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Abstract: Understanding sustainable livestock production requires consideration of both qualitative and quantitative factors in a temporal and/or spatial frame. This study adapted Qualitative Comparative Analysis (QCA) to relate conditions of social, economic, and governance factors to changes in livestock inventory across several counties and over time. This paper presents an approach that (1) identified factors with the potential to relate to a change in livestock inventory and (2) analyzed commonalities within these factors related to changes spatially and temporally. This paper illustrates the approach and results when applied to five counties in eastern South Dakota. The specific response variables were periods of increasing, no change, or decreasing beef cattle, dairy cattle, and swine inventories in the specific counties for five-year census periods between 1992 and 2017. In the spatial analysis of counties, stable beef inventories and decreasing dairy inventories related to counties with increasing gross domestic products. The presence of specific social communities related to increases in county swine inventories. In the temporal analysis of census periods, local governance and economic factors, particularly market price influences, were more prevalent. Swine inventory showed a stronger link to cash crop markets than to livestock markets, whereas cattle market price increases associated with stable inventories for all animal types. Local governance tools had mixed effects for the different animal types across space and time. The factors and analysis results are context-specific. However, the process considers the various socio-economic processes in livestock production and community development applicable to agricultural sustainability questions in the Midwest and beyond.

Keywords: Qualitative Comparative Analysis (QCA); livestock; South Dakota; Boolean logic; socio-economic; sustainable agriculture; decision-making; rural development

1. Introduction

Animal agriculture production and surrounding rural and urban communities are inextricably connected across social, economic, and cultural realms. While national and global level changes in social, political, economic, environmental, and technological preferences can drive changes in agricultural production practices [1], the impacts of these and other issues also affect change at more local or regional scales. Raising farm animals and poultry (hereafter referred to as livestock) for commodities, such as meat, milk, and eggs, is a part of rural life in many regions of the United States (U.S.), but different communities react differently to livestock industry growth; this depends on the individuals, types of livestock, and real and perceived impacts [2].

Over time, modern agricultural technologies and practices increased the productivity of both the land and each agricultural worker. These developments enabled higher production and productivity on the farm, increased economic activity and wealth, and provided the food and fiber needed by people near and far [3,4]. A natural consequence of this activity was the congregation of similar production-type farms in specific regions due to climate and natural resources (i.e., soil), in addition to available infrastructures, such as processors, labor, banks, and other services [5,6]. Laws, regulations, and other policy tools from local to federal government levels supported or limited the natural development of this economic activity.

The economic benefits of such developments are rarely uniformly distributed, and neither are the negative impacts. Livestock operations provide employment, jobs, and tax revenue but impose nuisances, such as noise, traffic, and odor. Different perceptions and experiences of the benefits and drawbacks of these operations often lead to controversy. While numerous studies have looked at the acceptance of livestock production and other potentially objectionable operations, they narrowly focused on specific aspects of local installations. For example, Mann [2] used both qualitative and quantitative methods to determine the extent to which local residents were in favor of new large swine operations in Germany. They found that environmental and nuisance factors are important to local residents, but jobs and funding sources are important to decision-makers (e.g., mayors). However, the study did not consider other local issues, such as labor, training, or markets. Mann and Kogl [7] and Bergstra et al. [8] were similarly focused on local attitudes related to one installation or a few farms clustered in space and/or time rather than on larger changes in the system. Studies that examine economic impact look at changes in the number or type of livestock production [9], or vice versa, but rarely consider economic, governance—particularly local—, and social factors simultaneously with livestock inventory. For example, while Hendrickson et al. [1] included interactions among technology, society, politics, environment, and economics in their literature review, quantitative or qualitative analyses were not discussed.

This study started with a basic hypothesis that change in county-level livestock inventory is a multidimensional, multifactor phenomenon. Proving the hypothesis required a non-conventional approach that accommodated quantitative and qualitative data. This paper presents such an approach that (1) identified factors with the potential to relate to a change in livestock inventory, for snapshots in space and time, and (2) analyzed commonalities within these factors spatially and temporally. The approach was applied to show conditions corresponding to change for livestock inventories in five select South Dakota counties from 1992 to 2017. While the factors are specific in context to eastern South Dakota, the process illustrates various socio-economic processes in livestock production and community development applicable to agricultural sustainability scenarios in the Midwest and beyond. The Boolean logic analyses in this study are adapted from Qualitative Comparative Analysis (QCA), integrating qualitative and quantitative data derived from both case-oriented research and empirical investigations [10]. The flexible and modifiable method applies to other complex scenarios involving multiple stakeholders, local community, politics, and socioeconomics, all of which can evolve over time.

2. Methods

This study is the outcome of a graduate student cohort challenge, supported by the INFEWS-ER Virtual Resource Center for Transdisciplinary Graduate Student Training at the Nexus of Food, Energy, and Water [11]. The cohort challenge objective was to learn and use transdisciplinary skills to identify relationships between livestock development and local communities. The cohort was assigned a project setting of South Dakota by advisors (authors E.L.C., J.J.C., A.V.D., J.A.K.), but the ultimate method and analysis was a product of the cohort's learned perspectives of South Dakota livestock development and their transdisciplinary training. The virtual learning environment with cohort participants from across the U.S. influenced methodology throughout the challenge, as travel to South Dakota was not possible for monetary and COVID-19 pandemic reasons.

2.1. Project Scope and Background

County hearings and discussions are commonplace in South Dakota, during the potential and actual siting of livestock operations. From professional experience (author E.C.), and informal feedback solicited from a South Dakota-based agriculture development professional, a list of counties whose local government-supported or opposed livestock development was created. The list was narrowed to include two counties with populations less than 10,000 persons (Grant and Hutchinson) and two counties with populations greater than 10,000 persons (Brookings and Lincoln). An additional county (Yankton) with a population greater than 10,000 persons was included in the study, as the county was in the process of livestock development-related discussions during 2019 and 2020. Thus, the project scope included five counties in eastern South Dakota: Brookings, Grant, Hutchinson, Lincoln, and Yankton.

