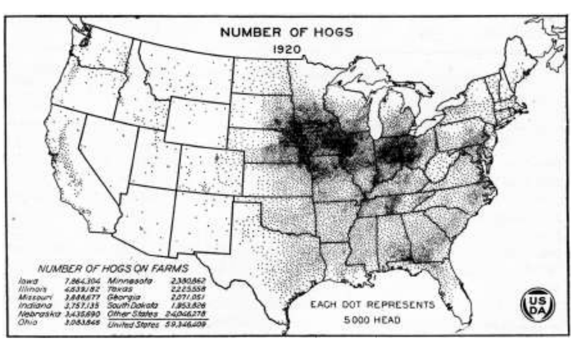
United States Production of Hogs, 1880
United States Department of Agriculture Yearbook 1922, Washington D.C.: Government Printing Office, 1922
Downloaded from *Maps ETC*, on the web at http://etc.usf.edu/maps [map #00159]

(d): 1900 Hog Points



United States Production of Hogs, 1900
United States Department of Agriculture Yearbook 1922, Washington D.C.: Government Printing Office, 1922
Downloaded from *Maps ETC*, on the web at http://etc.usf.edu/maps [map #00160]

(e): 1920 Hog Points

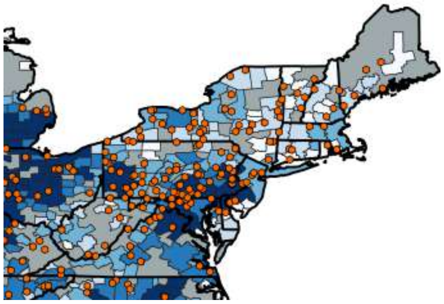


United States Production of Hogs, 1920
United States Department of Agriculture Yearbook 1922, Washington D.C.: Government Printing Office, 1922
Downloaded from *Maps ETC*, on the web at http://etc.usf.edu/maps [map #00161]

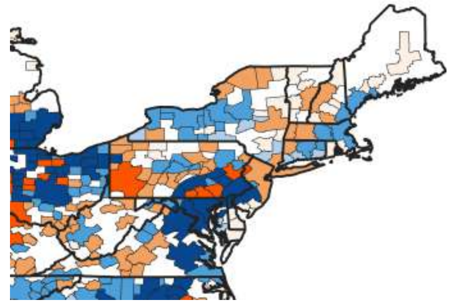
Note: Panels show maps of historic hog densities in the United States. Each dot represents 5000 hogs. Maps are from the 1922 US Department of Agriculture Yearbook.

