Hog barns and neighboring house prices:
Anticipation and post-establishment impacts

Chad Lawley
January 25, 2021

ABSTRACT

The impact of large-scale hog barns on residential property values is at the forefront of local concerns about livestock development. In this article, I examine the impact of hog barns on house prices in an intensive production region of Manitoba, Canada. Timing of barn establishment and precise locations of houses and barns are used to gain a better understanding of the dynamic impacts of hog barns on house prices. I find that houses within 2 kms of a hog barn sell for 5.7% less than similar houses located a little farther away from a barn. Quasi-myopic specifications indicate that house prices fall by 6.4% up to three years prior to barn establishment, consistent with market anticipation of the future location of hog barns. Accounting for anticipation increases the post-establishment discount to 8%, suggesting that ignoring anticipation of new barn establishment biases estimated post-establishment impacts downwards.

Keywords: air quality, anticipation, disamenity, hedonic pricing, intensive livestock, property values

JEL Codes: Q51; Q53; Q15; R31

Running head: Hog barns and neighboring house prices

This is a pre-copyedited, author-produced version of an article accepted for publication in the American Journal of Agricultural Economics following peer review. The version of record "Lawley, Chad. 2021. "Hog barns and neighboring house prices: Anticipation and post-establishment impacts," American Journal of Agricultural Economics" is available at https://doi.org/10.1111/ajae.12203.

Chad Lawley is an Associate Professor in the Department of Agribusiness and Agricultural Economics, University of Manitoba, Manitoba, Canada. I thank Amy Ando, three anonymous reviewers, Brady Deaton, and participants at the 2020 Canadian Agricultural Economics Society webinar seminar series for several insightful comments and suggestions that improved the article. The Manitoba Livestock Manure Management Initiative supported this research with funding from Agriculture and Agri-food Canada Growing Forward 2. Brian Miller provided highly capable research assistance with data collection and assembly, including construction of an improved barn and house spatial layer for rural Manitoba. Finally, I thank members of the MLMMI project advisory committee for sharing in-depth knowledge of land use planning and the livestock barn approval process in Manitoba.

Expansion of large-scale livestock operations is among the most contentious issues in rural North America. Hog barns, in particular, have been the subject of intense debate since the early 1990s. Proponents argue that hog sector expansion is an important rural development tool that brings new investment and employment to local economies, while opponents raise environmental, public health, and neighboring property value concerns.[1] Much of the conflict at the local level centers on the impact of large-scale hog barns on air and water quality. Their impact on neighboring residential property values has led to nuisance suits in several US states (Herriges, Secchi, and Babcock 2005; Isakson and Ecker 2008; Hellerstein and Fine 2017) and has played an important role in adoption of right-to-farm legislation in several North American jurisdictions (Gardner 1994; Reinert 1998). The impact of hog barns on the value of neighboring residences continues to be at the forefront of public opposition to new barn development (Johnson 1998; Ropeik 2016, 2017; Hellerstein and Fine 2017; Kirk 2020).

In this article I estimate the impact of hog barns on house prices in the intensive hog production region of southeastern Manitoba, Canada. Like other jurisdictions in North America, the southeastern region of Manitoba experienced substantial increases in the size of the hog sector beginning in the 1990s and continuing into the mid-2000s; several southeastern Manitoba municipalities have per acre hog densities within the range of some of the most intensive production regions in North America. This region of Manitoba is also considered a prime area for rural residential development since much of it is within the Winnipeg "commuter-shed." In Manitoba, new barn construction is approved by local municipal councils, based on information from a Technical Review conducted by the Provincial government, as well as submissions and testimony from barn proponents and neighboring residents. Casual inspection of public comments on new barn proposals posted to the Manitoba Livestock Technical Review Public Registry suggest that odour and its potential impact on property values are among the top concerns expressed by local residents opposed to new hog barn development.[2] This source of conflict between barn proponents and neighboring residents is due to the *uncertain* impact of hog barns on neighboring property values.

Prior research conducted by professional appraisers and economists has produced a wide range of potential impacts of hog barns on house prices and has done little to resolve this uncertainty.[3] In Manitoba, a 2004 appraisers report commissioned by the Manitoba Pork Council suggests that houses in close proximity to hog barns sell for higher prices in many Manitoba municipalities, and finds no evidence to suggest that hog barns reduce house prices (Royal LePage Stevenson Advisors 2004).[4] Boxall, Chan, and McMillan (2005) discuss similar industry-commissioned consultant reports assessing the impact of oil and gas wells on property prices in Alberta, Canada. Estimates presented by appraisers are drawn from case studies, where a sample of house sales close to barns are compared to sales of comparable houses farther from barns, before and after the barn is established. Economists have followed a similar approach, exploiting cross-sectional variation in house prices and proximity to a hog barn, but ignoring the timing of barn establishment. Palmquist, Roka, and Vukina (1997) present the first estimates of the impact of hog barns on house prices, using 1992 and 1993 house sales in southeastern North Carolina. They find that neighboring hog barns reduce the sale price of a house, and that the impact declines with distance from the house.

Subsequent studies follow a similar research design. Using a sample of house sales in southeastern Pennsylvania between 1998 and 2002, Ready and Abdalla (2005) find that an additional hog barn reduces house prices by 4% at ½ mile, with an outer limit impact at 1 mile. Herriges, Secchi, and Babcock (2005) examine 1992 to 2002 sales in north-central Iowa and find that a new moderate-sized hog facility located upwind and within ¼ mile of a house reduces the house price by 14 to 16%. A similar facility located ½ mile away reduces property values by 8 to 9%, and a facility within 1½ miles reduces house prices by between 0 and 4%. Isakson and Ecker (2008) examine the impact of hog barns on house sales that occur between 2000 and 2004 in a single county in northeastern Iowa. They present much larger impacts of hog barns on house prices; houses downwind and within 2 miles of a hog barn decrease in price by as much as 44%, houses that are downwind and within 2½ miles decrease in price by as much as 15%, and houses downwind and within 3 miles decrease in price by 10%.

Kim and Goldsmith (2009) use assessed property values to examine the impact of hog barns on house prices in a southeastern county in North Carolina. The authors present results suggesting that a hog barn 1 mile from a house decreases the assessed value of that house by 8%. Most recent among published studies, Kuethe and Keeney (2012) examine the impact of livestock barns within a single county in Indiana for the years 1993 to 2006. Quantile regression results suggest that a new livestock barn has no impact on sale prices of houses in the bottom half of the price distribution, while the price of a house at the 70th percentile increases by 31% if moved 1 mile farther from a barn.

All the prior published research derives estimates from repeated cross-sectional data; the timing of barn establishment is used to confirm that sales occur post barn establishment but is otherwise ignored. There are important limitations with this approach. The standard criticism of cross-sectional analyses relates to omitted variables bias arising out of correlation between hog barn location and unobserved landscape and house attributes that affect house prices. Spatial autocorrelation is addressed in several of the past studies; this accounts for spatial correlation in house prices but does not address non-random proximity of barns to houses.[5]

Unobserved timing of barn establishment relative to the date of sale of the house is an important limitation of cross-sectional analyses that has not been acknowledged in prior studies. A strand of the literature on the impact of "undesirable facilities" on residential property values pays close attention to the timing of the siting of the undesirable facility and finds evidence to suggest that price adjustments vary over time due to gradual adjustments to the new market equilibrium, learning about the extent of the disamenity, and changing preferences as the composition of neighboring households changes (Kohlhase 1991; Kiel and McClain 1995a; Kiel and McClain 1995b; Kiel 1995; Kiel and Williams 2007). Additionally, similar to arguments advanced in Galster (1986) and demonstrated empirically in Kohlhase (1991) and Kiel and McClain (1995a), participants in local real estate markets can anticipate the location of future undesirable facilities and market prices may adjust prior to actual establishment.

The past research estimating the impact of hog barns on property values has made only limited use of information about the timing of barn establishment relative to the sale date of the house. This approach potentially confounds short-term with long-term price adjustments and may under or overestimate the short-term adjustment costs incurred by some households. Prior research that ignores anticipation of future barn establishment will tend to underestimate the negative impacts of hog barns on house prices. A before and after comparison is biased if the market has incorporated the disamenity effect in the pre-establishment period. Similarly, a cross sectional analysis is biased if houses that serve as controls (because they are far from a barn at the time of sale) are close to a barn shortly after the sale and this is anticipated by market participants. In contrast to prior studies of the impact of hog barns, the approach used in this article provides a more thorough understanding of the dynamic impacts of hog barns on residential property values. Assessment of the capitalized impact of hog barns on house prices is important for the approval of new barn sites and for potential compensation schemes as proposed in Herriges, Secchi, and Babcock (2005). The importance of estimating short-term versus long-term house price impacts will likely increase as hog production continues to move into non-traditional production regions.

In this article, I use precise locations of hog barns and house sales as well as the timing of hog barn establishment and house construction to improve upon prior studies of the impact of hog barns on residential property values. I combine 21 years of rural residential sales data with assessment data that documents the characteristics and locations of houses involved in sales, the characteristics and locations of all livestock barns, and the years the houses and barns were built. The combination of these two datasets allows me to construct a detailed picture of the current and future landscape surrounding each house involved in a sale over the 21-year study period.

The primary estimation approach is based on a spatial difference-in-differences research design comparing changes in sale prices of houses very close to a barn with the sales prices of houses a little farther from a barn, before and after barn establishment. This is similar to the approach used in recent studies of the impacts of localized disamenities on residential property values, which exploit variation in the proximity of the disamenity to houses within small geographic areas (Linden and Rockoff 2008; Congdon-Hohman 2013; Dealy, Horn, and Berrens 2017; Vyn 2018). The difference-in-differences design accounts for pre-existing price differences between houses close to a hog barn and those that are a little farther from a barn, as well as intertemporal changes in house prices that would have occurred in the absence of the barn, for instance due to shifts in the local economic climate or due to interest rate movements. Timing of barn establishment relative to the date of sale of the house is used to estimate the impact of anticipated barn establishment as well as the dynamic impact of hog barns after establishment. In this study, houses close to a hog barn are defined as those that are within 2 kms of a barn, while those a little farther away are between 2 to 5 kms from a barn. This classification is motivated by past research in other jurisdictions, as well as Manitoba regulations that require neighbors be provided the opportunity to comment on barn proposals, that neighbors be notified about public hearings on barn proposals, and that dictate minimum separation distances between hog barns and residential buildings.

The results suggest that houses that are within 2 kms of at least one hog barn at the time of sale sell at a discount of approximately 5.7%, relative to houses that are 2 to 5 kms from the closest barn. Alternative specifications suggest that the impact of hog barns decline with distance from the house, such that a hog barn within 1 km of a house is estimated to reduce house sale prices by 11.5%, a hog barn that is between 1 and 2 kms reduces house sale prices by 5%, and a hog barn that is between 2 and 3 kms has no impact on house prices. The range of influence of hog barns in southeastern Manitoba therefore appears to be limited to 2 kms.

