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Urbanization and the industrialization of agriculture

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Abstract

As urban environments expand, urban pressure is likely to generate increased competition for resources used in the agricultural sector, such as land and labor. We assess the effects of this urban pressure on the size and exit patterns for local farms. Our results suggest that the effects of urbanization on nearby farms are fundamentally heterogeneous. Increasing urban pressure causes smaller farms in neighboring areas to downsize or exit the industry, whereas large farms scale up in the face of growing urban pressures. In other words, local competition for resources as a result of urbanization can serve as an important mechanism for agricultural industrialization.

Keywords: urbanization; agricultural industrialization; structural change.

JEL classification: Q12, R12

1. Introduction

Urbanization is one of the defining trends of the twenty-first century, transforming economies, societies and landscapes worldwide. Today, approximately 55 per cent of the global population lives in urban areas, a figure projected to rise to 68 per cent by 2050 (United Nations, 2018). This rapid urban expansion has profound implications for agriculture, creating pressures on land, labor, and other resources while simultaneously reshaping food systems. Understanding how urbanization affects agricultural industries, particularly at the micro level, is critical for informing policies that support food security and sustainable rural development.

Since the seminal work of Lewis (1954), extensive literature has explored the macro-level effects of urbanization on the food system, including rising incomes (Delgado, 2003), changing diets (Reardon *et al.*, 2014) and the emergence of complex retail food environments (Reardon *et al.*, 2012). However,

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less attention has been paid to the micro-scale relationship between urbanization and the industrial organization of proximate farming sectors. Urban expansion intensifies competition for agricultural resources, such as land and labor (Ortiz-Bobea, 2020), potentially driving significant changes in farm size, structure and survival (Nicholls, 1961; Thornton, 2010; Abu Hatab *et al.*, 2019).[1]

Our study investigates how urban pressure impacts the industrialization of agriculture, focusing on the UK beef cattle sector. We construct a dataset that combines monthly geocoded data on herd-level animal holdings and entry and exit patterns for all beef cattle herds in England and Wales with spatiotemporal price-paid data for nearby home sales (as a proxy for local urban pressure) between January 2008 and December 2018. Our results suggest that the effects of urbanization on nearby farms are fundamentally heterogeneous. Increasing urban pressure causes smaller farms in neighboring areas to downsize or exit the industry, whereas large farms scale up in the face of growing urban pressures.

This research offers three key contributions to the literature. First, we leverage highly detailed, geocoded data on farm operations and urban environments. This allows us to empirically establish a relationship between urban pressure and the size and exit patterns of local farms. To our knowledge, this is the first study to apply such a detailed dataset in this context.

Second, unlike existing work that emphasizes market access in developing countries (e.g., Masters *et al.*, 2013; Allen, 2018), we explore how local competition for resources underpins structural transformation in high-income settings. Our findings highlight the heterogeneous effects of urbanization: smaller farms downsize or exit under urban pressure, while larger farms scale up.

Finally, our findings yield valuable contextual insights. The UK's agricultural sector, characterized by functional markets and rising industrialization, provides a unique setting to study urbanization's effects. Recent debates on large-scale livestock operations and their environmental and societal impacts underscore the relevance of this analysis.

Our methodology builds on established empirical frameworks for analyzing farm-level investment, disinvestment and entry-exit decisions (Key and Roberts, 2006; Heim *et al.*, 2017; Kim *et al.*, 2020; Schaefer *et al.*, 2022). While these studies primarily examine average effects, we allow for heterogeneity, revealing how urbanization impacts farms differently based on scale. Importantly, our results confirm the findings of Masters *et al.* (2013) that

1 Beyond resource competition, urbanization may also affect farms through other channels. For instance, it can influence market efficiency by disrupting supply chains or creating new transaction costs, even in relatively functional agricultural markets like those in the UK (Allen, 2018). Urbanization may also generate demand-side pressures, such as increased demand for locally produced agricultural goods. These alternative mechanisms could amplify or interact with the effects of rising input costs, especially for larger farms that may be better positioned to capitalize on urban demand through economies of scale and access to premium markets. Small farms, in contrast, may face compounded challenges, including rising costs and limited market access, which drive their exit or downsizing.

urbanization exerts heterogeneous effects on farms but extend this insight to the developed world.

The remainder of this paper is organized as follows. Section 2 presents a conceptual framework for understanding how urbanization affects farm size and exit patterns in agricultural industries. Section 3 discusses our empirical setting and provides background on the British beef cattle sector and property market. Section 4 describes the econometric strategy, while Section 5 presents the empirical findings. Section 6 concludes with implications for policy and future research.

2. Conceptual model

The conceptual framework in Fig. 1 examines how farms with varying efficiency levels respond to urbanization-induced increases in input prices.[2] Farms use a composite input to produce a commodity good, with production efficiency varying across farms. Market prices for outputs are determined endogenously by the total supply of all active farms. Urbanization creates upward pressure on input prices,[3] leading to three distinct effects: (1) the least efficient farms, unable to cover costs, exit the market; (2) moderately efficient farms scale down production due to higher costs but remain operational; and (3) the most efficient farms expand their production, leveraging higher output prices to offset increased input costs. These heterogeneous responses drive structural changes in the agricultural sector, leading to fewer, larger and more industrialized farms as market concentration increases. This framework highlights how urbanization pressures alter the size, survival and production decisions of farms, ultimately reshaping the structure of the industry. Further details on the propositions and proofs of the conceptual framework, along with the derivation of key theoretical results, are provided in Appendix A in the Online Supplementary Material.