Figure A.4: 1948 Hog Population, 2019 Pork Slaughterhouses, and 2017 Truck Miles

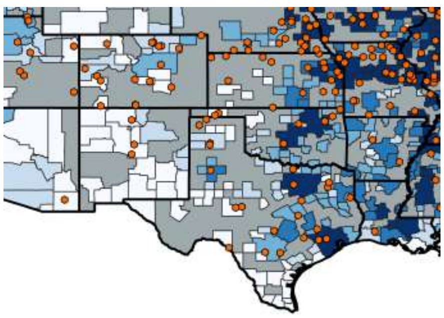
(a): First Stage: East North



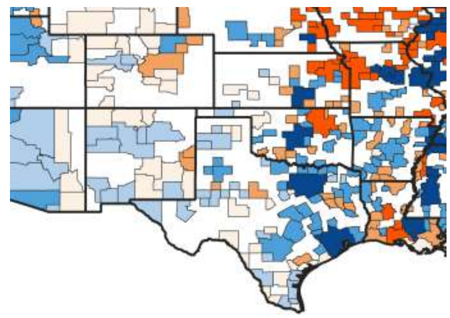
(b): Reduced Form: East North



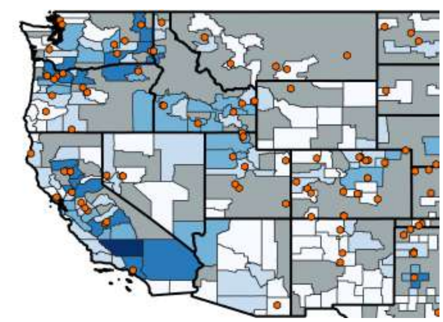
(c): First Stage: Midwest South



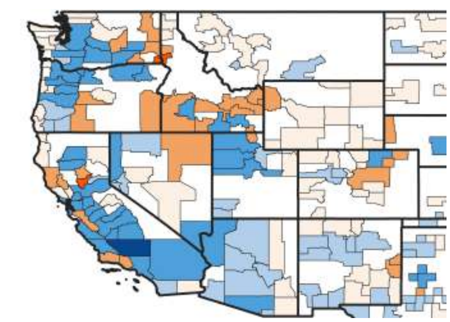
(d): Reduced Form: Midwest South



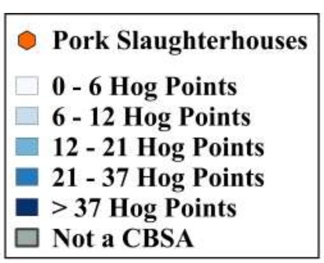
(e): First Stage: West



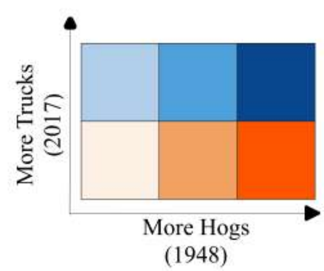
(f): Reduced Form: West



(g): First Stage Legend



(h): Reduced Form Legend



Note: Figure visually shows the first stage relationship between 1948 hogs and 2019 pork slaughterhouses at the CBSA level in the left column and the reduced form relationship between 1948 hogs and 2017 truck AADT in the right column. An orange point represents one pork slaughterhouse in 2019. Darker shades of blue in the left column are associated with more hog points in Figure A.1. Gray areas are not considered to be part of a metropolitan or micropolitan area. Cutoffs for the first stage legend split the data into equal quintiles. For the reduced form legend, hog groups: $0 < 7.47$; $7.47 \leq 32.69$; > 32.69; truck groups: $0 < 791$; ≥ 791.

Table A.1: 2SLS Estimates of Slaughterhouses on Average Daily Truck Miles

Dep. Var Panel D: Include Corn Bushels	(1) Reduced Form Ln(Truck AADT)	(2) First Stage Slaughterhouses	(3) Second Stage Ln(Truck AADT)
1945 Hogs (10,000's)	0.029 (0.019)	0.034*** (0.010)	
Pork Slaughterhouses			0.868 (0.530)
Observations	2991	2991	2991
Kleibergen-Paap F			12.54
A-R 95% Confidence Set			[-.117634, 2.60838]
A-R P-Value			0.0836

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Cluster-robust standard errors, by state, in parentheses. The table displays 2SLS regressions of contemporary truck traffic on pork slaughterhouses, using historic hog population as an instrument. Columns 1, 2, and 3 display the reduced form, first stage, and second stage respectively. All regressions include state X rucc fixed effects, land area, railway miles, and log corn grain bushel production as controls. The Kleibergen-Paap first stage F-statistic for historic hogs is shown. The corresponding Anderson-Rubin 95% confidence sets for the IV estimate, which are efficient for potentially weak instruments, as suggested by Andrews et al. (2019) for just-identified structural equations are also shown.

Table A.2: 2SLS Estimates of Slaughterhouses on Average Daily Truck Miles, Historic Hogs from Map

Dep Var Panel A: 1948 Hogs	(1) Reduced Form Ln(Truck AADT)	(2) First Stage Slaughterhouses	(3) Second Stage Ln(Truck AADT)
1948 Hogs (10,000's)	0.094*** (0.023)	0.067*** (0.017)	
Pork Slaughterhouses			1.391*** (0.348)
Observations	3037	3037	3037
Kleibergen-Paap F			16.62
A-R 95% Confidence Set			[.771784, 2.34142]
A-R P-Value			0.000617
Panel B: 1840 Hogs			
1840 Hogs (10,000's)	0.156*** (0.038)	0.062*** (0.023)	
Pork Slaughterhouses			2.504** (1.104)
Observations	3037	3037	3037
Kleibergen-Paap F			7.239
A-R 95% Confidence Set			[1.06217, ...]
A-R P-Value			0.00215

