Concentration and Resiliency in the U.S. Meat Supply Chains

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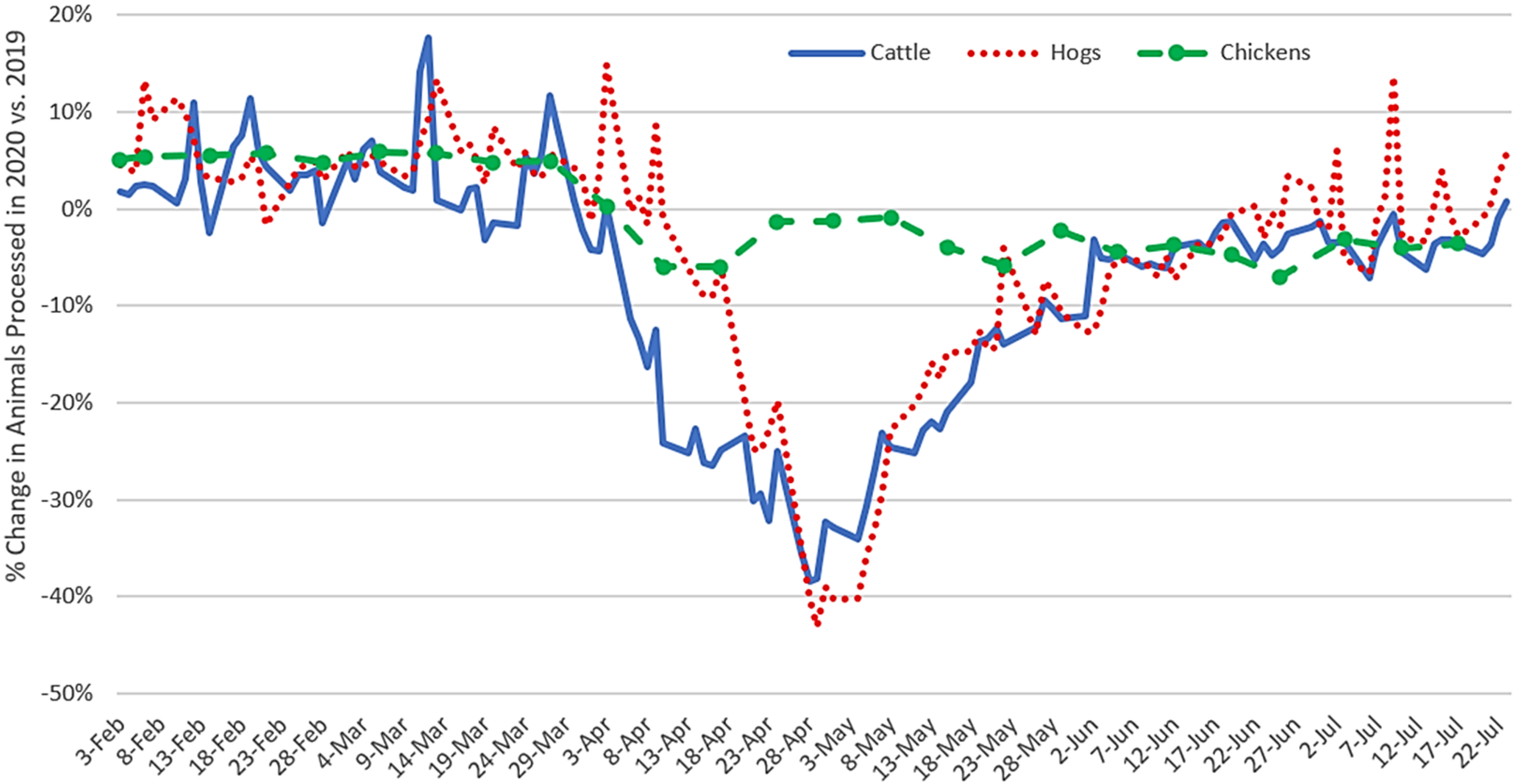
Background

- In the United States, supply chains for many agricultural products have an hour-glass shape
  - In between a sizable number of farmers and consumers is a smaller number of processors
- In particular, concentration in the U.S. meat packing sector has increased markedly from the 1960s to the 1990s (Wohlgenant, 2013)
  - CR4 of packing firms raises from ~25% in 1976 to ~85% now
- In 2019, the 22 largest beef packing plants, representing just 3.3% of all plants, were responsible for 71.7% of federal inspected cattle processing (NASS, 2020)
  - Similar structure for pork packing

The Concern

- The high level of horizontal concentration can be explained, at least in part, by the economies of scale in meat packing (Morrison Paul, 2001)
- But the concentrated nature of meat processing also implies that disruption of the processing capacity of any one plant has the potential to lead to system-wide disruptions
  - Due to accident, weather, worker illnesses from a pandemic, etc.
- COVID-19 shocks on labor health led to the shutdown of some large beef and pork packing plants, and some 40% of processing capacity was brought offline
  - An unprecedented increase in the farm-to-wholesale price spread and serious concerns over food security and meat supply (Lusk, Tonsor, and Schulz, 2021)

Meat Processing During COVID-19



Source: Calculations based on USDA data

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Policies Responses

- The hourglass structure seems the crux

- Policy makers have sought ways to encourage the entry of more small and medium-sized processors, hoping to enhance the resiliency of meat supply (e.g., Bustillo, 2020; Nickelsburg, 2020)
  - Several U.S. states recently considered or adopted legislation to subsidize the introduction of small- or medium-sized meat packers

- However, it remains unclear whether and to what extent a less concentrated meat packing sector would have performed better during the pandemic or other shocks on production

Objective and Approach

- We study the relationship between horizontal structure and supply-chain resiliency
- Construct a structural model that captures key features of the US beef industry
  - Concentrated nature, economies of scale, and packer market power in livestock buying and meat selling
  - Packing plants Cournot compete and differ in marginal costs and hence in equilibrium sizes and market power
- Measure output and welfare changes under different market structures, after an exogenous risk of shutdown
  - Focus on three horizontal structures: current, all small (diffuse), and all large (concentrated)