3. Empirical setting

The conceptual framework in Section 2 presents three testable hypotheses regarding the effects of local urbanization on the size and exit patterns for farms in the context of the British beef cattle industry:

- Urban pressure will cause small farming operations in neighboring areas to downsize production, *ceteris paribus*.

2 Although our model focuses on rising input costs driven by urbanization, it is important to note that urbanization may also influence farm productivity through demand-side dynamics (e.g., proximity to urban consumers) or localized market inefficiencies.

3 Our conceptual framework is based on the hypothesized mechanism that urban expansion causes the cost of production to go up. Some literature we discussed in Section 1 can support this hypothesis. But we also provide supporting statistics in Appendix D in the Online Supplementary Material to strengthen the empirical foundation of our hypothesized mechanisms.

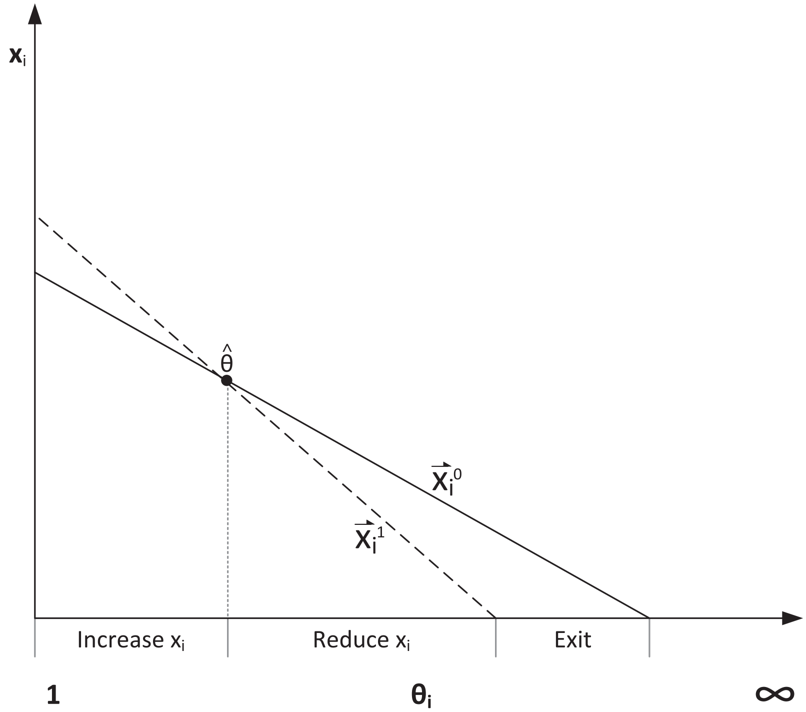


Fig. 1. Conceptual framework.
Note: figure presents a graphical illustration of the effects of local urbanization on the investment and exit patterns for a heterogeneous group of producers that produce a commodity product. The horizontal axis represents parameter θ_i—farm-specific efficiency—which is distributed uniformly for the N potential producers from $\theta_i \sim [1, \infty)$. The vertical axis corresponds to the level of production (x_i) chosen by the farm, which is the solution of the farm's profit maximization problem. Thus, x_i is endogenous in our model and it is decided by θ_i (a farm's efficiency), r (per-unit input cost) and some other variables. For some initial $r = r_0$, segment $\overrightarrow{x_i^0}$ describes the equilibrium production levels of all farms i, where total industry production is $Q_0 = \int_\theta \overrightarrow{x_i^0}\, \mathrm{d}\theta$. Suppose urbanization causes r to increase to some value r_1. This causes the segment describing production decisions to pivot at point $\hat{\theta}$ from $\overrightarrow{x_i^0}$ to $\overrightarrow{x_i^1}$, where industry production is now $Q_1 = \int_\theta \overrightarrow{x_i^1}\, \mathrm{d}\theta < Q_0$. Farms with $\theta < \hat{\theta}$ increase production as a result of the input price increase. Farms along segment $\overrightarrow{x_i^1}$ with $\theta > \hat{\theta}$ reduce production as a result of the input price increase. Finally, farms that had positive production along $\overrightarrow{x_i^0}$ but zero production under $\overrightarrow{x_i^1}$ exit the industry as a result of the price increase.

- Urban pressure will cause large farming operations in neighboring areas to scale up production, *ceteris paribus*.
- Urban pressure will cause the smallest farming operations in neighboring areas to exit the market, *ceteris paribus*.

To test these hypotheses, we combine monthly geocoded data on herd-level animal holdings and entry and exit patterns for all herds in England

and Wales with spatiotemporal price-paid data for nearby home sales (as a proxy for local urban pressure) between January 2008 and December 2018.

