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Where's the Beef (Going to Be)? How Changing Risk Perceptions Could Affect the Number and Location of Beef Processing Plants

by

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“Where’s the Beef (Going to Be)? How Changing Risk Perceptions Could Affect the Number and Location of Beef Processing Plants.”

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Abstract

This paper provides a framework to examine the potential impact of enhanced managerial focus upon the risk of plant shutdowns (and general production interruptions) on firms' spatial capital investment decisions, illustrated with an empirical application to beef production plants. We consider both the geographic location of each plant and its size, thus also choosing the optimal number of production plants to operate. In both risk neutral and risk averse settings, we examine the robustness of these plant capital investment decisions to shifts in the perceived risk of plant shutdowns. Both national (absolute) and location-specific (relative) shifts in risk perceptions are tested. We find that the optimal plant configurations for beef producers of diverse sizes are all quite robust to shifts in shutdown risk perceptions within individual model specifications. However the comparisons of the risk neutral to risk averse models or absolute to relative shift models do show differences in optimal plant configuration. These results lead us to conclude that the spotlight which Covid-19 shone on plant shutdown risk is unlikely to lead to substantial changes in the spatial configuration of animal production in the U.S, but that climate change may.

Key Words: Beef Production, Climate change, Covid-19, Investment, Risk Perceptions.

INTRODUCTION

Many different economic decision models incorporate assumptions about how the level and nature of risk involved gives rise to different optimal choices. The true level and nature of risk, however, are extremely hard, if not impossible, to know. This led to the development of models of risk under uncertainty such as in Knight (1921) or Bloom (2009). These models still generally hinge on knowing something about where true risk levels lie for different decision paths rather than the *perception* of the true risk which can be quite different (Garicano and Rayo, 2016). Could this distinction make any meaningful difference in decision outcomes? The *perception* of risk probability is surely heterogenous, based on a firm's individual experiences and own risk preferences, and also more prone to changes whereas the true risk probability is an objective single value (Anwar et al., 2022). This is especially interesting when risk perceptions for various supply complications are shifting by significant amounts, such as from the impacts of an event like COVID-19 or severe weather events. A natural question to ask is: How could shifts in a firm's risk perceptions impact the spatial organization of various industries, in particular the size, location, and number of production facilities firms choose to employ?

Risk perceptions can and have changed, rapidly and permanently in some cases, with new experiences and information (Weick, Sutcliffe, and Obstfeld. 2005). For example, in the wake of terrorist attacks on September 11, 2001, all air traffic in the United States was grounded. Along with the sudden halt of air traffic, all other transportation methods, including trucking, train, and shipping, were slowed to a glacial pace to allow for thorough inspection of possible threats if not halted all together. This affected the supply chain of auto parts making their way to automobile manufacturing plants all over the country (as well as a multitude of other industries), causing short term shutdowns of many production plants (Deutsch, 2001; Suder, Chailan, and Suder, 2008). The result was a major shift in auto manufacturers' perceptions about the risk of a supply chain disruption (Lampel, Shamsie, and Shapira, 2009). The short shutdown in transportation networks in 2001 led to new contract terms for suppliers to the auto industry where inputsupplying plants now are required by the auto manufacturer to be within a specific distance of the final manufacturing plant to alleviate the chance of shutdown risk from transportation disruptions in the future. This change in the geography of automotive supply chains stemming from one relatively short shutdown shows the possible impact of shifts in *perceptions* of risk on firm decision making, versus changes in the actual constant unobserved risk levels of a shutdown event. The risk of a supply chain disruption did not change from before the disruptions experienced in the wake of the terrorist attacks (terrorist attacks could have been anticipated before 9/11), but the automobile firms' *perception* of the risk that a sudden supply chain disruption could occur underwent a significant shift. These sorts of shifts can occur regionally as well. For example, the shutdown of gas production in southeast Texas after Hurricane Harvey in 2017 impacted gas prices all over the southeastern United States, but not in other regions of the United States. (Ivanova, 2017). Occurrence of similar natural disaster events, especially with the variation due to climate change in regard to the number, intensity, and the location of extreme weather, may shift relative risk perceptions of possible production locations, changing the optimal production decisions.

Heterogeneity in risk perceptions also likely accounts for some of the variation in tolerated earnings variability (Bronin et al. 2007). For some firms, especially those with publicly traded stocks, consistency in cash flow is extremely important. A bad quarter can have a major impact on stock prices and cause concern among investors. Privately held companies can withstand more variable cash flows, as they do not have to demonstrate profitability to investors in the same way. Differing risk perceptions relative to earnings consistency could drive heterogeneity in observed risk aversion levels.

Firms are updating their perception of the risks and potential losses to their businesses constantly. Therefore, accounting for the impact of risk perception-shifting events for firms making capital investment decisions should be part of a decision model, as the firm's post-shift event optimal decision may not be the same as the pre-shift decision (Aghion et al., 2021). Including perception shift impacts, if they are meaningful, would help policymakers better predict policy outcomes, as well as help economists more accurately model the real-world decisions firms make. If the risk perceptions are shown not to have an impact on optimal plant configurations, the insight would still be useful to policy makers. If changes in risk perception have no effect on plant configuration decisions, then firms can more confidently make long-term capital investments and policy makers can accurately predict responses to policies. If shifts in risk perceptions do change optimal firm investment strategies (e.g., higher shutdown risk perceptions lead to a larger number of smaller, more geographically dispersed plants), then firms and economists might want to describe risk perceptions with a (Bayesian) prior distribution and find the optimal decision averaged over possible risk perceptions. Understanding the stability of plant investment decisions in the face of potentially changing risk perceptions is especially important for smaller communities where a production facility may be a large, if not the largest, employer in the area. This is most frequently the case in rural areas where most food processing plants are located. Local communities need to know if the large local employer is likely to stay as some communities have suffered enormous disruption and financial losses when such a major employer closed down (Buchele, 2013).

This paper proposes a decision model to demonstrate the impact of risk perceptions about short-term plant closures on firm-level capital allocation decisions on the size, location, and number of their production facilities. This will provide insight into a firm's decisions about where to place a new plant, how many plants to build, and how big these plants should be. This model will have four versions; one where firms are risk neutral and facing absolute (national) shocks, one where firms are risk neutral and facing relative (locational-specific) shocks, one where firms are risk averse and facing absolute shocks, and one where firms are risk averse and facing relative shocks. Testing all models will more accurately account for the impact of increased variability in production and cash flows for a company. All models will be calibrated with plausible real-world numbers for a beef producing firm and the models testing for locational-specific shocks will be calibrated with plausible real-world numbers for changes in extreme weather based on IPCC climate change models and NOAA weather data.

While these plant capital decisions would have to be made by all manufacturing firms regardless of industry or place in the production chain, this paper focuses on animal protein producing firms for the empirical application, beef production plants in particular. Given the structure of the animal protein industry, where there is generally only one manufacturing firm between farm and consumer, the firm's decision about plant structure would not need to consider the impact of firms further up or down a production chain. Similarly, these firms need to consider a limited number of inputs and outputs, thus simplifying the model and the calibration requirements.

This paper contributes to the literature in several important ways. First, it provides a framework for analyzing changes in risk perceptions within the context of a firm's capital investment decisions in a manner that actual firms could employ, thus building on work such as Bloom (2009) and Aghion et al. (2021). Second, it provides policy-relevant results on the future stability of the current industrial organization of food processing at a time when shutdown risk perceptions are changing rapidly due to factors such as COVID-19, the instability of the Texas electric grid, and an overburdened international supply chain. Third, it presents evidence on the role of risk neutrality or the degree of risk aversion on a firm's capital investment decisions and, thus, the stability of those decisions in periods when risks are perceived to be changing rapidly. Lastly, it assesses the different impact of absolute and relative shocks. Taken together, these results provide some insight into the changes to be expected in the location and organization of food manufacturing in the U.S.