Main Findings

- The three structures differ in variance but not in expectation
- The extent to which a more diffuse packing performs better in ensuring a level of output depends on magnitude of the exogenous risk and the target output
  - E.g., if the shutdown risk equals 30%, a more concentrated sector performs better in ensuring <20% output reductions, and a diffuse is better at ensuring <40% reductions
- Contribute new insights into the role of market structure in short-run resiliency, which has key policy implications
  - Prior studies explore the market impacts as plants choose to shutdown (e.g., McKendree, Saitone, and Schaefer, 2021)

Roadmap

- Modeling
- Parameterization
- Baseline Findings
- Robustness
- Policy Discussion

Model Setup

- A static model of three stages: farms, packers, and retailers

- Homogeneous products (e.g., beef)

- Assume perfect competition among farms and retailers, while packers may exercise buyer and/or seller power

- The setup highlights the hour-glass shape of the meat supply chain

Model Setup

- Once a plant is built, the processor tries to, and often does, produce near full capacity where costs are minimized (Koontz and Lawrence, 2010)

- Let processing plants 1,…, n compete in the output scale

- Employ a Cournot competition model to characterize interactions of the n packing plants

- Allow plants to have different marginal costs
    - Marginal costs of processing decrease in the size of a plant thanks to the economies of scale (MacDonald, 2003)

Functional Forms

- Inverse demand and supply functions

$$P^{w} = P^{r} - c^{r} = D(Q^{r}|X) - c^{r}$$
$$P^{f} = S\left(Q^{f}\middle|Y\right)$$

  - r refers to the retail stage, w processing stage, and f farming stage
  - X and Y refer to demand and supply shifters, respectively

- Processor costs consist of cattle costs and other costs

$$C_i^w = c_i^w q_i + P^f(Q|Y)q_i$$

  - i refers to a plant, and c_i^w constant marginal costs of other inputs
  - Assume quasi-fixed proportions in processing: $Q^r = Q^w = Q^f = Q = \sum_n q_i$

Optimality Condition

- Packer's objective function is

$$\max_{q_i} \pi_i^w = (D(Q|X) - c^r)q_i - \left(c_i^w + P^f(Q|Y)\right) q_i$$

- Solve for the first-order-condition

$$P^r\left(1 - \frac{\xi_i^w}{\eta^r}\right) - c^r = P^f\left(1 + \frac{\theta_i^f}{\epsilon^f}\right) + c_i^w$$

  - $\xi_i^w/\theta_i^f = s_i \in (0,1)$ is the conjectural variation of a packer against retailer/farmer
  - η^r/ϵ^f is the demand/supply elasticity

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Analytical Solutions

- Analytical solutions are obtained by making demand and supply linear functions
  - $P^r = D(Q^r|X) = a - \alpha Q^r$
  - $P^f = S\left(Q^f\middle|Y\right) = b + \beta Q^f$

- Equilibrium total output and outputs of different plants
  - $Q^* = \frac{n}{n+1}\frac{(a-b)-c^r-\overline{c^w}}{\alpha+\beta}$ where $\overline{c^w}$ is the average marginal costs across all packers
  - Q^* increases in decreasing average marginal costs
  - $q_i^* = \frac{(a-b)-c^r-c_i^w}{\alpha+\beta} - Q^*$
  - q_i^* decreases in marginal costs

Parameterization

- Pre-shock, equilibrium outputs of different plants are generated to match the actual size distribution of U.S. beef packers in 2019

Size Distribution of U.S. Beef Processors in 2019

Table A1. Size Distributions of U.S. Meat Packing Plants

	Size group	# plants	% plants	Head/year	Head/plant/year	% total output
	Beef					
Small (91.8%)	1-999	480	71.6%	163.2	340.0	0.5%
	1,000-9,999	107	16.0%	261.5	2,443.9	0.8%
	10,000-49,999	28	4.2%	604.9	21,603.6	1.8%
Medium (4.9%)	50,000-99,999	6	0.9%	483.0	80,500.0	1.5%
	100,000-199,999	9	1.3%	1,270.7	141,188.9	3.8%
	200,000-299,999	4	0.6%	1,018.8	254,700.0	3.1%
	300,000-499,999	14	2.1%	5,554.3	396,735.7	16.8%
Large (3.3%)	500,000-999,999	10	1.5%	6,394.2	639,420.0	19.3%
	1,000,000+	12	1.8%	17,318.8	1,443,233.3	52.4%
	All	670	100%	33069.4		100%

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Parameterization

- Pre-shock, equilibrium outputs of different plants are generated to match the actual size distribution of U.S. beef packers in 2019
  - Relative production scales match actual statistics (i.e., small: medium: large ~ 1: 154: 660)
  - HHI: 250 (out of maximum 10,000)

- Post-shock, let remaining plants continue producing at q_i^*, because production capacities are unlikely to be increased in the short-run (i.e., a few weeks)
  - $Q' = \sum_{n'} q_i^*$, and "shadow marginal costs" increased to keep q_i at the pre-shock level

- Equilibrium P^r and Q under perfect competition normalized to 1
  - $f = 1 - c^r - c_S^w$, $\alpha = \frac{1}{\eta^r}$, $a = 1 + \frac{1}{\eta^r}$, $\beta = \frac{f}{\epsilon^f}$, $b = f - \frac{f}{\epsilon^f}$

Parameter Values

Table 1. Parameter Values in the Base Simulation

Parameter	Definition	Value
η^r	Magnitude of demand elasticity for beef	1.94
ϵ^f	Supply elasticity of cattle	1.00
c^r	Retail marginal costs	0.42
f	Farm share of the retail value under no risk	0.43
c_S^w	Processing marginal costs, small-sized under no risk	0.16
c_M^w	Processing marginal costs, medium-sized under no risk	0.15
c_L^w	Processing marginal costs, large-sized under no risk	0.12