Every 5 years, the U.S. Department of Agriculture's National Agricultural Statistics Service (NASS) conducts the Census of Agriculture, a complete count of U.S. farms, number of operators, and production. The 5-year census period formed the base unit for comparisons over time. In 2017, 43.8% of total agricultural products sold in South Dakota were from livestock production: cattle and calves (32.8%); hogs and pigs (5.9%); and milk from dairy cows (5.1%). Crop production (grains, oilseeds, dry beans, and dry peas) was 51.3%, and all other agricultural products, including poultry and eggs, were less than 1.7% [12]. The cattle and calves category includes beef cows, milk cows, replacement heifers, bulls, and calves [13]. The cattle and calves category includes beef cows, milk cows, replacement heifers, bulls, and calves [13]. Therefore, this work focused on beef cattle (Beef), dairy cows (Dairy), and hogs and pigs (Swine) as the influential types of livestock in South Dakota. Census inventory data for swine became available in 1987 [14].

The early 1990s brought a shift in state governance for many livestock operations. In 1993, the U.S. Environmental Protection Agency (US EPA) granted the South Dakota Department of Environment and Natural Resources (SD DENR) authority to administer a program for animal feeding operations and water quality protection. The SD DENR first issued a general permit for swine operations in 1997 and a general permit for other types of livestock in 1998, with reissuances in 2003, 2008, and 2016. The general permits contained. All concentrated animal feeding operations (CAFOs) require permits [15] that contain standard conditions and limits required by state or federal law to protect water quality. The SD DENR passed the right to enforce additional setbacks in consideration of odor or zoning to counties. It is important to mention there was a short-term piece of legislation titled South Dakota Prohibit Corporate Farming Amendment (or S.D. Const. amend. E) passed in 1998, prohibiting corporate or contract farming in the state [16]. However, 5 years later, in 2003, Amendment E was deemed unconstitutional and revoked in *South Dakota Farm Bureau v Hazeltine*, 340 F3d 583 (8CA 2003) [17]. The project scope was set from 1992 to coincide with the census data and presence of state regulation through 2017, being the latest census data available at the time of analysis.

Figure 1 and Appendix A show livestock inventories for the counties and census dates of interest. Visual inspection of census data indicated inconsistent changes in livestock inventories. This led to an investigation of factors to explain the fluctuations over time across the five counties of interest. The average change in inventory over each census period for the type of livestock became the response variable in this study. A 5% increase or 5% decrease between census years relative to the initial year value in the calculation was considered a significant increase or decrease, respectively.

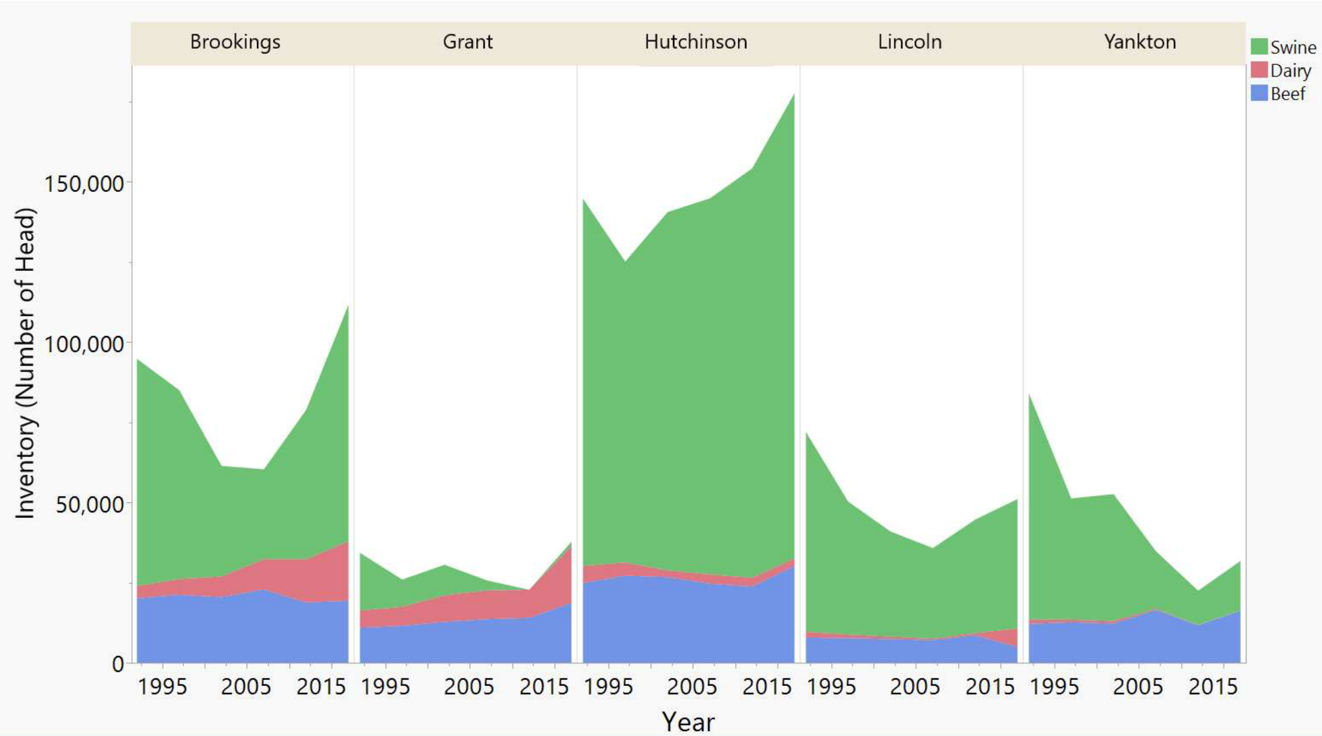

Figure 1. Livestock inventories in counties of interest over time. Each portion of the stacked areas represents the total inventory for the type of livestock; the totals are not overlayed.