Specifications that allow for anticipation of new barn establishment suggest that the impact of a hog barn within 2 kms of a house is to reduce sale prices by as much as 8%. Anticipation effects extending to three years prior to barn establishment are consistent with the perception that a new barn can take more than three years to be built, including more than a year in the approval process. There is little evidence to suggest that there are significant differences in the short-term and long-term price impacts of barns in this traditional production region of Manitoba. The results also suggest that barns established later in the study period have the same impact as barns established earlier in the study period, and that multiple barns within 2 kms of a house appear to have the same impact as one barn.

Comparison of the results in this article to results using methods from prior research conducted in several U.S. locations suggests that research design influences estimated discounts in important ways. Utilizing a cross-sectional analysis appears to increase the discount due to hog barns. Ignoring anticipation decreases the house price discount, and this appears to be most problematic in studies conducted prior to or during significant expansion of the livestock sector (or other undesirable facilities). Finally, the use of spatial proximity indices employed in prior studies generates large price discounts due to barns very close to houses, but much smaller discounts only a little farther from the house. Overall, using the spatial proximity indices employed in prior studies result in lower estimated house price discounts due to neighboring hog barns.

The remainder of this article proceeds as follows. The next section provides a brief discussion of the study region and describes the data used in the analysis. This is followed by a description of the empirical strategy in section three and results in section four. Section five discusses the methods and results in the context of the prior research on this topic. The final section provides concluding remarks.

Study Region and Data

The study sample covers Census Division No. 2, Manitoba, which includes the rural municipalities of De Salaberry, Franklin, Hanover, La Broquerie, Ritchot, Ste. Anne, and Tache. In 2011, this region accounted for 45% of the total pigs in Manitoba and 10% of the total pigs in

Canada.[6] Several of these municipalities have per acre hog densities within the range of some of the most intensive production regions in North America, including those studied in prior research. In 2011, the total number of pigs per acre of land in farming was 2.1 in the rural municipality of Hanover, 4.7 in Tache, and 6.5 in La Broquerie. The other municipalities examined in this study have approximately 0.5 hogs per acre. These densities are comparable to the 2012 hog densities in the U.S. counties examined in prior research: hog densities range from 0.5 to 2.3 hogs per acre in the Iowa counties examined in Herriges, Secchi, and Babcock (2005), less than 1 hog per acre in the Pennsylvania county in Ready and Abdalla (2005) and the Iowa county examined in Isakson and Ecker (2008), and 8.9 and 9.7 hogs per acre in two of the counties in Palmquist, Ruka, and Vukina (1997).[7]

There is substantial variation in 2010 population densities in the U.S. counties examined in prior research, ranging from 7 to 21 people/km in the Iowa counties studied in Herriges, Secchi, and Babcock (2005), 90 people/km in the Iowa county examined in Isakson and Ecker (2008), and 185 people/km in the Pennsylvania county examined in Ready and Abdalla (2005). Population densities in the three Manitoba rural municipalities with the largest hog densities are closest to those found in the Iowa counties in Herriges, Secchi, and Babcock (2005): in 2011 there are 9 people/km in La Broquerie and approximately 19 people/km in Tache and Hanover. These municipalities also experienced substantial population growth during the study period, increasing by 10 to 47% between 1996 and 2006.[8] Online supplementary appendix A provides a brief history of hog development in Manitoba, an overview of the approval process, required public notifications prior to barn construction, and required separation distances between barns and residential buildings.

House Sale Values

House sales data was obtained from Manitoba Assessment Online, a web portal maintained by the Manitoba Provincial Assessor. The house sale data documents the transaction prices of actual house sales and is used to construct the house sale values used in this analysis. The sales data documents the date of the sale, the assessment roll number for land parcels in each sale, the sale price, and the sale category. The sale records indicate the class of sale as 1) residential with buildings, 2) residential bare land, 3) farmland with buildings, and 4) bare farmland. The data used in this analysis is limited to sales classified as residential with buildings. The available sample includes all rural house sales in Census Division No. 2, Manitoba between 1987 and 2017.

Covariates

The Manitoba Provincial Assessor provided access to two confidential data sources: 1) the 2018 assessment database that includes information for each roll parcel (an individual unit of land and associated property that are assessed for taxation purposes) in Manitoba and 2) a georeferenced spatial layer indicating the location of each roll parcel in Manitoba (outside of Winnipeg). The assessment records document characteristics of primary houses and the presence of other buildings. House characteristics include the year the house was built, square footage, number of stories, and a categorical measure of construction quality. The assessment data also records the presence of a basement, an air conditioner, a fireplace, or a brick exterior. The data indicates the number of attached or detached garages, the presence of large buildings such as a non-livestock barn, a machine shed, or a workshop, and the total acres in the sale. Important for this study, the data indicates the year each building was constructed. This makes it possible to reconstruct the landscape as it existed for each year in the sales data.[9]

Data on livestock barns is extracted from Manitoba assessment records. Assessment data includes the livestock species housed in the barn, the date the barn was built or expanded, the square footage, and construction features of the barn. Not all hog barns in the data are modern large-scale operations. Hog barns are sorted according to square footage and barns in the bottom two quintiles are dropped from the sample. As a result, all barns in the sample are at least 14,000 square feet in size. In 2015, construction budget estimates suggest a barn size of just over 18,000 square feet for a new 2,000 head finisher hog barn (Small, Hodgkinson, and Plohman 2015). The 14,000 square foot cut off used in this sample of barns built in the 1990s to mid-2000s is below *current* (post-2015) minimum sustainable finishing barn capacity in Manitoba. It is unlikely that barns smaller than 14,000 square feet were being used for pig production during the study period.[10]

Land characteristics are obtained from several sources. Agricultural capability classes (ACC) index soil productivity based on several factors including soil type, natural drainage, slope, and salinity. The ACC classifications were conducted by the Canadian Land Inventory (CLI) and are made publicly available by Agriculture and Agri-Food Canada (AAFC).[11] I classify ACC 1 and 2 as high productivity soil; ACC 3 and 4 as medium productivity soil; and ACC 5, 6, and 7 as low productivity soil. Low productivity soil is the omitted category in this analysis. Elevation and slope of each sale parcel is obtained from the Manitoba Land Initiative Digital Elevation Models and the CLI, respectively.

Several variables capturing surrounding characteristics of the land base and population are collected from Statistics Canada Census of Agriculture data. These variables are collected for the year 1980 in an effort to control for pre-determined aspects of the surrounding physical landscape and population. The Census of Agriculture data is publicly available at the census subdivision (rural municipality) level. The intent of these covariates is to document features of the surrounding landscape. Some sale parcels lie close to the border of two or more rural municipalities. To increase the accuracy of this measure, an eight-kilometer buffer is drawn around each sale parcel in order to compute the share of the surrounding landscape within each municipality. The value of these covariates for each sale is then a weighted average of the value of the covariate in each municipality with positive weight for that sale. Constructing these controls in this manner also ensures that they are not perfectly correlated with the municipality fixed effects that are included in the regressions. Census of Agriculture data is used to capture the share of the surrounding eight kilometers in cropland or grassland, the average value of farmland, and the average value of buildings and livestock. These covariates control for pre-existing differences in the extent of agricultural activity in the surrounding area. Statistics Canada Census data is used to control for the number of houses in the surrounding area, the average income, and the average value of dwellings.

Spatial Locations of Houses and Livestock Barns

The assessment data links houses and barns to a roll parcel but does not provide the exact location of the house and barn within the roll parcel boundary. A simple approach to locating buildings within a roll is to place them at the centroid of the roll parcel. Locating buildings at the centroid of a small roll will result in little error, but the same approach on a large parcel may place the building far from its actual location. As an example, a quarter section parcel is approximately 805 metres by 805 metres. If a building is located at the corner of a quarter section, the centroid may place that building more than ½ km from its actual location. The spatial proximity of houses and barns is important for this analysis since the impact of hog barns on house prices is expected to be highly localized and to depend on distance. Since there are thousands of houses and barns on large or irregularly shaped parcels, the potential consequences of incorrect locations are substantial.

Several steps are taken to improve the spatial precision of house and barn locations. ArcGIS was used to identify all parcels that are larger than 20 acres or are irregularly shaped. As an alternative to using the centroid, the point locations of all primary houses and barns were relocated (point, click, move, and drop) using an overlay of the roll parcel layer with ortho photography provided on the Manitoba Land Initiative.[12] After performing this relocation procedure for the thousands of houses and barns in the study region, the locations of houses and barns on large and irregularly shaped parcels are very close to their actual locations.[13]

Empirical Strategy

The objective of this analysis is to identify the impact of hog barns on house prices. The primary empirical challenge arises due to potential unobserved factors that are correlated with house prices and that also influence the location of hog barns. For example, producers might choose to locate hog barns in regions with lower priced land in an effort to minimize land financing costs. Bayoh, Irwin, and Roe (2004) provide a clear description of the issues that might arise out of this form of endogeneity. Alternatively, hog barns might systematically locate in regions with access to strong labour and capital markets. In Manitoba, hog production has tended to concentrate in relatively high-income rural municipalities that were experiencing significant population increases in the late 1990s (Broadway 2006). Lower land values are likely associated with lower house prices, whereas strong labour and capital markets are likely associated with higher house prices. Failure to account for these unobserved factors generates biased estimates of the impact of hog barns on house prices, and the direction of the bias is uncertain.

This study employs a spatial difference-in-differences approach comparing changes in sale prices of houses very close to a barn with changes in prices of houses a little farther from a barn, before and after barn establishment. The assumption underlying this approach is that these two sets of houses are similar along observed and unobserved characteristics and that their prices follow the same path over time (in the absence of a barn). Houses that are within 2 km of a hog barn (either before or after the house is sold) are classified as treated sales and houses that are 2 to 5 kms from a hog barn (before or after the house is sold) are classified as control sales.

I draw on two information sources to help guide the distinction between treated and control houses. First, the prior empirical literature suggests that the impact of hog barns on house prices is local; hog barns reduce house prices within a narrow buffer surrounding the barn but have little to no impact beyond that buffer. Although there is substantial variation in past estimates of the magnitude and spatial range of influence, the prior literature suggests that the effect of hog barns on house prices is strongest within 1 to 1 ½ miles (1.6 to 2.4 kms) of the house and that the influence of hog barns may extend to houses located 3 miles (4.8 kms) from the barn (Ready and Abdalla 2005; Herriges, Secchi, and Babcock 2005; Isakson and Ecker 2008).

Second, regulatory guidelines set out by the Manitoba provincial government determine minimum separation distance requirements, as well as requirements to notify neighbors prior to a technical review and prior to public hearings about construction or expansion of hog barns. The barn approval process begins with a report prepared by the provincial Technical Review Committee (TRC). Public comments are solicited by the coordinator of the TRC over a 30-day period and posted on a public registry prior to the conditional use hearing. Further, potential neighbours of the proposed barn are required to be notified 14 days prior to the conditional use hearing. Before the year 2000, all neighbors within 100 metres of a proposed barn site were notified. This was extended to 2 kms in 2000 and extended again to 3 kms in 2008.