Baseline Simulations

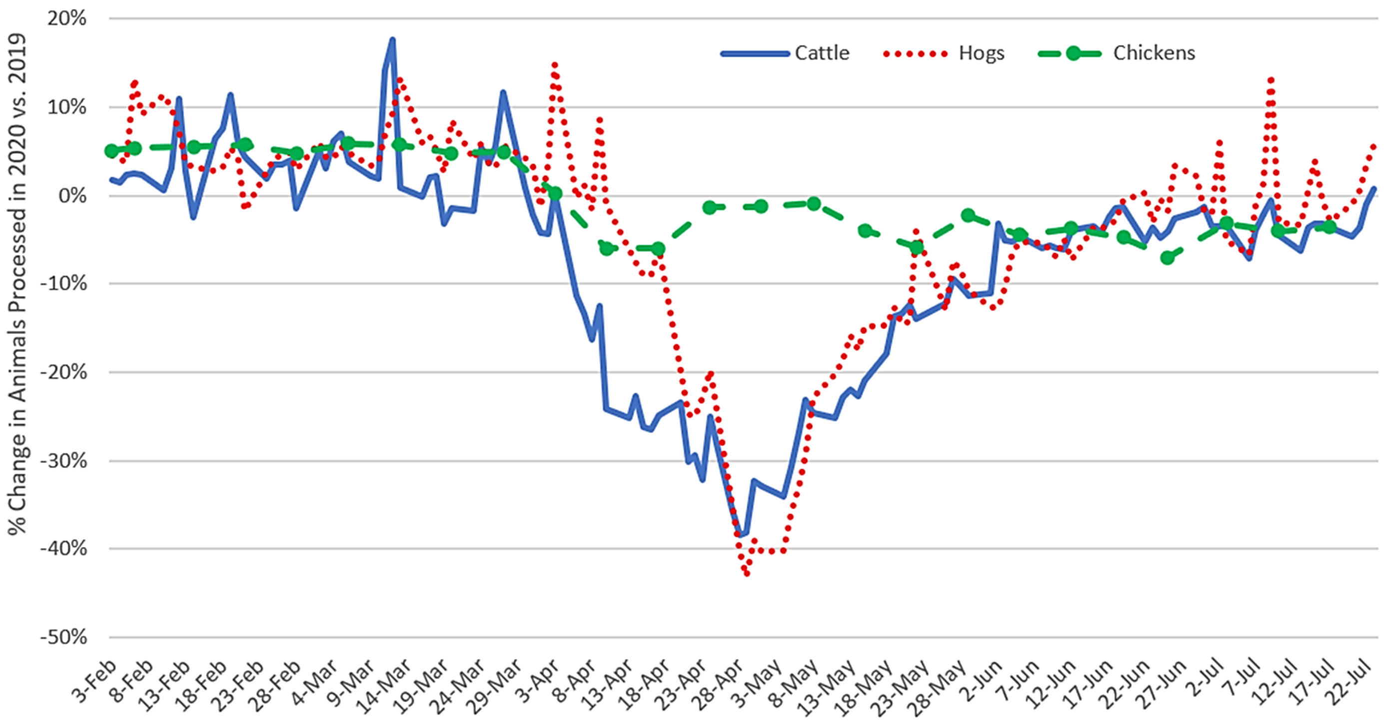
- Focus on three structures: current, all-small, and all-large
  - For easier comparison, let all start with the same pre-shock total output level
- Risk levels: 5%, 10%, 20%, 30%, 40%, and 50%
  - Risk realized randomly for each plant
  - 1,000 simulations

Table 2. Plant Size Distributions under Different Market Structures

Scenario	No. small plants	No. medium plants	No. large plants	No. plants
Current	615	33	22	670
All-small	22,000	0	0	22,000
All-large	0	0	30	30

Actual Changes under COVID-19

- In April and May 2020, daily number of federally inspected cattle processed fell 20-40% year-over-year for eight weeks



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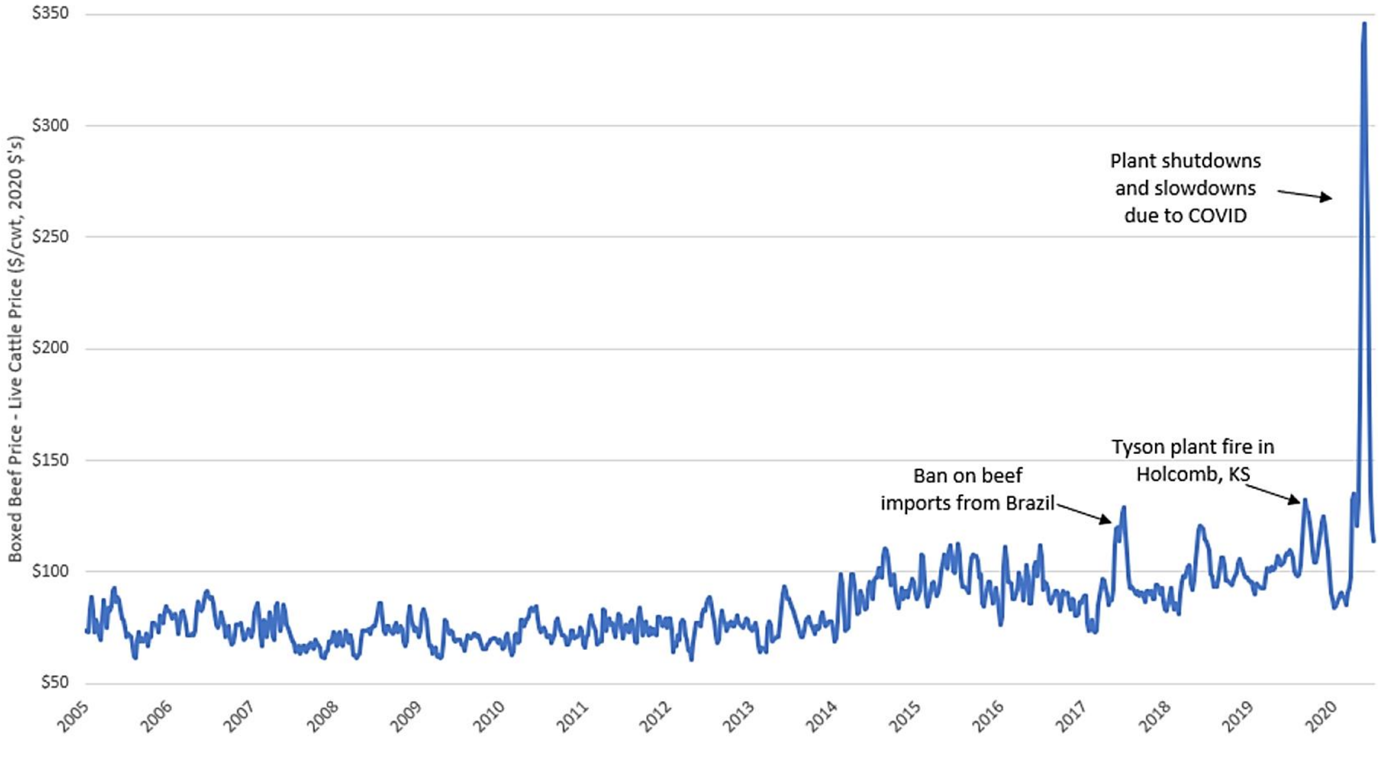
Actual Changes under COVID-19

