THE BOUNDARY OF THE FARM: HOMEGROWN VERSUS PURCHASED FEED ON ONTARIO SWINE FARMS

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The Boundary of the Farm: Homegrown versus Purchased Feed on Ontario Swine Farms

Abstract

Transactions can be facilitated by mechanisms such as markets, contracts, and hierarchies. We treat the mechanisms as black boxes and depict the efficiency of each mechanism by the mean and variance of the output costs. The boundaries of livestock farms are measured by the percentage of homegrown feed in total feed requirement. A theoretical model is proposed which explains how farm boundaries are shaped by the efficiency of two alternative transaction-facilitating mechanisms: markets and hierarchies. Using tax file data from Ontario swine farms, this article analyzes the impact that mechanism efficiency has on farm boundaries. To identify the causal relationship, monthly CAD/USD exchange rates are used as the instrumental variable for corn prices in Ontario. The findings suggest that the boundaries of Ontario swine farms are not arbitrary, rather they are shaped by the relative efficiency of the mechanisms. It is estimated that if the average corn price were doubled, *ceteris paribus*, the average Ontario swine farmer would grow all required corn by themselves (i.e., the farm boundary is 100%). If the variance of corn prices were doubled, the average farm boundary would increase from 44% to 49.8%. The costs for doubling farm boundary are estimated to be C$9,841.

Key words: farm boundary, make-or-buy, alternative marketing arrangements, transaction cost, vertical integration, pork industry

JEL classification: Q12, D22, L25

Just like the physical world is made up of trillions of atoms, our economic world consists of trillions of transactions of goods, services and financial assets. We understand the physical world by examining individual atoms and how they work together to form our physical world. The same is true in our economic world. We cannot properly understand the economic world without understanding individual transactions and the mechanisms which govern them. For the economy to function well, we need to ensure that each transaction is efficient and evolving in scale and scope. There are at least three transaction-facilitating mechanisms: markets, contracts and hierarchical bureaucracies as seen inside firms. Should we facilitate transactions by markets with spontaneous order, by contracts with omniscient foresight, or by dictation from visionary authorities? Economists have devoted much effort to answer this question. For transactions through markets, significant progress has been made to understand the role of transaction costs (e.g., Coase 1937; Klein, Crawford, and Alchian 1978; Williamson 1971, 1973, 1979, 1985; Joskow 1987). For transactions through contracts, work such as Hart (2009), Hart and Moore (1990) and Hart and Holmstrom (2010) enhance our understanding of incomplete contracts. For transactions inside a firm directed by authorities, work by Holmstrom and Milgrom (1987, 1991, 1994) and Holmstrom (1989) show the importance of incentive instruments within firms.

There is a trade-off between different transaction-facilitating mechanisms as they each have their advantages and disadvantages. For example, a livestock farmer can buy corn from markets whenever necessary to save the inventory cost, but the transaction costs such as monitoring, information, and negotiation costs could be high (Hobbs 1997). Alternatively, the swine producer can sign a contract with his neighbor who is a crop farmer to provide corn at $3 per bushel. The contract may work well under normal circumstances. However, if an unexpected drought raises the corn price to $8 per bushel, his neighbor might hold up the transaction. Contracts, particularly under volatile circumstances, may fail as mechanisms to facilitate transactions. Upstream vertical integration, where the livestock farmer buys his neighbor's crop farm and hires him as farm manager, may be a better way to guarantee smooth transactions. The livestock farmer now has the advantage of being able to direct the farm manager (his neighbor) on corn transactions. It is even possible to replace the manager. This prevents the hold-up problem. This simplified example demonstrates the trade-offs between markets, contracts, and hierarchies where hierarchies refer to the farm management system under vertical integration.

We construct a formal model to illustrate the trade-offs among different mechanisms. Transactions of feed may be facilitated off farm through mechanisms such as markets or contracts. Alternatively, the transactions can be facilitated on farm through hierarchical farm management system. The boundary of the livestock farm, in terms of feed production, lies on a continuous spectrum ranging from buying all feed to making all feed. We model how a livestock farmer maximizes his expected utility by choosing the boundary of his farm. This is the typical "make-or-buy", firm boundary or vertical integration (in this case, upstream vertical integration) problem. Our model suggests that not only does the boundary of the farm expand when the cost of buying feed increases, but also when that cost is more volatile. This indicates that vertical integration may act as an insurance against input cost uncertainty. Interestingly, Bellemare, Lee, and Novak (2017) show that contracts can also act as partial insurance. Our model predictions are in line with Alchian (1950) that people are not simply choosing the mechanism which yields lower costs, but rather the mechanism whose potential outcome distribution is preferable.

To test the theoretical predictions, we utilize the substantial change of corn price around 2008 as a natural experiment to explore whether the level and volatility of input costs are associated with the boundaries of swine farms in Ontario. To measure feed costs and their variabilities, daily corn prices from 2003 to 2014 are collected from the Grain Farmers of Ontario daily commodity report. Farm production and financial data on a total of 2006 swine farms in Ontario are drawn from tax files. The boundary of a swine farm is measured by the percentage of homegrown corn in total corn requirement: 0% means separation (transactions facilitated off farm by mechanisms such as markets or contracts) and 100%

means full integration (transactions facilitated on farm by hierarchies). The mean and variance for the cost of purchased corn, the mean and variance for the cost of homegrown corn, and other control variables (such as farm size, operation type, diversification index) are used in regression models to explain farm boundaries.

Previous studies suggest that adoption of alternative marketing arrangements (AMAs), such as production contracts, causes price volatility on the spot market (Kim and Zheng 2015; Schroeter and Azzam 2003). However, utilizing CAD/USD exchange rates as an instrumental variable, our findings suggest that the opposite might be true: the volatilities of spot price cause the adoption of AMAs such as vertical integration. We show, for the first time, that the boundaries of Ontario swine farms are not at all arbitrary but rather shaped by the relative efficiency of alternative transaction-facilitating mechanisms. *Ceteris paribus*, we estimate that if the average corn price in Ontario on the spot market was doubled, the average swine farm would expand its boundary and produce all of the required corn itself (i.e., the share of homegrown corn increases from 44% to 100%). If the variance of corn price on the spot market was doubled, the average swine farm would increase the share of homegrown corn from 44% to 49.8%. We also estimate that, for an average swine farmer in Ontario to double the share of homegrown corn from 44% to 88%, the associated costs are C$ 9,841. The causal relationship that we identified between mechanism efficiency and farm boundary may shed light on why swine and other livestock industries are shifting towards non-market arrangements.

Theoretical Framework

Consider a business where the transaction of θ_i ($0 \leq \theta_i \leq 1$ and $\sum_{i=1}^{n} \theta_i = 1$) share of the total input (I_f) is facilitated by mechanism i, $i = 1, 2, ..., n$. That is, mechanism i facilitates the transaction of $\theta_i I_f$. Let the vector of output prices and quantities be P and Q. The profit is then

$$\Pi = PQ(I_f, \Omega) - \sum_{i=1}^{n} (M_i + \theta_i I_f C_i), \tag{1}$$

where Ω is the technology representing how efficient input is converted into output, M_i is the cost of using mechanism i to coordinate the transaction of $\theta_i I_f$. C_i is the average input cost under mechanism i. If mechanism i is efficient in facilitating transactions, the distribution of C_i should have small mean and small variance. The business evaluates the efficiency of all n mechanisms and then maximizes its objective function by adjusting θ_i. If the business buys 100% of the input from the market, then θ for market mechanism would be 1 and other mechanisms such as contracts, hierarchies or auctions would all be 0. Note that the choice of the business is not on input sources but the transaction-facilitating mechanisms. To keep the model concise while still conveying key insights, we only model the trade-offs between two transaction-facilitating mechanisms: markets and hierarchical bureaucracies. It should be noted that there are many kinds of hierarchical structures ranging from the typical pyramid structures to only one layer where decisions are made democratically. We use hierarchical bureaucracies to represent the transaction-facilitating mechanisms inside an organization loosely. Under such mechanisms, transactions are typically facilitated by directions and leaderships from the superiors such as managers in firms, directors in research institutes or family heads on farms. Although sometimes financial incentives are involved, this is different from the market mechanism where the resource allocations are coordinated spontaneously by prices.

To be more specific, consider a livestock farmer who makes θ ($0 \leq \theta \leq 1$) of the required feed (I_f) by himself and buys the rest, $(1-\theta)I_f$, from the market. As in Coase (1937), θ measures the farm boundary: the farm boundary expands as more transaction of feed is coordinated on farm through hierarchical direction; the farm boundary shrinks as the farmer "abandons the organization of such transactions" and leaves the coordination task to the market mechanism. In this model, hierarchical bureaucracy may be only one layer where the farmer works together with his family members. Farm profit is given by

$$(2) \quad \Pi = PQ(I_f, \Omega) - M_m(\theta) - \theta I_f C_m - M_b(\theta) - (1-\theta) I_f C_b - C_o,$$

where P is the livestock price. Q is the quantity of livestock sold. Ω is a vector of farm technology and operator characteristics affecting the conversion ratio from feed intake to livestock weight gain. M_m, a function of θ, is the cost of using hierarchy as a mechanism to coordinate the transaction of θI_f. M_m is the management costs. Adding crop production to livestock operation complicates the management process; the costs of coordinating additional transactions on farm increase. Thus, M_m is assumed to increase at an increasing rate as the farm boundary expands. That is $\frac{\partial M_m}{\partial \theta} = M_{m\theta} > 0$, and $\frac{\partial M_{m\theta}}{\partial \theta} = M_{m\theta\theta} > 0$. C_m is the average cost of feed made by the livestock farmer himself. M_b, a function of $1-\theta$, is the cost of using market as a mechanism to coordinate the transaction of $(1-\theta)I_f$. M_b is the transaction costs. As the quantity of purchased feed increase, feed from the familiar supplier may not be sufficient. This forces the livestock farmer to find unfamiliar supplier resulting higher transaction cost. It is assumed that M_b decreases at an increasing rate as the farm boundary expands. That is $\frac{\partial M_b}{\partial \theta} = M_{b\theta} < 0$, and $\frac{\partial M_{b\theta}}{\partial \theta} = M_{b\theta\theta} > 0$. C_b is the average cost of feed bought from the market (i.e., the price of feed). C_o is the other costs.

It is often true that, in one geographic region, a few meat processors are surrounded by a large number of livestock farms. Meat processors may have more market power (Zheng and Vukina 2009). For example, there are hundreds of swine farms in Ontario while only two major meat packers: Sofina and Conestoga Meat Packers[1]. As a result, the livestock farmers are assumed to be price-takers. Based on the central limit theorem, C_b and C_m, as average costs, are normally distributed: C_b with mean μ_b and variance σ_b^2, C_m with mean μ_m and variance σ_m^2.