Separation distance requirements vary by the size of the barn (in animal units), type of manure storage facility, and the nature of the neighboring land use, and tend to cover relatively short distances no more than 4 kms from the largest sized barn. It is important to note here that the average size of barn in Manitoba is well below the largest size described in the *Provincial Planning Regulation*. The minimum separation distance for the average barn in the study region ranges from 400 to 500 metres from a residence, or 1.6 to 2 kms from a designated residential area.[14]

Both regulatory guidelines suggest that the influence of hog barns on neighboring properties is highly localized. If these guidelines have been set to minimize the potential for conflict between neighbors, they imply that the externality of a hog barn does not extend beyond 2 to 3 kms. Consistent with these regulatory guidelines, Zhang et al. (2005) present evidence from a Manitoba-based odour dispersion model that barns more than 2 kms from a house generate a relatively low level of annoyance for neighboring residents (online supplementary appendix A describes the Zhang et al. results in more detail). I conduct a series of robustness checks to assess the sensitivity of results to alternative classifications of houses into treatment and control groups.

The presentation of results begins with a graphical display of the evolution of house sale prices within 2 kms of a hog barn relative to house sale prices 2 to 5 kms from the nearest hog barn. This impact is estimated in regression form based on the following equation:

$$\ln(p_{ht}) = \beta X_h + \delta_t + \sum_{s=-10}^{s=10} \rho_s D_h^2 \times e_{ht} + \theta_5 D_h^5 + \pi_5 D_h^5 \times \tau_{ht} + \varepsilon_{ht} \qquad (1)$$

where h indexes individual houses that have sold and t indexes the calendar year the sale occurred. The dependent variable is the log of sale price, $\ln(p_{ht})$, for each house, deflated by the Canadian Consumer Price Index and expressed in 2017 dollars; X_h includes a set of covariates controlling for house and land parcel characteristics, including region-specific fixed effects that control for fixed differences in house prices across regions due to differences in proximity to local amenities, investment in local infrastructure, and tax rates; δ_t includes year fixed effects that control for factors that vary by year and are common across the study region, including macroeconomic factors such as interest rates, exchange rates, and the general economic climate within the region, as well as month fixed effects to control for seasonal variation in residential real estate markets; and ε_{ht} is the error term. Standard errors are clustered by Statistics Canada dissemination areas, which are the smallest aggregated regions provided in Statistics Canada data.

Two buffers are drawn around each sold house h where buffer 2 corresponds to the area within 2 kilometres of the house, and buffer 5 corresponds to the area within 5 kilometres of the house. The impact of hog barns on house prices is estimated by the set of parameters on the dummy indicators D_h^f, where $D_h^f = 1$ if there is at least one hog barn in the $f = (2, 5)$ buffer, and zero otherwise. The dummy variable τ_{ht}, interacted with D_h^5, is equal to one if the sale occurs after the hog barn is built. The omitted comparison group is comprised of house sales that do not have a barn within 5 kms over the entire study period. The estimated coefficient θ_5 provides an estimate of the pre-existing difference in prices of houses within 5 kms of a barn compared to houses in the comparison group, while π_5 provides an estimate of the average post-establishment impact of a barn within 5 kms of a house.

The primary coefficients of interest are the ρ_s, which capture the impact of a barn within 2 kms of a house, relative to prices of houses that are 2 to 5 kms from a hog barn. The dummy indicator D_h^2 is interacted with normalized annual event years, denoted e_{ht}, which range from house sales occuring ten or more years prior to hog barn establishment to sales occuring ten or more years after hog barn establishment and are normalized such that a house sold in the same year the barn is established is assigned to event year zero. The specification in equation (1) estimates 20 values of ρ_s, one for each of the normalized event years. The graph presented in the results section plots estimates of ρ_s against normalized event years, tracing out the evolution of prices of houses within 2 kms of a barn in the pre- and post-establishment periods.

Estimates of the average impact of a local hog barn on house prices reported in tables in the results section are based on variations of the following estimating equation:

(2) $$\ln(p_{ht}) = \beta X_h + \delta_t + \theta_2 D_h^2 + \pi_2 D_h^2 \times \tau_{ht} + \theta_5 D_h^5 + \pi_5 D_h^5 \times \tau_{ht} + \varepsilon_{ht}.$$

The series of coefficient estimates θ_2, θ_5, π_2, and π_5 have a standard pre-post difference-in-differences interpretation.[15] The θ_2 and θ_5 coefficients capture underlying differences in house prices in the respective buffers prior to barn establishment. For example, θ_2 captures the pre-existing difference in prices in houses in the 2 km buffer compared to houses in the 2 to 5 km buffer. An objective of the research design is to minimize pre-existing differences in the treatment and control groups; these coefficients are therefore expected to be close to zero.

The π_2 and π_5 coefficients capture the additional impact of a hog barn within each respective buffer that is present at the time of the sale. The π_2 coefficient is an estimate of the additional impact of having at least one hog barn within 2 kms, relative to having at least one barn in the control group of houses that are 2 to 5 kms from the nearest hog barn. This coefficient is the primary difference-in-differences estimate of interest; it captures the causal price impact of a hog barn within 2 kms of a house. Finally, the π_5 coefficient captures the extent to which prices in the control group change differently from prices in the rest of the sample, in this case houses 5 to 10 kms from the nearest hog barn.

Data Trimming

The spatial difference in differences approach compares prices of houses that are within 2 kms of a hog barn to prices of houses that are farther than 2 kms from a hog barn. I use a propensity score approach to trim the dataset in an effort to improve the covariate balance for these two groups of houses (Imbens and Rubin 2015). I begin by estimating a logit model of the likelihood that a house involved in a sale at any time in the study period is within 2 km of a hog barn, either before or after the sale. The results from the logit model are used to construct a propensity score for each house sale—the propensity score is the likelihood that the house sale is within 2 km of a current or a future hog barn. The ultimate objective of the trimming procedure is to reduce the sample to a set of treated and untreated sold houses that have comparable observed characteristics, such that the primary difference between the two sets of sold houses is that the treated group is within 2 km of a hog barn and the untreated group is not. I follow the approach outlined in Imbens and Rubin (2015) to calculate the range of propensity scores that will serve as the basis for trimming observations from the sample.

Normalized differences indicate that the overall balance between the two subsamples improves after trimming.[16] Table A1 in the online supplementary appendix presents summary statistics for the raw data and table A2 presents summary statistics for the trimmed sample, broken out by treated and control subsamples, as well as summary statistics for the discarded observations.

The estimation sample is further restricted to house sales that occur within five years (prior to or after the sale) of the construction or expansion of at least one hog barn within 10 kms of the house. Restricting the sample in this manner ensures that observed house sales occur in regions with an active hog sector. Robustness checks that vary this window from three years to nine years are reported in online supplementary appendix C. Finally, house sales on parcels larger than 40 acres are dropped to exclude parcels that are sold for use in production agriculture.

There are 95 unique hog barns that are within 2 kms of a house at some point during the study period. Approximately 33% of barns within 2 kms of a house were built by 1992 and 77% were built by 1999. As presented in table 1, the data contains a total of 1,255 house sales within 2 kms of a hog barn, 562 of those houses are sold prior to barn establishment within 2 kms and 693 are sold after a barn is established within 2 kms of the house. Among the 1,255 house sales within 2 kms of a barn, 253 are within 1 km of a barn and 1,146 are within 1 and 2 kms of a hog barn. There are 2,701 sales of houses that are 2 to 5 kms from a barn; 723 sold prior to barn establishment and 1,978 sold after barn establishment. More sales occur post-barn establishment than pre-barn establishment, consistent with the substantial expansion of the Manitoba hog sector in the 1990s.

Table 1 presents means of the house sale prices and covariates, broken out by treated and untreated house sales that occur before and after hog barn establishment (the full table of means and standard deviations are presented in online supplementary appendix B). Comparing the mean log of sale price reveals that the sale prices in the treated and control samples are approximately equal prior to barn establishment. House prices increase in both subsamples in the post barn period, with the treated sales experiencing a larger price increase than the control sales. This simple comparison of four means therefore suggests that establishment of a hog barn within 2 kms increases the average sale price of houses.[17] Figure B1 in the online supplementary appendix presents the mean log of sale prices for the treated and control samples relative to barn establishment date. Consistent with the summary statistics presented in table 1, figure B1 suggests that prices tended to move together and house prices in the treated sample are higher than house prices in the control sample after barn establishment.

A clear shortcoming of this simple comparison is that it does not control for important determinants of house prices that may differ across the four subsamples due to different compositions of those samples. Several characteristics are substantially different in the pre- and post-periods. The average age of house in the treated sample is constant across the pre- and post-periods, whereas the average age of house in the control sample increases by more than five years in the post period. The share of treated houses that are above average quality increases from 10 to 17% in the post-barn period, while the share of houses that are above average in the control group declines slightly. Distance to Winnipeg increases for the treated group in the post-barn period but is constant across the two periods in the control group. The analysis that follows controls for these and other important determinants of house sale prices.

Results

The presentation of results focusses on the impacts of hog barns on house sale prices, controlling for the set of covariates presented in table 1. Results from a house sale price hedonic regression are presented in table C1 in the online supplementary appendix. The results from this regression are largely consistent with expectations. Newer, larger houses sell for a premium, and house construction quality is among the most important determinants of price. Houses farther from Winnipeg tend to sell at a discount. As presented in online supplementary appendix C, a comparison of the mean sale price residuals from this hedonic regression suggests that the prices of houses within 2 kms of a barn fell relative to the prices of houses 2 to 5 kms from a barn, post barn establishment. The variables included in the specifications reported in table C1 are included as controls in each specification reported in the following figures and tables of results.

Estimating the Impact of Hog Barns on House Prices

Figure 1 displays estimates of ρ_s from equation (1) plotted against normalized event years. These coefficients trace out the evolution of price differences between treated and control sales, after conditioning on observable house and land parcel characteristics. The coefficient estimates vary significantly from year to year, partly due to the relatively small number of treated house sales within each year. Note that the confidence intervals on these coefficients are large; the general pattern in the coefficients over time is more informative than year to year variation. Inspection of figure 1 suggests that, after controlling for house and land parcel characteristics, treated houses sold for a small premium over untreated houses four or more years prior to barn establishment. Prices of treated houses appear to decrease relative to untreated houses prior to barn establishment. This is consistent with, but not necessarily due to, housing market anticipation of barn construction. After barn establishment, the event year point estimates suggest that nine out of ten years the prices of houses that are within 2 kms of a hog barn are lower than the prices of houses more than 2 kms from a barn. The estimates presented in figure 1 also suggest that the price discount post-establishment is relatively stable and does not decrease over time as might be expected if a sufficient number of indifferent households start to bid up the prices of houses close to barns several years after barn establishment.

Table 2 presents the first set of results based on estimation of the coefficients in equation (2). Column (1) presents results after controlling for the basic set of house and land parcel characteristics as presented in the hedonic specifications in online supplementary appendix table C1. Column (2) presents results with additional covariates capturing the proximity of houses to poultry barns, as well as the total counts of hog and poultry barns within 8 kms of the house. Including these additional covariates has costs and benefits for the research design. These variables are potentially problematic since they may be influenced by local hog barn development and controlling for them will absorb some of the impact on house prices that should be attributed to the local hog barn. Alternatively, failing to include these covariates may bias estimates of the impact of local barns if part of the price impact is due to a local poultry barn.[18] Columns (1) and (2) present both sets of results. Finally, column (3) presents results for the limited sample of house sales with at least one hog barn within 5 km. This limited sample accounts for potential differences in the way that house and land parcel characteristics are valued outside of the treatment and control groups of houses (the set of houses that are more than 5 kms from the closest hog barn).