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Cluster-robust standard errors, by state, in parentheses. The table displays 2SLS regressions of contemporary truck traffic on pork slaughterhouses, using historic hog population as an instrument. Columns 1, 2, and 3 display the reduced form, first stage, and second stage respectively. All regressions include state X rucc fixed effects and land area as controls. All panels show the Kleibergen-Paap first stage F-statistic for historic hogs. All panels show the corresponding Anderson-Rubin 95% confidence sets for the IV estimate, which are efficient for potentially weak instruments, as suggested by Andrews et al. (2019) for just-identified structural equations. Panel A uses 1948 hog population as the instrument and Panel B uses 1840 hog population as the instrument. For details on these data, see Section 2.2.1.

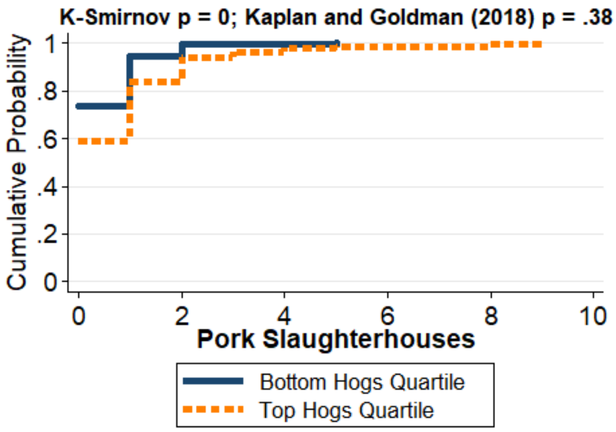
Table A.3: 2SLS Estimates of Slaughterhouses on Fatal Crash Outcomes

	(1)	(2)	(3)
Dependent Variable	Reduced Form Ln(People Involved)	First Stage Pork Slaughterhouses	Second Stage Ln(People Involved)
Panel A: People in Fatal Crashes			
1945 Hogs (10,000's)	0.047** (0.021)	0.044*** (0.011)	
Pork Slaughterhouses			1.038** (0.455)
Observations	2748	2999	2748
Kleibergen-Paap F			14.65
A-R 95% Confidence Set			[.22716, 2.38841]
A-R P-Value			0.0150
Dependent Variable	IHS(People Involved)	Pork Slaughterhouses	IHS(People Involved)
Panel B: People in Fatal Crashes			
1945 Hogs (10,000's)	0.054** (0.022)	0.044*** (0.011)	
Pork Slaughterhouses			1.233*** (0.478)
Observations	2999	2999	2999
IHS Semi-Elasticity	0.0811		0.230
Kleibergen-Paap F			15.64
A-R 95% Confidence Set			[.343005, 2.61563]
A-R P-Value			0.0101

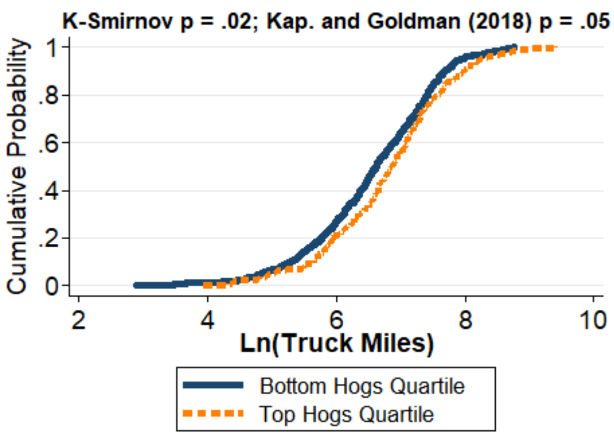
Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Cluster-robust standard errors, by state, in parentheses. The table displays 2SLS regressions of the effects of pork slaughterhouses on persons involved in fatal automobile accidents, using historic hog population as an instrument. Columns 1, 2, and 3 display the reduced form, first stage, and second stage respectively. All regressions include state by urbanicity fixed effects and land area as controls. Panel A uses the log transforms the dependent variable. Panel B uses the inverse hyperbolic sine of the dependent variable. Panel B reports the calculated semi-elasticity (Bellemare & Wichman, 2020). All panels show the Kleibergen-Paap first stage F-statistic for historic hogs. All panels show the corresponding Anderson-Rubin 95% confidence sets for the IV estimate, which are efficient for potentially weak instruments, as suggested by Andrews et al. (2019) for just-identified structural equations.