- In April and May 2020, daily number of federally inspected cattle processed fell 20-40% year-over-year for eight weeks

- From February to mid-May, the farm-to-wholesale price spread increased by over 250%



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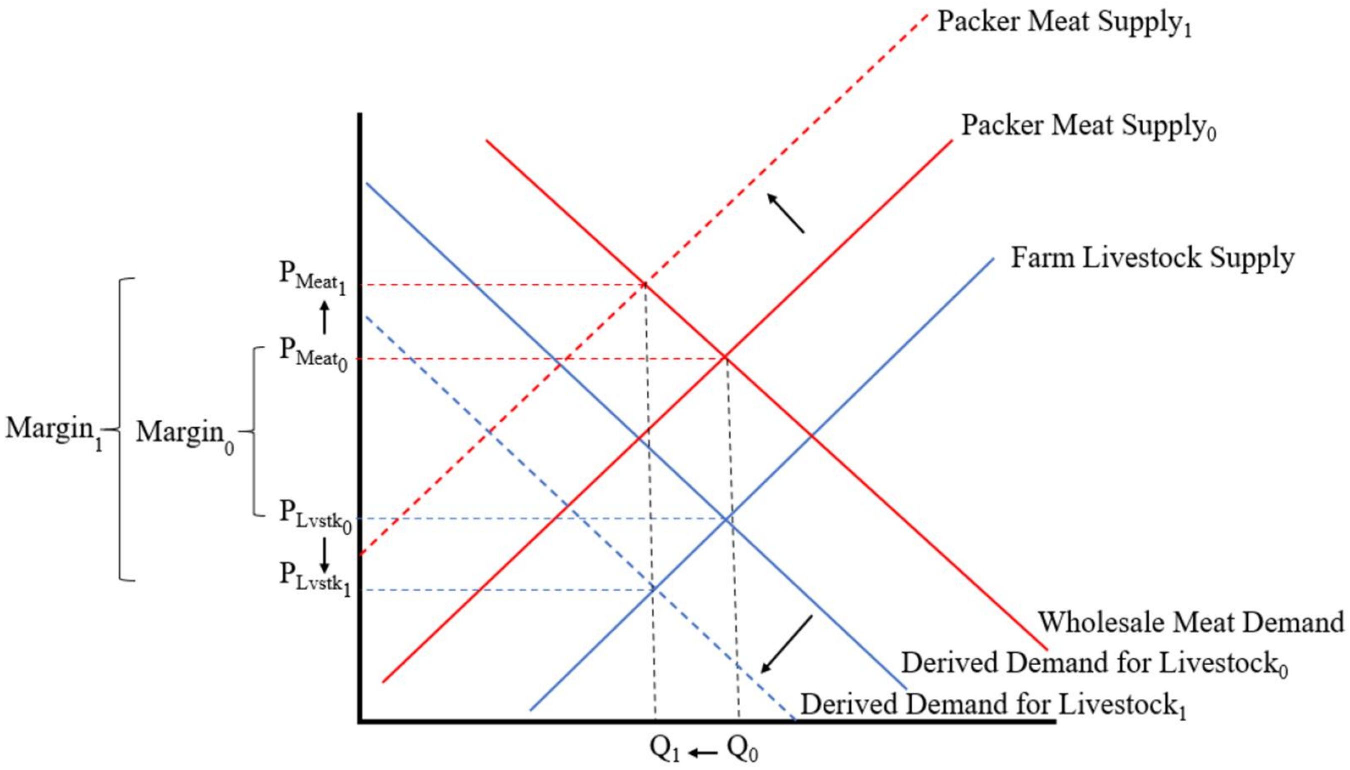
Compare with Actual Changes under COVID-19

- Setting the risk of shutdown to 30%, simulations lead to similar output falls based on the "current" market structure

- When the risk of shutdown is 30%, the farm-to-wholesale price spread raises from 0.16 to 0.44
  - Though HHI is small



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Insight 1: Indifferent Expectations of Outcomes

Table 3. Simulated Mean Values under Different Market Structures

Scenario	Risk=5%	Risk=10%	Risk=20%	Risk=30%	Risk=40%	Risk=50%
Price spread						
Current	0.622	0.671	0.762	0.856	0.951	1.045
All-small	0.623	0.670	0.764	0.858	0.952	1.046
All-large	0.624	0.671	0.765	0.859	0.950	1.042
Packer profits						
Current	0.023	0.021	0.019	0.017	0.014	0.012
All-small	0.000	0.000	0.000	0.000	0.000	0.000
All-large	0.030	0.028	0.025	0.022	0.019	0.016
CS						
Current	0.233	0.208	0.167	0.128	0.095	0.066
All-small	0.232	0.209	0.165	0.126	0.093	0.064
All-large	0.232	0.209	0.166	0.128	0.095	0.067
PS						
Current	0.192	0.172	0.137	0.106	0.078	0.054
All-small	0.191	0.172	0.136	0.104	0.076	0.053
All-large	0.191	0.172	0.136	0.105	0.078	0.056
Total welfare						
Current	0.448	0.402	0.323	0.251	0.187	0.133
All-small	0.424	0.381	0.301	0.230	0.169	0.118
All-large	0.453	0.409	0.327	0.255	0.192	0.139