Recall that $D^2 = 1$ if there is at least one hog barn within 0 to 2 km of the house at any time (before or after the house is built or sold), and $D^5 = 1$ if there is at least one barn within 0 to 5 km of the house at any time. The estimated coefficients on D^5 in all three columns of table 2 are small and statistically insignificant at conventional significance levels, suggesting that houses within 5 kms of at least one hog barn sell for the same price as houses that are more than 5 kms from a hog barn (after conditioning on the full set of covariates from specifications presented in online supplementary appendix table C1). The coefficient on D^2 picks up pre-existing differences in house prices between houses that are 0 to 2 kms from a hog barn and houses that are 2 to 5 kms from a hog barn. The coefficient on D^2 is small and statistically insignificant in all three columns in table 3. This suggests that, after conditioning on observed characteristics of the houses and land parcels, houses that are 0 to 2 kms from a hog barn sell at a similar price to houses that are 2 to 5 kms from a hog barn. This result is consistent with the research design; there is no evidence of systematic pre-existing differences in prices between the treated and control houses.

Results in all three columns suggest that close proximity to a hog barn decreases house sale prices. The coefficients on $D^2 \times \tau$ indicate that houses within 2 kms of an existing hog barn sell for 5.1 to 5.7% less than houses that are 2 to 5 kms from a hog barn. To put these results into perspective, consider an average house within 2 km of a barn that sold for \$104,596 prior to the barn being built. The results reported in table 2 suggest that this house will sell for 5.1 to 5.7% less after the barn is established, implying lost house value of \$5,334 to \$5,962.

Finally, the coefficients on $D^5 \times \tau$ capture different rates of change in prices of houses close to barns compared to those farther away (5 to 10 kms from a barn); the coefficients presented in columns (1) through (3) are imprecisely estimated and are statistically significant only at the 10% level in the specification presented in column (1). Overall, the results suggest that prices of houses that are 2 to 5 kms from an existing barn at the time of sale do not change in a substantive manner relative to their sale price prior to barn establishment.[19]

The following sections present the results of several efforts to assess the robustness of the baseline results presented in table 2. Several additional robustness checks are presented in online supplementary appendix D. The first investigates the impact of adjusting the size of the sample by varying the time between the closest barn construction date and the house sale to three, seven, and nine years (a sample based on five years is used in all results reported in this article). Adjusting the sample in this manner has little impact on estimates of the impact of hog barns on house prices. The robustness checks in the appendix also address several of the results from the prior literature concerning barn size and prevailing winds. The results presented in the appendix provide no evidence that these factors play an important role in the negative impact of hog barns on the prices of houses in this sample.

An alternative approach to estimating the impact of barns on house prices is to make use of repeat house sales—sales of the same house before and after barn establishment, in the treatment and control groups. In this approach, house sale fixed effects explicitly control for unobserved time-invariant differences between houses. There are a couple of potential disadvantages with this approach. First, there are a limited number of repeat sales available in this study region. Second, the sample of repeat sales may not be representative of the population of house sales (Clapp and Giaccotto 1992). In online supplementary appendix E, I present evidence that the repeat sales subsample is comprised of less desirable housing compared to the full population of houses sold in the study region. Appendix E presents results from a repeat sales analysis; the estimated impact of hog barns on house prices is close to the estimates presented in this article.

Finally, in online supplementary appendix F, I present the results from an alternative research design, similar to Cengiz et al. (2019), that exploits potential random timing of barn establishment. Estimates from this approach are similar to the main results presented in this article.

Spatial Extent of the Impact

The results presented in table 2 of the article are based on specific definitions of the treatment and control groups. In this section I present several alternative specifications that assess the sensitivity of the results to different assumptions about treatment and control group assignment.

Columns (1), (2), and (3) of table 3 present results from specifications that change the definition of treated house sales. Column (1) defines the treated group as house sales that are within 1 km of a hog barn. As expected, classifying the treated group using closer proximity to a hog barn generates a larger price discount: houses that are within 1 km of a hog barn sell for 9.5% less than houses that are 1 to 5 kms from a hog barn.

Columns (2) and (3) in table 3 present specifications with additional treatment groups to explore the spatial extent of the effect of hog barns on house prices. Column (2) reports results from a specification with two treated groups: 1) houses within 1 km of a barn and 2) houses within 2 km of a barn. In this specification, there is no evidence of pre-existing differences in house prices between those located between 2 and 5 kms from the nearest barn and those located between 1 and 2 kms from the nearest barn. The evidence also suggests that, prior to barn establishment, houses that are eventually within 1 km of a barn sell at a premium relative to houses that are eventually 2 to 5 kms from a barn. After the barn is built, a house that is between 1 and 2 kms from a barn sells for 4.4% less, and a house located within 1 km of a barn sells for an additional 6.4% less than a house that is 1 to 2 kms from a barn. Overall, this suggests that a barn within 1 km of a house at the time of sale reduces the house price by as much as 10.8%. Column (3) adds a third treated group: houses that are within 3 km of a hog barn. The results indicate that a barn that is 2 to 3 kms from a house has no impact on the sale price of that house. Overall, these results indicate that one or more hog barns within 2 kms of a house have substantial and statistically significant impacts on house prices, while one or more hog barns more than 2 kms from a house have no impact on house prices.

The next set of results in table 3 are based on alternative specifications that adjust the definition of the control group, while maintaining the default definition of treated houses as those within 2 kms of a hog barn. Columns (4), (5), and (6) present results comparing treated houses within 2 kms of a hog barn to control houses that are 2 to 3 kms from a hog barn, 2 to 4 kms from a hog barn, and 2 to 5 kms from a hog barn, respectively. Column (6), in bold, reproduces the baseline results as reported in column (2) of table 2. Results are consistent across all three specifications; there is no evidence of pre-existing differences in prices in the treated and control groups, and houses within 2 kms of a hog barn sell for 5.6 to 6.9% less after barn establishment. The set of results presented in table 2 appear to be robust to alternative definitions of the control group.

Several of the specifications reported in tables 2 and 3 suggest that the prices of houses between 2 and 5 kms from a hog barn change at different rates from those that are between 5 and 10 kms from a hog barn. House price changes in the 2 to 5 km range may or may not be due to the presence of a hog barn. Other factors may result in different rates of change in prices in the two regions—results based on specifications in tables 2 and 3 cannot distinguish the effects of hog barns in the 2 to 5 km range from the influence of these other factors. Column (7) of table 3 presents results with a control group of houses that are within 8 kms of a barn. This definition of the control group allows for a difference-in-differences interpretation of the house price impact of a hog barn within 2 to 5 kms of a house. Once again, there is no evidence of pre-existing differences in the prices of houses 2 to 5 kms from a barn and houses 5 to 8 kms from a barn. The results from this specification suggest that at least one barn within 2 kms decreases house prices by 5.7% and there is no evidence that houses 2 to 5 kms from a hog barn sell for a lower price due to barn establishment.

Anticipation of Barn Establishment

Malani and Reif (2015) outline the implications of ignoring anticipation in difference-in-differences studies. Inspection of figure 1 suggests the presence of pre-trends, where the sale price of treated houses relative to control houses appears to decrease prior to barn establishment. Pre-trends may be the result of 1) endogenous treatment due to new barn establishment in locations with declining house prices or 2) housing market anticipation of the location of future hog barns. Although it is not possible to cleanly separate the extent to which these pre trends are the result of endogenous treatment versus anticipation, in this setting it is reasonable to suspect that the housing market anticipates future locations of hog barns. Anecdotal evidence based on interviews with hog producers in Manitoba suggests that the time required to build a finisher barn in Manitoba in the early 2000s could take three to four years, partly due to a lengthy permitting process (Grier, Martin, and Mayer 2002). Recent estimates suggest that the approval process (prior to site preparation and construction) for a new barn in Manitoba likely takes more than one year (White 2017). At a minimum, the fact that public notice is required prior to preparation of the technical review and once again prior to conditional use hearings implies that local buyers and real estate agents are potentially aware of future barns well in advance of actual barn construction (a more detailed description of the barn approval process is provided in online supplementary appendix A). Moreover, local house owners learn about potential locations of future hog barns through word of mouth, local advertising requesting public comments, and public announcements of municipal conditional use hearings. This information may lower seller reservation prices at the time the house is sold.

If the market anticipates barn locations and house prices are bid down prior to barn establishment, then the pre-barn baseline is biased downward. In this case, ignoring market anticipation biases estimates downwards because the baseline period is assumed to span the entire pre-establishment period. Table 4 presents results that allow for anticipation of barn establishment through a series of quasi-myopic specifications following Malani and Reif (2015).[20] The specifications enter additional dummy variables indicating whether a hog barn will be established within 2 kms of the house within the next one, two, or three years. If the housing market anticipates the hog barn, then the estimated coefficients on these terms will be negative and the estimated treatment effect in the post-establishment period should increase, relative to the specification that ignores anticipation. I also include a dummy variable equal to one if the barn is established in the same year that the house sale occurs.

As shown in table 4, including anticipation terms increases the magnitude of post-establishment treatment effects. Column (1) in table 4 assumes that all anticipation occurs within one year prior to barn establishment. I find that accounting for anticipation in this manner increases the estimated treatment effect by 1.3 percentage points (a barn within 2 kms of a house reduces the sale price by 6.9%). Allowing anticipation to occur within one or two years prior to barn establishment has little additional impact on the estimated treatment effect. If anticipation is assumed to occur three or fewer years prior to barn construction, the post-barn treatment effect increases to 8%. The final column in table 4 estimates the aggregate impact of anticipation in years one, two, and three, indicating that house prices fell by an average of 6.2% over the three years prior to barn establishment and by 8% after barn establishment. An anticipation period of up to three years is consistent with the expected length of time to construct a new hog barn as suggested in Grier, Martin, and Mayer (2002).

As mentioned above, an alternative interpretation of these results is that the location of a hog barn within 2 kms of a house is an endogenous event, where hog barns systematically locate next to houses that are declining in value. Reverse causality is unlikely within the small geographic areas considered in this study for a couple of reasons. First, rural housing markets are thin, and the spatial density of houses is relatively low. In this setting, it is unlikely that barns are locating within 2 kms of houses that are falling in price, and within 2 to 5 kms of houses that are stable or increasing in price.

Second, conditional use applications are approved by local municipal councils after a technical review and input from proponents and opponents of barns. It might be argued that homeowners in locations with declining house prices are less resistant to new hog barns. One of two potential scenarios must unfold for this to be the case. First, barn proponents must systematically target land that is within 2 kms of houses that have recently declined in price relative to their neighbors. This kind of spatial targeting seems unlikely since barns are often built on or near previously established farms associated with the barn proponent. A second related scenario is that barn proposals close to houses that are declining in value are more likely to be approved by municipal councils. Given the low rejection rates for hog barn conditional use applications within this region during the study period, it is unlikely that municipal council targeting was a driving factor in the *precise* locations of hog barns. In online supplementary appendix F, I present results from an alternative research design that exploits the timing of hog barn establishment and is not subject to concerns arising out of endogenous treatment. Results from this alternative research design are consistent with the results presented in this article.