THEORETICAL MODEL

Risk Neutral Absolute Risk Shock Model

We assume a risk-neutral firm is working to meet a specific range of demand for its product(s), and thus will be maximizing its profit over both input usage and all plant configurations that produce within a pre-specified range of the level of demand they are currently meeting. The theoretical model is therefore grounded in the standard profit maximization model, with the firm's objective being to choose a plant configuration in order to maximize the discounted flow of expected profits per unit of production capacity over a known time horizon. To include temporary shutdown risk perception, the firm's forecast for the random variable of the percent of time that the plant will be operational is assumed to have expected value of φ; or more intuitively, $(1-\varphi)$ is the perceived share of time each production period that a plant is expected to be shutdown at a given location. The full model is as follows:

$$\text{Max}_{\Omega_j}\ E(\pi) = E\left\{\frac{\sum_{t=1}^{T}\left(\frac{1}{1+r}\right)^{t}\left[\sum_{i=1}^{I}\varphi_{it}\left(P_t^o Q_{it} - P_t^n X_{it} - \tau_{it}^o - \tau_{it}^n - L_{it} - U_{it}\right) - FC_{it}\right]}{Q_t}\right\} \quad (1)$$

subject to:

$$\Omega_j = \{S_i, I, g_i\}$$
$$\tau_{it}^o = \tau_t Q_{it} d_i^o$$
$$\tau_{it}^n = \tau_t X_{it} d_i^n$$
$$L_{it} = w_{ti} l_{it}$$
$$U_{it} = p_{kwti} e_{it} + p_{wit} h_{it}$$
$$\sum_{i=1}^{I} Q_{it} = Q_t$$
$$Q_{it} \leq F(X_{it} S_i, \varphi_{it})$$
$$FC_{it} = F(S_i)$$
$$X_{it} = F(S_i)$$
$$l_{it} = F(S_i)$$
$$u_{it} = F(S_i)$$
$$h_{it} = F(S_i)$$
$$|Q_t - B_t| \leq \varepsilon * B_t.$$

Thus, the firm maximizes expected profit per unit produced over a set of configuration variables, Ω_j, including scale of the plants, S_i, location of the plants, g_i, and the total number of plants, I.[1] The expected profit resulting from a firm's capital decision will be calculated over all time periods 1 through T, where the first time period will be the first fully operational time period, and over all possible plants, 1 through I. Profit in time periods after the first will be discounted at the discount rate r.

Revenue is shown by a vector of prices at the current time period for each output produced by the plant, P_t^o, in dollars per unit multiplied by the corresponding and conformable vector of output quantities for each type of good produced at the current plant and current time, Q_{it}. Similarly, the variable costs include the vector of total input good costs for all input goods, $P_t^n X_{it}$. The τ_{it}^o and τ_{it}^n represent the total transportation costs of the output goods to the consumer market and input goods into the plant, respectively. This cost is calculated using the cost of transport, τ_t, in dollars per mile per unit of good[2], Q_{it}^o or X_{it} respectfully, and the distance traveled, either from the plant location, g_i, to the consumer market, d_i^o, or from input production location to plant location, d_i^n, respectively.

L_{it} represents the total labor costs for a plant in one time period and is a function of wage rate in the current time period and location, w_{ti}, in dollars per hour, and the amount of labor hours needed for optimal plant production for the entire production time period, l_{it}. l_{it} is a function of the scale factor, S_i. These two variables, wages and labor hours can be formatted as

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[1] We optimize over profit per unit of output instead of profit because output is constrained to a finite range around goal production. Output is not a normal choice variable, but is most constrained, so maximizing profit per unit seems to make more sense here than focusing on total profit and favoring plant configurations that lean towards the upper end of the allowable production range.

[2] This may require some variables not listed in the equations as most fuel costs are in dollars per gallon, so things like fuel efficiency and weight capacity of the normal shipping method may be needed to fully calculate.

vectors depending on the level of production in a facility and to account for large differences in pay between plant management and floor workers. It is assumed the plants display increasing returns to scale as per Ball and Chambers (1982) and Morrison Paul (2001a, 2001b). All three papers find evidence of increasing returns to scale for meat production, and in particular beef production plants. Morrison Paul (2001a) notes the economies of scale are much higher for plants which diversify their production outputs, whereas plants specializing in only one product, like slaughter plants, where primal cuts of meat are the primary product, have returns to scale closer to constant returns. U_{it} represents the total utility cost of the firm per time period and is a function of energy price for the current time period and location, p_{kwti}, in dollars per kilowatts, the number of kilowatts needed for optimal production for the whole time period, e_{it}, the price of water services, p_{wit}, in dollars per 1,000 gallons[3], and the amount of water needed for one production time period, h_{it}. Similar to l_{it}, u_{it} and h_{it} are functions of the scale variable, S_i, and are also subject to differences in location.[4] The functional form is assumed to be, again, increasing returns to scale.

These variable costs will be multiplied by the expected value of the risk perception variable, φ_{it}. For simplicity, consider it the expected value of a binomial random variable representing the average amount of time a plant is expected to be operational in one given time period. φ_{it} is unique to every plant built and for every time period the plant will be operational and encompasses all the information the firm knows about the risks at that location, that size plant, that time period and relative to the number of total plants being considered. Location-specific shutdown risks include things like the possibility of natural disasters that would affect plant production; for example, hurricanes in the southeast would not affect a plant in the upper Midwest but could affect a plant in Texas or Louisiana. Wildfires are also included as they are more predominant in the western part of the United States versus other areas, so plants located in the west would have a higher likelihood of experiencing them. Plant size-related risks include the increased possibility of things breaking in a larger plant, as there is a larger opportunity for things to break with more equipment. As we have seen with the ongoing COVID-19 pandemic as well as many other viruses, with more people in a space there is also a greater chance of a large disease outbreak that could shut a plant down, especially if that plant is located in a more populated area versus a less populated one. This could also affect larger plants more so than smaller ones, shifting their φ distributions.

Lastly, the fixed costs will include all costs of building the plants and purchasing the machinery. FC_i is also assumed to be a function of scale, and as with other variables above it will display increasing returns to scale, but at a decreasing rate.

The optimization equation in (1) is subject to several constraints, listed below it. The first five indicate the relationships between group variables in the objective function proper and are used for ease of reading. The next two are feasibility constraints. The second feasibility constraint as well as the three constraints after it, are all functions of the plant scale. The last constraint states the difference between total production for the firm and their goal production is some small percentage, ε, of the goal production level. This goal production level is based on the firm's belief about demand for the product and allows us to consider plant configurations that

[3] Again, some intermediate price relations may be needed if water rate prices are presented in cubic feet instead of 1,000 gallons

[4] Water prices in particular are subject to locational differences in prices due to different water rate scales, which can unevenly affect plant costs for difference scales.

yield slightly different total firm outputs, but not configurations that stray too far from the firm's goal output.

This model serves as the basis for the other three model types where risk aversion or relative risk shock, or both are incorporated. Thus, for ease of reading, this model will be referred to as the 'base model'.

Incorporating the Perception of Relative Risk Shocks

This model can be generalized to show relative risk shocks, and climate change will be used here as an example of a shock to relative risk perceptions. The model uses the same objective function as the base model but changes the calculation of the φ variable. This change reflects the firm's beliefs about how risk levels at specific locations will change relative to each other over time, due to things like climate change or other time and locational variant risks. In the base model φ_{it} is the measure of risk perception a firm has for that plant location and time period. In this model it will be defined a bit more explicitly where:

$$\varphi it = F(\rho_t, \gamma_i, \eta_i t) \tag{2}$$
$$\rho_t = F(t)$$
$$\gamma_i = F(i)$$
$$\eta_i t = F(it)$$

ρ_t is the set of all time-variant risks affecting short term closure to the plant in time t, γ_i is the set of all locational-specific risks to the plant, and η_{it} is the set of all time- and locational-variant risks to plant i at time t. Risks that are not locational or time variant are not included as they affect all times and locations equally and therefore do not alter optimal configuration choice. Risks in the ρ set are a function of only time within the life of the plant, these could include things like machinery wear or obsolescence, and do not change between location. Risks in γ are risks which do change between location, these include risks due to plant size as well as plant location, but they do not change with time. These risks are the major contributor to differences in φ_{it} in the base model. Lastly, η risks are those that change with time and plant. These risks would include changes in the perception of extreme weather occurrences since that would, if climate change is accounted for, change over time and over location. Previously the values for η_t and ρ_t were constant throughout the productive life of the plant, but in this model, to focus empirically on climate change, which will affect both location and time risk, the η_{it} variable will now be a function of how the risk will change through time and by location. ρ_t continues to be held constant but could be made to change over time for other time variant and location constant risks the firm would like to consider.

Incorporating Risk Aversion

The risk averse model is similar to the risk neutral model. The firm is assumed to maximize a different objective function, using the common mean-variance formulation of the profit function that is the objective function for risk neutral firms. The formulation allows for the modeling of variable levels of risk aversion using λ as a firm-specific risk aversion parameter (Varian, 1992). The risk aversion parameter λ penalizes plant configurations with more variation in profit, with more risk averse firms imposing a larger weight on the variance penalization term.