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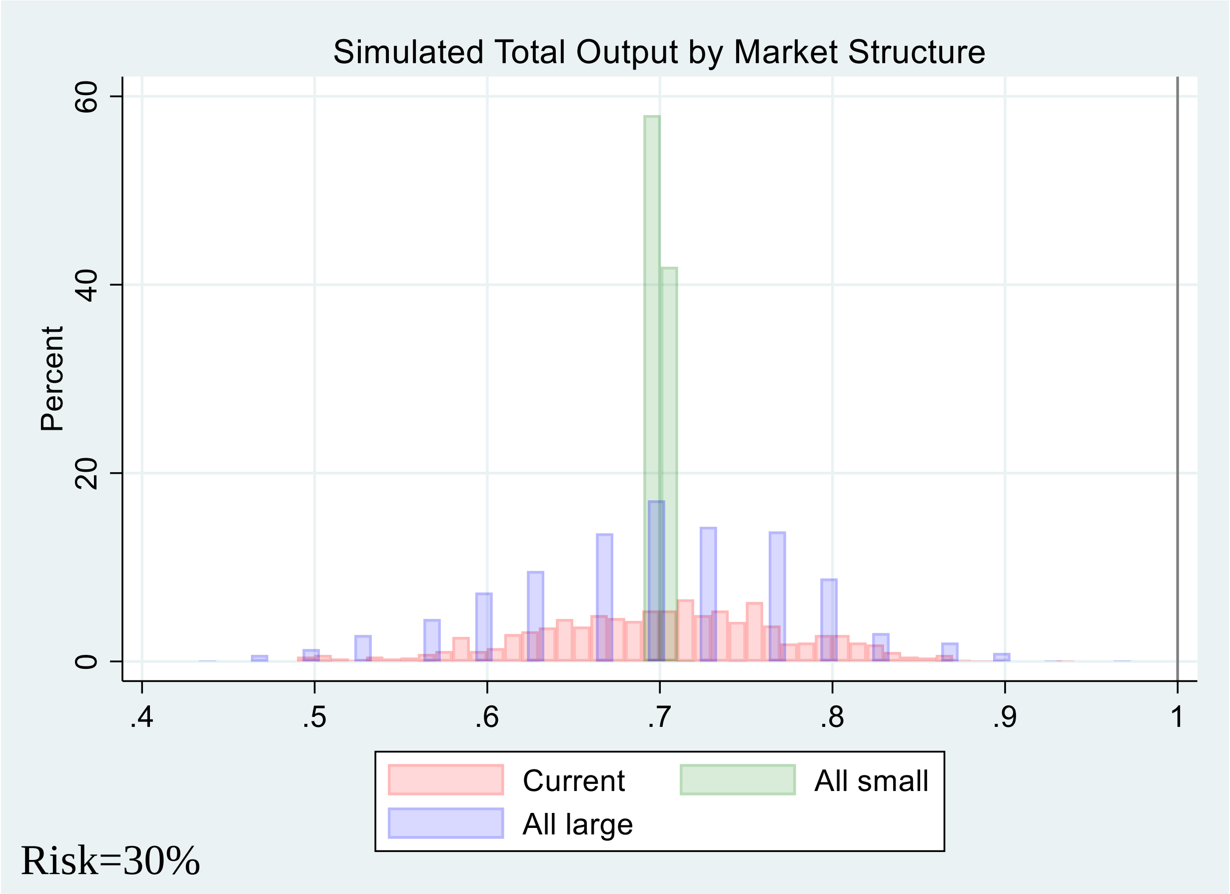
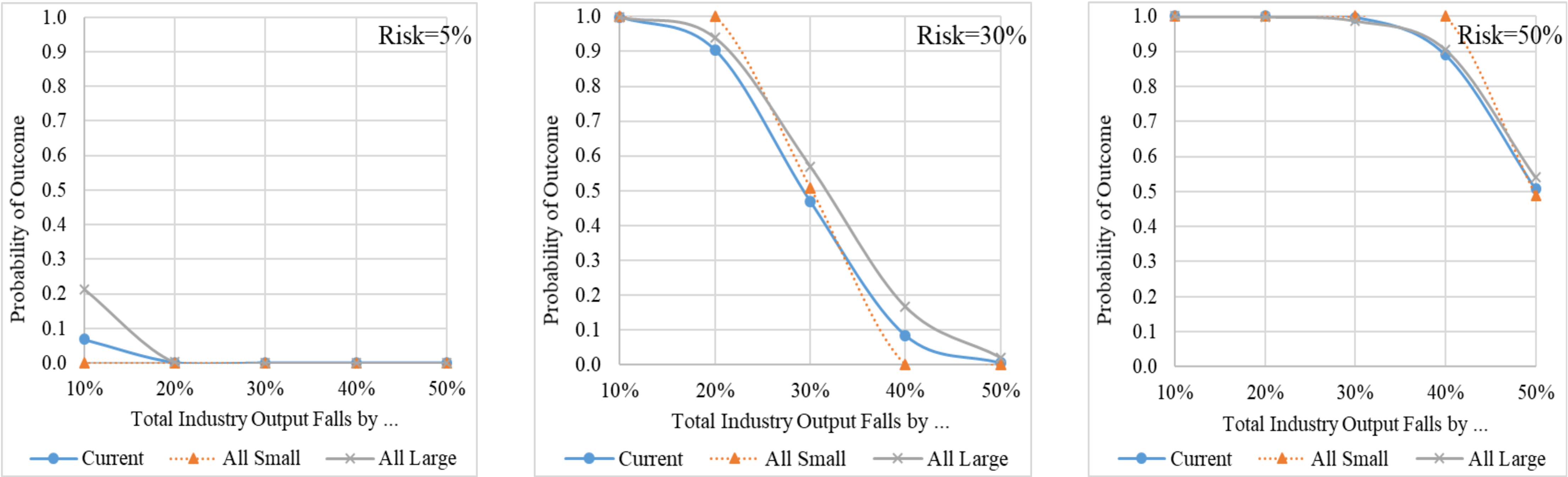
Insight 2: Different Distributions of Outcomes