2.2. Factor Identification

Per the project hypothesis, livestock inventories fluctuate based on multidimensional factors, including concerns, influences, and priorities of local communities. The factor selection process was iterative and included background reading, discussions with local professionals, data collection, and factor refinement (Figure 2).

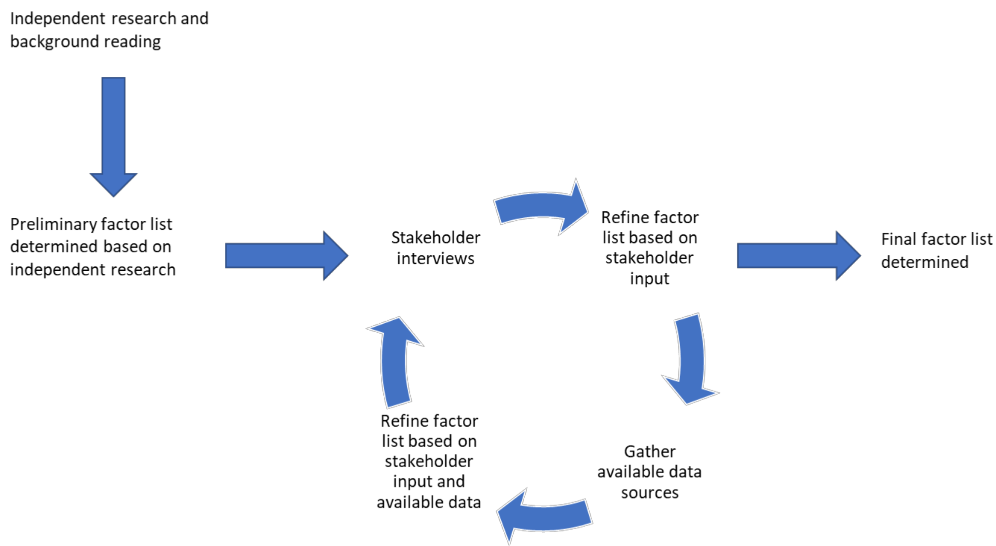

Figure 2. The factor list used in this study underwent internal and external review processes, with continual refinement based on feedback from stakeholders and available qualitative and quantitative data. This iterative review process ensured a robust list of factors that captured the concerns, influences, and priorities surrounding livestock development at the county and state levels within the last 30 years.

Quantitative data sources included U.S. Census and Survey data. Most data were county-specific, but commodity market prices were aggregated for the state of South

Dakota. Qualitative data was collected from local policy documents, such as land use plans, zoning ordinances, published goals of the county governing boards, and stories from local news outlets.

The cohort spoke by phone or video with South Dakota residents familiar with the livestock industry in the select counties through their past or present work, including livestock development specialists, South Dakota State University Extension personnel, and members of county governance; all interviewees are hereafter referred to as stakeholders. The cohort deemed stakeholder interviews preferable to survey research to understand the history, local climate, attitudes, and perspectives toward livestock development in the specific counties and for eastern South Dakota, in general, that come from a discussion format, versus a fixed set of survey questions. The outcome of these discussions was a list of quantitative and qualitative factors to further investigate potential data in the change in livestock development during the time period of interest.

All factors, both quantitative and qualitative, required (1) definition, (2) supporting data, and (3) qualification of the condition present for a snapshot in time. The final list of factors were those that demonstrated variable changes (e.g., increase or decrease, presence or absence) over time and/or between the five counties of interest. Factors that demonstrated a continuous trajectory (e.g., always increased) over time and were common across the five counties of interest were excluded from analysis; however, these factors have the potential to inform analyses for other areas or regions and are mentioned in the results.

2.3. Factor Analysis

To accommodate both quantitative and qualitative data, Qualitative Comparative Analysis (QCA) based on Boolean algebra was selected [10]. In brief, an increase, no change, or decrease in livestock inventory is related to the presence or absence of predictor variables. The QCA methodology integrates techniques from case study methods and variable-based methods of social analysis [10] and is rigorous even for small data sets [18]. Other data exploration techniques, such as factor analysis and principal component analysis, cannot accommodate, such mixed datasets. The QCA method has been applied to public health investigations [19], housing policy and evictions [20], and the adoption of sustainable drainage practices [21].

The approach was applied in two separate analyses with a common dataset that included five counties and 5 census periods. The first analysis considered commonalities in predictor variables to the livestock inventory outcomes across the five counties, referred to as the spatial analysis. The second analysis compared predictor variables to response outcomes for the 5 census periods between 1992 and 2017, referred to as the temporal analysis.

The full dataset and presentation of the method for both analyses are in S1.

2.3.1. Factor Transformation

The QCA method requires that all response and predictor variables be nominal-scale measures. Quantitative factors on an interval scale must be transformed. Several data can demonstrate the increase and decrease trends with time, and both conditions are important. Thus, several factors retained multiple conditions, each with thresholds to indicate the presence (1) or absence (0) of the condition. Although the transformation leads to the loss of some information, Ragin [10] reiterated that the restriction involved in the Boolean analysis does not hinder the analytical process because many independent and dependent variables are qualitative nominal-scale measures.

When quantitative data resolution was greater than every 5 years, the annual percent changes were calculated and averaged over the 5-year time interval coinciding with the livestock inventory data. For qualitative data, the condition present in at least 3 of the 5 years between census years was considered the average condition for the county and time period.

2.3.2. Truth Table Construction

The truth table relates the presence (1) or absence (0) of all predictor variables to the condition (increase, no change, decrease) of inventory for each of the types of livestock in each of the five counties for each of the 5-year periods between 1992 and 2017. For the spatial analysis across counties, the average condition (1 or 0) for each factor and livestock inventory result was the majority condition for the 5 census periods in a specific county. For the temporal analysis over time, the average condition (1 or 0) for each factor and livestock inventory result was the majority condition for the five counties for each census period.