3.1 British beef cattle industry

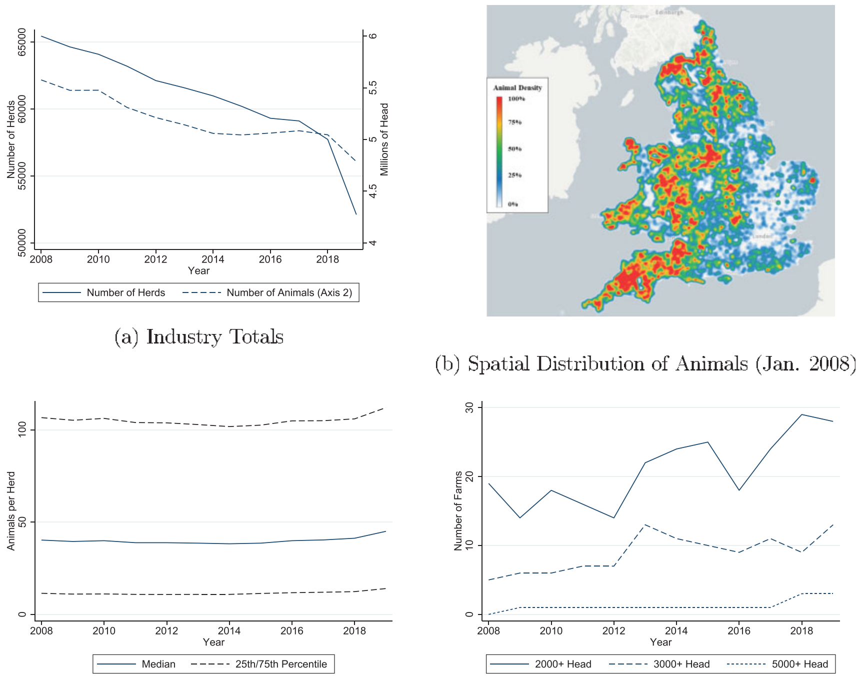
The British beef cattle industry provides a well-suited empirical setting in which to test our theoretical hypotheses. Rapid and large-scale urbanization in Great Britain (GB) began in the mid-eighteenth century and was mostly completed by the start of the First World War (Law, 1967). The share of the population living in urban areas increased from 50.2 per cent in 1851 to 78.1 per cent in 1911 (Law, 1967). In the 80-year period after the First World War, the urban population share stalled and remained stable around 78 per cent until 2000. However, since the beginning of the twenty-first century, the urban population share has risen steadily from 78 per cent in 2001 to 84 per cent in 2020 (World Bank, 2022).

Britain is home to approximately 5.5 million head of beef cattle (Fig. 2a). Beef cattle production occurs throughout Britain but is most heavily concentrated in Western England, Wales and Eastern Scotland (Fig. 2b).[4] Over our sample period, the British livestock industry has gone through substantial industrialization (Davies, 2017). From 2008 to 2018, the number of beef herds fell from 65,443 to 57,727 (Fig. 2a). Over this same period, the characteristics of the median herd and the number of large-scale farming operations have increased dramatically. The median herd increased from 40 head (11 head and 107 head for the 25th and 75th percentile, respectively) in 2008 to 45 head (14 head and 112 head for the 25th and 75th percentile, respectively) in 2018 (Fig. 2c). With respect to large-scale farming operations, there were nineteen farms with 2,000 head or more, five farms with 3,000 head or more and zero farms with 5,000 head or more in 2008. By 2018, this increased to twenty-eight farms with 2,000 head or more, thirteen farms with 3,000 head or more and three farms with 5,000 head or more (Fig. 2d). The dramatic increase in industrialization in British livestock industries prompted a joint investigation by *The Bureau of Investigative Journalism* and *The Guardian* in 2017 (Wasley and Davies, 2017). In response, Michael Gove, the UK Environment Secretary, stated, "I do not want to see, and we will not have, U.S.-style farming in this country" (Davies, 2017). Nevertheless, the industry has continued to concentrate and gravitate toward large-scale operations (Colley and Wasley, 2022).

3.2 Home price-paid as a proxy for local urbanization

To capture differences in this urban pressure at a granular level over time, we use spatio-temporal price-paid data for home sales. Home price-paid data

4 British cattle farming traditionally involves three stages: calf-rearing, growing and fattening. Farms tend to specialize in one of these three stages, and cattle usually move between farms during their growth (Wasley and Kroeker, 2018; Paton *et al.*, 2022).



(a) Industry Totals

(b) Spatial Distribution of Animals (Jan. 2008)