The farmer's utility function is represented by a negative-exponential expected utility function. The utility of the farmer is

$$(3) \quad U(\Pi) = -e^{-\alpha \Pi},$$

where $\alpha > 0$ is the coefficient of risk aversion. α increases as the farmer becomes more risk-averse. Denote the probability density function of C_b and C_m by $f(C_b)$ and $f(C_m)$, the farmer's expected utility is

$$EU(\Pi) = \iint -e^{-\alpha\Pi} f(C_b) f(C_m)\, dC_m dC_b \tag{4}$$

$$= \iint -e^{-\alpha\Pi} \frac{1}{\sqrt{2\pi}\sigma_b} e^{-\frac{(C_b-\mu_b)^2}{2\sigma_b^2}} \frac{1}{\sqrt{2\pi}\sigma_m} e^{-\frac{(C_m-\mu_m)^2}{2\sigma_m^2}} dC_m dC_b \tag{5}$$

$$= -e^{-\alpha(PQ-M_m-M_b-C_o)} \int e^{\alpha(1-\theta)I_f C_b} \frac{1}{\sqrt{2\pi}\sigma_b} e^{-\frac{(C_b-\mu_b)^2}{2\sigma_b^2}} dC_b \times \tag{6}$$

$$\int e^{\alpha\theta I_f C_m} \frac{1}{\sqrt{2\pi}\sigma_m} e^{-\frac{(C_m-\mu_m)^2}{2\sigma_m^2}} dC_m. \tag{7}$$

The range of integration is $[0, +\infty)$ as the cost of bought and made feed are no-negative. Maximizing $EU(\Pi)$ is equivalent to minimizing

$$\Psi = E(\Pi) - \frac{\alpha}{2}((1-\theta)^2 I_f^2 \sigma_b^2 + \theta^2 I_f^2 \sigma_m^2) \tag{8}$$

$$= PQ(I_f, \Omega) - M_m - \theta I_f \mu_m - M_b - (1-\theta) I_f \mu_b - C_o - \frac{\alpha}{2}((1-\theta)^2 I_f^2 \sigma_b^2 + \theta^2 I_f^2 \sigma_m^2). \tag{9}$$

(See proof in appendix).

The farmer chooses farm boundary θ to maximize the expected utility. We want to stress that, the choice of the farmer is no longer between the feed from the market and the feed produced on his farm. As a matter of fact, the quality of the feed would be most likely similar, if not identical. Nor is the farmer choosing among feed with different price tags. The farmer is now choosing between two organizational modes, two arrangements, two coordination systems, two mechanisms. One mechanism is the market where the transactions are facilitated by prices. The ups and downs of prices signal the participants in the market what to produce, how much to produce and for whom to produce. The other mechanism is the hierarchical farm management mechanism where the transactions are facilitated by leadership and direction. The farmer decides what to produce, how much to produce and how to produce based not on prices, but on his knowledge and belief. Each mechanism has its own cost and benefit, strength and weakness. One mechanism may substitute the other (Hu and Zheng 2012). As shown in figure 1, treating each mechanism as a black box, we use the mean and variance of the output to measure the efficiency of the transaction-facilitating mechanism. Efficiency can also be measured by partial and total factor productivity or technological improvement. Key and McBride (2003) show that contract as a mechanism yields higher factor productivity than hierarchy (i.e., independent production) for feeder pig-to-finish hog operations.

In choosing between the planned economy and market economy, Deng Xiaoping, the chief architect of China's economic reforms stated that "It doesn't matter whether a cat is white or black, as long as it catches mice." Acknowledging the career change from barn cats to pet cats, let's assume that cats are still interested in catching mice. Then in Deng's case, the two black boxes are the two cats. The output is the number of reduced mice. The efficiency of each cat is measured by the mean and the variance of the number of reduced mice. In our case, the two black boxes are the market mechanism and the hierarchical farm management mechanism. The output is feed costs. The efficiency of the mechanisms is measured by the mean and variance of feed cost under each mechanism.

The first order condition (FOC) is

$$(10)\quad \frac{\partial \Psi}{\partial \theta} = -M_{m\theta} - M_{b\theta} + I_f\mu_b - I_f\mu_m + \alpha(1-\theta)I_f^2\sigma_b^2 - \alpha\theta I_f^2\sigma_m^2 \equiv 0.$$

The optimal farm boundary is defined by

$$(11)\quad \theta^* = \frac{-M_{m\theta} - M_{b\theta} + I_f\mu_b - I_f\mu_m + \alpha I_f^2\sigma_b^2}{\alpha I_f^2\sigma_b^2 + \alpha I_f^2\sigma_m^2}.$$

To examine the impact of the mean of C_b and C_m on the optimal farm boundaries, total differentiate the FOC with respect to μ_b and μ_m, respectively. This yields

$$(12)\quad \frac{\partial \theta^*}{\partial \mu_b} = \frac{I_f}{M_{m\theta\theta} + \alpha I_f^2\sigma_b^2 + \alpha I_f^2\sigma_m^2} > 0,$$

and

$$\text{(13)} \quad \frac{\partial \theta^*}{\partial \mu_m} = -\frac{I_f}{M_{m\theta\theta} + \alpha I_f^2 \sigma_b^2 + \alpha I_f^2 \sigma_m^2} < 0.$$

Thus, as the expected cost of bought feed increases, farm boundary expands. On the other hand, if the expected cost of made (i.e., homegrown) feed increases, farm boundary shrinks.

The interesting symmetry that $\frac{\partial \theta^*}{\partial \mu_b} / \frac{\partial \theta^*}{\partial \mu_m} = -1$ should not be ignored. As μ_b and μ_m change, the farm boundary will adjust accordingly until a point is reached where no extra gain can be captured. Of course, this model only considers two alternative mechanisms. As one mechanism pushes the farm boundary to expand, the other must retreat with the same magnitude. That is, on the optimal farm boundary, the two forces (μ_b and μ_m) shaping the farm boundary are with the same magnitude and opposite directions.

To examine the effect of the variabilities for the average cost of bought feed on farm boundaries, total differentiation the first order condition with respect to σ_b^2 gives

$$\text{(14)} \quad -M_{m\theta\theta}\frac{\partial \theta}{\partial \sigma_b^2} - M_{b\theta\theta}\frac{\partial \theta}{\partial \sigma_b^2} - \alpha\frac{\partial \theta}{\partial \sigma_b^2} I_f^2 \sigma_b^2 + \alpha(1-\theta)I_f^2 - \alpha\frac{\partial \theta}{\partial \sigma_b^2} I_f^2 \sigma_m^2 = 0.$$

As $M_{m\theta\theta} + M_{b\theta\theta} > 0$, then

$$\text{(15)} \quad \frac{\partial \theta^*}{\partial \sigma_b^2} = \frac{\alpha(1-\theta)I_f^2}{M_{m\theta\theta} + M_{b\theta\theta} + \alpha I_f^2 \sigma_b^2 + \alpha I_f^2 \sigma_m^2} > 0.$$

This shows that when the cost of bought feed are more volatile, farm boundary expands. This may explain the vertical integration behavior: when a downstream firm requires raw materials but the upstream markets for raw materials often experience fluctuation, then more upstream vertical integration might be observed. Total differentiation of the first order condition with respect to σ_m^2 yields

$$\text{(16)} \quad \frac{\partial \theta^*}{\partial \sigma_m^2} = -\frac{\alpha \theta I_f^2}{M_{m\theta\theta} + M_{b\theta\theta} + \alpha I_f^2 \sigma_b^2 + \alpha I_f^2 \sigma_m^2} < 0.$$

This demonstrates that when the variabilities of the cost of homegrown feed increase, farm boundary shrinks. Conveniently, $\frac{\partial \theta^*}{\partial \sigma_b^2} / \frac{\partial \theta^*}{\partial \sigma_m^2} = -\frac{1-\theta}{\theta}$. The suggests that the ratio of the marginal effect is only a function of farm boundary. It is not affected by farmer's risk attitude, the quantity of feed, or even the size of the variabilities themselves. This dramatically simplifies the process to test such a prediction.

Finally, differentiate the FOC with respect to α, we have

$$(17)\quad \frac{\partial \theta^*}{\partial \alpha} = \frac{(1-\theta)I_f^2\sigma_b^2 - \theta I_f^2\sigma_m^2}{M_{m\theta\theta} + \alpha I_f^2\sigma_b^2 + \alpha I_f^2\sigma_m^2}.$$

From FOC we know that

$$(18)\quad (1-\theta)I_f^2\sigma_b^2 - \theta I_f^2\sigma_m^2 = \frac{M_{m\theta} + M_{b\theta} + I_f(\mu_m - \mu_b)}{\alpha},$$

plug this back into equation 17 yields

$$(19)\quad \frac{\partial \theta^*}{\partial \alpha} = \frac{M_{m\theta} + M_{b\theta} + I_f(\mu_m - \mu_b)}{\alpha(M_{m\theta\theta} + \alpha I_f^2\sigma_b^2 + \alpha I_f^2\sigma_m^2)}.$$

This demonstrates how a farmer's attitude toward risk increases his financial burden. Consider a case where the farmer slightly increases the share of homegrown feed, the consequential increased costs of using the hierarchy mechanism are positive ($M_{m\theta} > 0$) and the consequential costs saving on using the market mechanism ($M_{b\theta}$) are negligible. This enables $M_{m\theta} + M_{b\theta} > 0$. Under this condition, when the expected cost of homegrown feed is greater than the expected cost of bought feed ($\mu_m > \mu_b$), we have $\frac{\partial \theta^*}{\partial \alpha} > 0$. This indicates that as farmers become more risk-averse, they expand farm boundaries and make more feed even when it is cheaper to buy.

Data and Descriptive Statistics

The empirical study focuses on the swine industry. The boundary of a swine farm (θ) is represented by the share of homegrown feed in total feed required. Since corn is the main feed for pigs, in this study the boundary of a swine farm (θ) is measured by the share of homegrown corn in total corn required. Corn required to feed one market hog is assumed to be 10 bushels. $1-\theta$ is assumed to be the share of corn bought from the spot market. The main data we use is from the Ontario Farm Income Database (OFID). This farm-level dataset contains data on production, financials, and program payments of all tax-filing farm operations in Ontario from 2003 to 2014. Farms with more than 50% revenue from swine sales are defined as swine farms in this study. Specifically, the acreage of corn planted for feed on each swine farm is reported. This acreage is multiplied with county-level corn yield per acre to estimate the quantity of homegrown corn. The county-level corn yield is from the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA)[2].

The daily prices of corn for the counties in Ontario are from the Ontario commodity reports by Grain Farmers of Ontario. As the OFID data is yearly data and the swine industry experiences a cycle about every four years, we use the mean and variance of the corn prices of the previous four years, *Mean C Buy* and *Var C Buy*, respectively, to depict the efficiency of markets as the transaction-facilitating mechanism. The efficiency of the alternative transaction-facilitating mechanism is depicted by *Mean C Make* and *Var C Make*, the mean and variance of the costs of homegrown corn in the previous four years, respectively. As farm-level data on the costs of homegrown corn is not available, we use the average corn prices during the harvest season (October 15 to November 15) as the average costs of homegrown corn. We believe this is the time that the corn market is most likely, if not certainly, a perfectly competitive market. The reasons are: (a) there are no barriers to entry; (b) the supply of corn during this time is likely to be abundant compared to demand; (c) there is a large number of corn producers; and (d) corn produced by different farmers is likely to be similar, if not identical, in quality. Since on the perfectly competitive market, the price is equal to the average cost. This allows us to represent the average cost of homegrown corn by the average market price during the harvest season. The median and minimum of corn prices during the harvest season are also used to represent the cost of homegrown corn in our robustness check. Daily Ontario corn prices from 2003 to 2014 are shown in figure 3 with the harvest season highlighted. Prices between two harvest seasons are often higher than those during harvest seasons. Additionally, we calculate the average profit margin of corn production in Ontario from 2003 to 2015 using the province-level break-even prices from OMAFRA. The result is -1.5%, close to 0%, suggesting that the corn market is perfectly competitive[3].

Regarding our control variables, the variable *Diversification*, ranging from 1 to ∞, is the reciprocal of the Herfindahl index for a swine farm. The Herfindahl index is defined as the sum of the squared share of revenue generated from each commodity group on the farm. A more diversified swine farm which also grows multiple cash crops will have greater *Diversification* value compared to a swine farm which solely concentrates on swine production. The number of swine is the number of market hog equivalent (MHE) on the farm[4]. Total acreage is the total crop acres. Income is an 11-levels factor that indicates the range of total operating revenue of the farm[5]. The prime rate is the Bank of Canada prime lending rate.

