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Spatial Dynamics of the Livestock Sector in the United States: Do Environmental Regulations Matter?

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This study examines the factors affecting state annual share of national inventory for each of the hog, dairy, and fed-cattle sectors using data from the 48 contiguous states for 1976 to 2000. The paper develops a state-specific, time-series environmental stringency measure and introduces instrumental variables to control for the possible endogeneity bias between livestock production decisions and regulatory stringency. The results indicate that differences in the severity of environmental regulations facing livestock producers have had a significant influence on production decisions in the dairy, and particularly the hog sector.

Key words: environmental regulation stringency, fixed-effects model, instrumental variable, livestock production, location choice, panel data analysis, pollution havens

Introduction

The industrialization of the North American livestock sector has been associated with a geographic concentration of production in fewer regions and a shift in production to areas with little prior livestock experience. One of the reasons may be the increasingly important role of the processing sector and the integration of this sector back into production (Ogishi and Zilberman, 1999). Processing plants operating under economies of size are becoming larger and fewer, and scattered throughout the country with clusters of livestock farms around them (Apland and Anderson, 1996; Abdalla, Lanyon, and Hallberg, 1995). Such clusters tend to move to localities with better natural endowments, labor market conditions, and business environment due to agglomeration economies or tax policies (Roe, Irwin, and Sharp, 2002).

Changes in the spatial distribution of livestock production also may be directly affected by differences in the stringency of environmental regulations across administrative regions. A disparity in regulatory stringency among states arose in the 1980s when the federal government delegated the function of devising regulatory regimes to state authorities (Kraft and Vig, 1994; Lester, 1994; Levinson, 2000). As a consequence of the possible differences in these individual regimes, a potential emerged to foster the creation of "pollution havens," whereby lenient regulations in some regions might attract livestock

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producers to build their facilities in such localities. For example, Martin and Zering (1997) argue that large-scale intensive pork production has shifted to southern states such as North Carolina and Arkansas because "environmental regulations, zoning regulations, and anti-corporate farming regulations did not present insurmountable barriers to siting and building production units and processing plants in the region" (p. 49). By introducing or maintaining lax environmental regulations relative to competing regions and allowing tardy enforcement of those regulations, a region could lure "dirty" industry investments, which are important in employment creation and regional economic development (Fredriksson and Millimet, 2002; Kunce and Shogren, 2002; Levinson, 2000; Jafee et al., 1995). If regional and state governments really do engage in a race to the bottom, certain regions would have an inefficiently high number of concentrated animal feeding operations (CAFOs). Because the assimilative capacity of the environment is deliberately undervalued in a region where a race to the bottom has occurred, the heavier concentration of livestock operations in that region may pollute at a level higher than the socially optimal, and at a greater cost to the local community.

Despite the claim of its importance, the relevance of the pollution haven hypothesis in describing the relationship between environmental stringency and changes in regional livestock production has not been established. While the hypothesis has been tested for aggregated species (hog, beef cattle, dairy, and chicken) based on standard animal units (Park, Seidl, and Davies, 2002), for hog operations (Roe, Irwin, and Sharp, 2002; Metcalfe, 2001; Mo and Abdalla, 1998), and for dairy operations (Osei and Laxminarayan, 1996), the results are inconclusive. Several of these studies have unexpectedly found a significant positive association between environmental regulatory stringency and regional livestock inventories, suggesting that laws tightened after production levels rose.

The above studies have several limitations. First, most have modeled the state-level environmental regulatory stringency using a one-period cross-sectional measure based on either a general environmental indicator [e.g., the FREE Index or the Conservation Foundation Index used by Osei and Laxminarayan (1996), and Mo and Abdalla (1998), respectively] or an index based on regulatory policies directly applicable to livestock farms [e.g., Metcalfe's (2000) index as adopted by Roe, Irwin, and Sharp (2002) or the index developed by Clemson University (1998) for the National Survey of Animal Confinement Policies and used by Park, Seidl, and Davies (2002)]. However, because regulatory stringency has undoubtedly varied over time (Metcalfe, 2000), so should the variable used to proxy its effect when testing the pollution haven hypothesis. Second, the possible endogeneity bias of livestock inventories with environmental regulatory stringency has been ignored in almost all of the above studies. Park, Seidl, and Davis (2002) found strong evidence for this endogeneity bias, and noted that the positive regression coefficient on the number of environmental regulations in place for a state suggests an "industry-drives-policy" hypothesis, where states react to greater livestock activity by creating more regulations. No studies have attempted to control for this endogeneity bias which may explain, along with the use of a single-period stringency measure, the lack of empirical support for the pollution haven hypothesis in agriculture.

The objective of this analysis is to determine the effect of environmental regulations on changes in the spatial distribution of livestock operations in the United States. Changes in state production levels of hogs, dairy, and fed cattle are examined for the period 1975–2000.[1] The paper begins with a description of the regional and state changes in the geographical concentration of production for the three livestock sectors over time. The empirical model is then presented for determining factors affecting the location decision of livestock producers. The major categories of factors include an environmental regulatory stringency measure, relative prices, livestock infrastructure support, general business climate, and natural endowment (climatic) factors.

In addition to examining more than one livestock sector over a longer period of time than done in previous studies, another significant contribution of this analysis is the development of a state-level environmental stringency index through time. In the fourth section below, the econometric model is presented, with a discussion of the use of instrumental variables to control for the potential endogeneity bias between livestock production levels and regulatory stringency. The results of the estimation are then reported for each of the three livestock sectors. Conclusions of the study are given in the final section. A major conclusion is that the environmental regulatory stringency is an important determinant of the production shifts among states for both the hog and dairy sectors. Agglomeration economies and processing infrastructure are also important determinants of the shifts in state-level livestock intensities for all three sectors.

Geographical Changes in Livestock Production

An important prerequisite for testing the pollution haven hypothesis is noting the observed temporal changes in the concentration of livestock operations across geographical regions. In this section, the changes in absolute production levels, concentration measures, and patterns of geographical concentration are described for the U.S. hog, dairy, and fed-cattle sectors. Livestock inventories by state were collected from various U.S. Department of Agriculture/National Agricultural Statistics Service (USDA/NASS) online websites for the period 1975–2000.

Total hog inventories in the United States have increased from about 49 million in 1975 to approximately 59 million in 2000 (see table 1). After a large increase in the early 1980s followed by a sharp fall, production levels remained relatively constant over the last decade of the study period. However, there have been significant regional changes. In 2000, the largest hog-producing area continued to be the Great Plains region, still accounting for approximately 50% of total hog production in the United States. The Great Lakes region had the second largest production levels of hogs in 1975, but since 1996, inventory levels have been higher in the Southeast region—as reflected by a rise in its share of national production from 16% in 1975 to 21% in 2000. The 54% increase in total production from this region is accounted for by the large increases in North Carolina and Arkansas (and a small increase in Mississippi), since all other Southeast states reported reduced hog numbers. In 2000, the Southwest region had the fourth largest number of hogs among the eight U.S. regions. As with the Southeast region, the regional growth is due primarily to a large increase in production from one state (Oklahoma). The Great Plains, Southeast, and Rocky Mountain regions have exhibited an augmentation pattern of change in hog production over the last 15 years of the study period as inventory levels and geographical concentration have increased.

[1] The broiler sector is not included in this study. Broiler producers have not relocated recently (McBride, 1997), and their concentration severely constrains access to data.