Timing of Barn Establishment and Multiple Neighboring Barns

Spatial agglomeration of hog barns is a common feature in many regions with intensive livestock production (Roe, Irwin, and Sharpe 2002). An implication of spatial clustering of livestock production in this region is that a house may be within two kilometres of more than one hog barn. The estimates presented in tables 2, 3, and 4—based on specifications that include a dummy variable for houses with *at least* one hog barn within 2 kms—are therefore picking up the effects of the first barn as well as any additional effects due to two or more neighboring barns. Treatment timing can also bias estimates of the impact of hog barns on house prices in the presence of heterogeneous treatment effects (Goodman-Bacon 2018).

Table 5 reports results from alternative specifications exploring potential issues that might arise due to differential treatment timing and multiple barns. Column (1) of table 5 reports the results of a specification that allows for heterogeneous treatment effects through an additional variable equal to one if the first barn was built in the later half of the sample period (after 1998), and zero otherwise. The results suggest that barn establishment in the later half of the study period does not have an additional statistically significant impact on house prices. This preliminary evidence indicates that the impact of a neighboring barn on house prices does not depend on the timing of hog barn establishment.

A second aspect of the role of treatment timing relates to the possibility that a house has more than one hog barn within 2 kms. The specification reported in column (2) of table 5 drops all observations that have more than one neighboring hog barn within 2 kms at any time during the study period. This eliminates the potential concern that a house with multiple barns (constructed at different times) is serving as a control for other houses with exactly one neighboring hog barn. As reported in table 5, the impact of a single hog barn within 2 kms is a 5.3% reduction in house prices, which is comparable to the baseline estimate of 5.7% reported in table 2. Column (3) of table 5 reports the results of a specification that 1) drops all observations with more than one neighboring hog barn and 2) estimates the additional impact of later timing of hog barn establishment. Once again, there is no evidence of heterogeneous treatment effects due to the timing of hog barn establishment.

The specification presented in column (4) of table 5 takes a different approach to investigating the role of multiple barns. Rather than dropping all observations with multiple neighboring barns, this specification allows for a differential impact due to development of the second hog barn. The point estimate suggests that establishment of a second barn reduces prices further, but this estimate is not statistically significant at conventional significance levels. Overall, it appears as though treatment timing and development of multiple neighboring hog barns do not have differential impacts on house prices.

Comparison to Methods Used in Prior Research

A series of results based on research designs used in the prior literature are presented in online supplementary appendix G. I evaluate the impact of 1) modeling distance from a barn using a continuous spatial proximity index, 2) using a cross-sectional design, and 3) ignoring anticipation in a cross-sectional study. Prior studies have used specific functional forms to construct spatial proximity indices of barns to houses; most studies use the inverse of distance to the nearest barn or the log of distance to the nearest barn. Using these spatial proximity indices, the past studies have estimated relatively large impacts due to barns very close to houses, with much smaller discounts due to barns that are only a little farther away. For example, Ready and Abdalla (2005) use the inverse of distance to the nearest barn and estimate a price discount of 6.4% at 500 metres, a discount of 1.6% at 1,200 metres, and zero discount at 1,600 metres. Simlarly, Herriges, Secchi, and Babcock (2005) use the log of distance to the nearest barn and estimate a large discount of approximately 15% at ¼ mile from a barn, but the discount drops to 0 to 4% at 1 ½ miles from a barn.

As reported in online supplementary appendix G, applying the spatial proximity indices used in the prior literature to the Manitoba data used in this article generate results differenjt from those reported in this article. Specifically, using the inverse of distance to nearest barn I find that a house within 634 meters of a barn (the average distance to the nearest barn for houses that are within 1 km of a barn) sells at a discount of 4.6 to 7.1%. The same specification suggests that a barn within 1,576 metres (the average distance to the nearest barn for houses that are within 1 to 2 kms of a barn) sells at a discount of 0.6% to 1%. This sharp drop in the estimated discount across a small distance is consistent with the results presented in prior studies. In this study region, use of spatial proximity indices suggest that the negative impact of barns on house prices is limited to the small number of houses that are within 1 km of a barn. This is at odds with the results presented in this article, which suggest that a house that is between 1 to 2 kms from a barn sells for a discount of approximately 5%.

A comparison of the cross-sectional approach employed in the prior research to a difference-in-differences approach (using the continuous spatial proximity index within 2 kms) suggests that the cross-sectional approach estimates larger price discounts. This is consistent with the presence of unobservables that are correlated with lower house prices for those houses close to barns. If this carries over to the study regions in prior research, it implies that the cross-sectional approach tends to overstate the negative impacts of barns on house prices.

This article makes explicit use of timing of barn establishment to gain a better understanding of the dynamic impact of hog barns on house prices. The results presented in the article indicate that ignoring anticipation reduces the estimated house price discount. The results presented in online supplementary appendix G investigate the potential impact of ignoring anticipation in a cross-sectional analysis. Unobserved anticipation is a concern if barns established after the study period are incorrectly classified as control sales by the econometrician, but are considered treated house sales by market participants who are able to anticipate future locations of hog barns. This is likely most problematic in studies that are conducted prior to or during an expansionionary period with many new facilities being established.

As reported in online supplementary appendix G, there is evidence to suggest that ignoring anticipation in a cross-sectional analysis biases estimated discounts downwards. Ignoring anticipation in a cross-sectional analysis leads to a substantial understatement of the house price discount using a subsample from an expansionary period in the Manitoba pig sector, from 1993 to 1998. Ignoring anticipation has a smaller impact on estimates in the post-expansionary phase from 2005 to 2010, which includes introduction of a moratorium on new hog barn establishments in 2006 (partially lifted in 2008). Overall, these results indicate that ignoring anticipation underestimates the price discount in a cross-sectional analysis, and the impact of ignoring anticipation is greatest during or prior to an expansionary period.

Concluding Remarks

In this article, I estimate the impact of hog barns on house prices in southeastern Manitoba, a region with an active rural housing market and several rural muncipalities with spatial densities of hogs comparable to some of the most intensive production regions in North America. The prior literature on this topic relies on cross-sectional variation in house prices and proximity to barns. I explicitly account for the timing of barn establishment relative to house sale date in an effort to better understand the dynamic impacts of hog barns on house prices, including potential pre-establishment impacts due to market anticipation of future barn locations.

I find that, on average, a hog barn within 2 kms of a house decreases the house sale price by approximately 5.7%. Robustness checks suggest that the negative impact of hog barns on house prices may be as high as 8% if potential anticipation of barn establishment is considered. Ignoring anticipation of future barn establishment therefore reduces estimated price discounts, both in the difference-in-differences setting used in this article and potentially in the cross-sectional approaches used in prior studies. These results correspond to total impacts on an average house within 2 kms of a hog barn that range from $5,962 to $8,368.

Alternative specifications suggest that the impact of hog barns decline with distance from the house, such that a hog barn within 1 km of a house is estimated to reduce house sale prices by up to 11.5%, a hog barn that is between 1 and 2 kms reduces house sale prices by 5%, and a hog barn that is between 2 and 3 kms has no impact on house prices. As expected, the impact of hog barns decreases with distance to the house and the results suggest the impact does not extend beyond 2 kms. I find no evidence that post-establishment price discounts changed across the post-establishment period.

This study is conducted in a traditional livestock production region. Increasingly stringent restrictions that limit the density of large-scale hog barns in the more intensive production regions of North America will shift future expansion of the industry to non-traditional production regions. Residents in non-traditional regions are less likely to accept the disamenities associated with hog barns and household sorting will likely play a bigger role in the price dynamics that prevail in those regions. This increases the importance of distinguishing short-term versus long-term impacts of hog barns. For example, the short-run impact of a hog barn locating in a non-traditional region may be quite large if local residents have a low tolerance for hog barns. Over the long-term, the composition of households will adjust such that "indifferent" households move into the region and the price discount due to hog barns decreases. Cross-sectional studies that do not account for timing of barn establishment provide an average estimate of the short and long-term impacts of hog barns on house prices; these average estimates may hide substantial short-term adjustment costs incurred by original homeowners. Understanding the dynamics of hog barn expansion, household sorting, and price adjustments in pre- and post-barn establishment periods will become increasingly important as hog barns expand into these non-traditional production regions.

References

Bayoh, Isaac, Elena Irwin, and Brian Roe. 2004. “The value of clean dairy air: Accounting for endogeneity and spatially correlated errors in a hedonic analysis of the impact of animal operations on local property values.” Paper presented at the Annual Meeting of the Agricultural and Applied Economics Association Annual Meeting, Denver, CO, August 1-4, 2004. http://ageconsearch.umn.edu/record/20364/files/sp04ba04.pdf

Boxall, Peter C., Wing H. Chan, and Melville L. McMillan. 2005. "The impact of oil and natural gas facilities on rural residential property values: a spatial hedonic analysis." *Resource and Energy Economics* 27(3):248-269.

Broadway, Michael J. 2006. "Pigs on the Prairies." *Geographical Review* 96(1):122-138.

Cengiz, Doruk, Arindrajit Dube, Attila Lindner, and Ben Zipperer. 2019. "The effect of minimum wages on low-wage jobs." *The Quarterly Journal of Economics* 134(3):1405-1454.

Clapp, John M., and Carmelo Giaccotto. 1992. "Estimating price indices for residential property: a comparison of repeat sales and assessed value methods." *Journal of the American Statistical Association* 87(418):300-306.

Congdon-Hohman, Joshua M. 2013. "The lasting effects of crime: The relationship of discovered methamphetamine laboratories and home values." *Regional Science and Urban Economics* 43(1):31-41.

Dealy, Bern C., Brady P. Horn, and Robert P. Berrens. 2017. "The impact of clandestine methamphetamine labs on property values: Discovery, decontamination and stigma." *Journal of Urban Economics* 99:161-172.

Galster, George C. 1986. "Nuclear power plants and residential property values: A comment on short-run vs. long-run considerations." *Journal of Regional Science* 26(4):803-805.

Gardner, Bruce L. 1994. "Commercial agriculture in metropolitan areas: Economics and regulatory issues." *Agricultural and Resource Economics Review* 23(1):100-109.