There were instances of missing data, and these were excluded from consideration in the averaging process; in the case of an even number of 1s and 0s, the average condition was set to 1. In the case where data were missing for entire census periods, such as the gross domestic product (GDP) between 1992 and 2002 in the temporal analysis, the predictor variable was ignored in the formation of Boolean formulas in the next step.

2.3.3. Boolean Formulas for Analysis across Counties or across Time

A unique letter value (Latin or Greek) equated to each predictor value, where an uppercase letter was equivalent to a “1” or presence of a factor, and a lowercase letter equivalent to a “0” or absence of a factor, for each increment in the time or county analysis.

The result for each county (or census period) was a series of 29 letters representing the condition of all the predictor variables to the condition of the inventory for the type of livestock in the county (or census period)—or “Boolean formula”.

2.3.4. Common Conditions for a Type of Inventory Change

For each type of livestock, Boolean formulas for each county or census period associated with common results for a particular type of livestock (e.g., increase in the swine inventory) were added together, with common letters factored out and retained for further analysis in the next step.

2.3.5. Differentiating Conditions Based on the Type of Inventory Change

For each type of livestock, the resulting formulas were compared for increase, no change, or decrease in livestock inventory. Unique letters for each condition were retained. An uppercase and lowercase version of the same letter were considered unique. Letters were back-transformed to factor and condition descriptions (i.e., Table 1) for presentation.

3. Results

3.1. Factors Associated with Changes in Livestock Inventory

Table 1 presents the list of factors compiled from literature and interviews that demonstrated variability over time or among the five select counties. For example, a “vocal local” (i.e., individuals or organized groups in favor of or opposed to expansion that frequently attended board and/or community meetings in the county) emerged as a condition that stakeholders felt had influence over livestock development in a given region. Thresholds for a change of condition that were considered important are also defined in Table 1.

Factors were grouped into categories to aid in interpretation. There is an unequal distribution in the number of factors by category and potential overlap between factors. However, the analysis method treats each factor individually and does not consider interactions among factors.

Table 1. Summary of factors (categories), conditions/thresholds to indicate the presence, and data sources used in the Qualitative Comparative Analysis to understand changes in livestock inventory. Factors are specific to South Dakota counties from 1992–2017.

Factors (Category)	Threshold [1] to Indicate a Factor *Condition* Was Present
County population (Economic/Social)	The county population *increased* or *decreased* ≥5% between census reports relative to the initial report [22]
Hutterite colonies [2] (Social)	Hutterite colonies were present in the county during the time period [23]
Overall GDP (Economic)	The county's gross domestic product (GDP) *increased* or *decreased* ≥3% [24]
Ag GDP (Economic)	The county's GDP contributed by agriculture, hunting, and fishing industries *increased* or *decreased* ≥ 3% [24]
Ag/Total GDP (Economic)	The county's GDP contributed by agriculture, hunting, and fishing industries, relative to total county GDP, *increased* or *decreased* ≥3% [24]
Land use plan [3] (Governance)	A land-use plan or equivalent analysis was published and in effect for the county for the time period [25–29]
Zoning ordinance [4] (Governance)	Zoning ordinance(s) for the county were in place for the time period [30–33]
Setbacks increase (Governance)	Setbacks between livestock operations and other fixtures in the county *increased* in length during the time period, through a change in a county rule or ordinance [30–33]
Goal of ag expansion (Governance)	The land-use plan for the county includes a statement that one of the county's goals is to promote the growth of the agricultural economy during the time period [25–29]
Fertilizer price (Economic)	The average fertilizer price *increased* or *decreased* ≥3% [14]
N fertilizer use for corn (Economic)	The percent of corn acres in South Dakota that received nitrogen (N) fertilizer *increased* or *decreased* by 5% [14]
Hog market price (Economic)	The price received per market hog ($/100 lb) *increased* or *decreased* by 3% [14]
Cattle market price (Economic)	The price received per head ($/100 lb) *increased* or *decreased* by 3% [14]
Corn market price (Economic)	The price received for corn ($/bushel) *increased* or *decreased* 3% [14]
Soybean market price (Economic)	The price received for soybeans ($/bushel) *increased* or *decreased* 3% [14]
Swine processing capacity (Economic)	There was an *increase* in swine processing capacity within 322 km (200 miles) of the county border through a new facility or expansion of an existing facility (R. Thaler, personal communication, 29 September 2020)
Dairy processing capacity (Economic)	There was an *increase* in dairy milk processing capacity within 96 km (60 miles) of the county border through a new facility or expansion of an existing facility (R. Thaler, personal communication, 29 September 2020)
Vocal locals (Social)	There was a presence or absence of outspoken individuals or organized groups *in favor of* or *opposed to* expansion that frequently attended board and/or community meetings in the county; these persons were not part of county governance

[1] % change is the difference in value between census periods (i.e., 2017 minus 2012 value), relative to the initial value (i.e., 2012). [2] Hutterites refer to "a communal people, living on hundreds of scattered colonies throughout the prairies of Northwestern North America, where they farm, raise livestock and produce manufactured goods for sustenance" [23]. [3] A land use plan is a document that serves as a guide to policymakers for decision-making on the future use of public and private land resources over a 10 to 20-year period after adoption. [4] A zoning ordinance dictates land parcels where livestock and/or agriculture development is permitted. Ag = agriculture. GDP = Gross domestic product.

Additional factors were considered but ultimately excluded from further analysis. The change in condition for these factors was either indistinguishable, increased or decreased with time for all five counties or lacked a reliable metric for consistent evaluation in space and time. These factors were:

- Weather events: Extreme weather events in South Dakota and elsewhere, such as droughts, tornados, floods, and heavy snow loads, have a significant impact on crop and livestock production. Assuming the influence of weather on crop and feed production is greater than for confined/housed livestock for a county or state, crop market prices likely reflect the impact.