To compute the variance in profit, we leverage the assumed binomial nature of the shutdown risk for which given an expected value of φ, the variance will be φ(1- φ). Thus, given an expected value of φ for the shutdown risk, the variance of profit will be φ(1- φ) multiplied by the square of the variable part of the profit function. Only the variable components of the profit function need be included since random plant closures do not affect fixed components like construction or equipment costs and loan payments. The risk averse optimization model is thus,

$$\mathrm{Max}_{\Omega_j}\ \mathrm{E}(\pi) - \lambda \mathrm{var}(\pi)/2 \ =$$
$$E\left\{\sum_{t=1}^{T}\left(\frac{1}{1+r}\right)^{t}\left[\sum_{i=1}^{I}\varphi_{it}(P_t^o Q_{it} - P_t^n X_{it} - \tau_{it}^o - \tau_{it}^n - L_{it} - U_{it}) - FC_{it}/Q_{it}\right] - \left(\frac{\lambda\varphi(1-\varphi)\left(\sum_{i=1}^{I}\varphi_{it}\left(P_t^o Q_{it} - P_t^n X_{it} - \tau_{it}^o - \tau_{it}^n - L_{it} - U_{it}\right)/Q_{it}\right)^2}{2}\right)\right\} \quad (3)$$

subject to the same constraints as in the risk neutral decision model and where the parameter λ is the measure of risk aversion for the firm.

Incorporating Relative Risk Perception Shocks and Risk Aversion
To incorporate both relative risk perception shocks and risk aversion the last model uses the same optimization equation (3) as in the risk averse model above, but also uses equation (2) to incorporate possible time and locational shocks in the calculation of φ. Thus, this fourth model accounts for both risk aversion and relative risk perception shocks. It does not add additional changes to the model over those described in the three models above but does include all additional changes described separately above into one single model.

EMPIRICAL MODEL: PLANT CONFIGURATIONS IN BEEF PRODUCTION

Risk Neutral Empirical Model

While the theoretical model of this paper can be generalized to most firms making plant building decisions, to allow for empirical analysis several assumptions limiting the generality of the model will be made. The first of these assumptions is the kind of firms being considered. The empirical model presented here is calibrated to match plants rendering live cattle into primal cuts of beef.[5] Because primal beef production has few variable inputs (live animals, water, energy, labor) and has a simple production function (primal cuts of beef are pretty close to constant proportions per carcass), this application allows for more accurate, feasible modeling than many industries. The production time period considered will be one year. We assume three firm sizes (or types) in this calibration, each with its own goal production level B_t. This is based on the structure of the beef industry where four very large firms share 80% of the market, and the rest of the fringe firms share the remaining 20%. These fringe firms can be either large or small. The total goal production for these firms is as follows: 4 million, 800,000, and 400,000 head per year, for representative big four, large fringe, and small fringe firms, respectively. Given the significant differences in these goal production levels, the scale variable will be assumed discrete such that there are five sizes of plants: small, medium, large, jumbo, and titan processing 100, 500, 1,000, 2,000, and 5,000 head a day, respectively, effectively covering the entire range of plant sizes observed in the U.S. beef industry. Firms can choose to have any number of plants from one to twelve. The fringe firms will only be given a choice between small, medium, and large plants, whereas big four firms will only be given the options of large, jumbo, and titan plants. These scale assumptions will affect all variables that are a function of scale, making those variables discrete with three choices per firm type as well. For these scale-dependent functions,

[5] This will exclude all animal protein goods that are further processed, like pre-marinated cuts or retail cuts, but include all primal cuts of meat, i.e., boxed beef.

increasing returns to scale will be assumed. Using the findings of Morrison Paul (2001a and 2001b), the increasing returns are such that for every 1% increase in production there is a 0.95% increase in costs. While it would be preferable to have different variable-specific returns to scale levels for each of the variables, there is a limited amount of data on the non-animal costs associated with meat production plants (Lusk et al., 2021), and therefore the above form of increasing returns is applied to all scale-dependent variables.

These plant production levels line up with the industry designations of small, medium, and large plants, and anything over 1,000 head a day is considered larger still. The use of the jumbo and titan plants allows the big four firms to stay within the 12-plant maximum but also produce within their goal production range. This 12-plant limit is consistent with industry reality, as no current firm, including the big four sized firms like JBS, Cargill, or Tyson, operates more than this number of beef processing plants.[6]

The value used for the live animal costs, P_{it}^{n}, is a weighted average of monthly accumulated 5-area[7] prices for both heifer and steer as reported by USDA-AMS from November of 2018 until August of 2021. These are reported in dollars per hundred-weight (cwt). The average weight of cattle will be 14 cwt, as this is the average weight between steers and heifers in the reports weighted by the total amount for each sex. The value for input quantity will be dependent on the scale of the plant as noted above. The output good is boxed beef, or primal, cuts, of beef. Output prices will be an average of the daily box beef cutout values taken from the same USDA-AMS reports, again in dollars per hundred-weight. Given that boxed beef cutout estimates are a calculated value of a full carcass based on the prices from the individual primal cuts, output units will be the same as the number of head per day input levels, but the weight per head will be 65% of the live animal weight (Saner and Buseman, 2020). Using the cutout prices allows the functional form of the production function to remain flexible in empirical calculations and limits the output to one good. Labor costs per state come from the U.S. Bureau of Labor Statistics' occupational employment and wage statistics for slaughterers and meat packers. Price per gallon of diesel for transportation costs is an average of #2 diesel prices for the United States[8] over the last 20 years, with an average fuel economy of 6.5 miles per gallon (Andrews, 2021). The numbers and sources for these variables are listed in Table 1.

Table 1: Location and Size Constant Variables[1]

Variable	Values	Source
Price of Cattle	\$114.24/ cwt	USDA 5 Area Average Prices
Price of Beef	\$240.71/ cwt	USDA Boxed Beef Cutout
Price of Gas	\$2.72/gal	US Energy Information Administration

[1] These values stay the same throughout time and location for the entirety of the model.

[6] Fewer than 12 beef production plants that produced boxed beef, this does not include plants that do further processing.
[7] The five area prices include Texas/Oklahoma/New Mexico, Kansas, Nebraska, Colorado, and Iowa/Minnesota feedlots.
[8] The average price of diesel over the entire United States is used due to the shipping truck moving through more than one state or area while transporting goods.

The locations available for plants are all locations of actual beef production plants. By specifying the location choices, area-specific electric prices, water rates, and construction cost can be used as well as enabling us to estimate shutdown risks based partly on real-world natural phenomena.[9] The labor costs per hour and electric prices per kilowatt hour are listed in Table 2 along with the locations. Given the differences in how water rates are scaled in different municipalities, water rates will be presented as total cost of water for the entire production time for each plant scale and location. These are presented in Table 3.

Table 2: Location Variant, Size Constant Variables[1]

Location	Mean Wage Rate($/hour)	Electric Cost ($/kWh)
Source	Bureau of Labor Statistics	Electricity Local
Cactus, TX	14.15	0.0404
Dodge City, KS	16.23	0.0723
Fort Morgan, CO	17.56	0.0432
Friona, TX	14.15	0.0404
Grand Island, NE	15.35	0.073
Greeley, CO	17.56	0.0604
Hyrum, UT	14.87	0.0549
Milwaukee, WI	14.74	0.0811
Omaha, NE	15.35	0.0538
Plainwell, MI	15.14	0.0718
Schyler, NE	15.35	0.0692
Tolleson, AZ	16.44	0.061

[1] These values are the unit costs of labor and electricity, quanitities of labor and electricity are found in table six below.

Table 3: Water Costs per Month in Dollars[12]

Location	Small[3]	Medium	Large	Jumbo	Titan
Cactus, TX	165,084.75	644,442.83	1,211,550.74	2,301,324.19	5,243,356.39
Dodge City, KS	131,436.85	513,069.23	1,402,762.27	1,832,165.76	4,174,412.18
Fort Morgan, CO	208,049.45	812,171.97	1,526,883.31	2,900,296.43	6,608,063.04
Friona, TX	226,117.71	882,772.62	1,659,632.77	3,152,473.12	7,182,654.21
Grand Island, NE	45,373.99	176,539.73	331,716.26	629,908.65	1,434,930.67
Greeley, CO	206,985.26	808,017.64	1,519,073.16	2,885,461.15	6,574,262.20
Hyrum, UT	51,305.43	199,632.19	375,111.19	712,317.48	1,622,664.27
Milwaukee, WI	92,082.13	352,348.00	660,257.33	1,251,946.18	2,849,312.70
Omaha, NE	124,983.54	486,794.40	914,837.26	1,737,378.67	3,957,971.69
Plainwell, MI	152,210.95	594,101.07	1,116,882.26	2,121,476.00	4,833,550.80
Schuyler, NE	101,798.48	397,179.58	746,632.24	1,418,152.12	3,231,036.35
Tolleson, AZ	223,511.13	872,440.69	1,640,161.31	3,115,438.83	7,098,206.03

[1] These are the total costs for all water usage for a month by location and plant size.
[2] Water costs are presented in this fashion due to large unit and price rate differences between locations.
[3] Plant sizes are 100, 500, 1,000, 2,000, and 5,000 head a day, respectively.