Goodman-Bacon, Andrew, 2018. “Difference-in-differences with variation in treatment timing.” National Bureau of Economic Research (No. w25018). https://www.nber.org/system/files/working_papers/w25018/w25018.pdf

Grier, Kevin, Cher Brethour, Beth Sparling, and Al Mussell. 2007. “Economic analysis of the hog production industry in Manitoba in relation to the Clean Environment Commission Review of Environmental Sustainability.” George Morris Centre Final Report. Last accessed from the World Wide Web January 29, 2020. http://dx.doi.org/10.22004/ag.econ.289848

Grier, Kevin, Larry Martin, and Holly Mayer. 2002 “Country of origin labelling: implications for the Manitoba hog industry.” George Morris Centre Final Report. Last accessed from the World Wide Web February 26, 2020. https://ideas.repec.org/p/ags/gmcemp/18099.html

Haines, John, and Laurel Staley. 2004. “Risk Assessment Evaluation for Concentrated Animal Feeding Operations.” EPA/600/R-04/042 2004. Last accessed from the World Wide Web January 1, 2021 https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=901V0100.txt

Mubarak, Hamed, Thomas Gordon Johnson and Kathleen K. Miller. 1999. "The impacts of animal feeding operations on rural land value." Report R-99-02. Community Policy Analysis Center, University of Missouri. Last accessed from the World Wide Web January 20, 2021 https://www.researchgate.net/publication/258399091_The_Impacts_of_Animal_Feeding_Operations_on_Rural_Land_Values#:~:text=operations%20(CAFOs)%20create%20positive%2

0impacts,handling%20facilities%20and%20livestock%20barns.&text=proximity%20to%20a%20CAFO%20and%20the%20value%20of%20property.&text=CAFO%20would%20be%20approximately%20%242.68%20million.

Hellerstein, Erica and Ken Fine. 2017. “A million tons of feces and an unbearable stench: life near industrial pig farms.” *The Guardian* September 20, 2017. Last accessed from the World Wide Web January 28, 2020. https://www.theguardian.com/us-news/2017/sep/20/north-carolina-hog-industry-pig-farms

Herriges, Joseph A., Silvia Secchi, and Bruce A. Babcock. 2005. "Living with hogs in Iowa: the impact of livestock facilities on rural residential property values." *Land Economics* 81(4):530-545.

Imbens, Guido W., and Donald B. Rubin. 2015. *Causal Inference in Statistics, Social, and Biomedical Sciences.* New York: Cambridge University Press.

Indiana Business Research Center. 2008. “The effect of regulated livestock operations on property values in selected Indiana counties.” Last accessed from the World Wide Web November 12, 2019, www.ibrc.indiana.edu/studies/RLOs_and_Indiana_Property_Values.html

Isakson, Hans R., and Mark D. Ecker. 2008. "An analysis of the impact of swine CAFOs on the value of nearby houses." *Agricultural Economics* 39(3):365-372.

Johnson, Dirk. 1998. “Growth of factory-like hog farms divides rural areas of the Midwest,” *The New York Times*, June 24, 1998. Last accessed from the World Wide Web January 7, 2020, https://www.nytimes.com/1998/06/24/us/growth-of-factory-like-hog-farms-divides-rural-areas-of-the-midwest.html

Kennedy, Peter E. 1981. "Estimation with correctly interpreted dummy variables in semilogarithmic equations." *American Economic Review* 71(4):801-801.

Kiel, Katherine A. 1995. "Measuring the impact of the discovery and cleaning of identified hazardous waste sites on house values." *Land Economics* 71(4):428-435.

Kiel, Katherine A., and Katherine T. McClain. 1995a. "House Prices during Siting Decision Stages: The Case of an Incinerator from Rumor through Operation." *Journal of Environmental Economics and Management* 2(28):241-255.

Kiel, Katherine A., and Katherine T. McClain. 1995b. "The effect of an incinerator siting on housing appreciation rates." *Journal of Urban Economics* 37(3):311-323.

Kiel, Katherine A., and Michael Williams. 2007. "The impact of Superfund sites on local property values: Are all sites the same?" *Journal of Urban Economics* 61(1):170-192.

Kilpatrick, John A. 2015. "Animal operations and residential property values," *The Appraisal Journal* Winter:41-50.

Kim, Jungik, and Peter Goldsmith. 2009. "A spatial hedonic approach to assess the impact of swine production on residential property values." *Environmental and Resource Economics* 42(4):509-534.

Kirk, Mitchell. 2020. "Barns for 5,000 hogs planned for northeastern Hancock County." *Greenfield Daily Reporter* February 12, 2020. Last accessed from the World Wide Web February 12, 2020. http://www.greenfieldreporter.com/2020/02/12/barns_for_5000_hogs_planned_for_northeastern_hancock_county/

Kohlhase, Janet E. 1991. "The impact of toxic waste sites on housing values." *Journal of Urban Economics* 30(1):1-26.

Kuethe, Todd H., and Roman Keeney. 2012. "Environmental externalities and residential property values: externalized costs along the house price distribution." *Land Economics* 88(2):241-250.

Lawley, Chad, and Hartley Furtan. 2008. "The political trade-off between environmental stringency and economic development in rural America." *Journal of Regional Science* 48(3):547-566.

Linden, Leigh, and Jonah E. Rockoff. 2008. "Estimates of the impact of crime risk on property values from Megan's laws." *American Economic Review* 98(3):1103-1127.

Malani, Anup, and Julian Reif. 2015. "Interpreting pre-trends as anticipation: Impact on estimated treatment effects from tort reform." *Journal of Public Economics* 124:1-17.

Manitoba Agricultural Guidelines Development Committee. 2007. “Farm Practices Guidelines for Pig Producers in Manitoba.” Accessed from the World Wide Web January 29, 2020 https://www.gov.mb.ca/agriculture/livestock/production/pork/pubs/farm-practices-guidelines_complete.pdf

Manitoba Pork Council. 2004. “Hog Barns vindicated.” *Council News and Views*. August 2004, Issue #56. Last accessed on the World Wide Web February 12, 2020 http://digitalcollection.gov.mb.ca/awweb/pdfopener?smd=1&did=11920&md=1

Palmquist, Raymond B., Fritz M. Roka, and Tomislav Vukina. 1997. "Hog operations, environmental effects, and residential property values." *Land Economics* 73(1):114-124.

Park, Dooho, Andrew Seidl, and Stephan Davies. 2004. “The effect of livestock industry location on rural residential property values,” Economic Development Report, Colorado State University Cooperative Extension. Last accessed on the World Wide Web November 12, 2019 http://agebb.missouri.edu/commag/cafo/sources/Park2004.pdf

Ready, Richard C., and Charles W. Abdalla. 2005 "The amenity and disamenity impacts of agriculture: estimates from a hedonic pricing model." *American Journal of Agricultural Economics* 87(2):314-326.

Reinert, Alexander. 1998. “The right to farm: Hog-tied and nuisance-bound.” *New York University Law Review* 73:1694-1738.

Roe, Brian, Elena G. Irwin, and Jeff S. Sharp. 2002. "Pigs in space: Modeling the spatial structure of hog production in traditional and nontraditional production regions." *American Journal of Agricultural Economics* 84(2):259-278.

Ropeik, Annie. 2016. “In tiny, rural Hope, large hog farms spark economic fears,” WBAA NPR, July 1, 2016. https://www.wbaa.org/post/tiny-rural-hope-large-hog-farms-spark-economic-fears#stream/0

Ropeik, Annie. 2017. “Bartholomew County scraps CAFO neighbor tax break plan, sends appeal to State,” WBAA NPR, March 14, 2017. https://www.wbaa.org/post/bartholomew-county-scraps-cafo-neighbor-tax-break-plan-sends-appeals-state

Royal LePage Stevenson Advisors. 2004. “Impact analysis of intensive livestock operations on Manitoba rural residential property values: Five case study locations,” Prepared for Manitoba Pork Council.

Small D., I. Hodgkinson, and G. Plohman. 2015. “Construction costs for a 2,000 head hog finishing facility in Manitoba.” Prepared for Manitoba Pork Council. https://www.manitobapork.com/images/producers/pdfs/Report%E2%80%93Construction-Costs-for-a-2000-Head-Hog-Finishing-Facility-in-Manitoba-June2015.pdf

Sneeringer, Stacy. 2009. "Does animal feeding operation pollution hurt public health? A national longitudinal study of health externalities identified by geographic shifts in livestock production." *American Journal of Agricultural Economics* 91(1):124-137.

Sneeringer, Stacy. 2010. "A national, longitudinal study of the effects of concentrated hog production on ambient air pollution." *American Journal of Agricultural Economics* 92(3):821-835.

Sneeringer, Stacy E., and Thomas Hertz. 2013. "The effects of large-scale hog production on local labor markets." *Journal of Agricultural and Applied Economics* 45(1):139-158.

Taff, Steven, Douglas Tiffany, and Sanford Weisberg. 1996. “Measured effects of feedlots on residential property values in Minnesota: A report to the Legislature.” Staff Paper P96-12, Department of Applied Economics, University of Minnesota. Last accessed from the World Wide Web January 27, 2020 https://ageconsearch.umn.edu/record/14121/?ln=en

van Garderen, Kees, and Chandra Shah. 2002. "Exact interpretation of dummy variables in semilogarithmic equations." *The Econometrics Journal* 5(1):149-159.

Vyn, Richard J. 2018. "Property value impacts of wind turbines and the influence of attitudes toward wind energy." *Land Economics* 94(4):496-516.

White, Ed. “Hog barn restrictions eased but red tape remains: Manitoba Pork.” 2017. *The Western Producer*, December 7, 2017 https://www.producer.com/2017/12/hog-barn-restrictions-eased-but-red-tape-remains-manitoba-pork/

Zhang, Q., Z. Gao, A. La, and H. Guo. 2012. “Development of dispersion-based setback distance guideline for Manitoba,” Final Report. Last accessed from the World Wide Web February 10, 2020 https://www.manitobapork.com/images/MLMMI/2009-11/Final%20Report%202009-11%20Zhang%20Dispersion-based%20setback%20distance.pdf

Tables

Table 1. Means for Estimation Sample

	Within 2 km of a hog barn		Between 2 and 5 km from a hog barn		Between 5 and 10 km from a hog barn
	Sale before barn	Sale after barn	Sale before barn	Sale after barn	
ln(Price)	11.58	11.83	11.58	11.70	11.65
Slope	0.50	0.52	0.42	0.38	0.63
Elevation (metres)	76.29	77.01	77.93	77.52	80.26
High capability soil (%)	39.60	36.57	35.03	28.93	25.29
Medium capability soil (%)	60.06	63.16	64.42	70.82	73.11
Parcel area (acres)	5.53	5.47	4.45	3.28	5.55
Age of house at sale date	30.88	30.34	21.49	26.64	25.08
Quality: good (Yes=1)	0.02	0.02	0.03	0.01	0.01
Quality: average-good (Yes=1)	0.08	0.15	0.10	0.11	0.11
Quality: average (Yes=1)	0.56	0.56	0.61	0.62	0.61
Quality: fair (Yes=1)	0.30	0.20	0.21	0.21	0.21
Stories: Multiple (Yes=1)	0.27	0.26	0.22	0.18	0.24
Stories: Split (Yes=1)	0.10	0.11	0.13	0.17	0.11
Square footage (Yes=1)	1151.26	1252.40	1203.95	1178.87	1244.36
Air conditioning (Yes=1)	0.31	0.40	0.37	0.40	0.31
Brick exterior (Yes=1)	0.21	0.22	0.24	0.20	0.16
Fireplace (Yes=1)	0.15	0.20	0.18	0.15	0.16
Basement (Yes=1)	0.85	0.83	0.81	0.80	0.68
Number of attached garages	0.45	0.58	0.47	0.54	0.40
Number of detached garages	0.34	0.39	0.39	0.36	0.51
Number of non-species barns	0.19	0.21	0.11	0.08	0.11
Number of machine sheds	0.16	0.19	0.13	0.10	0.13
Number of workshops	0.04	0.06	0.02	0.03	0.02
Distance to Winnipeg (kms)	27.80	30.03	31.95	32.13	34.98
Nearest centre: Steinbach (Yes=1)	0.48	0.55	0.61	0.65	0.37
Nearest centre: Ste. Anne (Yes=1)	0.14	0.17	0.21	0.10	0.59
1980 cropland within 8 km (%)	45.24	46.81	46.18	47.56	34.13
1980 grassland within 8 km (%)	20.27	18.92	18.94	17.36	24.37
1980 land value within 8 km ($)	876.11	873.81	852.79	862.16	780.93
1980 livestock value within 8 km ($)	123.06	127.96	130.84	129.54	128.07
1980 number of houses within 8 km	1656.41	1695.48	1782.60	1865.68	1339.31
1980 average income within 8 km ($)	31826.61	31070.37	30658.64	30320.85	30233.60
1980 avg. house value in 8 km ($)	66323.08	65471.83	64608.84	64382.33	60621.33
Number of hog barns within 8 km	14.75	16.29	12.40	17.70	3.47
Number of poultry barns in 8 km	13.70	14.37	14.66	15.13	7.52
Observations	562	693	723	1,978	419