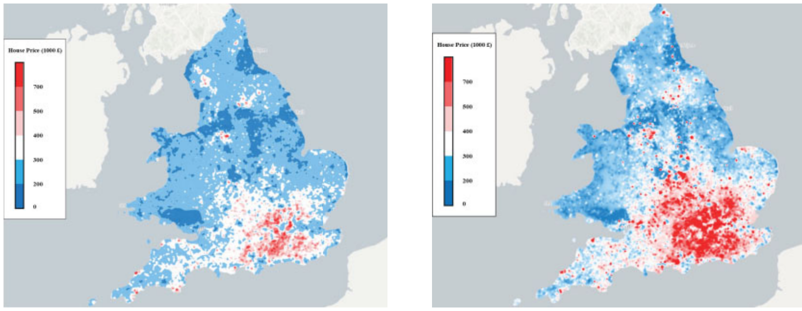
(c) Animals per Herd

(d) Number of Large Farms

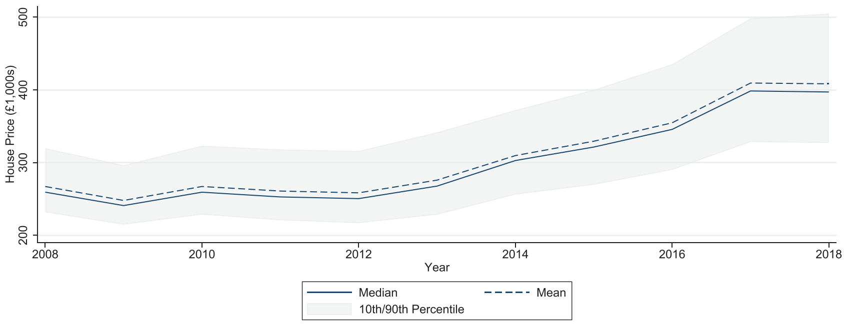
Fig. 2. Overview of the British beef cattle industry.
Notes: panel (a) of the figure reports the total number of beef cattle herds (left axis) and beef cattle animals (right axis) in Britain between 2008 and 2018. Panel (b) shows the spatial distribution of cattle farms as of January 2008. Panel (c) of the figure reports the number of head on the median (and 25th and 75th percentile) beef cattle farm in Britain between 2008 and 2018. Panel (d) reports the growth in "large" cattle farms over the period, and these statistics are constructed by the authors based on data from the APHA Sam database.

serve as a highly useful proxy for local urban pressure for several reasons. First, previous research has shown that home prices are highly correlated with the prices of inputs, such as land and labor, that are most affected by urbanization (Bover *et al.*, 1989; Thomas, 1993; Awaworyi Churchill *et al.*, 2020). Second, location information on each house that is sold allows us to construct fine-scale measures of local urban pressure, rather than relying on national or regional aggregates. Finally, the price-paid data are publicly available for all home sales in England and Wales during our period of study. HM Land Registry tracks price-paid data for all property sales registered in England and Wales. Records are released each month and provide information on sales price, address of the property, date of transfer and postcode for each transaction. With these data, we observe approximately 1 million home sales each year.

We use the spatial aggregation procedure described in Appendix B of the Online Supplementary Material to convert the individual HM Land Registry



(a) Spatial Distribution of Home Prices (2008) (b) Spatial Distribution of Home Prices (2018)



(c) Evolution and Dispersion of Home Price-Paid

Fig. 3. Overview of house prices-paid in England and Wales.
Note: figure summarizes the evolution of home prices in England and Wales over time. Panels (a) and (b) show the spatial distribution of home prices in 2008 and 2018, respectively. Panel (c) plots median and mean house prices (as well as the 10th and 90th percentile) for all years.

transactions information into a panel variable that represents home prices over time across a series of 46,998 individual 1 km-by-1 km squares enveloping the whole of England and Wales. Using this spatially aggregated data, Fig. 3 summarizes the evolution of home prices in England and Wales over time. As shown in the figure, concurrent with the resurgence of urbanization throughout the twenty-first century, British house prices have increased and become more regionally dispersed. Referring to panels (a) and (c) of Fig. 3, in 2008, the median (mean) home price was approximately £259,300 (£267,102). As shown in panels (b) and (c) of Fig. 3, by 2018, the median (mean) home price had risen 53.2 per cent (52.9 per cent) to approximately £397,340 (£408,358).

4. Methodology

To quantify the effects of localized urbanization on the size and exit patterns for beef cattle herds in England and Wales, we construct a dataset that combines monthly geocoded observations on animal holdings and the timing of entry and exit obtained from the Animal and Plant Health Association (APHA) Sam database with spatially aggregated price-paid data for all home sales (as a proxy for local urban pressure) between 2008 and 2018. We allocate cattle herds across the 46,998 1 km-by-1 km house price land squares according to their geocoded location.

4.1 Herd-level econometric models

Using these data, we estimate a series of herd-level econometric models designed to assess the impacts of localized urbanization (proxied by price paid for local home sales) on (1) the size of nearby cattle farm operations (evaluated in terms of animal holdings) and (2) the existence of cattle farms. These models are constructed as follows:

(1) Impacts of localized urbanization on herd size: we estimate the following econometric model to test the impact of current house prices on the size of nearby herds:

$$y_{i,t} = \alpha + \beta_0 H_{i,t} + \sum_{q=2,3,\ldots,10} \left(\alpha_q \iota^q_{i,t-1} + \beta_q \iota^q_{i,t-1} H_{i,t}\right) + \gamma_i + \delta_t + \epsilon_{i,t}, \tag{1}$$

where variable $y_{i,t}$ is the natural logarithm of the number of animals in herd i observed at time t.[5] Variable H is the natural logarithm of annual average house price associated with the 1 km-by-1 km land square corresponding to the location of herd i.[6] The terms in parentheses in equation (1) allow responses to urbanization to differ based on the size of the herd in 1 year before. To allow for this, we interact variable $H_{i,t}$ with nine dummy variables $\iota^q,\ q \in (2, \ldots, 10)$. These variables represent "size" categories based on decile group herd i belongs to in time $t-1$ (i.e., a 1-year lag).[7] Herds in category $q = 1$ correspond to the smallest 10 per cent of herds. Thus, variable $\iota^1 = 1$ for these herds and is equal to 0 for all other herds. Herds in categories $q = 2$ through $q = 10$ correspond to increasing decile groups. Category $q = 10$ corresponds to the largest 10 per cent of herds.