Lastly, the instrumental variable we use as a source of exogenous variation in the price of corn is the monthly exchange rate between the Canadian dollar and US dollar. These monthly exchange rates are obtained from the "Quandl" package in R[6]. The monthly exchange rates highly correlate with the corn prices in a given county-year, but not with the boundary of the farm. The correlations between the boundary of the farm, the mean and variance of the cost of bought and homegrown corn in a given county-year are presented in table 1.

Figure 2 presents the number of swine farms in our study from 2003 to 2014. The total number of swine farms decreases over the years: the highest number is 1361 in 2004 while only 503 are left in 2014. 228 of the swine farms are continuously operating from 2003 to 2014, merely 17.5% of 2003, the first data reporting year.

Table 2 presents the descriptive statistics for the dependent variable (i.e., farm boundary), for the variables of interest (i.e., mean of the costs of bought corn, variance of the costs of bought corn, mean of the costs of homegrown corn, and variance of the costs of homegrown corn), for the control variables, and finally for the instrumental variable (i.e., monthly CAD/USD exchange rates).

The average swine farm grows 44% of the corn required. The average cost of corn bought from spot market (i.e., the average market price) is 3.776 CAD/Bushel compared to 3.669 CAD/Bushel when produced on the farm. The average variance of the costs of bought corn is 0.605 while the homegrown counterpart is only 0.379. The average swine farm has a diversification index of 0.795 with majority income from swine operation. The total number of market-hog-equivalent (MHE) sold per year on the average farm is 6500. The average swine farm has 310 acres of farmland with operating revenue between C$400,000 to C$500,000. The average prime rate is 4.19%. Finally, the average CAD/USD exchange rate on different months in the average county-year for the period we study is 1.1. A positive constant one is added to all numerical data in our dataset to ensure the log-log models work properly[7].

Empirical Framework

We stress again that we want to investigate potential causal relationship flowing from the efficiency of transaction-facilitating mechanisms (markets or hierarchies) to farm boundary. By efficiency, we mean the mechanism's ability to consistently (smaller variance) yield output with lower cost (smaller mean). For example, transactions of corn can be facilitated by mechanism A or B. If the variances of corn costs under the two mechanisms are the same, but the average cost under A is smaller than under B, then A is more efficient. If the means are the same, but the variance of the costs under B is smaller than under A, then B is more efficient. We hypothesize that the change of the relative efficiency of the two mechanisms will induce a reallocation of transactions.

In this section, we discuss the main model, a log-log ordinary least square (OLS) estimation. We explain our strategy to identify the causal relationship using monthly exchange rate as the instrumental variable. Additional identification strategies that ensure the robustness of our findings are also discussed.

Estimation Strategy

From our theoretical model, we know that the optimal level of the farm boundary is a ratio (see equation 11). Therefore we choose log-log form OLS regression such that

$$(20)\quad log(y_{it}) = a + \beta_1 log(\mu_{b_{it}}) + \beta_2 log(\sigma^2_{b_{it}}) + \beta_3 log(\mu_{m_{it}}) + \beta_4 log(\sigma^2_{m_{it}}) + \gamma X_{it} + \varepsilon_{it},$$

where y_{it} is our dependent variable of interest, the boundary of the swine farm (i.e., the share of homegrown corn in the total corn required to feed the pigs on farm i in year t). a is a constant. The treatment variables are $\mu_{b_{it}}, \sigma^2_{b_{it}}, \mu_{m_{it}}$, and $\sigma^2_{m_{it}}$ (i.e., the mean of corn costs on the local spot market for farm i in year t, the variance of corn costs on the local spot market for farm i in year t, the mean of the costs of homegrown corn on farm i in year t, and the variance of the costs of homegrown corn on farm i in year t, respectively). X_{it} is a vector of control variables, and ε_{it} is an error term with mean zero.

Our purpose is to study how farm boundary is affected by the efficiency under two transaction-facilitating mechanisms by estimating β_1, β_2, β_3, and β_4. If $\mu_{b_{it}}, \sigma^2_{b_{it}}, \mu_{m_{it}}$, and $\sigma^2_{m_{it}}$ were randomly assigned, the four estimated coefficients $\hat{\beta}_1$, $\hat{\beta}_2$, $\hat{\beta}_3$, and $\hat{\beta}_4$ would measure the causal effect of 1% increase of the mean of the costs of bought corn, the variance of the costs of bought corn, the mean of the costs of homegrown corn, and the variance of the costs of homegrown corn on the percentage change of the boundary of the average swine farm, respectively. The main null hypotheses are then H_i: $H_0 : \beta_i = 0$ with alternative hypotheses $H_A : \beta_i \neq 0$ where $i = 1,2,3,4$. Additionally, we also test the theoretical predictions on the ratios of the marginal effects of the means and variances of feed costs on farm boundary. The null hypotheses are $H_0^{r1} : \frac{\beta_1}{\beta_3} = -1$ and $H_0^{r2} : \frac{\beta_2}{\beta_4} = -\frac{1-\theta}{\theta}$ with alternative hypotheses $H_A^{r1} : \frac{\beta_1}{\beta_3} \neq -1$ and $H_A^{r2} : \frac{\beta_2}{\beta_4} \neq -\frac{1-\theta}{\theta}$, respectively.

Identification Strategy

The factors which may potentially undermine the identification of β_i, $i = 1,2,3,4$, are discussed in this section. These include (i) unobserved heterogeneity, (ii) measurement error, and (iii) reverse causality.

Firstly, we discuss endogeneity that may be caused by unobserved heterogeneity. To tease out the effect of the efficiency of mechanism on farm boundary, we need to control other variables which may affect farm boundary. The reasons why we choose the control variables in our model are as follows. The farm boundary may be affected by the number of pigs and the size of farmland. Swine farmers apply manure from pigs to their crop fields. It is possible that some swine farmers may base the size of their farmland on available manure which correlates to the number of pigs. Capital availability may affect the expansion of farm boundary as purchasing additional farmland for homegrown corn requires significant capital. Thus prime rates, which affect the cost of financing to buy additional farmland, are added. Machinery, which may influence the ability to expand farm boundary, is captured by the expenditure on machinery repair. It should be noted that swine farmers do have the option to rent additional farmland. This would allow them to adjust the farm boundary with less cost. The operation types of the swine farms may affect the farm boundary. Different operation types require different quantities of feed. A farrow-to-weaner swine farm, which requires small quantities of corn, may continue to buy from the market when corn prices are high while a farrow-to-finish farm, which requires significantly more feed, may turn to homegrown corn. Corn yield and farm location are also included as control variables. Swine farms with high yield farmland may grow more corn. The county where the farm is located is also included to capture unobserved heterogeneity across counties. Any remaining heterogeneity to bias our estimate of β_i must change systematically over time and is not captured by the variables on the right-hand side of equation 20.

The control variables and the county fixed effect would account for most of the heterogeneity. To eliminate the unobserved heterogeneity over time, we also estimate the main model with data from only one year. In this case, the unobserved heterogeneity which could potentially bias our estimate of β_i must vary consistently in the same year in the same county across different farms and must not be included in our model. Farmer's risk attitude could be such an unobserved heterogeneity (Zeuli and King 2004; Franken, Pennings, and Garcia 2017). Note in our theoretical model that farm's risk attitude affects the farm boundary. Risk-averse swine farmers may prefer growing some or all of the corn by themselves over relying entirely on the market. We have no direct control of risk attitude in our model. However, diversification and income may capture some, if not all, of the effect of risk attitude. Risk-averse farmers are more likely to diversify their farm operations, and farmers become more risk tolerant as their incomes increase. To further control the effect of risk attitude, we estimate the main model using a subset of the data which tracks the same farms from 2003 to 2014. The risk attitude of the swine farmers should be relatively stable over time especially after accounting for diversification index and income. Thus, the heterogeneity regarding risk attitude in this subset should be less compared to the entire dataset as the observations are from the same farms in different years. Should risk attitude significantly bias our estimate of β_i, the estimated coefficients from this subset will be significantly different from our main results.

There are potentially many unobserved heterogeneities and it is impossible to account for all of them. For example, Gillespie, Karantininis, and Storey (1997) discuss the importance of public and industry policy in the expansion of vertical integration in the Quebec hog industry. Farmer's preference of autonomy is also important in the selection of mechanisms (Gillespie and Eidman 1998; Hudson and Lusk 2004; Davis and Gillespie 2007). However, we believe we have captured the key factors in our model. We assume other unobserved heterogeneities do not significantly bias our estimation of β_i. This assumption is not groundless. We can verify the validity of this assumption by examining the relationship between the estimated coefficients. If our model correctly depicts how the farm boundaries are formed, then we should reject H_0^{r1} and H_0^{r2}. To do this, we estimate the main model with randomly selected subset of swine farms from the entire dataset. This process is repeated for n times which generates n pairs of coefficients. $\frac{\partial\theta}{\partial\mu_b}/\frac{\partial\theta}{\partial\mu_m}$ and $\frac{\partial\theta}{\partial\sigma_b^2}/\frac{\partial\theta}{\partial\sigma_m^2}$ are calculated for each pair. One-sample t-test is used to check if the average of $\frac{\partial\theta}{\partial\mu_b}/\frac{\partial\theta}{\partial\mu_m}$ and $\frac{\partial\theta}{\partial\sigma_b^2}/\frac{\partial\theta}{\partial\sigma_m^2}$ are equal to its theoretical predictions, -1 and $-\frac{1-\theta}{\theta}$, respectively. If the predicted ratios are not statistically different than the theoretical prediction, then the unobserved heterogeneities are less likely to be a problem.

Next, we discuss the endogeneity from measurement error. Recall that we assume that 10 bushels of corn are required to feed one MHE per year. This assumption will not contaminate the estimate of β_i. The reason is that corn required for an MHE per year is likely to be a constant. This is due to the wide adoption of artificial insemination technology. The pigs on the same swine farm are likely to be genetically identical thus on average require a similar amount of feed per year. The magnitude of this constant would only affect the estimated interception, not our coefficients of interest (see appendix). The other potential measurement concern is that the dependent variable and control variables are farm-level data while the treatment variables are county-level data. Swine farmers in the same county may get different quotes on corn. However, our treatment variables are not corn costs at each transition, but rather the distributional characteristics of the costs (mean and variance). Although the price quoted to an individual farmer may differ, it is likely that swine farmers in the same county are facing corn prices with similar mean and variance. When corn is homegrown, the farm-level costs might differ from the county-level. Firstly, corn production on swine farms may not be as efficient as on farms dedicated solely to crop production. Secondly, variations in the production costs of corn among individual swine farms may be significant due to different farm size, land quality, location, and weather. Thirdly, recall that we use county-level corn prices during the harvest season as the homegrown costs for individual farms. The lowest corn prices typically appear in the harvest season. Therefore, using county-level corn prices during the harvest season as the farm-level homegrown costs may underestimate the effect of the means and variances of homegrown corn costs on farm boundaries. That is $|\hat{\beta}_3| < |\beta_3|$ and $|\hat{\beta}_4| < |\beta_4|$. This bias would make one less likely to reject the null hypotheses H_3 and H_4, which means that rejection of these two hypotheses provides even stronger evidence. In this case, the estimated coefficients, $\hat{\beta}_3$ and $\hat{\beta}_4$, are the lower bound of the true effects. To further address this concern, we aggregate all farm-level data into county-level and re-estimate the main model as a robustness check. In the aggregation process, the average value of the swine farms in the same county is used as the county-level value. We also use the median value to avoid potential bias from extreme observations.