Table 1. Changes in U.S. Hog, Dairy, and Fed-Cattle Inventories, 1975–2000 (000 head)

	Hogs			Dairy			Fed Cattle		
U.S. Region	1975	2000	% Δ	1975	2000	% Δ	1975	2000	% Δ
New England:									
Connecticut	8	4	-52	54	26	-52	0	0	0
Maine	7	7	-6	61	40	-34	0	0	0
Massachusetts	50	20	-60	55	23	-58	0	0	0
New Hampshire	8	4	-51	33	18	-45	0	0	0
Rhode Island	8	3	-64	6	1.8	-70	0	0	0
Vermont	5	3	-40	193	159	-18	0	0	0
Subtotal	87	41	-53	402	267.8	-33	0	0	0
Mideast:									
Delaware	50	29	-42	11.7	10	-15	0	0	0
Maryland	182	58	-68	141	84	-40	22	17	-23
New Jersey	81	14	-83	47	16	-66	5	3	-40
New York	110	80	-27	917	686	-25	10	30	200
Pennsylvania	660	1,030	56	699	617	-12	83	75	-10
Subtotal	1,083	1,211	12	1,815.7	1,413	-22	120	125	4
Great Lakes:									
Illinois	5,600	4,150	-26	243	120	-51	500	230	-54
Indiana	3,900	3,350	-14	215	145	-33	250	120	-52
Michigan	700	950	36	411	300	-27	200	200	0
Ohio	1,675	1,490	-11	400	262	-35	290	190	-34
Wisconsin	1,150	610	-47	1,812	1,344	-26	135	160	19
Subtotal	13,025	10,550	-19	3,081	2,171	-30	1,375	900	-35
Great Plains:									
Iowa	12,600	15,100	20	401	215	-46	1,200	1,100	-8
Kansas	1,650	1,520	-8	142	91	-36	920	2,370	158
Minnesota	3,000	5,800	93	884	534	-40	380	285	-25
Missouri	3,200	2,900	-9	302	154	-49	200	100	-50
Nebraska	2,700	3,050	13	152	77	-49	36	70	94
N. Dakota	350	185	-47	174	102	-41	1,160	2,440	110
S. Dakota	1,400	1,320	-6	174	102	-41	345	350	1
Subtotal	24,900	29,875	20	2,229	1,275	-43	4,241	6,715	58
Southeast:									
Arkansas	302	685	127	88	42	-52	21	11	-48
Alabama	680	165	-76	90	25	-72	42	4	-90
Florida	240	40	-83	197	157	-20	60	0	-100
Georgia	1,300	380	-71	129	87	-33	68	3	-96
Kentucky	1,000	430	-57	287	132	-54	37	15	-59
Louisiana	155	29	-81	136	58	-57	10	0	-100
Mississippi	300	315	5	122	36	-70	10	0	-100
N. Carolina	1,900	9,300	389	145	71	-51	45	5	-89
S. Carolina	480	290	-40	58	23	-60	26	6	-77
Tennessee	920	230	-75	215	95	-56	10	10	0
Virginia	660	425	-36	173	120	-31	31	27	-13
W. Virginia	50	10	-80	41	17	-59	11	7	-36
Subtotal	7,987	12,299	54	1,681	863	-49	371	88	-76

(continued . . .)

Table 1. Continued

	HOGS			DAIRY			FED CATTLE		
U.S. Region	1975	2000	% Δ	1975	2000	% Δ	1975	2000	% Δ
Southwest:									
Arizona	97	9	-91	67	139	107	319	272	-15
New Mexico	53	3	-94	47	16	-66	135	116	-14
Oklahoma	300	2,310	670	119	91	-24	232	435	88
Texas	780	920	18	333	348	5	1,327	2,910	119
Subtotal	1,230	3,242	164	566	594	5	2,013	3,733	85
Rocky Mountains:									
Colorado	290	840	190	74	89	20	755	1,200	59
Idaho	60	24	-60	147	347	136	185	315	70
Montana	165	155	-6	26	18	-31	79	70	-11
Utah	47	550	1,070	79	96	22	52	35	-33
Wyoming	30	108	260	11.8	5.6	-53	38	90	137
Subtotal	592	1,677	183	337.8	555.6	64	1,109	1,710	54
Far West:									
Alaska	1	1	0	90	25	-72	0	0	0
California	138	150	9	800	1,523	90	688	415	-40
Washington	63	27	-57	181	247	36	11	0	-100
Hawaii	58	26	-55	13.1	8.1	-38	36	21	-42
Nevada	9	8	-17	14	25	79	68	50	-26
Oregon	95	32	-66	91	90	-1	135	235	74
Subtotal	364	243	-33	1,189.1	1,918.1	61	938	721	-23
Grand Total	49,268	59,138	20	11,301.6	9,057.5	-20	10,167	13,992	38
Gini Coefficient	0.72	0.77	7	0.56	0.62	11	0.70	0.80	14

Source: USDA/National Agricultural Statistics Service, various online websites.

The other five regions have exhibited varying forms of attrition in hog production over the last 15 years, with total inventories falling and geographical concentration increasing. The net result is the concentration of national production in fewer states as evidenced by the rise in the Gini coefficient (G) from 0.72 in 1975 to 0.77 in 2000 (table 1), with most of the increase occurring in the last decade.[2]

As reported in table 1, dairy cattle inventory for the United States fell from 11.3 million to 9 million cows, or by about 20%, from 1975 to 2000. Much like the hog sector, regional differences in dairy cattle inventories have declined as dairy cow numbers have fallen in the traditional dairy regions of the Great Lakes and the Great Plains regions while rising in the western regions of the country. Although regional differences in production have declined, there are significant concentrations of dairy cows in fewer states within many regions. All states within each of the five non-western regions of the country experienced a decrease in dairy cow inventory between 1975 and 2000, and the

[2] The Gini coefficient (G) is calculated as:

$$G = \left(\sum_{i=1}^{n} \sum_{j=1}^{n} \left| X_i - X_j \right| \right) \Big/ 2n^2\bar{X},$$

where X_i is inventory in the ith state in a given year, $\bar{X}$ is the average inventory for the n states in that year, and n is the number of states in the data set. The Gini coefficient can range from 0 (national livestock inventories are divided equally among the states) to 1 (national livestock inventories are concentrated in one state). Hence, the larger the Gini coefficient, the larger is the inequality in production levels among states.

percentage decrease was similar among states within the region. In contrast, the growth in dairy cow numbers in the three western regions coincided with a significant increase in geographical concentration. For example, the 61% increase in dairy cattle inventories in the Far West region was due largely to the 90% increase in California, which is that region's largest dairy-producing state. The changes in state production levels led to a steady increase in the concentration measure from 0.56 in 1975 to 0.62 in 2000.