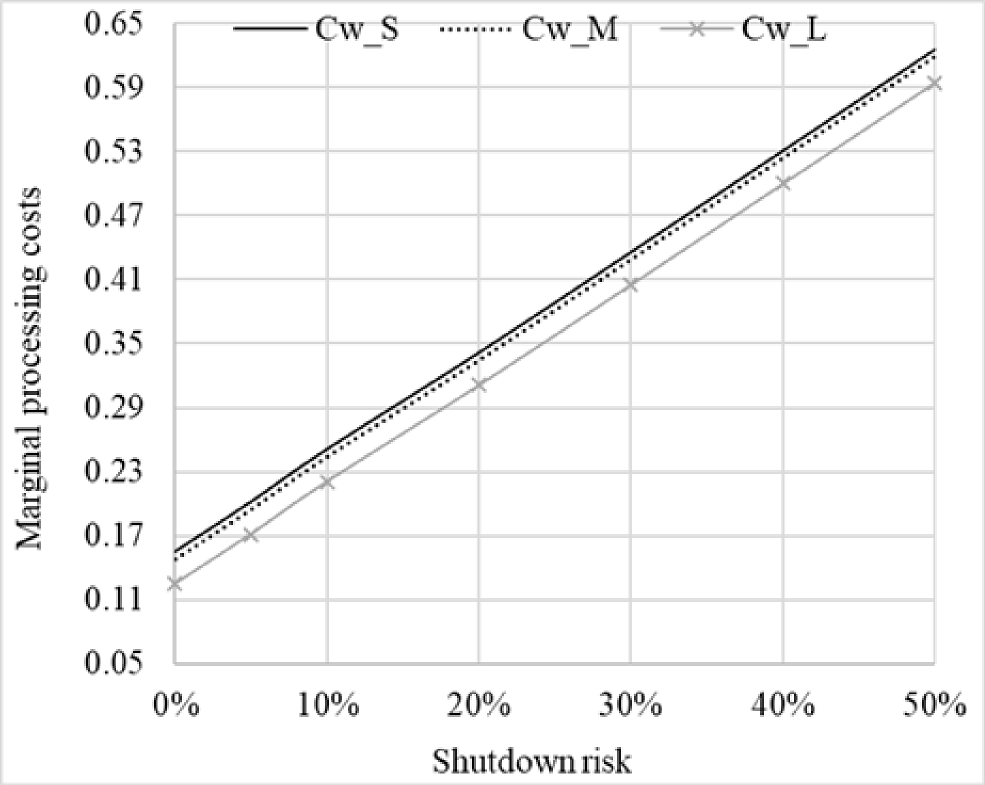
Insight 2: Relative Performance by Structure



Insight 3: Rising Marginal Costs

- Changes in the marginal processing costs for the three structures follow similar trends

- The substantial costs increases imply a tight bottleneck in processing at the full capacity and also increased operational costs
  - E.g., increased sanitation costs



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Insight 4: Loss Avoidance

- A social planner may care more than expectation or variance and want to avoid extreme losses in CS and PS
  - Risk measured as deviations from a target return

- For instance, the planner maximizes a utility function (Holthausen, 1981)

$$U(x) = x \ \forall x > \underline{x}$$

$$U(x) = x - \kappa(\underline{x} - x)^{\alpha} \ \forall x \leq \underline{x}$$

  - $\underline{x}$ is the bottom line set by the planner
  - $\kappa > 0$, and a large κ means stronger loss penalty
  - α represents the degree of risk aversion

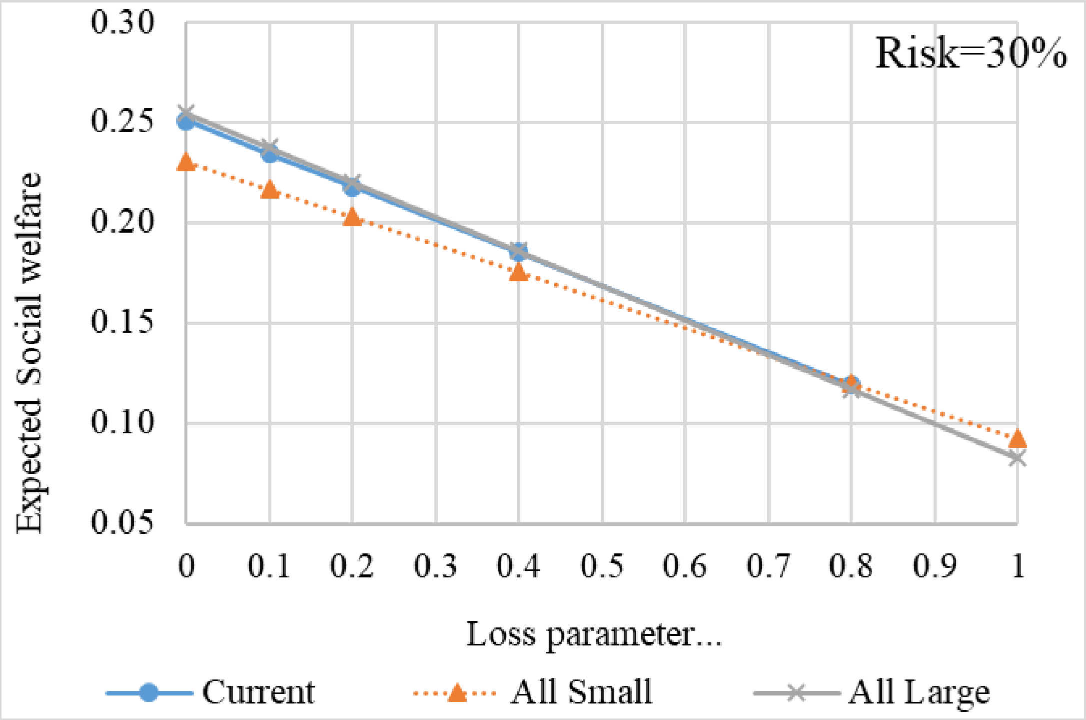
Insight 4: Loss Avoidance

- Consider a linear loss avoidance utility function where a social planner wants to avoid extremely low CS and PS