Table 2. Impact of Hog Barns on House Prices

	Full estimation sample: Houses within 10 km of at least one hog barn				Limited sample: Houses within 5 km of at least one hog barn	
	(1)		(2)		(3)	
	Coefficient (Std. Err.)		Coefficient (Std. Err.)		Coefficient (Std. Err.)	
Hog barn within 2 km (D^2)	0.008		0.011		0.009	
	(0.026)		(0.026)		(0.027)	
Hog barn within 5 km (D^5)	0.011		0.033		-	
	(0.034)		(0.041)		-	
Within 2 km × post barn $(D^2 \times \tau)$	-0.056	**	-0.057	**	-0.051	**
	(0.024)		(0.023)		(0.022)	
Within 5 km × post barn $(D^5 \times \tau)$	-0.036	*	-0.026		-0.018	
	(0.019)		(0.019)		(0.020)	
Neighboring poultry barn variables	No		Yes		Yes	
Hog/poultry counts within 8 km	No		Yes		Yes	
Observations	4,375		4,375		3,956	
R^2	0.572		0.574		0.602	

Note: All specifications include covariates included in specifications in online supplementary appendix table C1, year, month, and municipality fixed effects. Standard errors (in brackets) are adjusted for 27 Statistics Canada dissemination areas. Asterisks indicate the following: ***=statistical significance at the 1% level, **=statistical significance at the 5% level, and *=statistical significance at the 10% level.

Table 3. Alternative Treatment and Control Specifications

	1 km treatment, 5 km control		1 and 2 km treatments, 5 km control		1, 2, and 3 km treatments, 5 km control		2 km treatment, 3 km control		2 km treatment, 4 km control		2 km treatment, 5 km control		2 and 5 km treatment, 8 km control	
	(1)		(2)		(3)		(4)		(5)		**(6)**		(7)	
	Coeff. (Std Err)		Coeff. (Std Err)		Coeff. (Std Err)		Coeff. (Std Err)		Coeff. (Std Err)		Coeff. (Std Err)		Coeff. (Std Err)	
Hog barn within 1 km (D^1)	0.054	*	0.054	*	0.055	*								
	(0.028)		(0.028)		(0.028)									
Hog barn within 2 km (D^2)			-0.003		-0.002		0.012		0.015		**0.011**		0.009	
			(0.028)		(0.030)		(0.029)		(0.028)		**(0.026)**		(0.025)	
Hog barn within 3 km (D^3)					-0.005		0.003							
					(0.023)		(0.024)							
Hog barn within 4 km (D^4)									-0.009					
									(0.034)					
Hog barn within 5 km (D^5)	0.030		0.033		0.034						**0.033**		0.022	
	(0.038)		(0.039)		(0.040)						**(0.041)**		(0.041)	
Hog barn within 8 km (D^8)													0.143	**
													(0.062)	
Within 1 km × post barn ($D^1 \times \tau$)	-0.095	***	-0.064	**	-0.065	**								
	(0.028)		(0.031)		(0.031)									
Within 2 km × post barn ($D^2 \times \tau$)			-0.044	*	-0.050	*	-0.064	**	-0.069	**	**-0.057**	******	-0.057	**
			(0.025)		(0.027)		(0.026)		(0.026)		**(0.023)**		(0.023)	
Within 3 km × post barn ($D^3 \times \tau$)					0.013		0.002							
					(0.019)		(0.019)							
Within 4 km × post barn ($D^4 \times \tau$)									0.021					
									(0.021)					
Within 5 km × post barn ($D^5 \times \tau$)	-0.039	*	-0.032		-0.035	*					**-0.026**		-0.024	
	(0.020)		(0.020)		(0.020)						**(0.019)**		(0.021)	
Within 8 km × post barn ($D^8 \times \tau$)													-0.040	*
													(0.020)	
Observations	4,375		4,375		4,375		4,375		4,375		**4,375**		4,375	
R^2	0.573		0.573		0.573		0.573		0.573		**0.574**		0.574	

Note: All specifications include covariates included in specifications in online supplementary appendix table C1, year, month, and municipality fixed effects. Standard errors (in brackets) are adjusted for 27 Statistics Canada dissemination areas. Asterisks indicate the following: ***=statistical significance at the 1% level, **=statistical significance at the 5% level, and *=statistical significance at the 10% level.

Table 4. Anticipation

	Barn anticipated 1 year prior to establishment		Barn anticipated 2 years prior to establishment		Barn anticipated 3 years prior to establishment		Barn anticipated 3 years prior to establishment	
	(1)		(2)		(3)		(4)	
	Coefficient (Std. Err.)		Coefficient (Std. Err.)		Coefficient (Std. Err.)		Coefficient (Std. Err.)	
Hog barn within 2 km (D^2)	0.023		0.026		0.036		0.036	
	(0.026)		(0.027)		(0.029)		(0.029)	
Hog barn within 5 km (D^5)	0.034		0.034		0.034		0.034	
	(0.041)		(0.041)		(0.041)		(0.041)	
Within 2 km × post barn $(D^2 \times \tau)$	-0.069	***	-0.071	***	-0.080	***	-0.080	***
	(0.022)		(0.024)		(0.024)		(0.024)	
Within 5 km × post barn $(D^5 \times \tau)$	-0.028		-0.029		-0.029		-0.029	
	(0.019)		(0.018)		(0.018)		(0.019)	
Within 2 km, sold same year as barn built	-0.027		-0.030		-0.039		-0.039	
	(0.051)		(0.051)		(0.051)		(0.051)	
Within 2 km, sold 1 year before barn	-0.067		-0.070		-0.079			
	(0.051)		(0.050)		(0.047)			
Within 2 km, sold 2 years before barn			-0.030		-0.040			
			(0.065)		(0.067)			
Within 2 km, sold 3 years before barn					-0.062			
					(0.037)			
Within 2 km, sold 1 to 3 years before barn							-0.062	**
							(0.028)	
Observations	4,375		4,375		4,375		4,375	
R^2	0.574		0.574		0.574		0.574	

Note: All specifications include covariates included in specifications in online supplementary appendix table C1, year, month, and municipality fixed effects. Standard errors (in brackets) are adjusted for 27 Statistics Canada dissemination areas. Asterisks indicate the following: ***=statistical significance at the 1% level, **=statistical significance at the 5% level, and *=statistical significance at the 10% level.

Table 5. Treatment Timing and Multiple Barns

	Impact of late barn development		Exactly one hog barn within 2 kms		Exactly one hog barn within 2 kms; Impact of late barn development		Impact of multiple barns within 2 kms	
	(1)		(2)		(3)		(4)	
	Coefficient (Std. Err.)		Coefficient (Std. Err.)		Coefficient (Std. Err.)		Coefficient (Std. Err.)	
Hog barn within 2 km (D^2)	0.012		0.028		0.030		-0.027	
	(0.027)		(0.033)		(0.033)		(0.030)	
Hog barn within 5 km (D^5)	0.032		0.020		0.019		0.034	
	(0.040)		(0.039)		(0.038)		(0.041)	
Within 2 km × post barn $(D^2 \times \tau)$	-0.109	*	-0.053	**	-0.131	**	-0.054	**
	(0.055)		(0.025)		(0.060)		(0.023)	
Second barn within 2 km × post barn							-0.050	
							(0.033)	
Late hog barn within 2 km × post barn	0.039				0.057			
	(0.034)				(0.042)			
Within 5 km × post barn $(D^5 \times \tau)$	-0.027		-0.027		0.028		-0.027	
	(0.019)		(0.022)		(0.022)		(0.019)	
Observations	4,375		3,965		3,965		4,375	
R^2	0.574		0.580		0.580		0.574	

Note: All specifications include covariates included in specifications in online supplementary appendix table C1, year, month, and municipality fixed effects. Standard errors (in brackets) are adjusted for 27 Statistics Canada dissemination areas. Asterisks indicate the following: ***=statistical significance at the 1% level, **=statistical significance at the 5% level, and *=statistical significance at the 10% level.

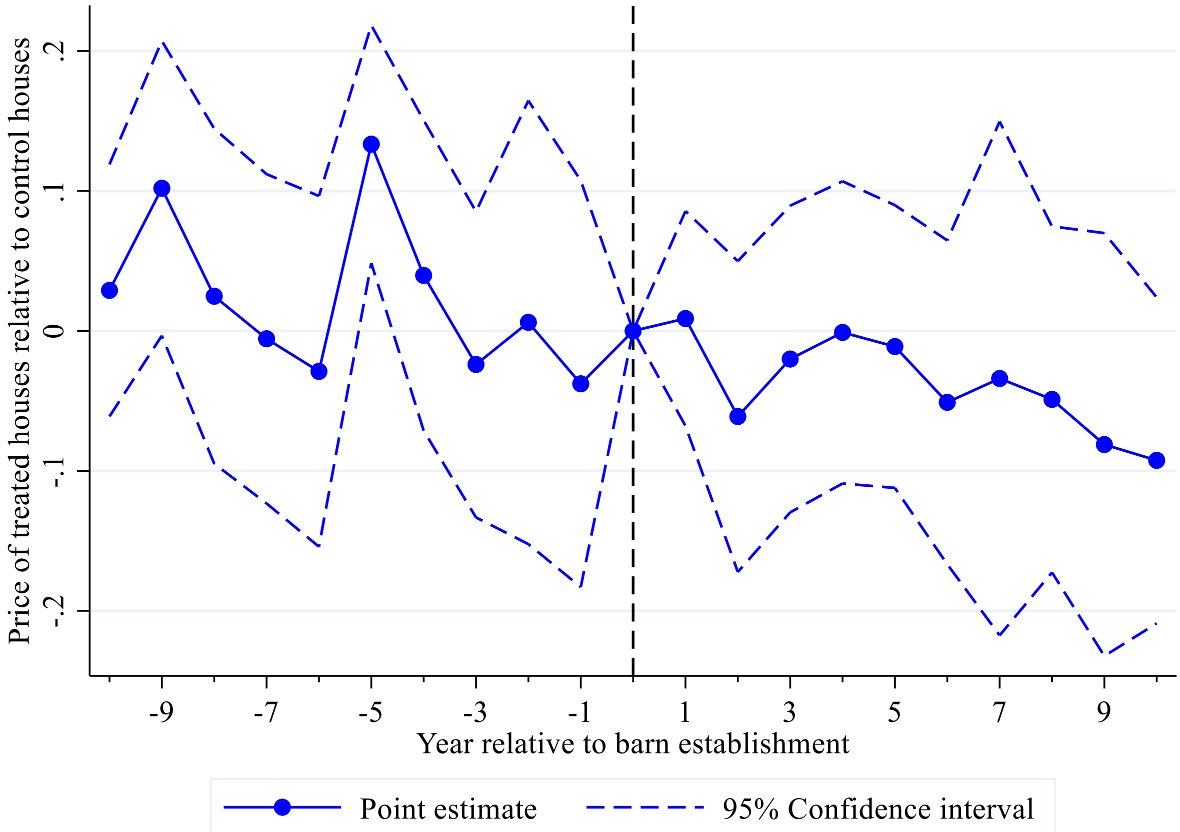

Figure 1. Prices of treated houses relative to control houses before and after barn establishment

Note: This figure plots the coefficients ρ_s from estimation of equation (1), normalized to 0 in the year the barn is established. Annual lags and leads 10 or more years before to 10 or fewer years after barn establishment.