- Change in demographics of the county: There has been a decrease in the number of operators for agriculture operations [14]. Several stakeholders reported that over the last 50 years, there had been a lower presence of younger generations on family farms with livestock and a greater interest in crop versus livestock production. There was also mention of immigrant workers that supported the livestock industry, which may alter the demographics of a county. However, the number of immigrants employed to support one farm, for example, is relatively low compared to other industries in a county or state, and this information is not readily available from census data.
- Technological advancements: Technological advancements in machinery and production efficiency generally require fewer persons but greater investment and education [1]. While early adopters may gain a short-term advantage, such advancements tend to impact all producers equally over the time scales represented in this analysis.
- Land prices: Land prices and land rent prices have increased over time [34]. Land prices also differ across neighboring states and regions.
- Local leadership: The presence of agriculture-oriented leadership in a county can dictate the increase or decrease of livestock inventory, as some of these individuals make final decisions with regard to permit approvals. There was no concrete way to categorize the presence of ag-oriented leadership across time. However, the goal of agriculture expansion outlined in a county comprehensive land-use plan is considered a reflection of agriculture-oriented leadership for a snapshot in time.

3.2. Livestock Inventory Factor Analysis across Counties (Spatial Analysis)

Table 2 presents the predictor variables common among counties associated with the same trend in a specific livestock inventory, but unique to a type of change in livestock inventory. The number of instances of counties with an increase, no change, or decrease trend, denoted by n in Table 2, varied from 0 to 4. As the number of instances increased, the number of factors tended to decrease; the step to identify common conditions for a type of inventory change (Section 2.3.4) becomes more powerful in elucidating critical factors. When there are instances for all three types of changes in livestock inventory, more factors are removed from consideration for being common across the different types of change.

Corn market price increase is the only market factor to appear in Table 2. Market-related factors were from state-level data, thus being common across counties. This factor appears as a result of a limited instance (n = 1) of an increase in beef inventory.

Table 2. Conditions associated with an increase, no change or decrease in animal inventory in a **spatial** analysis considering five counties in South Dakota (Brookings, Grant, Hutchinson, Lincoln, Yankton). For each county, the change in inventory and factor conditions (Table 1) were the prevailing change present for the five census periods between 1992 and 2017. The number of counties (*n*) with a specific change in inventory outcome are shown.

Type	Conditions Associated with Change in Inventory					
	Increase in Inventory		No Change		Decrease in Inventory	
	Presence of...	Absence of...	Presence of...	Absence of...	Presence of...	Absence of...
Beef	Ag/Total GDP decrease Land use plan Goal of ag expansion Corn market price increase	Population increase Hutterite colonies Ag GDP increase Ag/Total GDP increase Setbacks increase Vocal locals in favor of expansion Vocal locals opposed to expansion	Ag GDP increase Ag/Total GDP increase	Ag/Total GDP decrease Corn market price increase	n/a	n/a
	$n = 1$		$n = 4$		$n = 0$	
Dairy	Land use plan	Setbacks increase	n/a	n/a	Ag GDP increase Ag/Total GDP increase	Ag/Total GDP decrease Vocal locals in favor of expansion Vocal locals opposed to expansion
	$n = 2$		$n = 0$		$n = 3$	
Swine	Hutterite colonies	Land use plan	Ag/Total GDP decrease	Hutterite colonies Ag GDP increase Ag/Total GDP increase	**	Goal of ag expansion
	$n = 1$		$n = 1$		$n = 3$	

** No factors common among instances of an outcome type but unique to only this outcome type. Ag = Agriculture. GDP = Gross domestic product.

3.2.1. Beef

The common conditions related to the four instances of stable beef inventory among the select counties were an increase in agricultural GDP, by itself and relative to the total GDP for the county. Unless there were significant delay effects, the agricultural GDP did not increase because of beef cattle production, but rather because of changes in production of other agricultural commodities. In the one instance of an increase in beef in Grant County, there were corresponding trends in the form of local governance, demographic, markets, and social acceptance factors. These factors and their related conditions are distinct from the instances common to stable beef inventory. Land use plans that included a county goal of agriculture expansion with the absence of increased setbacks were associated with an increase in beef inventory across counties. Land use plans outline how a county intends to use its resources to achieve the goals of a community. A land-use plan making provisions for agricultural expansion implies the dedication of land area for continued expansion of agricultural activities per the county's long-term goals. For this reason, it was expected that livestock inventory would increase. This relationship was present for beef and dairy but not for swine. Beef inventory increased in the absence of: vocal locals in favor or opposed to expansion; an increase in population; and Hutterite colonies. The absence of these demographic and social factors may reflect the "transitioning" state referred to by an interviewee, but limited data (n = 1) prevents far-reaching conclusions.

In summary, increased GDP was associated with stable beef inventory. A limited case suggests the presence of local governance tools and the absence of social factors associated with increased beef inventory.

3.2.2. Dairy

Trends in dairy inventory by county were associated with factors that pertained to county governance, social acceptance, and market factors. An increase in dairy inventory aligned with the presence of a land-use plan and the absence of setback increases. Several stakeholders mentioned efforts by the state to increase dairy milk processing capacity in eastern South Dakota with access to Interstate-29 [35]. A report in 2012 estimated "for every dollar of economic activity generated in the dairy industry $0.52 of economic activity is created in the rest of the South Dakota economy" [36]. Agricultural GDP increases, alone and relative to total GDP, increased during the study period in counties where dairy inventory decreased. While large dairies are multi-million dollar investments and provide a continuous product, the relative contribution of dairies is small compared to other agricultural industries in these counties [14]. Interestingly, the absence of vocal locals either in favor or opposed to expansion relates to a decrease in dairy inventory. This suggests that the presence of vocal locals had inconsistent relationships with counties with an increase in dairy inventory.

In the spatial analysis comparing counties, the presence of county governance planning tools was associated with an increase in dairy inventory, whereas agricultural economic growth and a lack of vocal influencers were more consistent with a decrease in dairy inventory.