Finally, we discuss reverse causality which may contaminate the estimated coefficients. Our empirical model assumes that the mean and variance of costs of corn under different mechanisms affect farm boundary. However, it is plausible that farm boundary may affect the mean and variance of the input costs. Kim and Zheng (2015) show that as more productions of hogs are guided by alternative marketing arrangements (i.e., farm boundary expands), the spot prices of hogs decrease and the volatility of price increases. This is likely to be true when the volume of transactions via spot market is small (indeed, Kim and Zheng (2015) show only 5.2% of hogs were transacted on the spot market in 2010). However, this is less likely to be a problem in our case. The effect of the make-or-buy decisions of corn by Ontario swine farmers on the level and volatility of corn prices is not likely to be significant. The prices of corn on the spot market in Ontario are mainly shaped by the futures price of corn in the United States, the CAD/USD exchange rate, and other factors.

To further address the reverse causality problem, we investigate the potential causal relationship between the efficiency of mechanisms and farm boundary. We do this by estimating our main equation using the two-stage least squares (2SLS) method. The instrumental variable for means and variances of corn costs under the two mechanisms is the monthly CAD/USD exchange rates. We explain our rationale for choosing monthly CAD/USD exchange rates as instrumental variables (IV) as follows. An ideal IV should be exogenous, correlated with our variables of interest and uncorrelated with the dependent variables. Firstly, monthly exchange rates are affected by the demand and supply of Canadian dollars and U.S. dollars. Thus it is plausibly exogenous to the means and variances of the corn costs under two mechanisms and is uncorrelated with the error term. Secondly, on relativity, monthly exchange rates should affect the corn prices in Ontario. The corn prices in Ontario are influenced by the corn price in the U.S. futures market, exchange rates, transportation cost and other factors. The costs of homegrown corn may also be affected by the exchange rates as some of the farm inputs, such as equipment and fertilizers, may be bought from U.S. or priced in U.S. dollars. Thirdly, the causal relationship between our dependent variable, farm boundaries, and the monthly exchange rates should flow only one direction. That is, exchange rates affect farmer's make-or-buy decision, not the other way around. It is very unlikely that a decision on the farm boundary of an Ontario swine farmer would affect the monthly CAD/USD exchange rates.

The relationship between corn prices and IV is likely to be monotonic. As a result, our 2SLS specifications identify the local average treatment effects (LATE): the effects of the means and variances of corn prices on farm boundaries that are caused by exchange rates. We want to remind the reader that the magnitude of the LATEs of the means will not be comparable with the average treatment effects (ATE) from our OLS regressions. The magnitude of the LATEs of the variances will surely be amplified compared to the ATE from our OLS regressions. To be specific, if exchange rate changes from e to λe, the effect of the variances on farm boundary will be amplified by λ^2. Therefore, the magnitude of the coefficients estimated for the variances from 2SLS will be greater than those from OLS[8].

Placebo and falsification tests are conducted by (i) regressing farm boundary on the right-hand side (RHS) variables in the main model where the four treatment variables are replaced by four randomly generated variables and (ii) regressing a randomly generated dependent variable on the original RHS variables.

Estimation Results and Discussion

We present and discuss our main regression results in this section. The main results are presented in table 3. The three columns report results when the mean, the median and the minimum prices of corn during the harvest seasons are used as the costs of homegrown corn. No matter how the costs of homegrown corn are measured, the general conclusion is the same: after controlling for farm operation type, country fixed effect as well as other control variables discussed previously, there is a significant relationship between the efficiency of transaction-facilitating mechanisms and farm boundaries. (1) Farm boundaries expand as the average cost of corn under the market mechanism increases (i.e., swine farmers grow more corn for feed by themselves when the average corn price increases). (2) Farm boundaries expand as the variability of corn costs under the market mechanism increases (i.e., swine farmers grow more corn for feed by themselves when the market prices of corn are less certain). (3) Farm boundaries shrink as the average cost of corn under the hierarchy mechanism increases (i.e., swine farmers grow less corn for feed by themselves when the average cost of homegrown corn increases). (4) Farm boundaries shrink as the variability of the cost of corn under the hierarchy mechanism increases (i.e., swine farmers grow less corn for feed by themselves when the costs of homegrown corn are less certain). These results clearly suggest that swine farmers make decisions at the margin, as often seen in economic theory. They are allocating the transactions of corn under two alternative transaction-facilitating mechanisms based on their efficiency. The mechanism which consistently (lower variance) yields output (corn for feed) with lower cost will be chosen. This is exactly the same as what we predicted in the previously developed theory.

Table 4 presents the first stage of the 2SLS regression results where monthly CAD/USD exchange rates are used to predict the means and variances of the corn costs under the two mechanisms. Table 5 presents the 2SLS regression results where monthly exchange rates are used as instrumental variables for the means and variances of the costs under two mechanisms. The effect of the efficiency of the two transaction-facilitating mechanisms on farm boundaries appears to be robust. This suggests that the efficiency of transaction-facilitating mechanisms not only is associated with but also causes the changes of farm boundaries.

As previously mentioned, the magnitudes of the marginal effects from 2SLS are not directly comparable to those from the OLS. The corn prices on the spot market are more likely to be affected by exchange rates than the costs of homegrown corn. This explains why the difference between $\hat{\beta}_1^{2SLS}$ and $\hat{\beta}_1^{OLS}$ (i.e., $|0.641| - |0.524| = 0.117$) is greater than the difference between $\hat{\beta}_3^{2SLS}$ and $\hat{\beta}_3^{OLS}$ (i.e., $|-0.582| - |-0.508| = 0.074$). The magnitudes of the effects of cost variances on farm boundaries from 2SLS (i.e., 0.188 and -0.207) are greater than those from OLS (i.e., 0.107 and -0.092) as we previously explained.

We now recover the marginal effect of the efficiency of transaction-facilitating mechanisms on farm boundaries[9]. With a farm boundary of 0.44 on an average farm-year, the marginal effects of the mean and variance of bought corn costs and the mean and variance of homegrown corn costs are 0.158 (i.e., $0.158 = \hat{\beta}_1 \frac{1+mean(\theta)}{1+mean(\mu_e)} = 0.524 \times \frac{1+0.44}{1+3.776}$), 0.096 (i.e., $0.096 = \hat{\beta}_2 \frac{1+mean(\theta)}{1+mean(\sigma_e^2)} = 0.107 \times \frac{1+0.44}{1+0.605}$), -0.157 (i.e., $-0.157 = \hat{\beta}_3 \frac{1+mean(\theta)}{1+mean(\mu_i)} = -0.508 \times \frac{1+0.44}{1+3.669}$), and -0.096 (i.e., $-0.096 = \hat{\beta}_4 \frac{1+mean(\theta)}{1+mean(\sigma_i^2)} = -0.092 \times \frac{1+0.44}{1+0.379}$), respectively. *Ceteris paribus*, this means that if the average corn cost on the spot market were doubled, the average farm boundary would expand by 0.597 (i.e., 3.776×0.158) to 1.037 (i.e., 0.44 + 0.597). In this case, whether through buying or renting additional farmland, the average swine farm would produce all of the required corn (103.7% of required corn to be exact) by themselves. Symmetrically, if the average cost of homegrown corn were doubled, the average farm boundary would decrease by -0.576 (i.e., 3.669×-0.157). This implies that the average swine farmer would buy all the required corn from the spot market. It should be noted that there are costs for switching from markets to hierarchies. This may include the cost of finding the farmland to buy or rent, the cost of negotiation, the cost of maintaining contracts. The price and the price trend of farmland, the rent of farmland, the availability of farmland near the swine farm, and the liquidity of farmland may all affect the switching process. However, the wider the cost difference under the two mechanisms, the stronger the incentive for the farmers to switch. In our study, we put these factors in a black box and examine the relationship between the efficiency of the transaction-facilitating mechanisms and farm boundaries. It seems that the swine farmers will completely switch from one mechanism to another when the average cost under one mechanism doubles the other. This might partly explain why the prices of corn between two harvest seasons are generally higher than the prices during harvest season but rarely twice more expensive (see figure 3).

If the average variance of corn costs on the spot market were doubled, the average farm boundary would expand by 0.058 (i.e., 0.605×0.096) to 0.498 (i.e., 0.44 + 0.058). If the average variance of the costs for homegrown corn were doubled, the average farm boundary would shrink by 0.036 (i.e., 0.379×-0.096) to 0.404 (i.e., 0.44 - 0.036). These results suggest that not only higher cost, but also higher cost uncertainty induces swine farmers to adopt the hierarchical mechanism. This implicitly implies more demand for buying or renting farmland, resulting in higher farmland prices. Therefore, external factors triggering corn prices uncertainty, such as U.S. trade policies, may play important roles in shaping Ontario's local farmland prices by affecting livestock farmers' decisions on farm boundaries.

As previously mentioned, we can partially verify our proposed theory by examining H_0^{r1} and H_0^{r2}. Our theory predicts that the ratio of the marginal effect of average costs under different transaction-facilitating mechanisms should be -1. The empirical evidence from the main model in table 3 column (1) yields -0.994 (i.e., $-\frac{0.157}{0.158}$), almost identical to our theoretical prediction. Another prediction is that the ratio of the marginal effect of the variance of costs under different mechanisms should be -1.27 (i.e.,$-\frac{1-\theta}{\theta} = -\frac{1-0.44}{1-0.44}$ as the average farm boundary is 0.44). This is similar to -1 (i.e., $-\frac{0.096}{0.096}$), the ratio calculated from our main empirical model.

To further investigate this, we estimate the main model and calculate the ratios with a random subset of the data. This process is repeated for 100 times which yields 100 pairs of ratios. We then use the one-sample t-test to test whether the mean of these ratios is statistically different from our theoretical predictions. The estimated ratios of $\frac{\hat{\beta}_1}{\hat{\beta}_3}$ ($M = -1.002$, $SD = 0.11$) are not statistically different than the theoretical prediction -1, $t(99) = -0.18$, $p = 0.86$. Also, the estimated ratios of $\frac{\hat{\beta}_2}{\hat{\beta}_4}$ ($M = -1.20$, $SD = 0.77$) are not statistically different than the theoretical prediction -1.27, $t(99) = 0.87$, $p = 0.39$. These results provide additional empirical support to our theoretical model. Figure 4 presents the box plot of the results.

We attempt to quantify the magnitude of risk aversion of an average swine farmer in Ontario. Note from our theory that $\frac{\partial \theta}{\partial \sigma_i^2} / \frac{\partial \theta}{\partial \mu_i} = \alpha \theta I_f$ where α is the only unknown. Thus we can potentially recover α. Our estimate of the magnitude of risk aversion of an average swine farmer in Ontario is $\hat{\alpha} = 0.000021$. Figure 5 presents the potential relationship between utility and income of an average swine farmer in Ontario based on our estimate. This suggests that typical Ontario swine farmers are likely to be risk-averse, in line with the findings in other studies (e.g., Hildreth and Knowles 1986; De Brauw and Eozenou 2014). Similar to Kahneman and Deaton (2010), this indicates that the association between well-being and income is no longer significant after a certain income level.

We can also exploit the FOC to recover the marginal cost of using market and hierarchy. Our data covers 2006 unique swine farms with a long time span from 2003 to 2014. Swine farmers should have enough time to adjust their farm boundaries to the optimal level. Also, we fail to reject H_0^{r1} and H_0^{r2} that are true when the farm boundaries are optimal. Thus the farm boundary of the average swine farm in Ontario is likely to be optimal already. The marginal effect of farm boundary on the cost of using market and hierarchy (i.e., $M_{m\theta} + M_{b\theta}$) on an average swine farm is estimated to be C$22,366[10]. This means that for an average swine farmer in Ontario to double the share of homegrown corn (i.e., farm boundary increases from 0.44 to 0.88), the associated cost is C$9,841 (i.e., 0.44×22366).

It is the difference between the cost increased from using more hierarchy and the cost saved from using less market.