Total fed-cattle inventories in the United States increased by approximately 38% over the 25-year study period, from approximately 10 million head to nearly 14 million head (table 1). Three states accounted for the majority of this inventory increase: Texas (1.58 million), Kansas (1.45 million), and North Dakota (1.28 million). Two of these states are in the Great Plains region which continues to have the largest production base and accounts for about half of the fed cattle inventory in the United States. The second largest fed-cattle-producing region in 1975 was the Southwest. By 2000, its fed-cattle numbers had increased by about 85%, still ranking it as the second largest producing region. Since fed-cattle numbers in the largest two production regions have expanded at a much greater rate than the rest of the regions, between-region geographical concentration has increased in the fed-cattle sector in contrast to the other two sectors, particularly in the 1990–2000 decade. The specific question to be addressed in this study is: *What has caused these patterns of change in the production location of the hog, dairy, and fed-cattle sectors?*

The Empirical Model

Dependent Variable

Spatial production changes can be captured by the numbers of new farms or the intensity of production within a region. Bartik (1988) argued aggregate measures of regional economic activity, such as inventory levels, reflect a number of different types of economic decisions by agents. Production levels can change due to the expansion or contraction of existing facilities, the introduction of new facilities, or the closing of old ones. New firms considering locating in a region tend to face harsher environmental constraints than existing firms due to grandfathering arrangements. Hence, the opening up of new facilities will be lower in a region with more stringent environmental regulations (Bartik, 1988). While the number of new livestock operations may be the best measure of regional production changes due to environmental laws, these data are not available for an extended period of time for all states. Thus, livestock inventory is used as an aggregate measure of spatial production in this study. Data on hog, dairy, and fed-cattle production levels from 1975 to 2000 were collected for each of the 48 contiguous states (see table 1). In order to control for cyclical fluctuations of livestock inventories, annual inventory shares for each of the three livestock sectors from 1976 to 2000 were collected, resulting in 25 observations over time for each state for each livestock subsector.

Explanatory Variables

Decisions to expand or contract livestock operations or change into alternative enterprises depend on changes in relative profitability rather than absolute profitability of raising livestock. We assume that relative profitability of raising livestock compared to other alternative investment opportunities stays the same across states. Thus, as noted by Metcalfe (2001), the model cannot explain the decision of "when to change" production, but rather assumes that a change has already been determined to be necessary (relative profitability is favorable), and now the decision is "in which state" to alter production.

Several studies have examined the location choices of firms in a variety of settings including dairy farmers (Osei and Laxminarayan, 1996), forest harvesting activities (Sun and Zhang, 2001), foreign investment by multinational corporations (Friedman, Gerlowski, and Silberman, 1992; Coughlin, Terza, and Arromdee, 1991; List and Co, 2000), and new branch plant openings in the manufacturing sector (Bartik, 1988; Levinson, 1996; McConnell and Schwab, 1990). Drawing on this industry location literature to formulate the general drivers of where livestock production occurs, the explanatory variables are categorized into five groups: (*a*) regulatory stringency, (*b*) relative prices, (*c*) livestock infrastructure, (*d*) general business climate, and (*e*) natural endowment (climatic) factors. The variables used to proxy these five general drivers of spatial reorganization of livestock production and the sources of the data are summarized in table 2 and described below.

Regulatory Stringency

Regulatory stringency measures in previous studies have been constrained by data limitations. Rather than use a one-period cross-sectional stringency measure, as has been the approach used in other studies testing the pollution haven hypothesis in agriculture, a variable is developed for each state over time, as explained below.

State values of 14, one-period environmental stringency measures developed for various years by alternative studies are listed in table 3. The indices capture some aspect of a state's efforts in environmental protection and are not based on environmental outcomes, such as air or water quality status. [For details of these two qualitatively different indices, see List and McHone (2000)]. The higher the index value, the more stringent the environmental regulatory regime of the state. Since there are index values for 14 years over the 25-year period, the values for the years without an index were estimated by taking the adjacent year's index value. For example, 1975 values of per capita environmental quality control expenditures were used for 1976 (see the last row of table 3). Except for Metcalfe's 1994 and 1998 indices, all other indices were developed for each of the 48 contiguous states. The arithmetic mean values of Metcalfe's1994 and 1998 indices were assigned for those states that are not included in the 19 states of Metcalfe's (2000) study.

The last column of table 3 contains a measure for the year 2000 for all states, calculated for this study using the approach employed by Metcalfe (2000) in estimating regulatory pressures facing farmers for a subset of states in 1994 and 1998. The presence (or absence) of seven regulations for each of the 48 states was summed to form the 2000 stringency index, detailed in table 4. Data on regulations were obtained largely from the Environmental Law Institute (2001), and supplemented from the National Survey of Animal Confinement Policies (Clemson University, 1998), the State Compendium (U.S. Environmental Protection Agency, 2001), and the National Association of State Departments of Agriculture (2001).

Table 2. Definitions and Sources of Explanatory Variables Affecting Location Choice of Livestock Producers

Variables	Definition	No. of Observations	Mean	Standard Deviation	Sources
DEPENDENT VARIABLE: ***Livestock Share***	State inventory (000 head) of each sector (hog, dairy, fed cattle) divided by total national inventory	1,200 (ea. sector)	0.02081 (hog) 0.02083 (dairy) 0.02083 (beef)	0.0424 (hog) 0.0308 (dairy) 0.0402 (beef)	*Agricultural Statistics* for 1975–2000 (USDA/NASS). Online: http://usda.mannlib.cornell.edu/reports/nassr/other/plr-bb.
INDEPENDENT VARIABLES: ***Regulatory Stringency***					
Stringency Index	Relative regulatory stringency index	1,200	1.00	0.64495	Per capita environmental quality control expenditure–1975, 1978, 1979, 1986, 1988; Conservation Foundation Index (Duerkson, 1984); Renew America Index–1987/89 (Hall and Kerr, 1991); Status of 50 state policies (in Green Index–1991/92) (Hall and Kerr, 1991); Institute for Southern Studies Index–1994; Metcalfe (2000) indices–1994 and 1998; authors–2000, and years without an index were filled with adjacent year's index values, and normalized by dividing through with the arithmetic mean.
Relative Prices:[a]					
Output/Input Price Ratio	Hog, beef, dairy, and corn price ratio (hog prices are $/cwt, dairy prices are $/cwt for all milk, beef prices are $/head, and corn prices are $/bushel)	1,200 (ea. sector)	17.33 (hog) 5.296 (dairy) 21.238 (beef)	4.14 (hog) 1.14 (dairy) 6.92 (beef)	*Agricultural Prices* for 1975–1997 (USDA/NASS); *Agricultural Prices Summary* for 1998–2000 (USDA/NASS). Online: http://usda.mannlib.cornell.edu/reports/nassr/price/zap-bb.
Energy Price	State electricity prices for farms ($/kw hour); energy costs are proxied by the industrial sector energy price and expenditure estimate ($/mil. BTUs)	1,200	11.47	3.82	Energy Information Administration (2002). Online: http://www.eia.doe.gov/neic/historic/seperelectric.htm.
Labor Price	Farm labor wage rate ($/hour)	1,200	4.18	0.47	*Agricultural Statistics* for 1975–1979 (USDA/NASS); "Farm Employment and Wage Rates" for 1980–1990 (USDA/ NASS)—online: http://usda.mannlib.cornell.edu/datasets/inputs/91005; "Farm Labor" for 1991–2000 (USDA/NASS)—online: http://usda.mannlib.cornell.edu/reports/nassr/other/pfl-bb/2000/fmla1100.txt.
Farmland Price	Value of farmland ($/acre)	1,200	1,044	844	*Agricultural Statistics* for 1975–1997 (USDA/NASS); "Agricultural Land Values and Cash Rents" for 1998–2000 (USDA/NASS). Online: http://usda.mannlib.cornell.edu/reports/nassr/other/plr-bb.

(continued . . .)