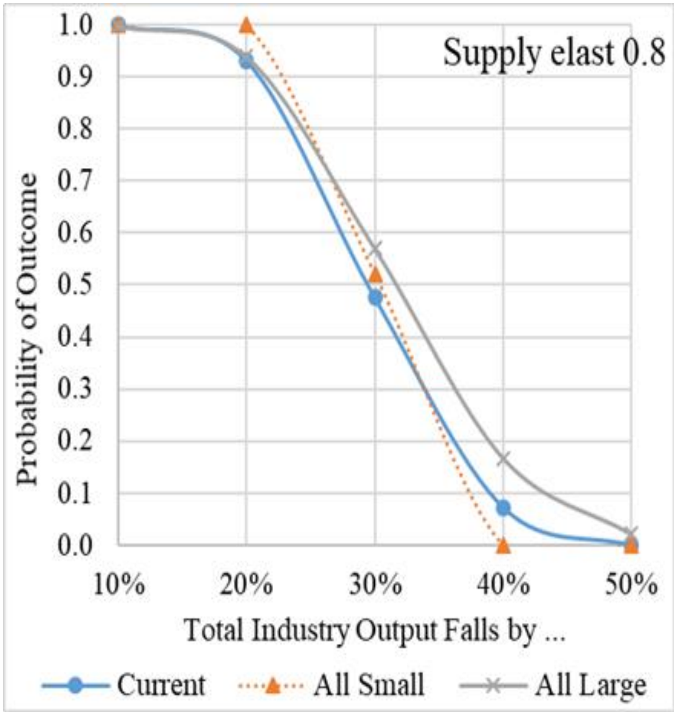
$$U(x) = x \ \forall x > \underline{x}$$
$$U(x) = x - \kappa(\underline{x} - x) \ \forall x \le \underline{x}$$

  - E.g., risk = 30%
  - Set the bottom line at 49% of the risk-free level CS and PS

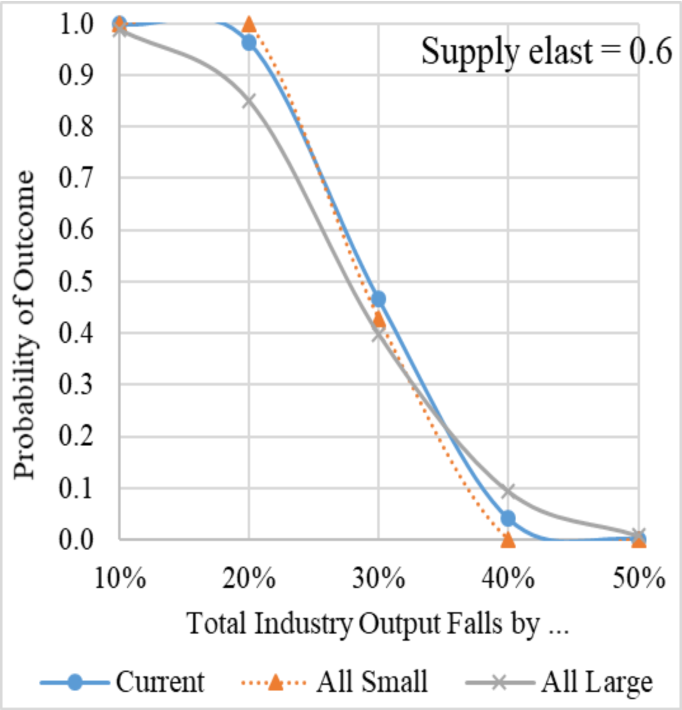
- Compute social welfare equal CS + PS + packer profits



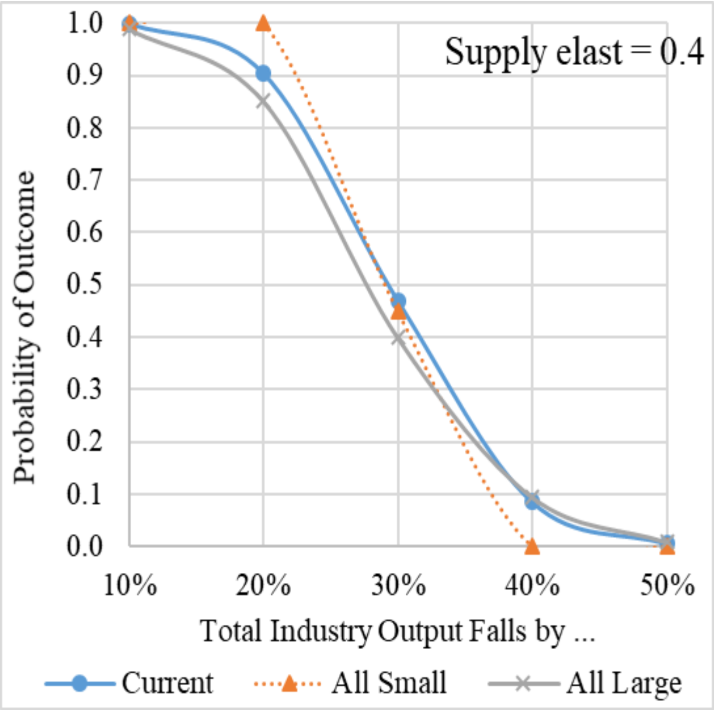
Robustness: Alternative Supply Elasticities