To check the robustness of the main results, we also aggregate the farm level data into county level. Farms in the same county with the same operation type at the same year are collapsed into one observation. The values for this one observation are the average of the values of all farms in the same county-year-operation type. We also use median instead of average as the aggregation function to dampen the effect of extreme values. The results are presented in table 6. The coefficients of the means and variances of corn costs from the two transaction-facilitating mechanisms are all statistically significant and are consistent with our main results. These results provide evidence that, even at county-level, farm boundaries are associated with the efficiency of the transaction-facilitating mechanisms.

It is not likely that the estimated effects of the efficiency of mechanisms on farm boundaries would be biased by the unobserved heterogeneity in farmer's risk attitude. Risk attitude should be relatively stable. Thus we estimate the main model with only the swine farms that continuously operated from 2003 to 2014 (presented in column (3) and (4) in table 7). Additionally, income levels, instead of diversification index, are used as a proxy for risk attitude (presented in column (2) in table 7). Comparing the results in column (1) and (2) in table 7, the effect of the mechanism efficiency on farm boundaries is similar no matter whether the proxy for risk attitude is diversification index or income. When we only use the continuously operated swine farms, the estimated effect of the variance of costs on farm boundaries is similar to that from the entire dataset. The effect of the mean of costs on farm boundaries is not statistically significant. This is possibly due to the fact that, for the continuously operated swine farms, the means of the costs of homegrown corn are very similar to the means of the costs on the spot market (see figure 6 and figure 7).

Table 8 presents the results where we change the historical data used to calculate the mean and variance of corn costs under the two mechanisms from the last four years to the last three (column 2) and last five years (column 5) for robustness check. Except for the estimated effect of the variance of the costs for homegrown corn on farm boundaries which is not statistically significant, all other estimates are statistically significant, and the signs align with the main model.

To ensure the length of harvest season assumed in the main model, October 15 to November 15 each year, is not affecting our main conclusion, we estimate the main model with different lengths of the harvest season. The results show that our findings are robust regardless of various specification on the length of the harvest season. They are presented in table 9.

To further verify our results, we split our dataset into three groups by farm operation type. They are farrow-to-finish, mix, and farrow-to-weaner. The farrow-to-finish swine farms require the most amount of feed, farrow-to-weaner farms require the least amount of feed while mix farms are in the middle. Intuitively, the effect of the efficiency of mechanisms on farm boundaries should weaken as the feed required decreases. We estimate the main model in each of the three groups and report the results in table 10. As expected, the farrow-to-finish operations show the most significant effect of mechanism efficiency on farm boundaries (column 2). The effect of the variance of the costs for homegrown corn is no longer statistically significant for mix operations (column 3). Finally, all four coefficients for the efficiency of mechanisms are not statistically significant for farrow-to-weaner farms.

For a placebo test, we estimate the main model with the mean and variance of corn costs all replaced by randomly generated numbers while keeping all other variables the same. For a falsification test, we regress randomly generated numbers on the RHS of the main model. The results are reported in table 11. As expected, the randomly generated numbers show no statistical significance in explaining farm boundaries (column 2). Similarly, the efficiency of transaction-facilitating mechanisms is not associated with randomly generated numbers (column 3). These results suggest our main estimation results are unlikely to be spurious.

Limitations

To keep the theory concise while still conveying our core message, we restrict the choices of the farmer to only two: markets or hierarchies. Livestock farmers either buy corn from the spot market or produce corn themselves. We show that Ontario swine farmers facilitate the transaction of corn with the more efficient mechanism. However, we recognize that there are other alternative mechanisms. For example, some swine farmers sign contracts with cash crop farmers or elevators in which the corn prices are fixed. In this case, swine farmers have three mechanisms to choose from: the hierarchy mechanism, the market mechanism, and the contract mechanism. Extending the empirical analysis to include multiple transaction-facilitating mechanisms would be beyond the scope of this study. However, the lessons from this study may still apply: more transactions will be allocated to the mechanisms that consistently yield output at lower cost.

Conclusions

Defining the boundary of a livestock farm as the percentage of homegrown feed to total feed required, the farmer can choose to expand the farm boundary to make more feed or to shrink the farm boundary to buy more feed. The transactions of purchased feed are facilitated by the market mechanism while the transactions of homegrown feed are facilitated by the hierarchical management mechanism. Adopting the right mechanism may enable the swine farms to survive longer (Dong, Hennessy, and Jensen 2010). We measure the efficiency of a transaction-facilitating mechanism by its ability to consistently yield output with low cost (i.e., the mean and variance of output costs are both low). A theory which explains how the boundaries of the livestock farms are shaped by the mechanism efficiency is proposed. Using farm-level tax file data from Ontario swine farms between 2003 and 2014, we investigate the relationship between *the efficiency of the transaction-facilitating mechanisms (markets or hierarchies)* and *farm boundary*. The results suggest that, as predicted by our theory, the boundaries of swine farms in Ontario are associated with the efficiency of the transaction-facilitating mechanisms. More specifically, the boundaries of Ontario swine farms expand when the market mechanism is less efficient (i.e., the means and variances of corn costs on spot market increase); and the boundaries shrink when the hierarchical mechanism is less efficient (i.e., the means and variances of the costs of home-grown corn increase). These findings are in line with the suggestion of Williamson (2005) for replacing the dichotomy of markets *or* hierarchies with an understanding and appreciation for both markets *and* hierarchies. In the U.S. swine industry, the trend of alternative marketing arrangements replacing the market mechanism has lasted for years and recently has stopped (Zheng and Vukina 2009). Our findings may explain why: transactions are constantly reallocated to the relatively more efficient mechanism and an equilibrium is reached recently. This equilibrium may last years until innovations and new technologies disrupt it. However, government regulations intentionally banning alternative marketing arrangements to protect the market mechanism would have adverse welfare implications (Wohlgenant 2010).

The findings are robust when we measure the efficiency of the transaction-facilitating mechanisms in different ways (i.e., different lengths of historical data used to calculate the efficiency; the mean, median or minimum corn price during harvest season used as the cost of homegrown corn); when we aggregate the farm-level data into county-level data by the mean or by the median; and when we use diversification index or income as a proxy for risk attitude.

The identified relationship between the efficiency of transaction-facilitating mechanisms and farm boundaries is likely to be causal. Firstly, placebo and falsification tests suggest that the identified relationship is unlikely to be spurious. Secondly, we split the data into groups by farm operating type and estimate the main model in each group. The results align with our hypothesis that the effect of mechanism efficiency on farm boundaries is more significant for swine farms which require more feed. Lastly, we estimate the impact of mechanism efficiency on farm boundary by using the monthly CAD/USD exchange rates as an instrument for the means and variances of the costs of homegrown and bought corn. The 2SLS results suggest that the relative efficiency of mechanisms causes the shift in farm boundaries.

All other factors being equal, we estimate that if the average spot price of corn were doubled, the average swine farm in Ontario would stop buying corn from the market. The farm would only use homegrown corn (i.e., the share of homegrown corn increases from 44% to 100%). If the average variance of spot price were doubled, the share of homegrown corn would increase from 44% to 49.8%. For an average swine farm in Ontario to double the share of homegrown corn from 44% to 88%, the associated costs are estimated to be C$9,841.

Notes

[1]See online appendix for the number of hog farms in Ontario from 2003 to 2014.

[2]http://www.omafra.gov.on.ca/english/stats/crops/index.html

[3]See online appendix for details.

[4]Swines at different growth stage are converted into market hog equivalent by different ratios. For example, one early weaner equals 0.25 market hog equivalent. The formula to calculate the number of MHE is: MHE = (number of early weaner pigs sold) $\times$ 0.25 + (number of weaner pigs sold) $\times$ 0.4 + (number of feeder pigs (weighted 90 lbs) $\times$ 0.45 + (number of feeder pigs (weighted 130 lbs) $\times$ 0.55 + (number of feeder pigs (weighted 170 lbs) $\times$ 0.65) + (number of marketable pigs sold) $\times$ 1.

[5]The 11 levels are 0: [\$0, \$10K); 1: (\$10K, \$25K]; 2: (\$25K, \$50K]; 3: (\$50K, \$100K]; 4: (\$100K, \$200K]; 5: (\$200K, \$300K]; 6: (\$300K, \$400K]; 7: (\$400K, \$500K]; 8: (\$500K, \$1M]; 9: (\$1M, \$3M]; 10: (\$3M, ∞).

[6]R code for getting monthly CAD/USD exchange rate:

```
library(Quandl); Quandl("FED/RXI_N_M_CA")
```

[7]This should not affect our main conclusion Other than change the constant in the regression results. We constructed a simulation to support our argument. The r code can be found in appendix.

[8]For illustration purpose, let's say CAD/USD exchange rate increased from 1 to 1.1, then all the corn prices will change from p to $1.1p$. The average price of bought and homegrown corn will be $1.1\mu_b$ and $1.1\mu_m$. However, the variance of bought and homegrown corn price will be the variance of $1.1C_b$ and $1.1C_m$, which is $1.1^2\sigma_b^2$ and $1.1^2\sigma_m^2$, respec-

tively. Thus, the same amount of change on exchange rate affects the mean and variance of corn prices differently.

[9]The estimated coefficient $\hat{\beta}_1 = \frac{\partial log(1+\theta)}{\partial log(1+\mu_e)}$, thus $\frac{\partial \theta}{\partial \mu_e} = \hat{\beta}_1 \frac{1+mean(\theta)}{1+mean(\mu_e)}$. Similarly the marginal effects of $\frac{\partial \theta}{\partial \sigma_e^2} = \hat{\beta}_2 \frac{1+mean(\theta)}{1+mean(\sigma_e^2)}$; $\frac{\partial \theta}{\partial \mu_i} = \hat{\beta}_3 \frac{1+mean(\theta)}{1+mean(\mu_i)}$; $\frac{\partial \theta}{\partial \sigma_i^2} = \hat{\beta}_4 \frac{1+mean(\theta)}{1+mean(\sigma_i^2)}$.

[10] The optimal level of farm boundary is

$$(21) \quad \theta^* = \frac{-M_{b\theta} - M_{m\theta} + I_f \mu_b - I_f \mu_m + \alpha I_f^2 \sigma_b^2}{\alpha I_f^2 \sigma_b^2 + I_f^2 \sigma_m^2}.$$

Assuming the average farm boundary (0.44) is optimal, with the previously calculated $\alpha = 0.000021$, the only unknown in this equation is $M_{b\theta} + M_{m\theta}$ which can be recovered.

References

Aghion, P., and R. Holden. 2011. "Incomplete Contracts and the Theory of the Firm: What Have We Learned over the Past 25 Years?" *The Journal of Economic Perspectives* 25:181–197.

Alchian, A.A. 1950. "Uncertainty, Evolution, and Economic Theory." *Journal of Political Economy* 58:211–221.

Arrow, K.J. 1969. "The Organization of Economic Activity: Issues Pertinent to the Choice of Market versus Nonmarket Allocation." *The Analysis and Evaluation of Public Expenditure: The PPB System* 1:59–73.

Atalay, E., A. Hortaçsu, and C. Syverson. 2014. "Vertical Integration and Input Flows." *The American Economic Review* 104:1120–1148.

Bellemare, M.F., Y.N. Lee, and L. Novak. 2017. "Contract Farming as Partial Insurance." Working paper, University of Minnesota.

Cheung, S.N. 1969. "Transaction Costs, Risk Aversion, and the Choice of Contractual Arrangements." *The Journal of Law and Economics* 12:23–42.

Coase, R.H. 1937. "The Nature of the Firm." *Economica* 4:386–405.

—. 1960. "The Problem of Social Cost." *The Journal of Law and Economics* 3:1–44.

Davis, C.G., and J.M. Gillespie. 2007. "Factors Affecting the Selection of Business Arrangements by U.S. Hog Farmers." *Review of Agricultural Economics* 29:331–348.

Dawling, P., O. Hart, and C.A. Zehndera. 2011. "Contracts as Reference Points - Experimental Evidence." *The American Economic Review* 101:493–525.