Table 2. Continued

Variables	Definition	No. of Observations	Mean	Standard Deviation	Sources
Livestock Infrastructure:					
Processing Capacity	Number of hogs and beef slaughtered (000 head) for hog and fed-cattle sectors; whole milk equivalent of manufactured dairy products (000 lbs.) for dairy sector	1,200 (ea. sector)	1,854 (hog) 1,731,301 (dairy) 745 (beef)	3,896 (hog) 3,548,710 (dairy) 1,489 (beef)	*Livestock Slaughter: Annual Summary* (USDA/NASS) for hogs and beef, 1975–2000; *Dairy Products: Annual Summary* (USDA/NASS) for dairy, 1975–2000.
Agriculture's Economic Importance	Agriculture's share of Gross State Product	1,200	0.0246	0.02854	U.S. Dept. of Commerce/Bureau of Economic Analysis (2002). Online: http://www.bea.doc.gov/bea/regional/gsp.
Business Climate:					
Unemployment Rate	Percentage of workforce unemployed	1,200	6.16	2.11	U.S. Dept. of Labor/Bureau of Labor Statistics (2002). Online: http://data.bls.gov/labjava/outside.jsp?survey=la.
Farmland Availability	Farmland area (000 acres)	1,200	20,742	22,474	*Agricultural Statistics* for 1975–2000 (USDA/NASS). Online: http://usda.mannlib.cornell.edu/reports/nassr/other/plr-bb.
Natural Endowment (Climatic) Factors:					
Temperature	Mean annual temperature (°F)	1,200	52.38	7.57	USDA/Economic Research Service, 1975–1994—online: http://usda.mannlib.cornell.edu; National Climatic Data Center, 1995–2000—online: http://lwf.ncdc.noaa.gov/oa/climate/research/cag3/state.html.
Precipitation	Mean annual precipitation (mm)	1,200	36.47	14.75	[same as for temperature, above]
Instrumental Variables for Regulatory Stringency:					
Resident Population	State resident population (000s)	1,200	5,070	5,313	U.S. Census Bureau (2002b). Online: http://www.census.gov/population/www/cen2000/respop.html.
Family Income[a]	Median annual income of four-member family ($)	1,200	30,777	4,264	U.S. Census Bureau (2002a). Online: http://www.census.gov/hhes/income/4person.html.
Growth Rate of Aggregate Livestock Unit (one-year lagged)	Annual growth in aggregate animal units (700 dairy cows, 1,000 beef cattle, 2,500 hogs are equivalent to 1,000 animal units)	1,200	-0.007	0.088	*Agricultural Statistics* for 1975–2000 (USDA/NASS). Online: http://usda.mannlib.cornell.edu/reports/nassr/other/plr-bb.
Growth Rate of Aggregate Livestock Densities (two-year lagged)	Annual growth rate in aggregate animal units per acre of farmland area	1,200	0.0174	0.409	[same as above]

[a] Energy price, labor wages, farmland price, and family income were deflated using the Consumer Price Index (U.S. Department of Commerce/Bureau of Labor Statistics, 2002a).

Table 3. Environmental Stringency Indices by State, 1975–2000

State	Per Capita Environmental Quality Control Expenditure[a] 1975	1978	1979	1980	Conservation Foundation Index 1984[b]	Per Capita Environmental Quality Control Expenditure 1986[a]	FREE Index 1987[c]	Per Capita Environmental Quality Control Expenditure 1988[a]	Renew America Index 1987/1989[d]	Status of 50 State Policies (Green Index 1991/1992)[d]	Southern Studies Index 1994[e]	Metcalfe Index 1994[f]	Metcalfe Index 1998[f]	Authors' Index 2000[g]
AL	1.107	1.637	1.897	1.730	10	15.47	16	15.73	53	10	681	6	9	2.59
AR	0.948	2.371	2.332	2.430	27	13.29	18	18.24	48	9	579	3.63	7.16	4.46
AZ	2.260	3.965	4.355	4.140	24	15.19	27	13.45	72	13	567	3.63	7.16	1.03
CA	3.774	5.855	7.216	8.120	46	50.70	48	52.76	134	38	423	3.63	7.16	0.08
CO	4.723	5.420	5.727	5.930	26	22.26	24	23.15	75	19	377	3.63	7.16	6.99
CT	6.129	7.058	5.792	5.650	32	12.44	44	19.13	117	32	442	3.63	7.16	2.96
DE	5.181	6.873	12.027	38.200	29	47.74	24	50.26	78	17	518	3.63	7.16	0.12
FL	5.195	2.019	2.011	1.960	31	17.57	41	37.62	114	25	461	3.63	7.16	1.21
GA	2.231	2.213	2.377	4.330	25	12.63	26	14.58	80	16	544	6	9	5.24
IA	2.097	2.787	2.431	3.010	29	16.16	29	31.07	107	23	491	4	9	3.25
ID	6.150	6.017	5.834	6.860	16	51.97	16	61.50	68	13	425	3.63	7.16	2.00
IL	4.376	7.949	8.626	7.210	28	15.92	28	34.03	97	22	563	2	8	4.00
IN	1.882	3.018	3.940	4.610	36	8.48	36	9.46	79	20	687	4	6	2.62
KS	1.316	2.165	2.150	2.030	23	12.88	29	19.23	74	18	625	4	9	4.71
KY	2.362	2.917	3.470	4.210	34	24.16	28	32.33	66	16	594	2	7	2.66
LA	0.788	1.302	1.785	2.400	21	17.38	21	43.85	52	19	708	3.63	7.16	1.00
MA	5.676	8.772	11.069	11.100	44	21.32	41	40.53	123	27	389	3.63	7.16	0.00
MD	10.189	10.135	9.181	11.220	37	20.33	34	32.32	101	26	413	3.63	7.16	4.51
ME	8.507	8.403	8.295	7.890	32	22.31	36	32.61	101	33	331	3.63	7.16	0.00
MI	3.402	2.746	4.601	5.900	30	18.68	43	23.81	107	28	541	1	3	2.00
MN	3.571	6.557	12.327	5.690	47	18.03	38	29.32	114	31	381	8	9	5.35
MO	1.888	3.767	3.541	6.570	14	25.07	31	23.33	79	22	530	6	7	3.33
MS	1.709	2.549	3.349	1.730	15	24.38	14	20.61	47	15	612	5	10	4.32
MT	4.021	6.640	6.570	6.570	37	69.55	23	86.52	70	13	559	3.63	7.16	2.00
NC	3.124	3.474	5.611	4.320	25	14.62	42	14.85	111	24	578	1	8	4.98
ND	1.570	3.110	3.063	3.460	22	31.08	16	49.06	61	12	458	3.63	7.16	2.49
NE	3.886	3.863	6.406	3.700	22	13.32	31	17.48	82	16	520	3	7	5.20
NH	9.852	30.697	24.735	23.010	21	32.41	32	30.62	92	19	310	3.63	7.16	1.00

(continued . . .)