[9] Here these include occurrences of extreme heat, extreme cold, tornados, ice storms, hurricanes, floods, blizzards, and wildfires.

The distance between the plant and the consumer market will be a weighted average of the distance from the plant location to the most populous city in each of the 48 contiguous states. The weights are population in that state relative to the total population of all included states. The distance from that plant to the input production site, assumed to be a feed lot, will be calculated the same way, an average of the distance between that plant and a series of feed lots.[10] While this manner of calculating for distance does not accurately reflect how goods are transported to the consumer market in reality,[11] the cost for transportation in this model comes to a mean of about 10% of profits for medium through titan sized plants. Some, but not all, small plants have negative profit levels, transportation costs are 42% of profits for small plant locations with positive profits. While it would be preferable to have each model calculate transport costs only to the areas they would cover in that configuration, computational limits did not allow for that kind of specification and the actual impact on simulated profits is likely to be small relative to total firm profits. Distances for inputs and outputs are listed in Table 4.

Table 4: Distance Variables[1]

Location	Distance to Consumer Market (mi)	Distance to Input Production (mi)
Source	GIS Population Weighted Average	GIS Average Distance
Cactus, TX	1027.90	329.82
Dodge City, KS	971.40	385.29
Fort Morgan, CO	1030.63	382.22
Friona, TX	1069.41	418.11
Grand Island, NE	938.37	547.00
Greeley, CO	1049.57	403.59
Hyrum, UT	1240.58	691.67
Milwaukee, WI	902.54	1174.00
Omaha, NE	902.23	671.87
Plainwell, MI	906.75	1255.67
Schyler, NE	925.03	628.44
Tolleson, AZ	1328.63	748.22

[1] These are the distances used to calculate transportation costs.

Fixed costs will include those costs for the construction of the plant as well as the machinery inside of it. According to Newlin (2020), a small processing plant would cost $400/ft^2 for construction cost and $400,000 total for equipment costs. The construction cost per square foot of space will be scaled by the cost of construction in that area versus the national baseline as per RSMeans (2022) construction data. The space requirements for small plants are based on Newlin (2020) and on individual plant descriptions provided by Cargill on their company website (Cargill, 2022). Once the total fixed costs for small plants at each location were calculated they were scaled up by location for the remaining plant sizes according to the assumed economies of scale stated earlier and taken from Ball and Chambers (1982) and Morrison Paul (2001a, 2001b). Total fixed costs are listed in Table 5.

[10] The locations for feedlots are Dalhart, TX, Hartley, TX, Kersey, CO, Malta ID, Scott City, KS, Texhoma, OK, Ulysses, KS, Wellton AZ, and Yuma, CO. These locations were chosen in a comparable manner to the possible plant locations, e.g., there is a feedlot currently operating in that location.

[11] Firms would split the consumer market between the different plants they own such that the plants would ship to the closest consumer markets and not to ones far away from them when another plant would be closer.

Table 5: Fixed Costs for Plant Construction and Equipment[1]

Location	Small [2]	Medium	Large	Jumbo	Titan
Cactus, TX	2,154,311.11	8,409,880.80	15,810,575.90	30,031,998.23	73,547,320.71
Dodge City, KS	1,968,000.00	7,682,569.77	14,443,231.16	27,434,743.39	67,186,733.81
Fort Morgan, CO	2,195,555.56	8,570,888.58	16,113,270.54	30,606,963.04	74,955,389.57
Friona, TX	2,154,311.11	8,409,880.80	15,810,575.90	30,031,998.23	73,547,320.71
Grand Island, NE	2,133,333.33	8,327,988.91	15,656,619.14	29,739,559.23	72,831,147.76
Greeley, CO	2,213,333.33	8,640,288.49	16,243,742.36	30,854,792.70	75,562,315.80
Hyrum, UT	2,544,000.00	9,931,126.77	18,670,518.33	35,464,424.38	86,851,143.70
Milwaukee, WI	2,592,000.00	10,118,506.52	19,022,792.26	36,133,564.47	88,489,844.53
Omaha, NE	2,234,666.67	8,723,568.38	16,400,308.55	31,152,188.30	76,290,627.28
Plainwell, MI	2,098,370.37	8,191,502.42	15,400,024.55	29,252,160.90	71,637,526.17
Schuyler, NE	2,142,666.67	8,364,423.86	15,725,116.85	29,869,669.80	73,149,784.03
Tolleson, AZ	2,277,333.33	8,890,128.16	16,713,440.94	31,746,979.48	77,747,250.23

[1] These values are spread over all output-producing time periods for the life of the plant.
[2] Plant sizes are 100, 500, 1,000, 2,000, and 5,000 head a day, respectively.

Labor, electric, and water quantity requirements are also scale dependent. Based on estimates from Maddock (2021), labor, electric, and water costs amount to 16%, 10%, and 3% of a plant's gross revenue per production cycle. The average total cost of each input was calculated by multiplying the gross revenue of each plant size by the requisite percentage and then scaling it appropriately to reflect the increasing returns to scale. The median price for each non-cattle input was then used to compute the appropriate quantity of inputs for each plant size. These quantities are listed in Table 6 below. This quantity was then used for all locations, combined with the location specific prices to produce input costs that vary by location. The discount rate will be 5% and the total life of the plant is assumed to be 50 years.

Relative Shock Empirical Model

The values of φ are varied over several calibrations and examples to assess the effect shifts in risk perception and recognition of climate change will have on the optimal choice set. Five sets of φ were used to test for a shift in the optimal plant configuration from the baseline, risk neutral scenario. The plant size variation in φ, as stated above, has smaller values of φ for larger plants, indicating those plants have a higher likelihood of temporary shutdown. φ will also have locational variation linked to weather specific risks, including extreme heat or cold, blizzards, and other weather phenomena listed in footnote 9. An index of weather hazard risk among the states, accounting for the state size, was created. This weather hazard index was multiplied by the general φ values for each plant size to make a full set of individual φ values for every plant location and size. The minimum and maximum for each plant size within the five φ sets is listed in Table 7, and the full set of φ values for all models is in appendix A.

Table 6: Quantity Amounts[1,2]

Variable	Size[3]	Value	Source
Cattle Quantity Head/Day	Small	100	Choice variable
	Medium	500	Choice variable
	Large	1,000	Choice variable
	Jumbo	2,000	Choice Variable
	Titan	5,000	Choice Variable
Beef Quantity Head/Day	Small	100	Calculated
	Medium	500	Calculated
	Large	1,000	Calculated
	Jumbo	2,000	Calculated
	Titan	5,000	Calculated
Labor Quantity hr/year	Small	513,723.75	Maddock(2021)
	Medium	2,005,446.43	Calculated
	Large	3,770,239.28	Calculated
	Jumbo	7,161,524.05	Calculated
	Titan	16,316,884.66	Calculated
Electric Quantity Kwh/year	Small	86,608,013.18	Maddock(2021)
	Medium	338,095,581.09	Calculated
	Large	635,619,692.45	Calculated
	Jumbo	1,207,351,939.67	Calculated
	Titan	2,750,842,169.02	Calculated
Water Quantity 1000 gal/year	Small	513,723.75	Maddock(2021)
	Medium	2,005,446.43	Calculated
	Large	3,770,239.28	Calculated
	Jumbo	7,161,524.05	Calculated
	Titan	16,316,884.66	Calculated

[1] Units for each variable are noted underneath each variable name.
[2] Production time period for this model is a year, so these values would be scaled up for the year time period based on the time unit listed per variable.
[3] Plant sizes are 100, 500, 1,000, 2,000, and 5,000 head a day, respectively.