Figure A.5: Cumulative Distribution Functions by Hog Quartile in 1840

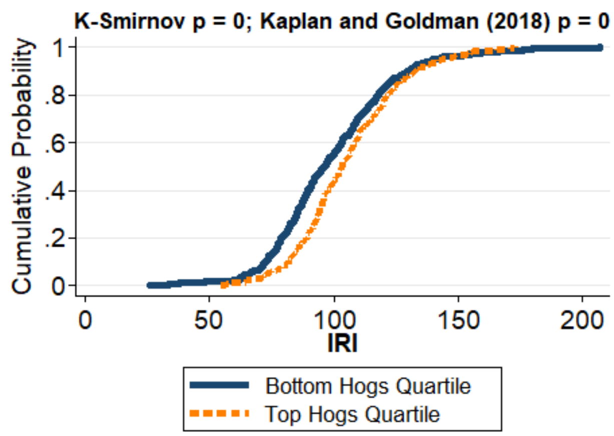
(a): First Stage: Pork Slaughterhouses



(b): Reduced Form: Log Truck AADT



(c): Reduced Form: Road Roughness



Note: Kolmgorov-Smirnov and Goldman and Kaplan (2018) p-values of testing the null hypothesis that the distributions are equal. Bottom hogs quartile is the bottom quartile of hogs in 1948. Tops hogs is the top quartile of hogs in 1948. In Panel A, the distribution is of 2019 pork slaughterhouses. In Panel B, the distributions are of 2017 log truck AADT. In Panel C, the distributions are of 2017 international (road) roughness index (IRI).

B Hog Industry Overview

In order to help understand the research design, we explain basic aspects of the hog industry. First, we review literature which establishes that live hogs are transported via truck. Next, we describe the reason slaughterhouses locate close to hog-raising areas. Finally, we explain factors that contributed to the vertical integration of the hog industry.

B.1 The Pork Slaughter Industry Uses Trucks

The preferred mode of transporting live hogs is trucks. Two main reasons to use trucks are to reduce financial loss from damaged goods and animal welfare (Food and Agriculture Organization of the United Nations, 2001).[23] Although most hogs are likely transported by truck to slaughter, there is a possibility pork products are transported from the slaughterhouse by transport modes other than truck, such as rail (Bai et al., 2007, pg. 33).[24] To isolate the relationship between pork slaughterhouses and truck traffic, the amount of non-passenger rail miles are controlled for.

Trucks are favored to transport live hogs, because it is less detrimental to meat quality than rail transport. Hogs are temperamental animals, easily stressed by changing environments.[25] In addition, pigs cannot stand and balance well while moving (Aradom & Gebresenbet, 2013), cannot regulate body temperature (Huynh, Aarnink, & Verstegen, 2005), and pigs easily get motion sickness (Randall & Bradshaw, 1998). Because of environmental stress, the quality of the pork meat has been shown to degrade as stress levels increase (Gajana, Nkukwana, Marume, & Muchenje, 2013).[26]

[23]Under US law, livestock are not allowed to be in a transport vessel for more than twenty-eight consecutive hours. For more temperamental livestock, such as hogs, constant confined conditions limit the consecutive hours of viable transport.

[24]Rail would be a substitute if hogs were moved by rail, instead of truck. It would be a complement if pigs were trucked into slaughterhouses, then the processed meat was transported out of slaughterhouses via rail. To our knowledge, this relationship has not been explicitly studied yet, although some studies examine if personal transportation choices are complements or substitutes (e.g. Hall, Palsson, and Price (2018)).