Table 3. Continued

State	Per Capita Environmental Quality Control Expenditure[a] 1975	1978	1979	1980	Conservation Foundation Index 1984[b]	Per Capita Environmental Quality Control Expenditure 1986[a]	FREE Index 1987[c]	Per Capita Environmental Quality Control Expenditure 1988[a]	Renew America Index 1987/1989[d]	Status of 50 State Policies (Green Index 1991/1992)[d]	Southern Studies Index 1994[e]	Metcalfe Index 1994[f]	Metcalfe Index 1998[f]	Authors' Index 2000[g]
NJ	5.182	3.953	15.145	5.480	45	27.25	47	67.86	125	31	464	3.63	7.16	1.00
NM	3.497	5.137	4.202	5.600	18	24.59	23	29.66	61	36	533	3.63	7.16	2.00
NV	1.695	13.115	4.739	4.070	22	21.77	23	34.42	56	12	434	3.63	7.16	2.00
NY	7.247	7.244	7.420	9.510	37	12.94	43	13.21	113	32	424	1	2	1.00
OH	15.836	25.164	21.120	35.280	30	8.54	36	11.56	88	24	586	5	7	3.63
OK	1.105	2.169	2.490	2.420	19	14.51	29	12.52	65	13	588	4	6	4.73
OR	3.065	7.299	9.259	8.780	42	49.01	35	68.02	116	33	395	3.63	7.16	0.03
PA	4.384	4.721	4.497	4.940	28	28.03	32	24.01	91	21	511	2	7	3.08
RI	5.371	9.404	9.626	12.220	26	26.16	30	36.06	95	31	397	3.63	7.16	0.00
SC	1.776	3.160	3.129	3.340	25	16.02	31	20.36	79	15	611	3.63	7.16	0.09
SD	1.468	2.915	2.903	4.010	30	75.90	23	29.74	63	5	396	2	8	2.11
TN	2.157	2.848	3.024	3.760	23	15.45	29	16.50	60	14	698	3.63	7.16	2.00
TX	1.634	2.002	2.182	2.330	22	7.09	26	6.78	66	18	703	3.63	7.16	2.09
UT	1.663	2.443	2.366	2.570	23	24.60	16	30.41	57	13	556	3.63	7.16	2.00
VA	4.015	2.981	3.116	3.000	28	16.33	33	25.38	95	19	521	3	5	1.06
VT	8.475	19.068	12.371	13.830	32	42.94	28	36.37	91	28	282	3.63	7.16	2.05
WA	5.620	7.198	6.561	9.240	39	38.80	29	53.45	91	28	430	3.63	7.16	2.00
WI	5.884	4.132	4.730	8.400	37	55.31	49	34.54	131	29	379	3.63	7.16	4.00
WV	2.223	3.295	3.765	6.110	23	23.68	15	29.82	56	11	652	3.63	7.16	1.00
WY	2.660	5.128	4.926	5.850	23	135.33	16	271.87	46	13	601	3.63	7.16	2.36
Used for years:	1976	1977		1981 1982	1983	1985			1990	1992	1993	1995 1996	1997 1998	1999 2000

Sources: [a] U.S. Department of Commerce/Bureau of the Census, *State and Metropolitan Area Data Book* (various years).
[b] Duerkson (1984).
[c] Scott (1987).
[d] Hall and Kerr (1991).
[e] Institute for Southern Studies (1994).
[f] Metcalfe (2000).
[g] Developed by the authors and presented in table 4.

In order to capture the temporal changes of regulatory stringency across states, it is necessary to compare the indices across time. However, the indices in table 3 are not comparable in their absolute magnitude since these are based on dissimilar variables in different periods. Thus, individual state values were normalized for all the above indices by dividing through with the arithmetic mean of the respective index. The normalized index values represent the position of the state relative to the arithmetic mean of each index. These normalized values are then used to approximate the relative regulatory stringency across time, allowing the different indices to be combined to form a single regulatory variable with a consistent scale measure.

Relative Prices

Increases in the relative profitability of livestock production, as measured by an output-to-feed price ratio, are expected to increase relative production intensity. Hog and beef prices have cycled over time, but there are no significant regional differences except that western states tend to have higher beef prices than those in the Northeast. In contrast, dairy prices do not fluctuate significantly over time, although there are persistent regional differences. Dairy prices have tended to be higher in the southeastern states and lower in the western states. Corn prices have varied much more than livestock prices, with the highest regional corn prices generally occurring in the Southwest.

A second input cost used in the model is the price of energy. Energy prices peaked in 1981 and 1991, and slumped in 1988 and 1998. Prices do vary somewhat from state to state, possibly due to different means of production. For example, some states (such as Oregon) have an abundance of hydroelectricity and lower energy prices as compared to other states relying on fossil fuels or nuclear power to generate electricity.

The cost of labor is a third input cost necessary in livestock operations. Labor costs are measured by the average farm wage rate, which has risen constantly over time. Despite the incentive to produce where labor is cheapest, and the general notion that large-scale production requires cheaper labor, there are no major differences in wage rates across the states.

A fourth input price used in the model is the value of farmland. Areas with cheaper land prices ceteris paribus are expected to have higher shares of national inventory. Since land cannot migrate, there are regional differences in the price of farmland with the highest values in areas with the largest urban pressures. In agriculture-intensive regions, farmland values are higher in the Corn Belt states than those in the Central Plains and Rocky Mountain regions, reflecting differences in land productivity.

Livestock Infrastructure Support

Market access and agglomeration economies are two externalities associated with livestock infrastructure support. Production shares are likely to increase in regions where the distance to market is smaller, since transportation and transaction costs will be lower. For example, access to slaughtering facilities was found to be positively related to the intensity of hog production within 15 states by Roe, Irwin, and Sharp (2002). Market access is measured in this study by the number of hogs and beef slaughtered within the state.[3] Iowa has the largest hog slaughtering capacity, and the number

[3] A more appropriate measure would be a spatially weighted average of a state's processing capacity since slaughtering facilities within a given state are likely to influence the market access of adjacent states.

slaughtered has increased significantly over time. Illinois, North Carolina, and Minnesota also increased hog slaughter capacity, but at levels less than half of that for Iowa. Beef slaughtering capacity increased significantly over time for Kansas, Texas, Nebraska, and Colorado. These states also had the highest capacity for cattle slaughter among all states. In contrast to the situation for hog slaughter, the number of beef slaughtered in Iowa decreased dramatically over the study period. Market access for dairy processing capacity is captured by whole milk equivalent in thousand pounds used in manufactured dairy products at the state level. Leading dairy states such as Wisconsin, California, Minnesota, New York, and Iowa had much higher processing levels than other states throughout the study period, but California and Wisconsin recorded marked expansions in capacity while the dairy processing capacity in Minnesota, New York, and Iowa remained almost unchanged during this 25-year period.

Agglomeration economies are the positive spillovers a farm may enjoy because of a higher concentration of farms in the region. For example, the presence of many dairy farms in a given region can attract input suppliers and other industry-specific infrastructure that lowers the transaction costs of exchange and the diffusion of information (Eberts and McMillen, 1999; Weersink et al., 1995). Roe, Irwin, and Sharp (2002) found such agglomeration economies had a positive effect on the total number of hogs raised at the county level. Agglomeration effects are proxied by the importance of agriculture to the state economy and the share of the population living in rural areas. States with the largest share of income from agriculture are the Dakotas, Nebraska, and Iowa, but this percentage is declining for all states. Livestock operations are assumed to meet less resistance in states with a greater percentage of the population tied to agriculture. Unlike farmland area, which is declining for all states, the percentage of rural population is increasing for approximately one-third of the states.

General Business Climate

Local business conditions conducive to the establishment of a livestock operation are proxied by unemployment rate and state farmland area. The unemployment rate can have an influence on farm location through the labor supply and receptiveness toward new operations. A region with a high unemployment rate is more likely to have excess labor available to work in agriculture. In addition, areas with higher unemployment may seek livestock operations to locate as a means to generate economic opportunities. The unemployment rate varies both over time and between states.