Table 7: Minimums and Maximums of ϕ Values by Plant Size [1]

Set	Small [2]	Medium	Large	Jumbo	Titan
Set 1	0.96	0.94	0.92	0.90	0.88
	0.88	0.86	0.85	0.83	0.81
Set 2	0.94	0.92	0.90	0.88	0.86
	0.86	0.85	0.83	0.81	0.80
Set 3	0.92	0.90	0.88	0.86	0.84
	0.85	0.83	0.81	0.79	0.78
Set 4	0.90	0.88	0.86	0.84	0.82
	0.83	0.81	0.80	0.78	0.76
Set 5	0.88	0.86	0.84	0.82	0.80
	0.82	0.79	0.76	0.76	0.74

[1] ϕ values are the expected capacity utilization for the plant with set 1 being the most optimistic and set 5 being the most pessimistic.
[2] Plant sizes are 100, 500, 1,000, 2,000, and 5,000 head a day, respectively.

The weather hazard index was developed from the projections for how extreme weather phenomena would change in several reports by the Intergovernmental Panel on Climate Change (IPCC) including the 2018 report on the impacts of warming by 1.5°C on natural and human systems and the 2012 report on managing extreme weather and disasters in advance of climate change. These projections show heat-based phenomena, extreme heat and wildfires increasing as climate change continues and cold based phenomena, extreme cold, blizzards, and ice storms, decreasing. Hurricane incidence is projected to decrease in number but increase in intensity and tornado incidence is unpredictable due to its highly localized nature. Wildfires, though not directly related to climate change, are highly correlated to the occurrence of drought, which is affected by climate change and increased temperature, and so projections of drought are used for wildfire projections. Both magnitude levels of changes in each of the included weather phenomena are detailed in Table 8

Table 8: Hazard Contribution Index (percents)

Location	Blizzard	Heat	Cold	Flood	Hurricane	Ice Storm	Tornado	Wildfire
Cactus, TX	0.56	3.90	0.93	31.54	1.11	0.93	32.84	28.20
Dodge City, KS	5.69	0.00	2.03	49.19	0.00	3.66	34.55	4.88
Fort Morgan, CO	7.14	0.00	2.20	8.79	0.00	1.10	31.87	48.90
Friona, TX	0.56	3.90	0.93	31.54	1.11	0.93	32.84	28.20
Grand Island, NE	13.51	1.62	8.11	33.51	0.00	1.62	36.76	4.86
Greeley, CO	7.14	0.00	2.20	8.79	0.00	1.10	31.87	48.90
Hyrum, UT	0.00	2.38	0.00	19.05	0.00	2.38	11.90	64.29
Milwaukee, WI	1.64	2.46	2.05	70.90	0.00	0.82	20.49	1.64
Omaha, NE	13.51	1.62	8.11	33.51	0.00	1.62	36.76	4.86
Plainwell, MI	4.55	1.14	4.55	53.41	0.00	6.82	28.41	1.14
Schuyler, NE	13.51	1.62	8.11	33.51	0.00	1.62	36.76	4.86
Tolleson, AZ	0.00	39.43	1.14	18.29	0.00	0.00	9.14	32.00

The reports project changes in these phenomena for global regions[12] which, when combined with the impact of each individual weather hazard on possible plant localities, can be used to model the regional impact of changes in different weather phenomena. The local hazard contribution index was created using data from the national oceanic and atmospheric administration (NOAA). This hazard contribution index gave a locational specific value for the impact each weather phenomena had on each locational hazard index shown in Table 9.

[12] The regions considered in this paper are the western north American region and the central north American region.

Table 9: Weather Phenomena Changes by End of Plant Productive Life

Phenomena	Direction of Change	Magnitude 1	Magnitude 2
Blizzards	-	50 %	66%
Extreme Heat	+	100 %	200%
Extreme Cold	-	50 %	66%
Floods	+	50 %	66%
Hurricanes	+	0 %	33%
Ice Storm	-	50 %	66%
Tornado	*[1]	0 %	0%
Wildfires	+	50 %	100%

[1] Tornadoes are not predictable weather phenomena using IPCC weather predictions due to their small geographic size and their short lifespan.

Risk Averse Empirical Model

Many of the calibration numbers for this model are the same as with the risk neutral model since the model is for the same firm types. However, the objective function is changed so instead of firms maximizing the expected present value of the discounted flow of future profits, they now maximize a function equal to the same expected present value of profits minus a scaled variance measure for the profits of that plant configuration, as discussed in the theoretical section above. This mean-variance framework serves to penalize plant configurations that produce more variable profit streams, thus being representative of the way in which a risk averse firm might choose to make decisions on plant numbers, locations, and sizes. The only additional parameter in this model is λ, which represents an absolute risk aversion coefficient. There were four values of λ employed to assess the impact of the level of risk aversion on the optimal plant configurations: 0.01, 0.05, 0.1, and 0.2. These are based on Holt and Laury (2002), designed to reflect a reasonable, but not extreme, level of risk aversion. All five φ sets were tested on each of the four λ values, resulting in a total of twenty optimal configurations for each firm type under risk aversion (plus another five risk neutral optimal configurations).

Risk Averse and Relative Shock Empirical Model

Similarly, as in the theory section, this model does not bring any new calibration values to the models, but simply combines all previously described calibrations into one single model. Thus, the calibrations of the base model are used, with the φ calibration as described in the relative risk shock section, and lastly the risk aversion is calibrated as described above in the risk aversion model section.

CALIBRATION AND RESULTS

Using the calibration values presented above, a grid search of all configurations was performed to find the optimal plant investments for each of the three firm types. To limit options to a feasible choice set, the set of admissible configurations will be constrained by a few limitations. First, there can only be one plant at each location; the decision at each location is only over the three admissible scales of plants for each firm type plus the option to not build a plant in that location. Second, the total amount of beef produced by the firm over the year must remain in a range around the goal production level B_t for that firm type. Plant configurations producing outside this production range were discarded. Once the set of configurations that meet that condition is calculated, the total discounted flow of profits over the 50-year planning horizon is computed using the calibrated parameters above for each configuration. The configuration with the highest profit per unit of output is the optimal configuration (thus controlling for the allowed differences in output across configurations). This profit calculation was repeated five times with each distinct set of φ's for each model type. The results of those calculations for both models are presented in the tables below.

Risk Neutral Absolute Shock Model

As seen in Table 10, for small fringe firms, the optimal configuration is two large plants, located in Cactus, TX and Hyrum, UT, and this does not change for any of the five φ sets Similarly for big fringe firms, also shown in Table 10, regardless of the φ set applied, the optimal configuration is a total of four large plants, located in Cactus, TX, Friona, TX, Hyrum, UT, and Omaha, NE. The big 4 firms, show in Table 10, also do not shift their investment decisions with changes in risk perception. The optimal configuration for big 4 firms is four titan plants located in Cactus, TX, Friona, TX, Hyrum, UT, and Omaha, NE.

Table 10: Results for All Firms in Risk Neutral Model

	Small Fringe[1]			Big Fringe			Big Four		
Location	S[2]	M	L	S	M	L	L	J	T
Cactus, TX			1[3]			1			1
Dodge City, KS									
Fort Morgan, CO									
Friona, TX						1			1
Grand Island, NE									
Greeley, CO									
Hyrum, UT			1			1			1
Milwaukee, WI									
Omaha, NE						1			1
Plainwell, MI									
Schuyler, NE									
Tolleson, AZ									

[1] Firm sizes are aiming to produce 400,000, 800,000, and 4 million head per year, respectively.
[2] Plant sizes are 100, 500, and 1,000 head a day, respectively.
[3] A 1 indicates presence of a plant at that location and size.

There are several results of note both within and across the firm types. The optimal configuration for risk neutral firms of any size remains the same regardless of risk perception. This makes intuitive sense as a risk neutral firm treats an increase in shutdown risk applied equally to all locations similarly to an increase in cost due to a lowering of all plants' expected capacity utilization.

Under risk neutrality all optimal configurations for firms of any size include plants in Cactus and Hyrum. This may be due to lower utility and fixed costs at those locations. Hyrum and Cactus also have lower locational risk than the average for all locations, making them more reliable in meeting production constraints. It should also be noted, both a big fringe firm's and a big four firm's optimal configuration consists of four of the largest plants available to them, adding plants at Friona and Omaha to the previous two discussed, located in the same areas for both firm types. Like Cactus and Hyrum, both of these additional locations have lower than average risk perceptions. This further supports the idea that changes in risk perception that affect all locations evenly will not easily trigger a change in the optimal configuration.