De Brauw, A., and P. Eozenou. 2014. "Measuring Risk Attitudes among Mozambican Farmers." *Journal of Development Economics* 111:61–74.

Dong, F., D.A. Hennessy, and H.H. Jensen. 2010. "Contract and Exit Decisions in Finisher Hog Production." *American Journal of Agricultural Economics* 92:667–684.

Fehr, E., O. Hart, and C. Zehnder. 2015. "How Do Informal Agreements and Revision Shape Contractual Reference Points?" *Journal of the European Economic Association* 13:120–1.

Forbes, S.J., and M. Lederman. 2010. "Does Vertical Integration Affect Firm Performance? Evidence from the Airline Industry." *The Rand Journal of Economics* 41:765–790.

Franken, J.R., J.M. Pennings, and P. Garcia. 2009. "Do Transaction Costs and Risk Preferences Influence Marketing Arrangements in the Illinois Hog Industry?" *Journal of Agricultural and Resource Economics* 34:297–315.

—. 2017. "Risk Attitudes and the Structure of Decision-making: Evidence from the Illinois Hog Industry." *Agricultural Economics* 48:41–50.

Gillespie, J.M., and V.R. Eidman. 1998. "The Effect of Risk and Autonomy on Independent Hog Producers' Contracting Decisions." *Journal of Agricultural and Applied Economics* 30:175–188.

Gillespie, J.M., K. Karantininis, and G.G. Storey. 1997. "The Expansion and Evolution of Vertical Coordination in the Quebec Hog Industry." *Review of Agricultural Economics* 19:350–370.

Grossman, S.J., and O. Hart. 1986. "The Costs and Benefits of Ownership: A Theory of Vertical and Lateral Integration." *Journal of Political Economy* 94:691–719.

Hanson, G.H. 1995. "Incomplete Contracts, Risk, and Ownership." *International Economic Review* 36:341–363.

Hart, O. 2009. "Hold-up, Asset Ownership, and Reference Points." *The Quarterly Journal of Economics* 124:267–300.

Hart, O., and B. Holmstrom. 2010. "A Theory of Firm Scope." *The Quarterly Journal of Economics* 125:483–513.

Hart, O., and J. Moore. 2008. "Contracts as Reference Points." *The Quarterly Journal of Economics* 123:1–48.

—. 1990. "Property Rights and the Nature of the Firm." *Journal of Political Economy* 98:1119–1158.

Hildreth, C., and G.J. Knowles. 1986. "Farmers' Utility Functions." *Bayesian Inference and Decision Techniques: Essays in Honor of Bruno De Finetti. Studies in Bayesian Econometrics and Statistics Series* 6:291–317.

Hobbs, J.E. 1997. "Measuring the Importance of Transaction Costs in Cattle Marketing." *American Journal of Agricultural Economics* 79:1083–1095.

Holmstrom, B. 1989. "Agency Costs and Innovation." *Journal of Economic Behavior & Organization* 12:305–327.

Holmstrom, B., and P. Milgrom. 1987. "Aggregation and Linearity in the Provision of Intertemporal Incentives." *Econometrica* 55:303–328.

—. 1994. "The Firm as an Incentive System." *The American Economic Review* 84:972–991.

—. 1991. "Multitask Principal-Agent Analyses: Incentive Contracts, Asset Ownership, and Job Design." *Journal of Law, Economics, & Organization* 7:24–52.

Hoppe, E.I., and P.W. Schmitz. 2011. "Can Contracts Solve the Hold-Up Problem? Experimental Evidence." *Games and Economic Behavior* 73:186–199.

Hu, W.Y., and X.Y. Zheng. 2012. "Testing for Complementarities and Substitutabilities among Marketing Arrangements Used by U.S. Farmers." *Taiwanese Agricultural Economic Review* 17:1–27.

Hudson, D., and J. Lusk. 2004. "Risk and Transactions Cost in Contracting: Results from a Choice-based Experiment." *Journal of Agricultural & Food Industrial Organization* 2.

Joskow, P.L. 1987. "Contract Duration and Relationship-Specific Investments: Empirical Evidence from Coal Markets." *The American Economic Review* 77:168–185.

Kahneman, D., and A. Deaton. 2010. "High Income Improves Evaluation of Life but Not Emotional Well-being." *Proceedings of the National Academy of Sciences* 107:16489–16493.

Key, N., and W. McBride. 2003. "Production Contracts and Productivity in the U.S. Hog Sector." *American Journal of Agricultural Economics* 85:121–133.

Kim, J.J., and X. Zheng. 2015. "Effects of Alternative Marketing Arrangements on the Spot Market Price Distribution in the U.S. Hog Market." *Journal of Agricultural and Resource Economics* 40:242–65.

Klein, B., R.G. Crawford, and A.A. Alchian. 1978. "Vertical Integration, Appropriable Rents, and the Competitive Contracting Process." *The Journal of Law and Economics* 21:297–326.

Lafontaine, F., and M. Slade. 2007. "Vertical Integration and Firm Boundaries: The Evidence." *Journal of Economic Literature* 45:629–685.

Lieberman, M.B. 1991. "Determinants of Vertical Integration: An Empirical Test." *Journal of Industrial Economics* 39:373–391.

Masten, S.E. 2009. "Long-Term Contracts and Short-Term Commitment: Price Determination for Heterogeneous Freight Transactions." *American Law and Economics Review* 11:79–111.

Reimer, J.J. 2006. "Vertical Integration in the Pork Industry." *American Journal of Agricultural Economics* 88:234–248.

Schroeter, J.R., and A. Azzam. 2003. "Captive Supplies and the Spot Market Price of Fed Cattle: The Plant-Level Relationship." *Agribusiness* 19:489–504.

Walker, G., and D. Weber. 1984. "A Transaction Cost Approach to Make-or-Buy Decisions." *Administrative Science Quarterly* 29:373–391.

Williamson, O.E. 1985. *The Economic Institutions of Capitalism: Firms, Markets, Relational Contracting*. Free Press.

—. 2005. "The Economics of Governance." *The American Economic Review* 95:1–18.

—. 1973. "Markets and Hierarchies: Some Elementary Considerations." *The American Economic Review* 63:316–325.

—. 1979. "Transaction-Cost Economics: The Governance of Contractual Relations." *The Journal of Law and Economics* 22:233–261.

—. 1971. "The Vertical Integration of Production: Market Failure Considerations." *The American Economic Review* 61:112–123.

Wohlgenant, M.K. 2010. "Modeling the Effects of Restricting Packer-owned Livestock in the U.S. Swine Industry." *American Journal of Agricultural Economics* 92:654–666.

Zeuli, K.A., and R.P. King. 2004. "The Impact of Organizational Form on Producer Contracting Decisions." *Canadian Journal of Agricultural Economics/Revue Canadienne D'Agroeconomie* 52:147–164.

Zheng, X., and T. Vukina. 2009. "Do Alternative Marketing Arrangements Increase Pork Packers' Market Power?" *American Journal of Agricultural Economics* 91:250–263.

Appendix

Proof

The expected utility is

(A.1)

$$EU(\Pi) = -e^{-\alpha(PQ-M_m-M_b-C_o)} \int e^{\alpha(1-\theta)I_f C_b} \frac{1}{\sqrt{2\pi}\sigma_b} e^{-\frac{(C_b-\mu_b)^2}{2\sigma_b^2}} dC_b \times$$
$$\int e^{\alpha\theta I_f C_m} \frac{1}{\sqrt{2\pi}\sigma_m} e^{-\frac{(C_m-\mu_m)^2}{2\sigma_m^2}} dC_b,$$

where

(A.2)

$$\int e^{\alpha(1-\theta)I_f C_b} \frac{1}{\sqrt{2\pi}\sigma_b} e^{-\frac{(C_b-\mu_b)^2}{2\sigma_b^2}} dC_b$$

(A.3)

$$= \int e^{\alpha((1-\theta)I_f(C_b-\mu_b)+(1-\theta)I_f\mu_b)} \frac{1}{\sqrt{2\pi}\sigma_b} e^{-\frac{(C_b-\mu_b)^2}{2\sigma_b^2}} dC_b$$

(A.4)

$$= e^{\alpha(1-\theta)I_f\mu_b} \int e^{\alpha(1-\theta)I_f(C_b-\mu_b)} e^{-\frac{(C_b-\mu_b)^2}{2\sigma_b^2}} \frac{1}{\sqrt{2\pi}\sigma_b} dC_b$$

(A.5)

$$= e^{\alpha(1-\theta)I_f\mu_b} \int e^{-\frac{(C_b-\mu_b)^2-2\sigma_b^2\alpha(1-\theta)I_f(C_b-\mu_b)+(\sigma_b^2\alpha(1-\theta)I_f)^2-(\sigma_b^2\alpha(1-\theta)I_f)^2}{2\sigma_b^2}} \frac{1}{\sqrt{2\pi}\sigma_b} dC_b$$

(A.6)

$$= e^{\alpha(1-\theta)I_f\mu_b} \int e^{-\frac{(C_b-\mu_b+\sigma_b^2\alpha(1-\theta)I_f)^2}{2\sigma_b^2}} e^{\frac{1}{2}\sigma_b^2\alpha^2(1-\theta)^2 I_f^2} \frac{1}{\sqrt{2\pi}\sigma_b} dC_b$$

(A.7)

$$= e^{\alpha(1-\theta)I_f\mu_b+\frac{1}{2}\sigma_b^2\alpha^2(1-\theta)^2 I_f^2} \int \frac{1}{\sqrt{2\pi}\sigma_b} e^{-\frac{(C_b-\mu_b+\sigma_b^2\alpha(1-\theta)I_f)^2}{2\sigma_b^2}} dC_b.$$

$\frac{1}{\sqrt{2\pi}\sigma_b} e^{-\frac{(C_b-\mu_b+\sigma_b^2\alpha(1-\theta)I_f)^2}{2\sigma_b^2}}$ is the probability density function of the normal distribution with mean $\mu_b - \sigma_b^2\alpha(1-\theta)I_f$ and variance σ_b^2. As the integration of a probability density function is 1, thus $\int \frac{1}{\sqrt{2\pi}\sigma_b} e^{-\frac{(C_b-\mu_b+\sigma_b^2\alpha(1-\theta)I_f)^2}{2\sigma_b^2}} dC_b = 1$. Therefore,

$$\text{(A.8)} \quad \int e^{\alpha(1-\theta)I_f C_b} \frac{1}{\sqrt{2\pi}\sigma_b} e^{-\frac{(C_b-\mu_b)^2}{2\sigma_b^2}} dC_b = e^{\alpha(1-\theta)I_f\mu_b+\frac{1}{2}\sigma_b^2\alpha^2(1-\theta)^2 I_f^2}.$$

Similarly, we have

$$\text{(A.9)} \quad \int e^{\alpha\theta I_f C_m} \frac{1}{\sqrt{2\pi}\sigma_m} e^{-\frac{(C_m-\mu_m)^2}{2\sigma_m^2}} dC_m = e^{\alpha\theta I_f\mu_m+\frac{1}{2}\sigma_m^2\alpha^2\theta^2 I_f^2}.$$

Plug equation A.8 and A.9 into equation A.1 yields

(A.10)

$$EU(\Pi) = -e^{-\alpha(PQ-M_m-M_b-C_o)} e^{\alpha(1-\theta)I_f\mu_b+\frac{1}{2}\sigma_b^2\alpha^2(1-\theta)^2 I_f^2} e^{\alpha\theta I_f\mu_m+\frac{1}{2}\sigma_m^2\alpha^2\theta^2 I_f^2}$$

(A.11)

$$= -e^{-\alpha} e^{PQ-M_m-M_b-C_o-\theta I_f\mu_m-(1-\theta)I_f\mu_b-\frac{\alpha}{2}I_f^2(\theta^2\sigma_m^2+(1-\theta)^2\sigma_b^2)}.$$

Here $-e^{-\alpha}$ is a negative constant. $EU(\Pi)$ is a monotonic transformation of

(A.12)

$$\Psi = PQ - M_m - M_b - C_o - \theta I_f\mu_m - (1-\theta)I_f\mu_b - \frac{\alpha}{2}I_f^2(\theta^2\sigma_m^2 + (1-\theta)^2\sigma_b^2)$$

(A.13)

$$= E(\Pi) - \frac{\alpha}{2}I_f^2(\theta^2\sigma_m^2 + (1-\theta)^2\sigma_b^2).$$

That is

$$\text{(A.14)} \quad EU(\Pi) = -e^{-\alpha}e^{\Psi}.$$

Therefore, maximizing $EU(\Pi)$ is equivalent to minimizing Ψ.