Of course, urban pressure is not the sole (or even the primary) driver of the size of a given herd. We estimate a two-way fixed effects (TWFE) model to isolate the effects of urban pressure via within-herd variation. Variables γ_i and δ_t, respectively, are herd-specific and time-specific fixed

5 More specifically, we use ln(animals+1) to avoid the problem that the natural logarithm is undefined at 0.

6 Here, we use ln(house price + 1) to be consistent with the dependent variable.

7 The evolution of these decile groups is shown in Appendix Figure E.1 in the Online Supplementary Material.

effects.[8] The herd-level fixed effects control for time-invariant differences across herds such as geography and climate and management performance. The time-fixed effects control for changes in market factors, such as output prices and policy changes, as well as GB-wide temporal shocks. We assume additional factors not included explicitly in the model are orthogonal to the error term.

(2) Impacts of localized urbanization on farm existence: to estimate the effects of localized urbanization on neighboring farms' exit from farming, we re-estimate the model described above in equation (1), except that the dependent variable $y_{i,t}$ is defined as a dummy variable to indicate whether herd i continues to operate at time t. If the herd still existed,[9] this dummy variable takes value 1.

4.2 Model identification

The analyses described above are subject to two data issues that could potentially jeopardize model identification. First, because our sample includes all herds that have been active at some point over our period of analysis (January 2008–December 2018), our sample necessarily includes attrition. Indeed, this attrition is the focus of the second analysis. If this attrition is systematic (as hypothesized in the second analysis), failure to address the issue could potentially bias our estimates. The second empirical issue is that—according to our hypotheses—the observed "size" decile group of a herd is contemporaneously correlated with our local house price-paid variable and our dependent variable.

Accordingly, we consider a purposeful sampling approach to address sample attrition and assign herds to the "size" or decile categories described in equation (1). To estimate the impacts of local urbanization on herd size (i.e., analysis (1) above), we create a cohort of all herds that were active over our entire sample period. This allows us to avoid the attrition issue. Similarly, for our farm existence analysis (i.e., analysis (2) above), we perform a cohort analysis where we keep all herds that were active as of January 2008 and study attrition patterns based on this cohort. To address the endogeneity of our size category indicators, we construct these decile categories using a

8 We note that Sun and Shapiro (2022) argue that—if the effects of a treatment are heterogeneous across different groups—TWFE can perform poorly such that it can fail to estimate the average (or even weighted average) of the different groups' treatment effects. In our context, we are precisely trying to estimate the heterogeneous effects of treatment on different groups (consistent with Sun and Shapiro, 2022). This likely alleviates (or at least reduces) the biases discussed in Sun and Shapiro (2022). Additionally, Sun and Shapiro (2022) explain that "this problem can be so severe that it affects any estimator, not just the TWFE estimator." Thus, it is hard to say whether there is an alternative specification that can perform better than TWFE. However, as discussed above, in Appendix C in the Online Supplementary Material, we assess the sensitivity of our results to several alternative specifications. Our results are qualitatively robust to these alternative modeling approaches.

9 Note that "existence" here is defined based on the number of animal holdings for the farm is bigger than zero.

twelve-month lag of herd size.[10] For the herd size analysis, our parameters of interest are β_0 for group 1, and the linear combinations $\beta_0 + \beta_q$ for deciles groups 2–10. For each decile group, this linear combination describes the elasticity with respect to the effects of local house price changes on herd size. For our farm existence analysis, we form an 11th dummy variable for the decile group category indicators. This 11th group takes value one for all "0" observations (i.e., firms that have exited). Thus, size categories 1–10 continue to contain information only for active herds. For this analysis, coefficients of interest are $\beta_0 + \beta_q, \forall q \in (1, 2, ..., 10)$.

All herd-level models are estimated using ordinary least squares (OLS) with standard errors corrected for cross-sectional spatial dependence and panel-specific serial correlation (Conley, 2010). The spatial correlation kernel cutoff is set at 100 km, and the serial correlation kernel cutoff is set at twelve periods.

4.3 Spatially aggregated econometric models

We assess the robustness of the analyses described in Section 4.2 by conducting our herd size and existence analyses where the unit of observation is the 1 km-by-1 km land square, as opposed to the herd-level analyses described by equation (1). To do so, we estimate models of the following form:

$$y_{s,t} = \alpha + \beta_0 H_{s,t} + \left(\sum_q \alpha_q \iota^q_{s,t-1} + \beta_q \iota^q_{s,t-1} H_{s,t} \right) + \gamma_s + \delta_t + \epsilon_{s,t}, \qquad (2)$$

where dependent variable $y_{s,t}$ is alternatively specified as

(i) the natural logarithm of the number of total beef animals in land square s evaluated at time t, and
(ii) a dummy variable that takes value one if square s includes at least some cattle at time t, and is otherwise equal to 0.

10 We note that the approach of using a lagged definition of herd size to construct our decile categories is not without shortcomings. The fixed effects model assumes that the error term is uncorrelated with past and future values of the independent variables (denote as $X_{i,t}$), for example, $\epsilon_{i,t}$ is uncorrelated with $X_{i,t+1}$. Our model includes herd size dummy variables in period t in $X_{i,t+1}$, so it must be correlated with $\epsilon_{i,t}$. In other words, the strict exogeneity assumption must have been violated. Ideally, one could use a quantile regression to measure these treatment effects. Unfortunately, quantile regression has several shortcomings that render it inappropriate for our research question. To the best of our knowledge, quantile regression does not allow quantile groups to evolve dynamically. This is a major problem in our setting because—as shown in Fig. 2—the number of animals per head has increased over time. Thus, in effect, lower quantile values are simply fit (primarily) via the earlier observations, whereas higher quantile values are fit (primarily) with observations that occur later in time. In contrast, our goal is to compare differences in the response to urbanization across the distribution of firms at any given time. Additionally, quantile regression is problematic (biased and inconsistent) when used in combination with TWFE (Canay, 2011). [More recent quasi-solutions to the TWFE problem with quantile regression produce divergent estimates (Machado and Silva, 2019; Powell, 2022).]