3.2.3. Swine

Across the counties (Table 2), there were instances of increase (Hutchinson), no change (Grant), and decrease (Brookings, Lincoln, Yankton) in swine inventory. The few common conditions amongst the three counties with a decrease in swine inventory were further culled as being common with conditions for the increase and no change trends in swine inventory over time with the other counties. The presence of Hutterite colonies was associated with an increase in swine inventory, while the absence of Hutterite colonies was associated with no change in pig inventory. Hutterite colonies produce approximately 40% of hogs produced in South Dakota [37], so it makes sense that growth is associated with the presence of colonies and their activity. Local government oversight was connected to both increasing and decreasing pig inventories. While the absence of a county goal of agriculture expansion was associated with a decrease in pig inventory, Hutchinson County had an increase in pig inventory but did not have a land-use plan for much of the study period. Changes in county economic factors were associated with instances of no change in the pig inventory across counties.

Overall, factors related to a change in pig inventory at the county-level were linked to governance and social structures, whereas changes in market factors were associated with no change in inventory.

3.3. Livestock Inventory Factor Analysis across Time (Temporal Analysis)

Table 3 presents the predictor variables common between census periods associated with the same trend in a specific livestock inventory but unique to a type of change in livestock inventory. Similar to Section 3.2, the number of instances (n) varied from 0 to 4. Market factors from state-based reports are more prevalent in Table 3 compared to Table 2. The only appearance of a social factor was the absence of vocal locals when there was no change in beef inventory.

There is potential for time-delay effects by, or for, the factors with respect to the livestock inventories that are not captured in this type of analysis; this analysis does not connote cause-effect relationships.

3.3.1. Beef

When comparing the three census periods (2002–2017) with an increase in beef inventory, the presence of a zoning ordinance was the only common factor. Zoning ordinances are often included in land use plans, and their purpose is to ensure that agricultural expansion and construction can occur without harming the surrounding environment. In the other two time periods with no change in beef inventory, the common factors and conditions were many: the presence of increased N fertilizer use for corn; cattle market price; and the absence of increased setbacks; ag expansion goals; vocal locals in favor or opposed to expansion; and increased swine processing capacity. It is interesting that an increase in cattle market price is related to stable cattle inventory. However, the cattle market cycle involving accumulation and liquidation lasts approximately 10 years [38]; delays in cause-effect relationships are not captured with the analysis approach herein.

The relationships between beef inventory and local governance varied. Economic factors were more prevalent for stable cattle inventory in this temporal analysis.

3.3.2. Dairy

Census periods with an increase in dairy inventory were associated with an overall increase in GDP, the presence of a land-use plan and increased setbacks, and the absence of a decrease in cash crop market prices. Conversely, the unique conditions accompanying a decrease in dairy inventory were a goal of agricultural expansion, the absence of land use plans, and a decrease in hog and cattle market prices. Stable dairy inventory periods were related to cattle market price increases and N fertilizer use.

These relationships suggest corn and other markets do not influence dairy inventory, whereas local governance tools, such as land use plans, have distinct relationships with the dairy inventory.

Table 3. Conditions associated with an increase, no change or decrease in animal inventory in a **temporal** analysis considering 5-year census periods between 1992 and 2017. For each census period, the change in inventory and factor conditions (Table 1) were the prevailing change present for five counties in South Dakota (Brookings, Grant, Hutchinson, Lincoln, Yankton). The number of census periods (*n*) with a specific change in inventory outcome are shown.

Type	Conditions Associated with Change in Inventory					
	Increase in Inventory		No Change		Decrease in Inventory	
	Presence of...	Absence of...	Presence of...	Absence of...	Presence of...	Absence of...
Beef	Zoning ordinance	**	N fertilizer use for corn increase Cattle market price increase	Setbacks increase Goal of ag expansion N fertilizer use for corn decrease Cattle market price decrease Vocal locals in favor of expansion Vocal locals opposed to expansion Swine processing capacity increase	n/a	n/a
	n = 3		*n* = 2		*n* = *0*	
Dairy	Overall GDP increase Land use plan Setbacks increase	Overall GDP decrease Ag GDP decrease N fertilizer use for corn increase Corn market price decrease Soybean market price decrease	N fertilizer use for corn increase Cattle market price increase	Cattle market price decrease	Goal of ag expansion Hog market price decrease Cattle market price decrease	Land use plan Hog market price increase Cattle market price increase
	n = 2		*n* = 2		*n* = 1	
Swine	Overall GDP increase Land use plan Corn market price increase Soybean market price increase	Overall GDP decrease Ag GDP decrease Corn market price decrease Soybean market price decrease	N fertilizer use for corn increase Hog market price decrease Cattle market price increase Corn market price decrease Soybean market price decrease	Land use plan Zoning ordinance Setbacks increase Hog market price increase Cattle market price decrease Corn market price increase Soybean market price increase	**	**
	n = 2		*n* = 1		*n* = 2	

** No factors common among instances of an outcome type but unique to only this outcome type. Ag = Agriculture. GDP = Gross domestic product. N = Nitrogen.

3.3.3. Swine

The two census periods with an increase in swine inventory were associated with the presence of GDP increase, land use plans, and an increase in soybean and corn market prices. In situations where there were no changes in swine inventory, there were decreases in the corn and soybean market prices. Diersen [39] related growth in the South Dakota swine industry in the early 2000s to an influx of feeder pigs to finish with relatively inexpensive feed. Corn and soybean meal are primary components in pig feed, so a strong relationship makes sense. Hog market price decreases, increases in cattle market prices, and the absence of local governance tools, such as land use plans, zoning ordinances, or increased setbacks, were associated with no change in swine inventory. Stakeholders indicated manure nutrients were a consideration for local producers to invest in swine production in recent years, so it makes sense that an increase in nitrogen fertilizer use for corn is associated with no change in swine inventory. There were no unique factors or conditions related to periods of a decrease in swine inventory.

A lack of restrictive local governance tools was associated with an increase or no change in inventories, while an increase in swine inventory showed a stronger link to cash crop markets than to livestock markets.

3.4. Comparing Time-Based Analyses

The QCA approach is sensitive to the number of census periods or counties available for consideration. Table 4 compares the conditions associated with analyses using five census periods from 1992 to 2017 as compared to three census periods from 2002 to 2017, using swine inventory as an example. The loss of one period of no change and one period of decreased inventory removed local governance factors and shifted many factors and conditions associated with no change to decreased inventory.