Figures

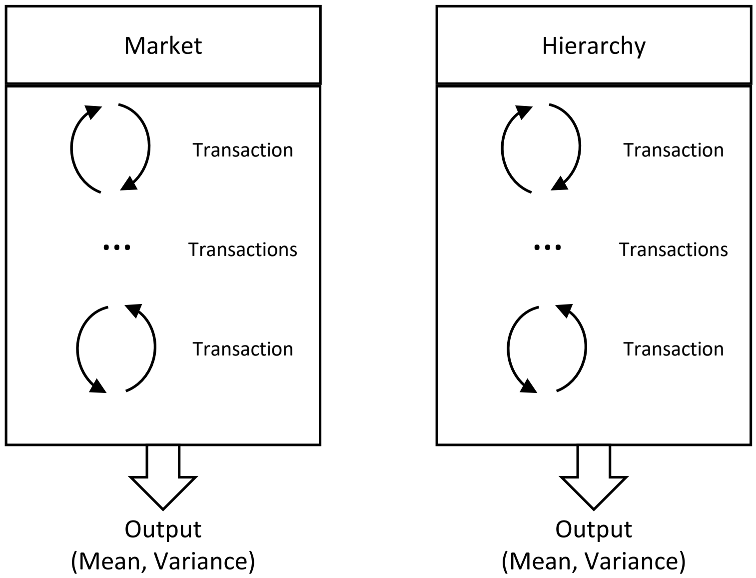

Figure 1. Two transaction-facilitating mechanisms with their efficiency measured by the mean and variance of output

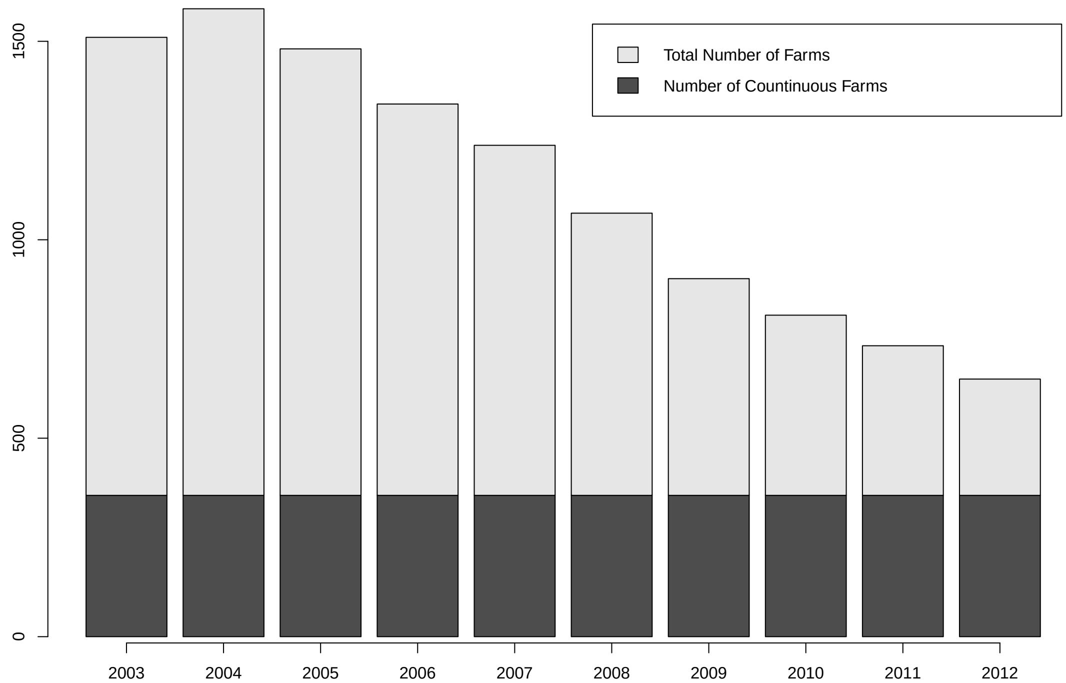

Figure 2. Number of swine farms in Ontario, 2003-2014

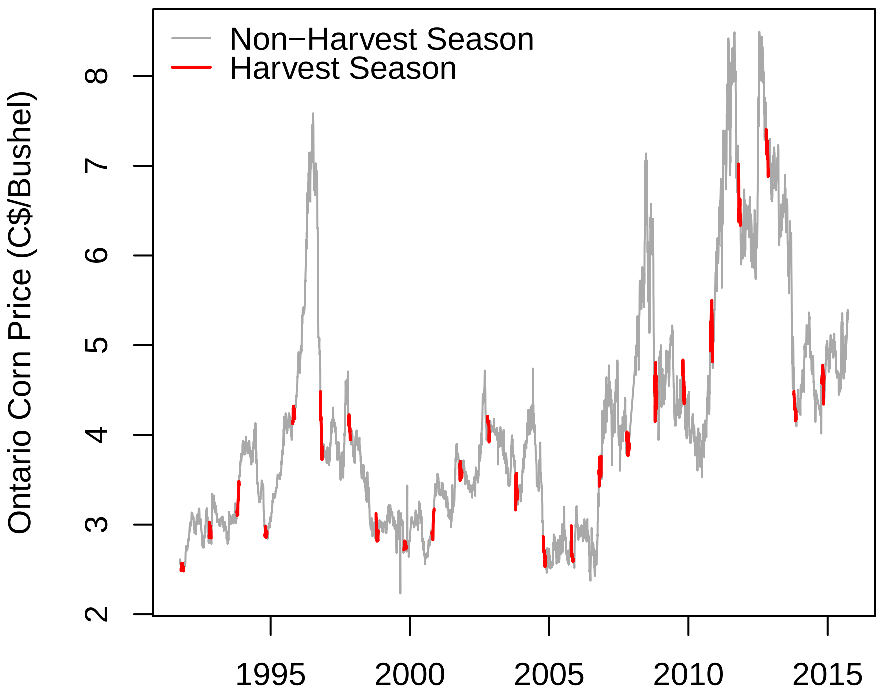

Figure 3. Daily corn prices in Ontario, 2003-2014

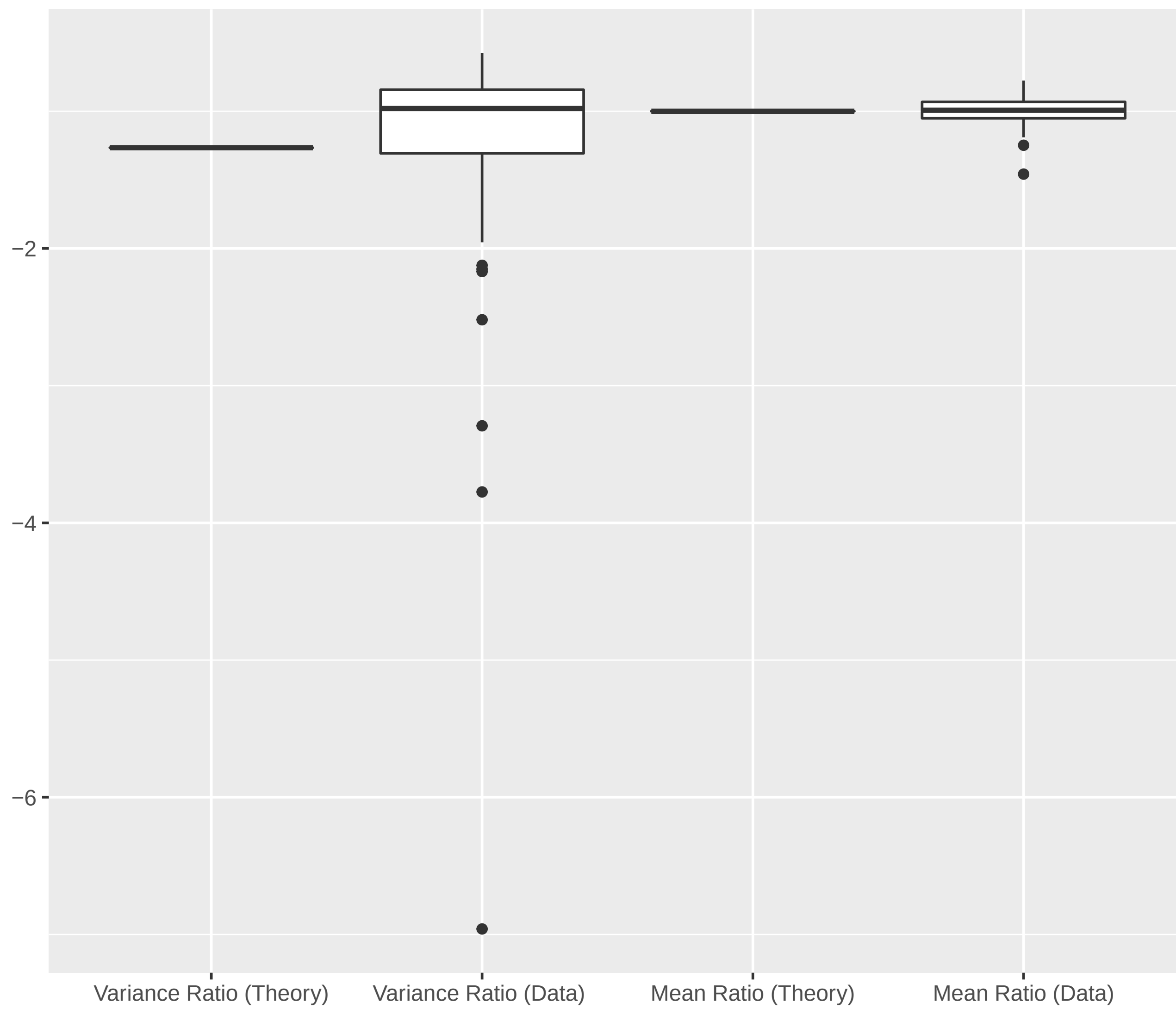

Figure 4. The ratios of the marginal effects of the means and variances of corn costs on farm boundaries: theoretical predictions and empirical evidence