State farmland area is an important determinant for both general receptivity of farming operations and assimilative capacity for land-based manure disposal. States with greater farming areas are assumed to be more receptive to livestock operations. The most important and widely practiced manure disposal method is to spread the manure onto farmland as a valuable source of organic nutrients. However, Gollehon et al. (2001) found that about 72% of large livestock operations had inadequate land capacity to utilize all the manure-based organic nitrogen produced from their operations, and required alternative disposal arrangements. Thus, the costs of manure disposal are likely to be lower in states with more available farmland.

Table 4. Environmental Stringency Measure by State for 2000

	Environmental Regulation							
State	Anti-Corporate [a]	Moratoria [b]	Local Control [c]	Bonding [d]	Cost Share [d]	Nutrient Standards [f]	Set-Back [g]	Total [h]
Alabama	0	0	0	0	0	2	0.59	2.59
Arkansas	0	1	0	0	1	2	0.46	4.46
Arizona	0	0	1	0	0	0	0.03	1.03
California	0	0	0	0	0	0	0.08	0.08
Colorado	0	1	1	1	1	2	0.99	6.99
Connecticut	0	0	1	1	0	0	0.96	2.96
Delaware	0	0	0	0	0	0	0.12	0.12
Florida	0	0	0	0	1	0	0.21	1.21
Georgia	0	1	1	1	1	1	0.24	5.24
Iowa	1	0	0	1	0	1	0.25	3.25
Idaho	0	1	1	0	0	0	0.00	2.00
Illinois	0	0	0	1	0	2	1.00	4.00
Indiana	0	0	1	0	0	1	0.62	2.62
Kansas	1	0	0	1	0	2	0.71	4.71
Kentucky	0	1	0	0	0	1	0.66	2.66
Louisiana	0	0	0	0	1	0	0.00	1.00
Massachusetts	0	0	0	0	0	0	0.00	0.00
Maryland	0	1	1	0	0	2	0.51	4.51
Maine	0	0	0	0	0	0	0.00	0.00
Michigan	0	0	0	0	0	2	0.00	2.00
Minnesota	1	1	1	0	0	2	0.35	5.35
Missouri	0	0	1	1	0	1	0.33	3.33
Mississippi	0	1	1	1	1	0	0.32	4.32
Montana	0	0	1	0	0	1	0.00	2.00
N. Carolina	0	1	1	0	0	2	0.98	4.98
N. Dakota	1	1	0	0	0	0	0.49	2.49
Nebraska	1	1	1	0	0	2	0.20	5.20
New Hampshire	0	0	0	0	1	0	0.00	1.00
New Jersey	0	0	0	0	1	0	0.00	1.00
New Mexico	0	0	0	0	1	1	0.00	2.00
Nevada	0	0	1	0	1	0	0.00	2.00
New York	0	0	0	0	0	1	0.00	1.00
Ohio	0	0	1	0	0	2	0.63	3.63
Oklahoma	0	1	0	1	0	2	0.73	4.73
Oregon	0	0	0	0	0	0	0.03	0.03
Pennsylvania	0	0	1	0	0	2	0.08	3.08
Rhode Island	0	0	0	0	0	0	0.00	0.00
S. Carolina	0	0	0	0	0	0	0.09	0.09
S. Dakota	1	0	1	0	0	0	0.11	2.11
Tennessee	0	0	0	0	0	2	0.00	2.00
Texas	0	0	0	0	0	2	0.09	2.09
Utah	0	0	1	0	0	1	0.00	2.00
Virginia	0	0	0	0	0	1	0.06	1.06

(continued . . .)

Table 4. Continued

State	Environmental Regulation							Total[h]
	Anti-Corporate[a]	Moratoria[b]	Local Control[c]	Bonding[d]	Cost Share[e]	Nutrient Standards[f]	Set-Back[g]	
Vermont	0	0	0	0	0	2	0.05	2.05
Washington	0	1	1	0	0	0	0.00	2.00
Wisconsin	1	0	1	0	0	2	0.00	4.00
West Virginia	0	0	0	0	1	0	0.00	1.00
Wyoming	0	0	0	1	1	0	0.36	2.36

Source: Developed by the authors.

Environmental Regulation Descriptions:

[a] Anti-Corporate: Corporations are prohibited from owning farmland or engaging in confined livestock operations (yes = 1, no = 0).

[b] Moratoria: Limits imposed on total production or number of operations within state (yes = 1, no = 0).

[c] Local Control: Government agencies that administer and enforce major policies and regulations affecting confined livestock operations (county/township = 1, other = 0).

[d] Bonding: Bonding or financial assurance requirements to pay for costs of cleanup of any spills or for closure of abandoned facilities (yes = 1, no = 0).

[e] Cost Share: Cost-sharing or incentive programs provided by the state to encourage compliance with regulations, not including Environmental Quality Incentives Program (EQIP) (yes = 1, no = 0).

[f] Nutrient Standards: Restrictions on manure application or timing (N, P, or other standard = 2; N standard = 1; no restrictions = 0).

[g] Set-Back: Minimum set-back distance required by state multiplied by average farmland price in state (value normalized by dividing through by maximum set-back measure).

[h] Total = sum of numerical values of the scores under all seven regulations. Note: The final index captures intensity of some variables (set-back distance and nutrient standard). However, in the process of estimating time-series values for the environmental regulatory stringency variable, the index is normalized along with other stringency indices representing relative position of the states where absolute values do not have implications for the relative stringency.

Natural Endowment (Climatic) Factors

Physical features of the region are captured by average annual precipitation and temperature. Precipitation does not vary greatly within states when measured over several years, although precipitation does fluctuate on an annual basis more than temperature. Mean temperature is negatively related to both latitude and altitude, and so does not fluctuate greatly among states over time.

Empirical Specification

The factors affecting the changes in regional livestock production were estimated through the following regression model:

$$Y_{it} = \sum_{k=1}^{K} \beta_k X_{it} + V_i + U_t + \varepsilon_{it}, \quad (1)$$

$$i = 1, \ldots, 48; \; t = 1, \ldots, 25,$$

where Y_{it} is the share of national inventory for state i (for the 48 contiguous states) in year t (from 1976 to 2000); $\mathbf{X}$ is the vector of exogenous variables affecting the relative profitability of livestock farming across locations; β is the vector of coefficients associated with the explanatory variables; V_i is the time-invariant, unobserved state-specific effect; U_t is the state-invariant, unobserved time-specific effect; and ε_{it} is the random disturbance term. The independent variables (X_i) included in the analysis do vary across states and time. However, there may be other unobservable (and therefore omitted) state-specific (V_i) or time-specific (U_t) variables, which might affect changes in livestock inventory and mask the true relationship between the dependent variable and independent variables in the model.

Two specifications to control for V_i and U_t are the fixed-effects model, which assumes V_i and U_t are constants and conditional on the sample not randomly distributed, and the random-effects model, which assumes V_i and U_t are randomly distributed and not conditional on the sample. A random-effects model is likely inappropriate for this analysis given that our sample (48 states) is not a random selection of a large sample frame. However, a Hausman specification test was used to determine if the covariance between V_i and X_i is zero, as required to produce consistent estimates with a random-effects model. The null hypothesis of no correlation between state-specific effects (V_i) and independent variables (X_i) was rejected for all three livestock sectors.[4] Therefore, a fixed-effects model was used in the regression for the three sectors.