A similar comparison of beef and dairy inventories showed shifts in factors and conditions, with more factors and conditions concentrated where there was only one time period for an inventory condition. The time period selected for analysis should emphasize a manageable number of outcomes, ideally with two or more common outcomes within the dataset, but also needs to consider data availability for predictor variables and any broader contexts influencing the result. Publicly available GDP data for the counties of interest began in the year 2000. In the spatial comparison (Table 2), there was no implication because the missing period was common. In the comparison of different number of time periods (Table 4), changes in GDP that are associated with an increase in livestock inventories (e.g., swine) in the 1992 to 2017 analysis appeared to be associated with a decrease in the 2002 to 2017 analysis. In this study, the evolution of the CAFO permit process by the SD DENR was a background influence common across counties for the selected study period from 1992 to 2017.

Table 4. Comparison of temporal analysis results that considered 3 and 5 census periods. For each census period, the change in inventory and factor conditions (Table 1) were the typical changes present for each of five counties in South Dakota (Brookings, Grant, Hutchinson, Lincoln, Yankton). The number of time periods (n) with a specific change in inventory outcome are shown.

Type (Time Period)	Conditions Associated with Change in Inventory					
	Increase in Inventory		No Change		Decrease in Inventory	
	Presence of...	Absence of...	Presence of...	Absence of...	Presence of...	Absence of...
Swine (1992–2017)	Overall GDP increase Land use plan Corn market price increase Soybean market price increase	Overall GDP decrease Ag GDP decrease Corn market price decrease Soybean market price decrease	N fertilizer use for corn increase Hog market price decrease Cattle market price increase Corn market price decrease Soybean market price decrease	Land use plan Zoning ordinance Setbacks increase Hog market price increase Cattle market price decrease Corn market price increase Soybean market price increase	**	**
	$n = 2$		$n = 1$		$n = 2$	
Swine (2002–2017)	Corn market price increase Soybean market price increase	**	n/a	n/a	Ag GDP increase Ag/Total GDP increase Setbacks increase Hog market price increase Cattle market price increase	Ag/Total GDP decrease N fertilizer use for corn increase Hog market price decrease Cattle market price decrease Corn market price increase Soybean market price increase Vocal locals in favor of expansion Vocal locals opposed to expansion Swine processing capacity increase
	$n = 2$		$n = 0$		$n = 1$	

** No factors common among instances of an outcome type but unique to only this outcome type. Ag = Agriculture. GDP = Gross domestic product. N = Nitrogen.

4. Discussion

4.1. Factor Identification and Interpretation

The response variables (inventories) and multiple predictor variables had multiple conditions (Table 1). Data availability was a key consideration in the selection of factors used in this analysis. Some data, such as county ordinances and changes in setbacks, have a variable or limited presence on publicly available websites; prior versions can be difficult to track. Many county land-use plan documents contain a preamble on the history of planning in the county, identifying important changes (i.e., References [25,26]). It is interesting to note that every factor, except an increase in dairy milk processing capacity, appeared at least once in Tables 2 and 3, although not every condition associated with a factor appeared.

The resolution of data and differences in resolution across factors typically poses a challenge to gain useful insight into which factors affect livestock development [40]. The benefit of the QCA approach is that it treats factors and their conditions individually. Additional factors could be added to extend the analysis if appropriate and reliable data are available [10]. One challenge is integrating different types of datasets, such as the 5-year census, with those that do not match that time interval or whose impacts may or may not be immediately evident in data.

All predictor and response variables in the illustration of this method required classification into nominal-scale measures. Quantitative factors had to be transformed based on thresholds. The "significant" thresholds for conditions (Table 1) are somewhat arbitrary but arose from consideration of typical and important changes over time. For example, the county populations ranged from less than 10,000 to greater than 100,000. A percent change seemed appropriate, as 500 people represent a town for smaller counties, while 5000 people may represent a suburb for cities in more populous counties; each level of growth (or decline) is relevant. This approach standardizes all levels of growth, regardless of whether growth is 6% or 60%. The classification into "1" or "0" implies that factors have an all or nothing impact. In reality, there are gray areas, where different levels of associated factors relate to levels of response variables. However, applying a fuzzy logic approach requires weighting each factor, which would introduce a higher level of complexity to the analysis. The Boolean logic approach was selected as a relatively simple method to identify associations between individual factors and the perceived outcomes.

4.2. Qualitative Comparative Analysis Approach

A Boolean approach is valid and useful when both qualitative and quantitative data are contained in a given set of explanatory factors for assessing one or more response variables. Every county, as in every community or system, has unique nuances and situations that are important and will appear in a Boolean formula (Section 2.3.3). This QCA method focuses on synthesizing common quantitative and qualitative data to answer the question of "how things happen", broadening the application of results to a broader set of counties or time periods, similar to work by Cragun et al. [41]. The occurrence of and need to consider factors both quantitative and qualitative is inherent to complex systems. The use of letter formulas is advantageous because they are straightforward, easy to learn and understand. The method simplifies appending individual factors or conditions but still retains focus on the combination of predictor variables to the different cases of changes in livestock inventories [10]. Ragin [10] demonstrated examples of this Boolean approach with fewer predictor variables and two response variable conditions. More variables and conditions add complexity, but superfluous variables disappear if sufficient instances of a response condition are available.

A greater number of cases of an outcome (*n* in Tables 2–4) typically resulted in fewer common variables associated with an outcome. Thus, this approach should reduce the occurrences of coincidental relationships. However, if the number of cases for different outcomes was not evenly weighted (e.g., Beef in Table 2), there was less opportunity to evaluate whether a predictor variable was truly unique to a specific outcome. This was also evident in Table 4, where predictor variable association shifted, usually to categories with fewer *n*.