[25]To ease the stress of hogs, some slaughter facilities have implemented rules which govern the truck routes to and around slaughterhouses. some slaughterhouses force trucks to take detours to avoid wait times at the slaughterhouse and to keep the truck moving as to not cause stress for the hogs (Miranda-De La Lama, Villarroel, & María, 2014, pg. 11).

[26]When a hog becomes stressed, it leads to lower lactic acid production in the animal. The lower lactic acid production causes a higher pH in the meat; higher pH levels are associated with lower meat quality (Gajana et al., 2013).

B.2 Why Slaughterhouses Locate Close to Hogs

Slaughterhouses locate near hogs to reduce costs. There is a positive association between travel distance from farm to slaughter and hog mortality (Gosálvez, Averós, Valdelvira, & Herranz, 2006). As the transportation distance via heavy truck increases, the mortality of hogs also increases. Pig deaths in transit are estimated to cost the US pork industry \$50 to \$100 million annually (Fitzgerald, Stalder, Matthews, Schultz Kaster, & Johnson, 2009, pg. 1156). If not dead from transit, stress and "damage" caused by long transport times decreases pork meat quality (Gajana et al., 2013; Guàrdia et al., 2005).

B.3 Evolution of the US Hog Industry since the 1940s

B.3.1 Vertical Integration

The hog industry has vertically integrated over the last 70 years. Throughout the 1990s, the pork industry saw rapid use of contracting production. The share of hog production under contract increased from about 18% in 1990, to about 28% in 1995, to almost 60% in 2000. (Key, 2004, pg. 255).

Several reasons exist for why the industry has become more vertically integrated; most relate to economies of scale. Factors that have changed include: industrialization leading to demand for factory-like development with highly specialized labor (Rhodes, 1995), advances in gene practices (Wang, Huang, & Zhao, 2017, pg. 2793), selective breeding led to shorter weaning and bigger litters (Kemp, Da Silva, & Soede, 2018), disease control (Chen, Madson, Miller, & Harris, 2012; Colomer, Margalida, & Fraile, 2020), and improved farm biosecurity practices (Pig Progress, 2015).[27] In sum, hog farms were housing bigger litters with higher survival rates. These advances lead to greater economies of scale and vertical integration followed.

[27] Hogs were traditionally bred to be large and produce fatty cuts of meat; advances in gene manipulation allowed the hog industry to cater to consumer demand for leaner cuts of pork (Wang et al., 2017, pg. 2793). The development of hog vaccines for H1N1 and other swine illnesses (Chen et al., 2012; Colomer et al., 2020) specifically decreased hog infection rates.

B.3.2 Locational Persistence

In the US, hog farms and producers traditionally located close to corn farms because pigs eat corn (McBride & Key, 2013). Often, farmers would raise both corn and hogs to save on corn transport costs. This explains the large concentration of hogs in the Corn Belt region of the US as shown in Figure A.1.[28]

Over time, corn transportation became cheaper due to increased railroad construction and usage, causing hog producers to move out of traditional hog production areas. Also, the increasing amount of environmental and land use regulations in Corn Belt states pushed out less profitable hog production to other areas, including North Carolina and western states (Roe, Irwin, & Sharp, 2002). Nevertheless, the Corn Belt still remains as the key hog producing region in the US today.[29]

The hog production that remained in the Corn Belt changed from small farms to larger, integrated operations. The integration increased capacity and decreased the number of individual operations. Between 1994 and 1999, "the number of U.S. hog farms fell by more than 50%, from over 200,000 to less than 100,000, while the hog inventory remained relatively stable." (Key, 2004, pg. 255) Despite farms leaving the region, in 2009, the Corn Belt still contained 76% of all feeder-to-finish farms across the United States Department of Agriculture (USDA)'s Agricultural Resource Management Survey.

[28]The "Corn Belt" in the US include the states of Ohio, Indiana, Illinois, Iowa, and Missouri.

[29]The dispersion of activity can be seen in (Pork Checkoff, 2015, pg. 85).