If environmental regulatory stringency is endogenous to state livestock inventory shares, then ε_{it} would be correlated with the stringency variable, and least squares estimators would be inconsistent. The potential endogeneity can be tested using a Durbin-Wu-Hausman test, which first requires specifying appropriate instrumental variables for the endogenous right-hand-side variables (Davidson and MacKinnon, 1993). As sources of exogenous variations in environmental regulatory stringency, we have used one-year lagged values of the growth rate in aggregate livestock units,[5] two-year lagged values of the growth rate in aggregate livestock densities,[6] total residential population of the state, and the state median income of a four-member family.

If the intensity of livestock operations were to influence a state's environmental regulatory stringency, it must be manifested through the potential hazards of manure disposal and odor-related nuisances, as captured by the growth rates in aggregate livestock inventories and their densities. Higher growth rates in aggregate livestock inventories and/or higher growth rates in aggregate inventories relative to available manure disposal area could prompt harsher regulatory regimes. Concerns over environmental quality are observed to increase with income, and generally, families who are financially better off will not want polluting industries in their backyards. Moreover, the greater the residential population in rural areas, the greater will be the likelihood of an increase in nuisance complaints from neighbors regarding livestock farms.

These four instrumental variables have been used to carry out a Durbin-Wu-Hausman test to ascertain the endogeneity of livestock shares on regulatory stringency.[7] The residuals from regressing environmental stringency on each of the explanatory variables,

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[4] If the model specification is correct and X_i and V_i are orthogonal, the coefficients estimated by the fixed-effects model and the random-effects model should not differ significantly. The null of zero systematic difference is rejected by the Hausman specification test, with calculated χ^2 values for the hog, dairy, and fed-cattle sectors of 1,085, 18, and 630, respectively.

[5] Aggregate livestock inventories are calculated with the U.S. Environmental Protection Agency (2001) approach of taking 1,000 animal units as equivalent to 1,000 slaughter and feeder cattle, 700 mature dairy cattle, and 2,500 swine, each weighing more than 25 kilograms.

[6] Livestock density is calculated by dividing aggregate livestock units through by the state farmland area.

[7] The results of the first-stage regression (with p-values in parentheses) are:

$$\underset{}{\textit{Stringency Index}} = \underset{(0.00)}{1.927} - \underset{(0.04)}{0.409}\,\textit{Growth Rate}_{-1} + \underset{(0.21)}{0.053}\,\textit{Density}_{-2} + \underset{(0.01)}{0.0006}\,\textit{Population} - \underset{(0.00)}{0.0004}\,\textit{Income}.$$

including the four instrumental variables, are then used in a second regression where the dependent variable is the livestock share and all explanatory variables are used with the exception of the four instrumental variables. The null hypothesis is that the coefficient for the residual of the first regression is zero and, if the coefficient for the residual of the first regression is not statistically significant in the second regression, then there is an endogeneity bias. The resulting p-values for the coefficients of the residuals of the first regression were 0.27 for the hog sector, 0.00 for the dairy sector, and 0.24 for the fed-cattle sector. Therefore, the fixed-effects model was estimated with two-stage least squares for the hog and fed-cattle sectors, and with ordinary least squares for the dairy sector. Estimation results and elasticities evaluated at mean values of the variables are presented for all three sectors in table 5.

Results

Hog Sector

Of the 12 variables used to explain the variability in the share of national hog production among states, seven were significant at a 10% or lower significance level (see table 5). The coefficient for the environmental regulatory stringency is negative and statistically significant, supporting the pollution haven hypothesis. A 10% increase in the degree of relative stringency was estimated to decrease the state share of national hog production by 3%. The relationship runs counter to previous studies in agriculture where livestock was found to increase with environmental stringency (Metcalfe, 2001; Osei and Laxminarayan, 1996; and Mo and Abdalla, 1998). The results of those studies suggest that inventory levels increase first and regulations follow, rather than the regulations being set ex ante with production decisions constrained by those laws. The support for the pollution haven hypothesis in this study could be due to the use of a time-varying regulatory stringency measure and accounting for possible endogeneity between the measure and hog production shares.

Relative prices generally have signs consistent with theory. The one-year lagged value of the hog corn price ratio is positively related with the growth rate of hog inventory, albeit statistically insignificant. A 10% change in the hog-corn price ratio would increase a state's share of national hog production by 1%, keeping all else the same. The largest price effect was found for the farm wage rate, with an elasticity of −0.5. The only statistically significant input price coefficient with an unexpected sign is that associated with the price of farmland. It was expected that increases in the value of farm real estate would curtail relative hog production. The opposite result suggests hog farmers bid up the price of land as part of their expansion and potential concerns regarding land availability relative to the volume of manure generated.

As shown by table 5, livestock infrastructure has significant effects on changes in hog production levels. Hog slaughtering capacity is positively related to production increases, a finding consistent with those of Roe, Irwin, and Sharp (2002) for 15 states. The result supports the "animal clusters" argument—i.e., states with a larger inventory density tend to have a greater slaughtering capacity (Pagano and Abdalla, 1994). States with a larger proportion of agricultural output in their gross state product tend to have a larger share of national hog production, and the result is statistically significant at the 1% level. Availability of common agricultural infrastructure (veterinary services, feed

Table 5. Regression Results of Model Explaining Changes in National Inventory Shares of the U.S. Hog, Dairy, and Fed-Cattle Sectors

	HOG SECTOR		DAIRY SECTOR		FED-CATTLE SECTOR	
Variable	Coefficient	Elast.	Coefficient	Elast.	Coefficient	Elast.
Regulatory Stringency:						
Relative Regulatory Stringency Index	-0.0062** (0.020)	-0.3019	-0.0003** (0.023)	-0.0160	0.00267 (0.119)	0.1284
Relative Prices:						
Output/Corn Price Ratio	0.000096 (0.145)	0.0805	-2.24e-04** (0.012)	-0.0571	0.00011*** (0.000)	0.1175
Energy Price	0.00015 (0.327)	0.0852	0.0001*** (0.001)	0.0995	-0.00014 (0.141)	-0.0797
Farm Labor Wage	-0.0244** (0.020)	-0.4910	-0.0008*** (0.005)	-0.1633	-0.0007 (0.258)	-0.1453
Farmland Price	2.57e-06** (0.020)	0.1287	1.57e-06*** (0.000)	0.0786	1.38e-06** (0.045)	0.0690
Livestock Infrastructure:						
Processing Capacity	4.08e-06*** (0.000)	0.3638	5.06e-09*** (0.000)	0.4200	1.34e-05*** (0.000)	0.4805
Agriculture's Economic Importance	0.09318*** (0.001)	0.1103	0.05359*** (0.000)	0.0634	0.00852 (0.645)	0.0100
Rural Population Share	-0.000837*** (0.002)	-1.307	-0.00027*** (0.000)	-0.4235	0.0007*** (0.000)	1.1520
Business Climate:						
Unemployment Rate	0.00005 (0.797)	0.0140	1.25e-06 (0.984)	0.0003	0.00013 (0.242)	0.0404
Farmland Availability	-1.78e-07 (0.235)	-0.1774	-1.82e-07*** (0.000)	-0.1812	-3.93e-07*** (0.000)	-0.3917
Natural Endowment (Climatic) Factors:						
Temperature	0.00035* (0.079)	0.8866	-1.20e-04* (0.078)	-0.3036	-0.00001 (0.911)	-0.0358
Precipitation	0.000026 (0.573)	0.0458	-0.00033 (0.389)	-0.0235	0.000044 (0.127)	0.0773
Test Statistics:	Wald χ^2 [12 d.f.] 7,714 (0.0000)		F-Test [12, 1,140] 208.2 (0.0000)		Wald χ^2 [12 d.f.] 20,278 (0.0000)	