[1] Recent U.S. research finds that county-level farm and non-farm net employment and income increase due to increased hog inventories on large-scale operations (Sneeringer and Hertz 2013). Evidence from the U.S. also suggests that there can be significant environmental and public health consequences of hog sector expansion due to water and air pollution (Haines and Staley 2004; Sneeringer 2009; Sneeringer 2010). The trade-off between rural economic development and environmental externalities is investigated by Lawley and Furtan (2008).

[2] The Public Registry can be found at https://www.gov.mb.ca/mr/livestock/public_registries.html.

[3] Past estimates range from zero or a small positive effect to substantial discounts for houses very close to barns. Kilpatrick (2015) surveys the published and unpublished literature examining the house price impacts of hog barns in the U.S. and finds a wide range of impacts. For example, one study suggests that the value of a neighboring house falls by 88% if the house is within 0.1 miles of a hog barn (Mubarak, Johnson, and Miller 1999). In contrast, using Minnesota data, Taff, Tiffany, and Weisberg (1996) find that houses located near barns tend to sell at a higher price, potentially due to increased local demand for houses from hog barn owners and workers.

[4] The Manitoba Pork Council commissioned this report to address allegations "heard at public meetings, in coffee shops, and…in local newspapers" that hog barns decrease prices of neighboring properties (Manitoba Pork Council 2004).

[5] Isakson and Ecker (2008) mention selection bias due to livestock barns clustering around lower valued houses. This issue is addressed by controlling for the number of livestock barns within 1 ½ miles of the house. This count variable does not have a statistically significant impact on house prices in the regressions reported in Isakson and Ecker (2008), which is interpreted as evidence that selection bias is not an issue. Alternatively, the lack of statistical significance of the count variable may be a result of correlation with other variables included in the regressions that capture neighboring animal units and distance to closest barn.

[6] The total number of pigs in Census Division No. 2 in Manitoba was 1,291,085 in 2011. The total number of pigs in 2011 was 2,850,581 and 12,679,104 in Manitoba and Canada, respectively. Source: Statistics Canada Table 32-10-0426-01 Pigs on Census Day, https://doi.org/10.25318/3210042601-eng.

[7] Although it is difficult to directly compare hog inventories across borders due to differences in data collection practices between statistical agencies, the following is an attempt to estimate 2011/2012 hog densities in the municipalities used in this article and the U.S. counties used in prior research on this topic. Canadian calculations are based on pig inventories from Statistics Canada Table 32-10-0426-01 Pigs on census day and land in crops, summerfallow, tame or seeded pasture, and natural land for grazing from Statistics Canada Table 32-10-0406-01 Land Use. The density calculations for U.S. counties are based on total hog inventory in 2012 at the end of December and total farmland area, which is the sum of cropland and pastureland (https://quickstats.nass.usda.gov/). Herriges, Secchi, and Babcock (2005) analyze sales in five counties in Iowa, Franklin has 1.6 hogs per acre, Hamilton has 2.1, Hardin 2.3, Humboldt 0.7, and Webster 0.5. Berks County, Pennsylvania, examined in Ready and Abdalla (2005), has a 2012

density of 0.3 hogs per acre. Isakson and Ecker (2008) examine Black Hawk County in Iowa, with 0.8 hogs per acre. The Iowa counties with the largest hog inventories are Sioux and Washington, with 2.6 and 3.5 hogs per acre, respectively. Hog densities in 2012 in two of the North Carolina counties examined in Palmquist, Ruka, and Vukina (1997) are substantially higher at 9.7 and 8.9 hogs per acre in Duplin and Sampson counties, respectively. Kim and Goldsmith (2009) study Craven County in North Carolina, which has 1 hog per acre in 2012. Keuthe and Keeney (2011) examine transactions within Tippecanoe County, Indiana, which has a hog density of 0.2 in 2012 and is neighbored by Carroll, Clinton, and White Counties with 2012 densities of 1.3, 0.8, and 0.7 hogs per acre, respectively.

[8] As with hog densities, care must be taken when comparing population densities gathered and calculated by different statistical agencies. U.S. county population densities are obtained from U.S. Census Bureau QuickFacts: https://www.census.gov/quickfacts/fact/table/US/PST045219. Population density and growth for the Manitoba RMs are obtained from the Statistics Canada 1996, 2006, and 2011 Census Population and Dwelling Count Tables: https://www150.statcan.gc.ca/n1/c1996-r1996/dwelling-logements-eng.htm; https://www12.statcan.gc.ca/census-recensement/2006/dp-pd/hlt/97-550/Index.cfm?Page=INDX&LANG=eng; https://www12.statcan.gc.ca/census-recensement/2011/dp-pd/hlt-fst/pd-pl/Table-Tableau.cfm?LANG=Eng&T=304&SR=11&S=51&O=A&RPP=5&PR=46&CMA=0

[9] One limitation of this data is that teardowns are not observed; buildings that existed decades ago but were removed prior to 2018 are not captured when reconstructing the landscape. However, since the landscape in this rural region evolves slowly, this is not expected to be a significant source of error.

[10] Barn closures (or shut downs) are not observed. With access to this information, the impact of a closure on house prices could be estimated, similar to estimation of the impact of methamphetamine lab decontamination in Dealy, Horn, and Berrens (2017). In theory, this would help to distinguish visual disamenities and stigma from production-related disamenities (odour, noise, traffic, dust) of hog production.

[11] The Canada Land Inventory is available at http://sis.agr.gc.ca/cansis/nsdb/cli/index.html.

[12] The Manitoba Ortho Photo Refresh can be found at http://mli2.gov.mb.ca/ortho/index_ortho_refresh_all.html.

[13] Due to the selection criteria, houses and barns on parcels smaller than 20 acres may be up to 200 metres from their actual location. A 20 acre square plot of land is approximately 284.5 metres by 284.5 metres. The distance from the centre of the plot to a corner is therefore $\frac{1}{2}\sqrt{2 * 284.5^2} = 201$ metres. In most cases the error on these small parcels will be less than 200 meters since buildings tend to be set back from the boundaries of parcels.

[14] In 2002 the average herd size per farm was approximately 1,600 hogs and in 2007 had increased to 2,258 hogs (Grier et al. 2007). In 2017, the average herd size is 5,146 finisher pigs (Manitoba Agriculture). Using an animal unit equivalent of seven finisher pigs per animal unit (Manitoba Agricultural Guidelines Development Committee 2007), the average sized operation was 229 animal units in 2002, 323 animal units in 2007, and 735 animal units in 2017. The minimum separation distance from a residence (designated residential area) is 400 meters (1600 meters) for a

201-300 animal unit operation, 450 meters (1800 meters) for a 301-400 animal unit operation, and 500 meters (2 kms) for a 401-800 animal unit operation.

[15] Each estimating equation in this study is a semilogarithmic equation, which implies that coefficient estimates on the dummy variables need to be adjusted. All tables of results present transformed coefficient estimates on all dummy variables following Kennedy (1981) ($\hat{g} = \exp(\{\hat{\gamma} - \frac{1}{2}\hat{V}(\hat{\gamma})\} - 1)$) and transformed standard errors as suggested in van Garderen and Shah (2002) ($\hat{V}(\hat{g}) = \exp(2\hat{\gamma})\left\{\exp\left(-\hat{V}(\hat{\gamma})\right) - \exp\left(-2\hat{V}(\hat{\gamma})\right)\right\}$).

[16] The normalized difference for a variable X with control and treatment subsamples $i = C, T$ is given by $\Delta_X = \frac{\bar{X}_T - \bar{X}_C}{\sqrt{S_C^2 + S_T^2}}$, where S_i^2 is the sample variance of X_i.

[17] This result is consistent with some of the prior unpublished research on this topic that finds houses in close proximity to barns sell at higher prices than comparable houses farther from barns. In a report to the Minnesota legislature, Taff, Tiffany, and Sanford (1996) find that closer proximity to a feedlot increases house sale prices. This study is based on 1993 to 1994 sales data from two counties in southeastern Minnesota. A report prepared by the Indiana Business Research Center (2008) presents evidence that each livestock barn within one mile increases house sale prices by $12,700 and each barn within one and three miles increased sales price by $1,070. Intensity matters and it is possible that a hog barn with more than 2300 hogs within one mile will reduce house sale prices. In a Colorado State University Fact Sheet, Park, Seidl, and Davies (2004) present mixed evidence where some barns increase neighboring residential property values and some barns decrease prices of neighboring houses. Similar to the peer-reviewed research summarized in this articles introduction, each of these studies uses a cross-sectional approach to assess the impact of livestock barns on rural residential property values.

[18] In Canada, poultry and dairy production are controlled by a system of supply management that limits entry into the sector. Production quota is required in order to market dairy and poultry products; quota is often passed across generations and in some cases is traded on a (thin) quota exchange market. Due to these limits on production, there is limited *new* poultry barn establishment within the region over the study period.

[19] The specification in column (3) of table 3 is the conventional difference-in-differences design. The D^2 variable accounts for pre-existing differences in sales prices across the control and treated groups, while the $D^5 * \tau$ variable accounts for underlying trends in prices across the two time periods (pre-barn and post-barn). The coefficient on $D^2 * \tau$ is the difference-in-difference estimate of the impact of a hog barn on local house prices.

[20] Myopic specifications ignore anticipation, while quasi-myopic specifications limit the time horizon over which market participants can anticipate new barn establishment. A quasi-myopic specification implicitly assumes perfect foresight over the time horizon considered, and also ignores expectations beyond the time horizon considered.