There are potential delays for livestock inventory changes in response to social, economic, and environmental changes. The beef market cycle [38] is one example discussed earlier. Passage of policy at the federal, state, or local level can take time and induce uncertainty in the building or expansion of livestock operations. While this approach identifies association and common patterns among variables, it does not equate to causation. The response variables may be cause or effect for changes in predictor variables. The QCA approach makes sense as a preliminary action to identify key variables for process-based, systems thinking, or systems dynamics analyses.

4.3. Conditions for Change in Livestock Inventory

The study period of 1992 to 2017 encompassed evolving state oversight over livestock expansion by CAFOs. The increase in permit requirements and CAFO regulation almost certainly impacted livestock development during this time. While some see permits and policies as restrictive, livestock industries often consider permits and policies as protection from future prosecution. For example, the South Dakota Pork Producers Council was a cooperator in developing the first permit [15].

Local governance encompasses many potential tools (Table 1). Similar to state permit programs, zoning ordinances and setbacks are not necessarily restrictive to livestock inventory growth if they provide clear guidance. The presence of a land-use plan was associated with periods of growth in dairy and swine inventories (Table 3) and dairy inventory by county (Table 2). Increased setbacks and a goal of agriculture expansion seemed to have mixed effects between types of livestock across counties (Table 2) and across time (Table 3).

The influence of livestock development on society at the county level was mentioned during every stakeholder discussion. The effects of livestock development or contraction on county population and social acceptance are key considerations for local governments, echoing results of Mann [2]. The absence of population increase only emerged for the one instance of inventory increase for beef in Table 2. Vocal locals in favor of or opposed livestock development tended to follow each other based on public press articles and organization formation. Interestingly, only the absence of vocal locals emerged as a common occurrence for multiple outcome types, but never their presence. Hutterite colonies were an important consideration for the South Dakota counties but would not be a factor for most other states. While social factors were key for stakeholders, the influence of those factors identified in Table 1 was low in this analysis for both the counties studied and the study period.

There were more economic factors than other categories (Table 1), likely due to data availability. There was an increase in overall GDP related to periods with growth in dairy and swine (Table 3). Table 2 indicates these GDP increases did not appear in counties with an increase in dairy or swine inventories. However, the GDP increases in time appear concurrently with cash crop market prices. Livestock market increases tend to relate to periods of no change and may be related to market cycles [38]. There was no factor for dairy milk price, but dairy milk processing capacity was considered. Whether for time delay reasons, or perhaps stronger influence in counties not included in the analysis, this variable did not emerge in Tables 2–4.

While the results of the adapted QCA analyses are context- and scope-specific and dependent on the list of factors and thresholds identified (Table 1), the overall approach can be applied to other geographic locations at similar or expanded scales or even other social-economic challenges outside of the animal agriculture realm. The temporal analysis (Table 3) has regional implications, and results apply to a broader population segment. The spatial analysis considering select counties (Table 2) has greater implications for local decision-makers, demonstrating the influence of local governance and social factors.

5. Conclusions

Evaluating agricultural sustainability requires understanding the connections between livestock production and surrounding rural and urban communities. The Qualitative Comparative Analysis approach adapted herein identified commonalities in conditions for a set of social, economic, and local governance-related factors to livestock (beef, dairy, and swine) inventory changes in five counties in South Dakota and for census periods between 1992 and 2017.

In the spatial analysis across the five counties, many social, economic, and local governance factors emerged with specific conditions related to an increase, no change, or decrease in livestock inventories for beef, dairy, and swine. Stable beef inventories related to counties with increasing gross domestic products. Dairy inventory increases associated with county governance planning tools (i.e., land use plans), but inventory decreases associated with increasing gross domestic products. The presence of specific social com-munities related to increases in county swine inventories. In a temporal analysis of commonalities between census periods, local governance and economic factors, particularly market price influences, were more prevalent. Local governance tools, such as land use plans and setbacks, had variable relationships with inventories across animal types. Census periods with increasing cattle market price increases related to stable beef, dairy and swine inventories. Periods of increasing cash market price increases related to increasing swine inventories.

The results are context-specific for the counties and time periods included in the analyses. However, the adapted QCA approach lends itself to other complex scenarios that require analysis across multiple dimensions and data types.

Supplementary Materials: The following are available online at https://z.umn.edu/S1_Qual_Comp_Analyses, Workbook S1: Quantitative Comparative Analyses.

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Appendix A

Table A1. Animal inventory [14] and percent change (%) between census values (relative to earlier census value).

County	Types	1992	%	1997	%	2002	%	2007	%	2012	%	2017
Brookings	Beef	20,129	5	21,189	−3	20,527	11	22,870	−18	18,792	3	19,353
	Dairy	3844	29	4953	29	6405	47	9437	43	13,514	37	18,551
	Swine	70,832	−17	58,890	−41	34,483	−19	28,015	66	46,580	59	73,820
Grant	Beef	10,942	6	11,548	11	12,762	7	13,635	3	14,014	34	18,718
	Dairy	5357	11	5938	40	8294	8	8959	−2	8762	102	17,697
	Beef	18,005	−53	8482	12	9517	−67	3117	n/a	No data	n/a	1380
Hutchinson	Beef	24,873	9	27,170	−2	26,728	−8	24,678	−4	23,805	27	30,221
	Dairy	5308	−23	4110	−48	2127	36	2900	−7	2707	−15	2301
	Beef	114,595	−18	93,863	19	111,708	5	117,257	9	127,676	14	145,125
Lincoln	Beef	7799	−1	7717	−4	7413	−5	7064	22	8598	−42	4955
	Dairy	1896	−41	1121	−31	776	−45	427	59	677	746	5728
	Beef	62,289	−34	41,406	−21	32,741	−14	28,302	25	35,377	14	40,388
Yankton	Beef	12,133	4	12,672	−3	12,241	35	16,488	−29	11,694	39	16,265
	Dairy	1309	−41	770	3	794	−56	349	−73	96	8	104
	Beef	70,567	−46	37,823	5	39,568	−55	17,981	−40	10,712	44	15,405

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