Further sensitivity analysis was done where all φ were randomly assigned an increase or decrease but all increases and decreases for each test were the same magnitude. The optimal configuration did not change from the locations of plants in the baseline results above but did add additional plants in Friona or Grand Island. The changes in φ to trigger these shifts are relatively large, and possible to test computationally, but are unlikely to occur in reality. These sensitivity tests indicate the results of the risk neutral model above are both stable and correct. Given that the optimal configurations, even when they did change, did not shift away from previously chosen locations, another set of φ sensitivity tests was conducted where the φ value for only one of the previously chosen locations, Cactus, TX, was lowered by 20%. This test resulted in a similar result of additional plants being added to compensate for the expectation that the Cactus plant would be open less often.

A final set of sensitivity analyses on costs was performed to test if changing costs for locations would change optimal configurations. This was done similarly to the first set of φ sensitivity tests, where direction of the perturbance and magnitude were randomly assigned. The results of this analysis show changes in the costs for plants can trigger an optimal configuration change much more quickly than changes in φ. This may be due to the construction of the φ variable where locations within the same state have the same φ value, meaning when costs increase in one location within the state and decrease in another, the movement of plants from one location to the other does not cost the firm in increases of risk. Movement of plants within similar locations based on changes in φ do not have the same luxury, as costs are different between locations within a state and moving to a location with lower risk may incur higher production costs. Although the values of the percent difference may change between plant sizes, all plants sizes maintain the rank relationship between locations. Cactus, TX, is cheaper than all other plant locations and is closely followed by Hyrum, UT, another often chosen plant location. Overcoming the difference in cost between locations requires the shifts in φ to be larger than reasonably expected.

In reality however, all plant locations in the model do have a processing plant located there, even if they are routinely suboptimal in the model. This could be for a number of reasons. First, beef processing firms do not want all of their production plants bunched together with their competitors or with their own plants. This would present a drain on regional resources in terms of labor, utilities, and available cattle. By spreading out their plants, both within firms and across firms, resources can be used more efficiently. Second, firms can limit transportation costs by spreading out plants. Demand for beef is spread over the entire country and supply is distributed over a significant, albeit smaller, region; thus, it makes sense to spread processing plants out so as to more efficiently deliver product to customers. Also, this model represents a single firm as if no beef plants are currently operating, but in reality, a firm must consider other firms already operating within a region as separating geographically makes obtaining supplies of cattle and other inputs easier and less expensive.

Risk Neutral Relative Shock Model

This model follows the same calibration assumptions as those mentioned above in the base model section. As seen in Table 11, for small fringe firms, the optimal configuration of plants is two small plants located in Cactus, TX and Hyrum, UT. Similarly for big fringe firms, also shown in Table 11, the optimal configuration of plants is four large plants located in Cactus, TX, Friona, TX, Hyrum, UT, and Omaha, NE. The big 4 firms, shown in Table 12, have two sets of optimal configurations depending on which φ is being used, although they are very similar. The optimal configuration for φ sets 1-4 is four titan plants, located in Cactus, TX, Friona, TX, Hyrum, UT, and Omaha, NE. Set 5 is the same with the addition of one large plant located in Grand Island, NE.

There are several results of note both within this model and as compared to the base model. The lack of changes in fringe firms supports a similar conclusion as that of the base model, that changes in risk perceptions that do not affect the relative relationship between locations and plant sizes do not have an effect on optimal plant configurations for risk neutral firms. These results match those of the base model, even when including changes in relative risk perception such as for climate change. The only difference of the additional large plant for the big 4 firms in φ set 5 is assumed to be to maintain the level of production required by big 4 firms. The specific locations for each of the plants in the optimal configurations matches those in the base model as well, further supporting the risk relationship conclusion.

The differences between the two levels of climate change impact, one with the most expected climate change outcomes and with more severe levels of climate change outcomes, are nonexistent. Even for severe climate change the optimal plant configurations remain the same.

Table 11: Results for All Fringe Firms in Risk Neutral Realitive Shock Model (All ϕ Sets)

	Small Fringe[1]			Big Fringe		
Location	S[2]	M	L	S	M	L
Cactus, TX			1[3]			1
Dodge City, KS						
Fort Morgan, CO						
Friona, TX						1
Grand Island, NE						
Greeley, CO						
Hyrum, UT			1			1
Milwaukee, WI						
Omaha, NE						1
Plainwell, MI						
Schuyler, NE						
Tolleson, AZ						

[1] Firm sizes are aiming to produce 400,000 or 800,000, respectively.
[2] Plant sizes are 100, 500, and 1,000 head a day, respectively.
[3] A 1 indicates presence of a plant at that location and size.

Table 12: Results for Big 4 Firms in Risk Neutral Realitive Shock Model

	ϕ Set 1-4 [1]			ϕ Set 5		
Location	L[2]	J	T	L	J	T
Cactus, TX			1[3]			1
Dodge City, KS						
Fort Morgan, CO						
Friona, TX			1			1
Grand Island, NE				1		
Greeley, CO						
Hyrum, UT			1			1
Milwaukee, WI						
Omaha, NE			1			1
Plainwell, MI						
Schuyler, NE						
Tolleson, AZ						

[1] Firm sizes 4 million head per year.
[2] Plant sizes are 1,000, 2,000, and 5,000 head a day, respectively.
[3] A 1 indicates presence of a plant at that location and size.

While these models do have some differences between location, appears that the changes between location as φ deteriorates over the life of the plant, are not enough to trigger a change in optimal configuration.

Risk Averse Absolute Shock Model

These models include a set of four full models for each firm size, each with its own risk aversion level, represented by an absolute risk aversion coefficient λ, as discussed above. Results are presented grouped by firm size. As seen in Table 13, for small fringe firms with a low level of risk aversion, the optimal configuration is four medium plants, located in Cactus, TX, Friona, TX, Hyrum, UT, and Omaha, NE, and this decision does not change with changes in shutdown risk perceptions. This optimal configuration of four plants at these locations appears at least once for every level of risk aversion as an optimal configuration for all small fringe firms in the risk averse model (Tables 13-16). These models show a preference for a larger number of smaller plants as compared to the risk neutral models above, which is the expected outcome for decisions made under risk aversion. Interesting to note, however, is that the level of risk aversion does not seem to increase the affect, since higher levels of risk aversion do not result in a larger skew towards smaller plants. The differences in optimal configuration are due to either maintenance of required production levels or of extremely close profit levels where even slight changes lead to a switch in the optimal configuration.

Table 13: Results for Small Fringe Firms [1] in Risk Adverse Absolute Shock Model ($\lambda = 0.01$)(all ϕ sets [2])

	Small Fringe		
Location	S[3]	M	L
Cactus, TX		1[4]	
Dodge City, KS			
Fort Morgan, CO			
Friona, TX		1	
Grand Island, NE			
Greeley, CO			
Hyrum, UT		1	
Milwaukee, WI			
Omaha, NE		1	
Plainwell, MI			
Schuyler, NE			
Tolleson, AZ			

Table 14: Results for Small Fringe Firms[1] in Risk Adverse Absolute Shock Model ($\lambda = 0.05$)

	ϕ Set 1[2]			ϕ Sets 2-5		
Location	S[3]	M	L	S	M	L
Cactus, TX		1[4]			1	
Dodge City, KS	1					
Fort Morgan, CO						
Friona, TX					1	
Grand Island, NE						
Greeley, CO						
Hyrum, UT	1				1	
Milwaukee, WI	1					
Omaha, NE			1		1	
Plainwell, MI	1					
Schuyler, NE						
Tolleson, AZ						

Table 15: Results for Small Fringe Firms [1] in Risk Adverse Absolute Shock Model ($\lambda = 0.1$)

	ϕ Set 1 [2]			ϕ Set 2			ϕ Sets 3-5		
Location	S [3]	M	L	S	M	L	S	M	L
Cactus, TX	1[4]				1		1		
Dodge City, KS		1							
Fort Morgan, CO	1								
Friona, TX					1			1	
Grand Island, NE	1							1	
Greeley, CO	1								
Hyrum, UT		1			1			1	
Milwaukee, WI		1							
Omaha, NE					1			1	
Plainwell, MI									
Schuyler, NE	1								
Tolleson, AZ	1								

Table 16: Results for Small Fringe Firms [1] in Risk Adverse Absolute Shock Model ($\lambda = 0.2$)

	ϕ Set 1 [2]			ϕ Sets 2-5		
Location	S[3]	M	L	S	M	L
Cactus, TX	1[4]				1	
Dodge City, KS	1					
Fort Morgan, CO						
Friona, TX	1				1	
Grand Island, NE		1				
Greeley, CO	1					
Hyrum, UT			1		1	
Milwaukee, WI						
Omaha, NE	1				1	
Plainwell, MI						
Schuyler, NE						
Tolleson, AZ	1					

[1] Firm sizes are aiming to produce 400,000 head per year.
[2] ϕ values are the expected capacity utilization for the plant with set 1 being the most optimistic and set 5 being the most pessimistic.
[3] Plant sizes are 100, 500, and 1,000 head a day, respectively.
[4] A 1 indicates presence of a plant at that location and size.