Representation (i) is approximately equivalent to the herd-level "size" analysis in Section 4.1, and representation (ii) is approximately equivalent to the herd-level "existence" analysis. As above, variable $H_{s,t}$ in equation (2) corresponds to the natural logarithm of contemporaneous average house price in square s,[11] variables $\iota^{q}_{s,t-1}$ are a series of dummies representing the "density" category for a given square s. As in Section 4.2, we include in the analysis only those land squares that include cattle at the beginning of our sample period (January 2008). We assign land squares to the ten decile groups ($\iota^{q}_{s,t-1}$) based on the number of animals observed in the land square at time $t-1$ (i.e., a 1-year lag). As above, for the existence analysis, we also include an eleventh "0" group, which includes all land squares that do not include animals. Consistent with equation (1), we also include in equation (2) TWFE γ_s and δ_t. These models are estimated using OLS with standard errors corrected for cross-sectional spatial dependence and panel-specific serial correlation (Conley, 2010).[12] As above, the parameters of interest are the linear combinations $\beta_0 + \beta_q, \forall q \in (1, 2, ..., 10)$.

4.4 Model reliability and robustness

In Appendix C of the Online Supplementary Material, we conduct a number of additional analyses to gauge the reliability and robustness of our results. We first consider the validity of housing prices as an instrument for urbanization. We then estimate specifications designed to control for additional time-variant confounders. We next assess the sensitivity of our analysis to the choice of 1 km-by-1 km land squares by considering different units of spatial aggregation for our house price-paid data. We then estimate our binary outcome existence models using a population-averaged probit design rather than via linear probability modeling. We further check the robustness by aggregating house price-paid data at a broader geographic area—Local Authority District level. We then discuss the result consistency with time-invariant relative size groups defined at the baseline year and an alternative approach with size groups based on the absolute cattle number per herd. After that, we test the results consistency by using real herd sizes instead of size categories. Finally, we provide some placebo tests.

4.5 Summary statistics

Table 1 presents summary statistics for the herd-level econometric specifications described in Sections 4.1 and 4.2 and the spatial-aggregate econometric

11 Note that variables $H_{i,t}$ in Section 4.1 and $H_{s,t}$ described here are effectively identical. In the herd-level analyses, we use subscript i to make clear that it is the housing price matched to the land square in which the herd is located. In the spatial aggregate analysis, we use subscript s to convey that the panel group is the land square. However, for a given herd i located in a given land square s, variable $H_{i,t} = H_{s,t}$.

12 Again, the spatial correlation kernel cutoff is set at 100 km, and the serial correlation kernel cutoff is set at twelve periods.

Table 1. Summary statistics.

	Herd size analysis					Herd existence analysis				
Sample specification	Var.	Mean	SD	Min.	Max.	Var.	Mean	SD	Min.	Max.
Herd-level analysis										
	$y_{i,t}$	4.10	1.18	0.69	8.69	$y_{i,t}$	0.77	0.42	0.00	1.00
	$H_{i,t}$	12.54	0.44	5.30	18.53	$H_{i,t}$	12.54	0.45	5.30	18.53
	Herds: 27,550					Herds: 49,738				
	Observations: 3,306,000					Observations: 5,968,560				
Spatial aggregate analysis										
	$y_{s,t}$	4.34	1.17	0.69	9.80	$y_{s,t}$	0.84	0.37	0.00	1.00
	$H_{s,t}$	12.54	0.43	5.30	18.53	$H_{s,t}$	12.55	0.45	5.30	18.53
	Land squares: 24,046					Land squares: 36,768				
	Observations: 2,885,520					Observations: 4,412,160				

Note: Table presents summary statistics for the herd-level econometric specifications described in Sections 4.1 and 4.2, and the spatial-aggregate econometric specifications described in Section 4.3. In the "Herd Size Analyses," variable $y_{i,t}$ denotes the natural logarithm of the number of animals in a given herd i at time t. Variable $y_{s,t}$ denotes the natural logarithm of the number of animals in land square s at time t. Variables $H_{i,t}$ and $H_{s,t}$ denote the natural logarithm of the average house price-paid for the corresponding land square. In the "Herd Existence Analyses," variable $y_{i,t}$ is an indicator to represent whether herd i is still operational as of period t. Variable $y_{s,t}$ is an indicator for whether there are *any* operational herds remaining in land square s as of time t. Again, variables $H_{i,t}$ and $H_{s,t}$ denote the natural logarithm of the average house price-paid for the corresponding land square.

specifications described in Section 4.3. In the "Herd Size Analyses," variable $y_{i,t}$ denotes the natural logarithm of the number of animals in a given herd i at time t. Variable $y_{s,t}$ denotes the natural logarithm of the number of animals in land square s at time t. Variables $H_{i,t}$ and $H_{s,t}$ denote the natural logarithm of the average house price-paid for the corresponding land square. In the "Herd Existence Analyses," variable $y_{i,t}$ is an indicator to represent whether herd i is still operational as of period t. Variable $y_{s,t}$ is an indicator for whether there are *any* operational herds remaining in land square s as of time t. Again, variables $H_{i,t}$ and $H_{s,t}$ denote the natural logarithm of the average house price-paid for the corresponding land square.