Risk=30%



Risk=30%



Risk=30%

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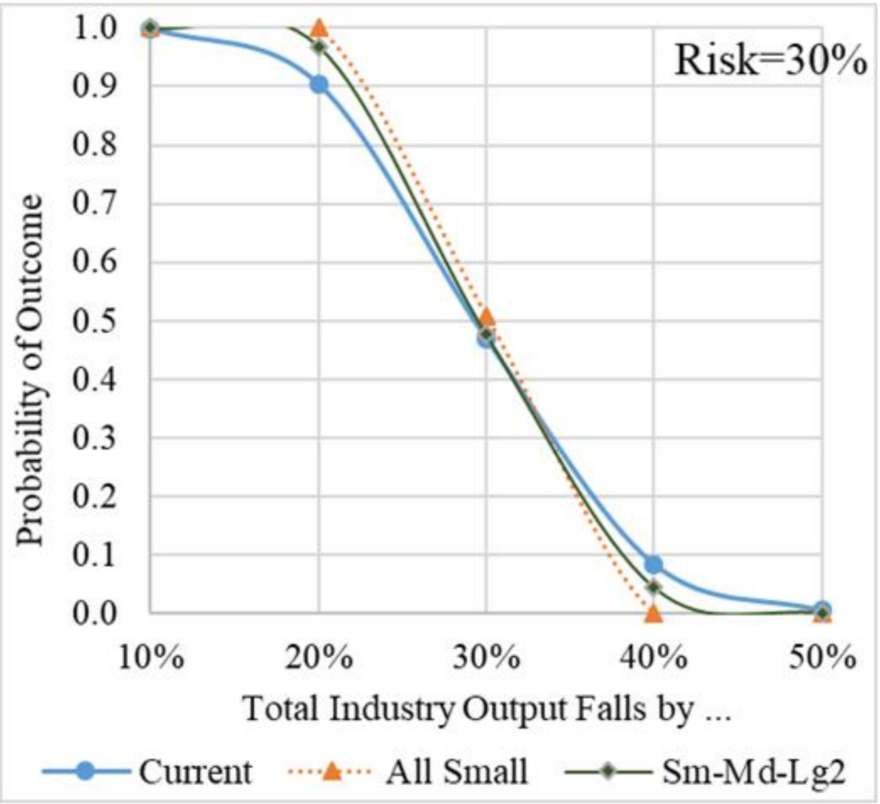
Robustness: Alternative Market Structure

- So far, we have considered two extreme alternative structures

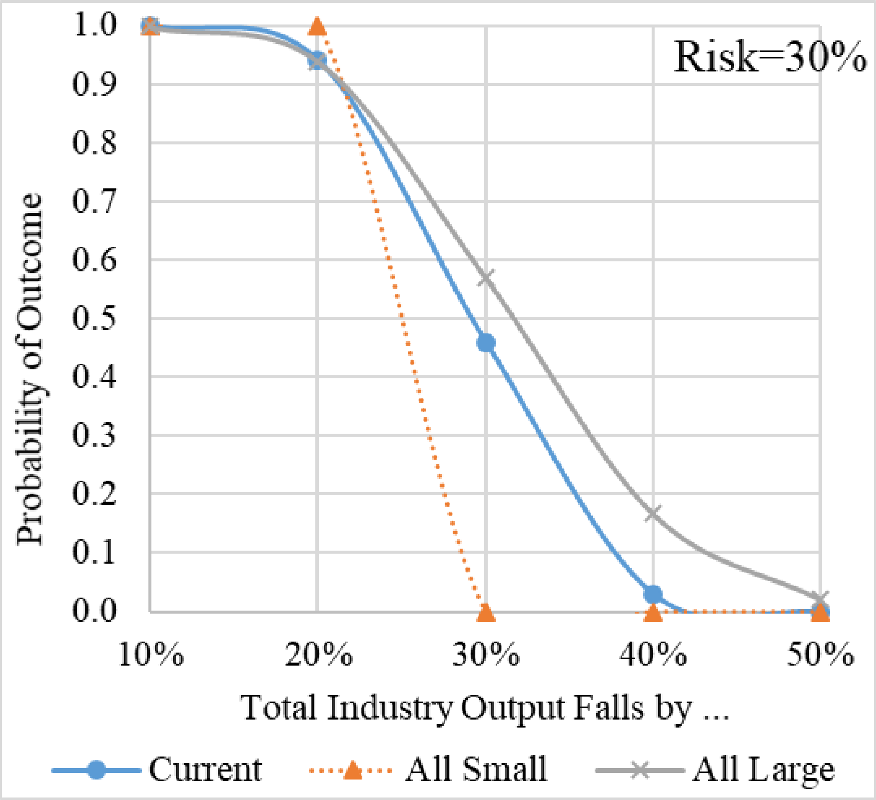
- Assume, instead, some large-sized plants are replaced by small-sized plants and the medium-sized plants remain unchanged
  - 12 large-sized plants, 33 medium-sized plants, and 7,215 small-sized plants
  - Instead of 22 large-sized plants , 33 medium-sized, and 615 small-sized plants



Robustness: Alternative Expansion Potentials

- Let small-sized plants to be able to expand production scale in the short-run, but other plants cannot

- All-small structure consistently produce outcomes equal risk-level minus the expansion rate
  - E.g., risk is 30% and expansion is 5%, then total output almost always decreases by 25% in simulations



Policy Discussion

- State and federal level bills have been proposed to encourage more capital investments and allow small processors to access larger markets (e.g., Feedstuffs, 2020; Hagstrom, 2020)
- Simulations reveal complexity in the consequences of efforts aimed at increasing the resiliency of the food supply chain through changing the horizontal market structure
- Replacing large-sized plants by small-sized tend to reduce the variance but not the expectation of output/welfare outcomes under risks
- More comprehensive policy designs may be needed to add resilience in the supply chain

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Geographical Distribution of U.S. Meat Processors

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Size Distribution of U.S. Pork Processors in 2019

Size group	# plants	% plants	Head/year	Head/plant/year	% total output
Pork					
1-999	396	64.0%	125.4	316.7	0.1%
1,000-9,999	123	19.9%	337.9	2,747.2	0.3%
10,000-99,999	39	6.3%	1,529.4	39,215.4	1.2%
100,000-249,999	18	2.9%	2,967.6	164,866.7	2.3%
250,000-499,999	7	1.1%	2,501.0	357,285.7	1.9%
500,000-999,999	3	0.5%	2,074.1	691,366.7	1.6%
1,000,000-1,999,999	6	1.0%	7,849.1	1,308,183.3	6.1%
2,000,000-2,999,999	12	1.9%	31,794.8	2,649,566.7	24.6%
3,000,000+	15	2.5%	80,031.5	5,335,433.3	61.9%
All	619	100%	129210.8		100%

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Normal vs. Emergency Times

- Assume that the shutdown risk is positive only in some periods over a large number of periods
  - Almost periods are risk-free – normal times
  - Some periods contain risks at various levels

- Compare current, all-small, and all-large structures

- Similar outcomes as in the baseline setup
  - Structures differ in variance but not expectation