For large fringe firms there is a similar pattern of one configuration occurring in all models regardless of risk aversion levels. The optimal configuration here is a set of eight medium plants located in Cactus, TX, Fort Morgan, CO, Friona, TX, Grand Island, NE, Hyrum, UT, Milwaukee, WI, Omaha, NE, and Schuyler, NE (Tables 17-20). Again, deviations from the "baseline" eight medium plant configuration occur, but all changes represent increases in plant size at a location already present and are explained as a function of maintaining production levels while facing lower assumed production capabilities due to lower φ levels.

Table 17: Results for Big Fringe Firms [1] inRisk Adverse Absolute Shock Model ($\lambda = 0.01$)

	ϕ Set 1-4 [2]			ϕ Set 5		
Location	S[3]	M	L	S	M	L
Cactus, TX		1[4]			1	
Dodge City, KS					1	
Fort Morgan, CO		1				1
Friona, TX		1			1	
Grand Island, NE		1			1	
Greeley, CO						
Hyrum, UT		1			1	
Milwaukee, WI		1				
Omaha, NE		1			1	
Plainwell, MI						
Schuyler, NE		1			1	
Tolleson, AZ						

Table 18: Results for Big Fringe Firms [1]in Risk Adverse Absolute Shock Model ($\lambda = 0.05$)

	ϕ Set 1-4[2]			ϕ Set 5		
Location	S[3]	M	L	S	M	L
Cactus, TX		1[4]			1	
Dodge City, KS					1	
Fort Morgan, CO		1				1
Friona, TX		1			1	
Grand Island, NE		1			1	
Greeley, CO						
Hyrum, UT		1			1	
Milwaukee, WI		1				
Omaha, NE		1			1	
Plainwell, MI						
Schuyler, NE		1			1	
Tolleson, AZ						

Table 19: Results for Big Fringe Firms [1] in Risk Adverse Absolute Shock Model ($\lambda = 0.1$)

	All ϕ Sets [2]		
Location	S[3]	M	L
Cactus, TX		1[4]	
Dodge City, KS			
Fort Morgan, CO		1	
Friona, TX		1	
Grand Island, NE		1	
Greeley, CO			
Hyrum, UT		1	
Milwaukee, WI		1	
Omaha, NE		1	
Plainwell, MI			
Schuyler, NE		1	
Tolleson, AZ			

Table 20: Results for Big Fringe Firms [1] in Risk Adverse Absolute Shock Model ($\lambda = 0.2$)

	ϕ Set 1-4[2]			ϕ Set 5		
Location	S[3]	M	L	S	M	L
Cactus, TX		1[4]			1	
Dodge City, KS					1	
Fort Morgan, CO		1				1
Friona, TX		1			1	
Grand Island, NE		1			1	
Greeley, CO						
Hyrum, UT		1			1	
Milwaukee, WI		1				
Omaha, NE		1			1	
Plainwell, MI						
Schuyler, NE		1			1	
Tolleson, AZ						

[1] Firm sizes are aiming to produce 800,000 head per year.
[2] ϕ values are the expected capacity utilization for the plant with set 1 being the most optimistic and set 5 being the most pessimistic.
[3] Plant sizes are 100, 500, and 1,000 head a day, respectively.
[4] A 1 indicates presence of a plant at that location and size.

Lastly, big four-sized firms show more variation than other firm types in this model as the level of risk aversion increases, although all levels of risk aversion show optimal configurations with one to two titan plants, a larger number of jumbo plants, and an even larger number of smaller plants (Tables 21-24). There does not seem to be a common optimal configuration like the other firm types, however. As compared to the risk neutral models, these results again support the conclusion that risk averse firms favor optimal configurations with larger numbers of smaller plants.

Table 21: Results for Big 4 Firms[1] in Risk Adverse Absolute Shock Model ($\lambda = 0.01$)

	ϕ Set 1[2]			ϕ Set 2-3			ϕ Set 4			ϕ Set 5		
Location	L[3]	J	T	L	J	T	L	J	T	L	J	T
Cactus, TX	1[4]			1			1			1		
Dodge City, KS		1			1			1			1	
Fort Morgan, CO	1				1			1		1		
Friona, TX	1			1			1			1		
Grand Island, NE	1			1				1		1		
Greeley, CO			1			1			1			1
Hyrum, UT	1			1			1			1		
Milwaukee, WI		1			1			1			1	
Omaha, NE	1			1			1			1		
Plainwell, MI		1			1			1				1
Schuyler, NE		1			1			1		1		
Tolleson, AZ		1			1			1			1	

Table 22: Results for Big 4 Firms [1] in Risk Averse Model ($\lambda = 0.2$)

	ϕ Set 1[2]			ϕ Set 2-4			ϕ Set 5		
Location	L[3]	J	T	L	J	T	L	J	T
Cactus, TX	1[4]			1			1		
Dodge City, KS		1			1			1	
Fort Morgan, CO	1			1			1		
Friona, TX	1			1			1		
Grand Island, NE	1			1			1		
Greeley, CO			1			1			1
Hyrum, UT	1			1			1		
Milwaukee, WI		1		1				1	
Omaha, NE	1			1			1		
Plainwell, MI		1			1			1	
Schuyler, NE	1			1			1		
Tolleson, AZ		1			1			1	

[1] Firm sizes are aiming to produce 4 million head per year.
[2] ϕ values are the expected capacity utilization for the plant with set 1 being the most optimistic and set 5 being the most pessimistic.
[3] Plant sizes are 1,000, 2,000, and 5,000 head a day, respectively.
[4] A 1 indicates presence of a plant at that location and size.

Table 23: Results for Big 4 Firms[1] in Risk Adverse Absolute Shock Model ($\lambda = 0.1$)

	ϕ Set 1[2]			ϕ Set 2			ϕ Set 3			ϕ Set 4			ϕ Set 5		
Location	L[3]	J	T	L	J	T	L	J	T	L	J	T	L	J	T
Cactus, TX	1[4]			1			1			1			1		
Dodge City, KS		1			1			1			1			1	
Fort Morgan, CO	1			1			1			1			1		
Friona, TX	1			1			1			1			1		
Grand Island, NE	1			1			1			1			1		
Greeley, CO			1			1			1			1			1
Hyrum, UT	1			1			1			1			1		
Milwaukee, WI		1		1			1				1			1	
Omaha, NE	1			1			1			1			1		
Plainwell, MI		1			1				1		1				1
Schuyler, NE		1		1			1			1			1		
Tolleson, AZ		1				1		1				1		1	

Table 24: Results for Big 4 Firms [1] in Risk Adverse Absolute Shock Model ($\lambda = 0.2$)

	ϕ Set 1[2]			ϕ Set 2-4			ϕ Set 5		
Location	L[3]	J	T	L	J	T	L	J	T
Cactus, TX	1[4]			1			1		
Dodge City, KS		1			1			1	
Fort Morgan, CO	1			1			1		
Friona, TX	1			1			1		
Grand Island, NE	1			1			1		
Greeley, CO			1			1			1
Hyrum, UT	1			1			1		
Milwaukee, WI		1		1				1	
Omaha, NE	1			1			1		
Plainwell, MI		1			1			1	
Schuyler, NE	1			1			1		
Tolleson, AZ		1			1			1	

[1] Firm sizes are aiming to produce 4 million head per year.
[2] ϕ values are the expected capacity utilization for the plant with set 1 being the most optimistic and set 5 being the most pessimistic.
[3] Plant sizes are 1,000, 2,000, and 5,000 head a day, respectively.
[4] A 1 indicates presence of a plant at that location and size.

Risk Averse Relative Shock Model

This model includes 20 sets of model results for each firm type as the model finds the optimal plant configuration set over five φ sets and four λ values. Again, the prevailing pattern of limited change in the optimal configuration within the model continues. For small fringe firms, across all λ values, the optimal configuration for the first φ set is two large plants, one in Cactus, TX, and Hyrum, UT. For all other φ sets (2-5), the optimal configuration is two large plants at Cactus TX, and Hyrum, UT, with an additional small plant in Friona, TX. These results are detailed in Table 25. For big fringe firms, the optimal configuration for φ sets 1-4 across all λ values is four large plants located at Cactus, TX, Friona TX, Hyrum, UT, and Omaha, NE. For φ set 5 across all λ values, the optimal plant configuration only adds a medium firm at Grand Island, NE. These results are detailed in Table 26. Big four firms show the largest variation, where for φ sets 1 and 2 the optimal configuration is four titan plants in Cactus, TX, Friona, TX, Hyrum, UT, and Omaha, NE, and two large plants at Grand Island, NE, and Schyler, NE. For φ set 3 and 4, the only change is the addition of another large plant located in Fort Morgan, CO. Lastly, φ set 5 adds another additional large plant located in Plainwell, MI. These results are detailed in Table 27.