Referring to Table 1, our herd-level "size" analyses include 3.3 million monthly observations from January 2008 to December 2018 for 27,550 unique beef cattle herds. The herd-level "existence" analysis includes 6.0 million observations for 49,738 unique beef cattle herds. The mean values for dependent variable $y_{i,t}$ in these analyses are 4.10 and 0.77, respectively. Our spatial-aggregate cohort analyses include 2.9 million observations for 24,046 unique land squares for the "size" analysis and 4.4 million observations for 36,768 unique land squares for the "existence" analysis. The mean values for dependent variable $y_{s,t}$ in these analyses are 4.34 and 0.84, respectively.

5. Empirical results

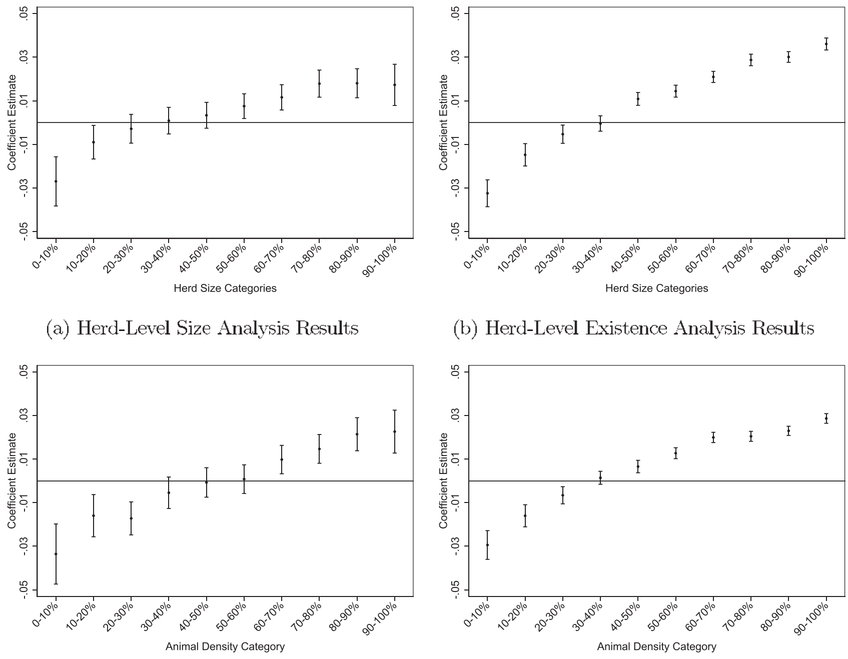
We use the coefficients obtained from estimating equations (1) and (2) to assess the validity of our conceptual hypotheses from Section 2 regarding the heterogeneous impacts of localized urbanization on herd size and existence. Figure 4 reports the coefficient estimates used for this purpose.[13] Panels (a) and (b) report results from estimating the herd-level specifications described by equation (1). Panels (c) and (d) report results from estimating the spatial-aggregate specifications described by equation (2). Broadly speaking, our empirical results bolster our theoretical conclusions—both with respect to the heterogeneous relationship between urbanization and local herd size and investment and with respect to urbanization as a driver for the exit of small herds.[14]

5.1 Impacts of localized urbanization on herd size

We turn first to panel (a) of Fig. 4, which summarizes the results of our herd-level econometric specification testing the impacts of urbanization on local herd size. These results suggest there is a clear relationship between urban

13 The full results from estimating the econometric models described in Section 4 are reported in Appendix Table E.1 in the Online Supplementary Material.

14 The observed heterogeneous effects of urbanization on farm size and exit may be partially explained by demand-side factors. Large farms may benefit from increased urban demand for local beef, enabling them to scale up despite rising input costs, while small farms lack the resources to access these opportunities.



(a) Herd-Level Size Analysis Results

(b) Herd-Level Existence Analysis Results

(c) Spatial-Aggregate Size Analysis Results

(d) Spatial-Aggregate Existence Analysis Results

Fig. 4. Urbanization and local herd size and existence.
Note: figure reports the coefficient estimates used to empirically assess the validity of our conceptual hypotheses from Section 2 regarding the heterogeneous impacts of localized urbanization on herd size and existence. Panels (a) and (b) report results from estimating the herd-level specifications described by equation (1). Panels (c) and (d) report results from estimating the spatial-aggregate specifications described by equation (2). In panels (a) and (c), coefficient estimates are expressed as $\hat{\beta}_0$ for group 1, and $\hat{\beta}_0 + \hat{\beta}_q$ for groups 2–10. In panels (b) and (c), coefficient estimates are expressed as $\hat{\beta}_0 + \hat{\beta}_q, \forall q \in (1, 2, ..., 10)$.

pressure and the size of local herds, and are strikingly similar to the predictions from our conceptual framework—graphically represented in Fig. 1. Based on our analysis, we see that—for the smallest decile of farms—a 1 per cent increase in the local housing price corresponds to a 0.027 per cent reduction (statistically significant at the 1 per cent level) in animal holdings. This is consistent with our hypothesis that urban pressure will cause farming operations in neighboring areas to downsize production.