Notes: Single, double, and triple asterisks (*) denote statistical significance at the 10%, 5%, and 1% levels, respectively. Numbers in parentheses are p-values.

availability, other input supplies) is also an important factor for hog industry expansion. All else equal, a 10% change in the agricultural share of gross state product increases the share of national hog inventory by about 1%. This variable also proxies the level of support for agriculture within a state and the likelihood of resistance to production expansion. It was expected that states with a larger share of total rural population would be more likely to experience increases in relative hog inventory levels. However, not only do the regression results reject this assertion, but the opposite effect is strongly supported. A possible explanation for this result is that the likelihood for conflict between farmers and neighbors is enhanced by population levels in rural areas when all other factors are constant, including land availability. Potential nuisance complaints from nonfarm rural residents could deter the expansion of livestock production capabilities.

Business climate and natural endowment variables have little explanatory power. The unemployment rate has a positive effect on hog inventory shares, but the result is statistically insignificant. The area of farmland is unexpectedly negative, but also insignificant. An increase in temperature was found to have a positive effect on the likelihood of an increase in relative hog production, which is consistent with the large increase in hog production in a few states that tend to be in the southern part of the country.

Dairy Sector

As with the hog sector, the coefficient on environmental regulatory stringency is negative and statistically significant for the dairy sector (table 5). This result suggests that a state's regulatory stringency curtails the share of national dairy numbers. However, the effect is less than for the hog sector, as indicated by the lower elasticity value of -0.01. Instead, relative prices and livestock infrastructure appear to be the main variables explaining the shifts in the state shares of national dairy production.

Relative prices have an effect on annual changes in relative state dairy numbers, but the results are not always consistent with a priori expectations. Although the milk-corn price ratio is statistically significant, it has an unexpected negative sign. Similarly, energy price has an unexpected positive effect on inventory levels. The unexpected positive sign on farm real estate values suggests that perhaps the growth rate in cow numbers may be due to profitability which is also associated with the value of major assets in production, such as land. The elasticities for these three price variables are less than 0.1. The largest effect was observed for the farm wage rate, as was also found for the hog sector. A 10% increase in the farm wage rate is predicted to decrease a state's share of national dairy inventory by 1.6%.

All three variables capturing livestock infrastructure support are statistically significant for the dairy sector and of the same sign as estimated for the hog sector. An increase in the processing capacity of the dairy sector was estimated to have an elasticity of 0.42, implying the access to markets is an important factor for dairy expansion, as has been hypothesized for the red meat sector. The coefficient on agriculture's share of gross state product is also positive, as expected, but the size of the impact is much less than for processing capacity. These regression results are also consistent with those of Weersink et al. (1995) who conclude that dairy farmers place a significant level of importance on the availability and quality of farm support services. As with the hog sector, an increase in the share of a state's rural population is found to decrease relative dairy cow numbers for the state, reflecting a potential increase in the likelihood of conflict between farmers and nonfarm rural neighbors.

The state unemployment rate is positively related with inventory growth, but the result is statistically insignificant. Farmland area is statistically significant but has an unexpected negative effect. The inverse relationship is consistent with the shift of dairy farming to the western states where there is less agricultural land as a share of total area due to the prevalence of mountains, as compared to traditional dairy regions in the central and northeastern regions of the country. The increase in production has been in relatively cooler regions and away from warmer states, particularly in the Southeast. Thus, the temperature variable has the expected negative sign.

Fed-Cattle Sector

In contrast to the hog and dairy sectors, there is no empirical support for the pollution haven hypothesis in the beef sector. The difference in effects across livestock types associated with the regulatory stringency index may be due to the nature of the production changes by sector. The increase in hog and dairy inventory has been in nontraditional production regions where environmental laws related to livestock farming appear to have had an effect on the location of production. In contrast, beef production increased only in the three states that had the largest numbers a generation ago (Texas, Kansas, and North Dakota). Because these remain relatively unpopulated regions, expansion may have been influenced by factors other than environmental regulations.

The beef-corn price ratio has a positive and statistically significant effect on relative production shares, as expected (table 5). While energy and labor prices have the anticipated inverse relationship with relative inventory levels, the coefficients are not statistically significant. The coefficient on the value of farmland is positive and statistically significant, as in the other two livestock sectors. This result may be due to locating in relatively productive agricultural regions after other factors, including farmland availability and demographics, are considered.

Livestock infrastructure has had a major effect on fed-cattle numbers between states, just as with the other two sectors. Slaughtering capacity shows a statistically significant positive effect on relative inventory levels, which supports the view that regional shifts in production have coincided with shifts in beef packing location. The larger the share of agriculture in the state economy, the higher the relative growth in fed cattle, but this effect is not statistically significant. In contrast to the other sectors, increases in the rural share of total population had a positive effect on production shares of national beef inventory.

As with the other two livestock sectors, business climate and natural climatic variables appear to have little influence on production decisions. The unemployment rate is directly associated with changes in state production shares of the fed-cattle inventory, but is not statistically significant. Farmland area has an unexpected negative effect, suggesting the fed-cattle sector is associated with regions having smaller areas available for expansion. However, the increases in production shares have occurred in three traditional fed-cattle-producing states with large amounts of agricultural land. The increase in production shares of fed cattle by these states has been driven by relative prices and infrastructure support.

Conclusions

This study has investigated the factors affecting the location choice of hog, dairy, and fed-cattle production in the 48 contiguous U.S. states from 1975–2000. The hog and dairy sectors are increasingly siting production toward western states and away from traditional production regions in the East. In contrast, production levels in the fed-cattle sector have increased over the last generation only in the three main producing states of Texas, Kansas, and North Dakota. The shifts could be due to livestock producers responding ex ante to the differences in environmental regulatory stringency or to factors such as relative prices and livestock infrastructure support.

Previous studies have tended to reject the pollution haven hypothesis in agriculture, and instead have found that inventory levels appear to increase first and environmental regulations follow, rather than the regulations being set and production decisions then constrained by those laws. By developing state-specific measures of regulatory stringency over time and accounting for the potential endogeneity between environmental regulations and production decisions, this analysis was able to conduct a more robust test of the pollution haven hypothesis. The results suggest that regional production shares for hogs, and to a lesser extent dairy, have increased in those regions with relatively more lenient regulatory regimes. In all sectors, livestock infrastructure support is a major determinant of changes in state production shares of national inventory levels. The observed clustering of production and processing has been supported by earlier analysis of the hog sector (Roe, Irwin, and Sharp, 2002), but this study also finds market access in terms of processing capacity to be important for the dairy sector.

Based on this study's findings, government regulators can directly and indirectly have a major influence on the size of the animal industry in their state. Tightening compliance requirements and enforcement can increase relative abatement costs to the point that livestock farmers may shift production to another location. Aside from this direct impact, regulators can alter the incentives faced by the processing sector to locate in their state. The location decisions of the fewer, but significantly larger, processors in turn have a major influence on the spatial production of the associated livestock sector.

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