Table 25: Results for Small Fringe Firms [1] in Risk Averse Relative Shock Model (All λ)

Location	ϕ Set 1[2]			ϕ Set 4-5		
	S[3]	M	L	S	M	L
Cactus, TX			1[4]			1
Dodge City, KS						
Fort Morgan, CO						
Friona, TX				1		
Grand Island, NE						
Greeley, CO						
Hyrum, UT			1			1
Milwaukee, WI						
Omaha, NE						
Plainwell, MI						
Schuyler, NE						
Tolleson, AZ						

[1] Firm sizes are aiming to produce 400,000 head per year.
[2] ϕ values are the expected capacity utilization for the plant with set 1 being the most optimistic and set 5 being the most pessimistic.
[3] Plant sizes are 100, 500, and 1,000 head a day, respectively.
[4] A 1 indicates presence of a plant at that location and size.

Table 26: Results for Big Fringe Firms [1] in Risk Averse Relative Shock Model (All λ)

Location	ϕ Set 1-4[2]			ϕ Set 5		
	S[3]	M	L	S	M	L
Cactus, TX			1[4]			1
Dodge City, KS						
Fort Morgan, CO						
Friona, TX			1			1
Grand Island, NE					1	
Greeley, CO						
Hyrum, UT			1			1
Milwaukee, WI						
Omaha, NE			1			1
Plainwell, MI						
Schuyler, NE						
Tolleson, AZ						

[1] Firm sizes are aiming to produce 800,000 head per year.
[2] ϕ values are the expected capacity utilization for the plant with set 1 being the most optimistic and set 5 being the most pessimistic.
[3] Plant sizes are 100, 500, and 1,000 head a day, respectively.
[4] A 1 indicates presence of a plant at that location and size.

Table 27: Results for Big Four Firms [1] in Risk Averse Relative Shock Model (All λ)

Location	ϕ Set 1-2 [2]			ϕ Set 3-4			ϕ Sets 5		
	L [3]	J	T	L	J	T	L	J	T
Cactus, TX			1[4]			1			1
Dodge City, KS									
Fort Morgan, CO				1			1		
Friona, TX			1			1			1
Grand Island, NE	1			1			1		
Greeley, CO									
Hyrum, UT			1			1			1
Milwaukee, WI									
Omaha, NE			1			1			1
Plainwell, MI							1		
Schuyler, NE	1			1			1		
Tolleson, AZ									

[1] Firm sizes are aiming to produce 4 million head per year.
[2] ϕ values are the expected capacity utilization for the plant with set 1 being the most optimistic and set 5 being the most pessimistic.
[3] Plant sizes are 1,000, 2,000, and 5,000 head a day, respectively
[4] A 1 indicates presence of a plant at that location and size.

Again, as with the previous relative risk shock model, two levels of relative risk shock, representing the different predictions of climate change outcomes were tested and there was no difference in optimal plant configuration between these two levels of climate change shock within the model. However, the results of this model do show some changes from the other model types. Optimal configurations for this model show more plants than both risk neutral models at times but less than the risk neutral absolute shock model. As noted previously, one explanation for any alteration in the optimal plant configurations as compared to the risk neutral models would be to maintain goal production levels over increasing assumed plant shutdowns. Previously in the risk averse absolute shock model, this risk was averted by increasing the total number of plants in the optimal configuration as all plant locations were suddenly equally more expensive. However, in this model, relative risk shocks can be better averted with spatial shifts in optimal configurations, leading to a level of plants in-between the risk neutral models and the risk averse absolute shock model. However, the same plant locations, Cactus, Hyrum, and then Friona appeared in all optimal plant configurations.

Discussion

Collectively these results point to several things. Risk perception shocks that alter the relative levels of risk perception are much more likely to alter optimal production configurations than risk perception shocks that affect the absolute level of risk perception. In terms of the beef industry this would mean shocks that have widespread effects would not alter the optimal industry organization, but regional risk changes, affecting only the local or regional area could. So, as far as the effect of the covid-19 pandemic is concerned, optimal beef plant configurations do not seem poised to change since that risk perception shock affected all locations and sizes equally. This makes economic sense if one considers the changes in φ as changes in expected costs for a firm to meet a specific level of production. If there is a global decrease in φ across all locations due to heightened visibility of a non-location-specific risk, costs at every location and plant size will have increased, meaning the optimal configuration for a firm will not change as that configuration is still the optimal, it is simply optimal at a higher cost. In comparison, a non-global φ change shifts the relative costs of production across competing locations, meaning the locations with decreased φ have become more costly to produce at than before the change. Such relative changes could trigger optimal configuration changes if one of the previously optimal locations and sizes becomes too costly to produce at as compared to another, previously unchosen location and size. However, the levels of relative change in φ values that must occur to trigger a change in optimal plant location are relatively high. Thus, local or regional risks are possible drivers of change in the spatial organization of beef processing but are likely to occur over longer periods of time.

The other collective result relates to the role of a firm's risk preferences. Comparing results from the risk averse and risk neutral models, we see that risk averse firms choose to build a larger number of smaller plants than firms that are risk neutral. This manifests in the real world as differences in behavior between firms which are risk neutral and risk averse, which as discussed above could be the difference in behavior between publicly traded and privately held firms. It should also be noted, these real-world conclusions are tied to the beef industry, and industries like it, since that is where the empirical values for the calibration come from. An industry that is sufficiently dissimilar to the beef industry may have different results, as they will surely have different optimal locations and different operating costs, although the same theoretical model and methodology can be applied.

CONCLUSIONS

The theoretical models presented in this paper introduce a shutdown risk perception variable to a firm's capital investment decision. Firms were modeled as both risk neutral and risk averse, allowing a comparison of the role of risk perceptions across firm objective functions. Two types of risk were also modeled, one absolute level absolute shock and one relative shock across both risk neutral and risk averse firms. This risk perception variable, φ, accounts for heterogeneous differences in perceived shutdown risks based on the firm's past experiences and future expectations about temporary plant shutdowns. The decision models were calibrated to approximate a real-world beef production firm considering twelve plant locations and three plant sizes per firm type. There were three firm types, representing distinct parts of the beef market: big four firms, which control the majority of the market, large fringe firms and small fringe firms. These differently sized firms have total annual production goals that differ by an order of magnitude.

The results show that changes in perceived shutdown risk that maintain relative risk relationships between plant locations and sizes do not change the optimal plant configuration decision for risk neutral firms. The results for risk averse firms show that shifts in risk perceptions can lead to changes in the optimal plant configurations. For absolute risk shocks these changes seem to arise from a need to maintain production levels in the face of increased closure risk in all locations. For relative risk shocks there is also an increase in optimal plant numbers to maintain production ability, but plant number increases were not as high as the risk averse absolute risk shock model. This is due to the firm's ability to alleviate risk in a more cost-effective way, through spatial shifts rather than in absolute numbers of plants.

Based on these results, heterogeneous plant closure risk perception variables and shifts in those perceptions do not appear to affect optimal plant configurations if the risk shock does not alter the relative risk between locations and the firm is risk neutral. However, if a firm is risk averse, the number of plants in the optimal configuration is higher than in the optimal configuration for a risk neutral firm. So, whether a firm is risk averse or risk neutral does have the expected effect on optimal plant configurations in that risk averse firms favor configurations with a larger number of smaller plants. If the relative risk between plant locations does change, risk can be alleviated with the additional plants in other locations. This is seen in both relative risk shock models, both risk neutral and risk averse.

Based on these results, we should anticipate little change in the organization of the beef processing industry in the United States as a result of the plant closures seen during the COVID-19 pandemic since this newly perceived pandemic risk affects all areas similarly. Even though the disruption to the beef supply chain was economically significant to processors and retailers, the pandemic is unlikely to lead processors to alter their plant sizes and locations beyond adding a small amount of reserve processing capacity. Optimal plant configurations will be maintained, with risk neutral firms operating a smaller number of larger plants than risk averse firms. However, relative risks, like climate change could trigger a spatial change over the next several years to alleviate potential future risk.

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