Moreover, as farm decile groups get incrementally larger, the effect of urban pressure diminishes. For the second decile group, a 1 per cent increase in local housing prices corresponds to a 0.01 per cent reduction in herd size. For the third, fourth and fifth farm decile groups, we do not observe a statistically significant relationship between urban pressure and farm size. This is akin to farms with efficiency parameter $\hat{\theta}$ in the conceptual framework whose production decisions remain unchanged in light of the increase in urban pressure. In contrast to the results for small herds, we find that—for herds in the largest four decile groups—an increase in urban pressure corresponds to an expansion of animal holdings. For the ninth and tenth decile groups, respectively, a 1 per cent increase in the local housing prices corresponds to a 0.018 per cent increase in herd size (both statistically significant at the 1 per cent level).

5.2 Impacts of localized urbanization on farm existence

Next, we turn to panel (b) of Fig. 4, which summarizes the results of the herd-level specification testing the impacts of urbanization on local herd exit patterns. These results support the hypothesis from Section 2 that urban pressure will cause the smallest farming operations in neighboring areas to exit the market, *ceteris paribus*. We see that—for the smallest decile of herds—a 1 per cent increase in local housing prices increases the probability that a neighboring herd will exit by 0.032 per cent (statistically significant at the 1 per cent level). Consistent with the farm size results in panel (a), the relationship between local housing prices and farm exit diminishes for larger decile groups and turns positive for the largest group of farms. For the largest decile of farms, a 1 per cent increase in local housing prices increases the probability of farm existence by 0.036 per cent (statistically significant at the 1 per cent level).

5.3 Results for spatially aggregated analysis

Our empirical findings remain qualitatively unchanged when we expand our unit of analysis to the spatially aggregated land square, rather than the herd level. Results for the spatial aggregate "size" analyses are shown in panel (c) of Fig. 4. Referring to this chart, a 1 per cent increase in local housing prices corresponds to a 0.034 per cent reduction in the number of animals falling in the smallest land square decile (statistically significant at the 1 per cent level). This negative effect diminishes for the second (0.016 per cent reduction) and third (0.018 per cent reduction) land square deciles and is statistically indistinguishable from zero for the fourth, fifth and sixth land square deciles. Consistent with the herd-level "size" analysis in panel (a), an increase in local housing prices corresponds to an increase in the number of animals in the largest land square decile groups. For the largest land square decile group, a 1 per cent increase in the local housing price corresponds to a 0.022 per cent increase in the number of animals located within the land square. Referring to panel (d) of Fig. 4, the spatial aggregate "existence" analyses are also consistent with the herd-level empirical findings and are supportive of our conceptual findings in Section 2. According to this specification, for the two smallest decile groups, a 1 per cent increase in housing prices reduces the probability that the associated land square will continue to carry beef cattle by 0.029 per cent and 0.016 per cent, respectively (both statistically significant at the 1 per cent level).

6. Policy implications

As urban environments expand, urban pressure is likely to generate increased competition for resources used in the agricultural sector, such as land and labor. We assess the effects of this urban pressure on the size and exit patterns for local farms. The setting for our empirical investigation is the British beef cattle industry. We construct a dataset that combines monthly geocoded data on herd-level animal holdings and entry and exit patterns for all beef cattle herds in England and Wales with spatiotemporal price-paid data for nearby home sales (as a proxy for local urban pressure) between January 2008 and December 2018.

Our results suggest that the effects of urbanization on nearby farms are fundamentally heterogeneous. Increasing urban pressure causes smaller farms in neighboring areas to downsize or exit the industry, whereas large farms scale up in the face of growing urban pressures. In other words, local competition for resources as a result of urbanization can serve as an important mechanism for agricultural industrialization.

Policy implications are many. Politicians often emphasize the importance of a countryside speckled with small farms for the sake of environmental amenities, the preservation of cultural heritage and increased capacity for system resilience. Our research has shown the inherent linkage between urbanization and the industrialization of the farm sector. Despite his or her desires, a politician's mere claim that "we will not have U.S.-style farming in this country" does not uncouple this relationship. Moreover, macro-policy changes aimed at urban development or revitalization may have indirect and unintended effects on the industrial organization of the food system.

Our findings also raise interesting questions regarding the political economy of agriculture over the twenty-first century in industrialized countries. As we see fewer and fewer but bigger and bigger operations, we will be dealing with a farm sector that is increasingly able to organize and lobby for what it wants. Thus, even amidst rising population shares in urban areas, the associated changes in the agricultural industry could spell more favorable regulatory treatment and favorable subsidies for (a shrinking group of) farmers.

Of course, our analysis is not without limitations. The magnitude and economic significance of the urbanization-agricultural industrialization relationship are almost certainly context-specific. Thus, while our econometric findings align with our conceptual outcomes, we are unable to assess the external validity of our empirical results. Further, our study focuses on input price pressures as the primary mechanism through which urbanization affects farms. Future research should investigate other channels, such as localized market inefficiencies or demand-side effects, to provide a more comprehensive understanding of urbanization's impact on agricultural markets.

Supplementary data

Supplementary data are available at *ERAE* online.

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