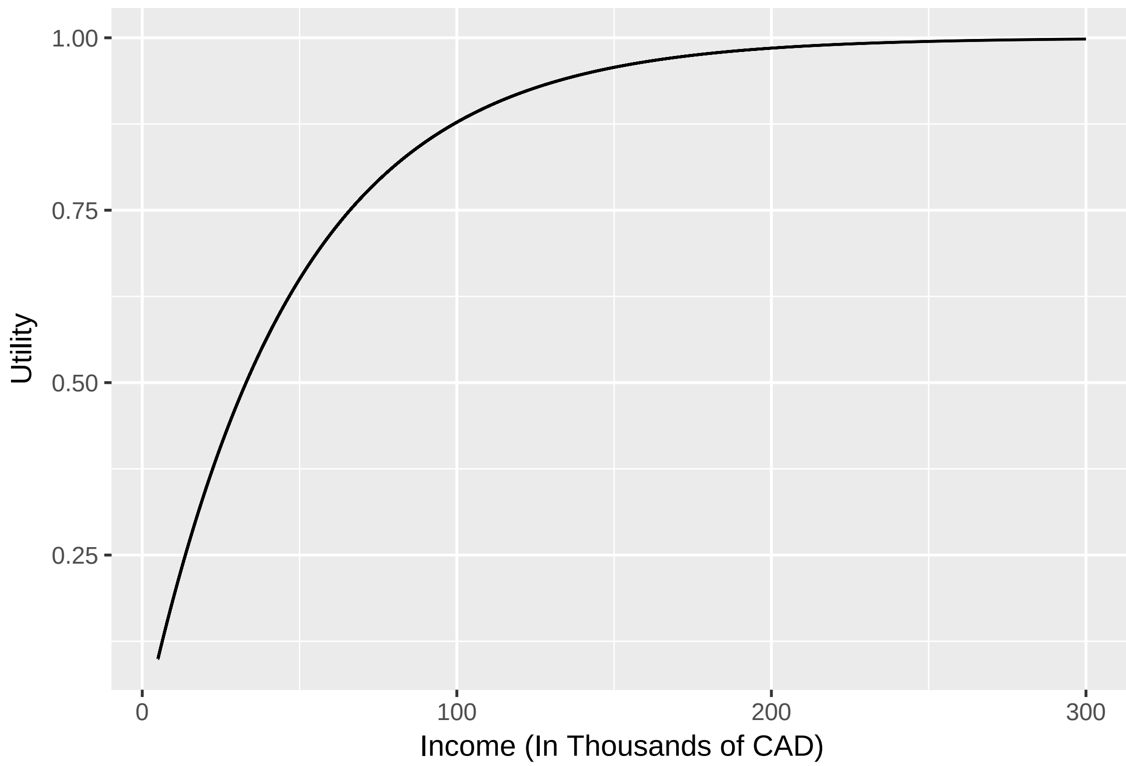

Figure 5. Estimated relationship between utility and income of an average Ontario swine farmer

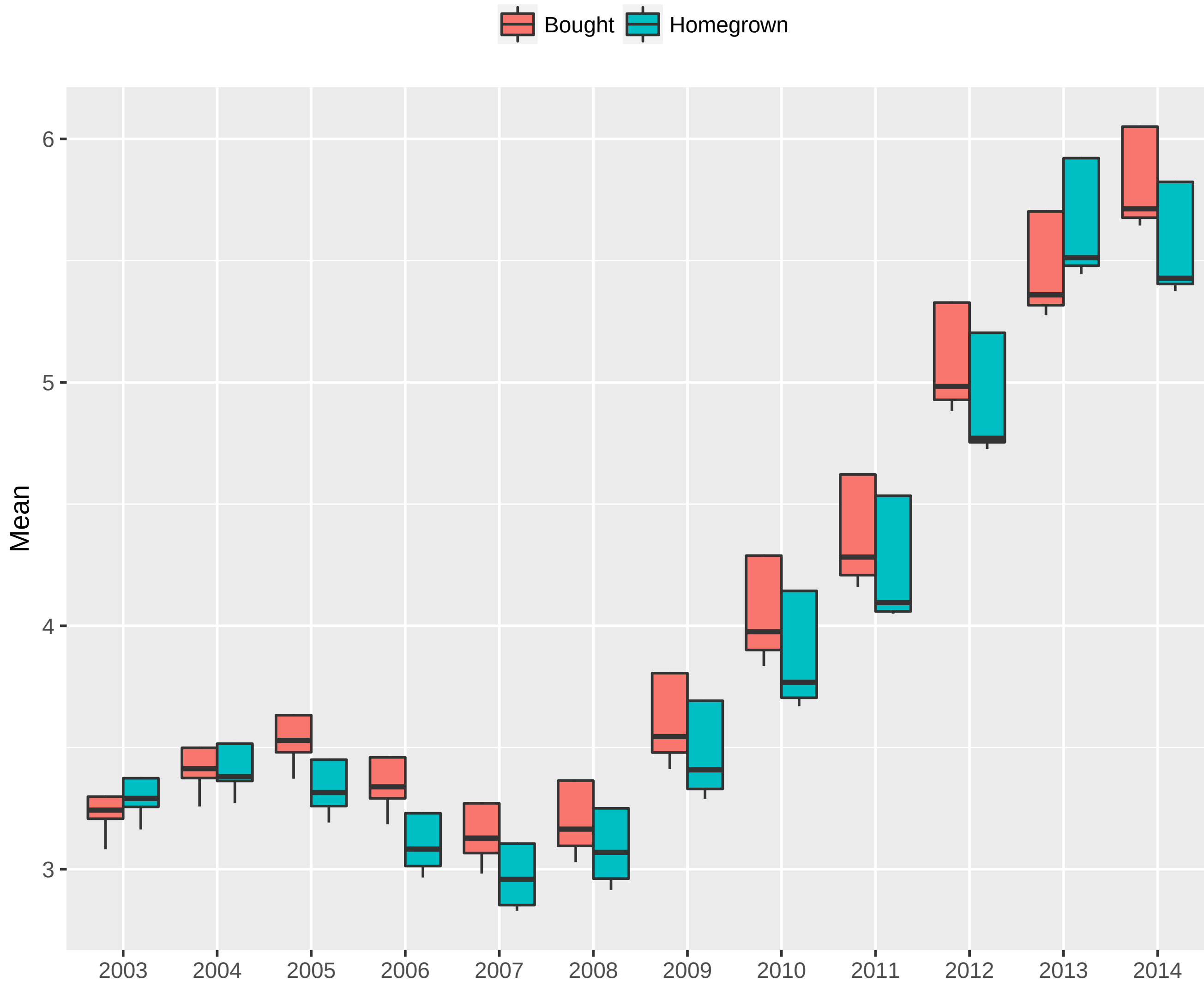

Figure 6. The mean of corn cost under two transaction-facilitating mechanisms for swine farms continuously operated from 2003 to 2014

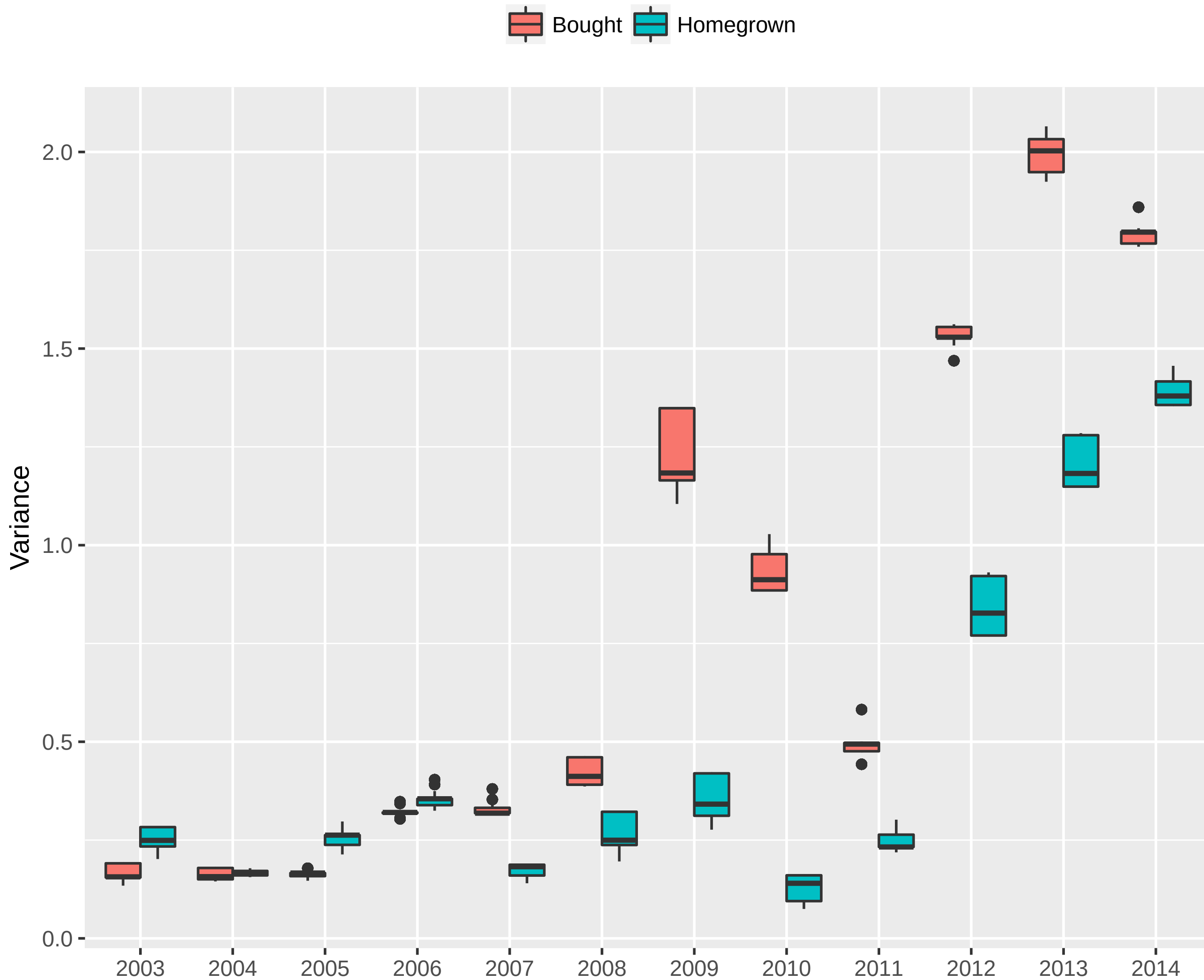

Figure 7. The variance of corn cost under two transaction-facilitating mechanisms for swine farms continuously operated from 2003 to 2014

Tables

Table 1. Correlation between Monthly US/CAD Exchange Rate and the Percentage of Homegrown Corn, Means, and Variances of Bought and Homegrown Corn Prices

	Homegrown %	*Mean C Buy*	*Var C Buy*	*Mean C Make*	*Var C Make*
Homegrown %	1.00	-0.00	-0.01	-0.01	-0.00
Mean C Buy	-0.00	1.00	0.85	0.99	0.86
Var C Buy	-0.01	0.85	1.00	0.84	0.83
Mean C Make	-0.01	0.99	0.84	1.00	0.86
Var C Make	-0.00	0.86	0.83	0.86	1.00
XR Jan	-0.02	-0.50	-0.52	-0.43	-0.34
XR Feb	-0.01	-0.49	-0.51	-0.42	-0.35
XR Mar	-0.02	-0.49	-0.48	-0.42	-0.32
XR Apr	-0.01	-0.49	-0.51	-0.41	-0.32
XR May	-0.01	-0.44	-0.53	-0.36	-0.33
XR Jun	-0.01	-0.42	-0.53	-0.34	-0.32
XR Jul	-0.01	-0.43	-0.52	-0.34	-0.30
XR Aug	-0.01	-0.44	-0.55	-0.35	-0.30
XR Sep	-0.01	-0.42	-0.54	-0.33	-0.28
XR Oct	-0.01	-0.40	-0.53	-0.33	-0.23
XR Nov	-0.00	-0.38	-0.49	-0.31	-0.17
XR Dec	-0.01	-0.40	-0.50	-0.33	-0.16

Table 2. Descriptive Statistics for Ontario Swine Farms, 2003-2014 (n=10,897)

	Mean	St. Dev.	Min	Median	Max
Share of Homegrown Corn	0.44	0.77	0.00	0.20	35.39
Mean C Buy (CAD/Bushel)	3.78	0.78	2.98	3.46	6.05
Var C Buy	0.60	0.57	0.13	0.32	2.07
Mean C Make (CAD/Bushel)	3.67	0.79	2.83	3.37	5.92
Var C Make	0.38	0.33	0.07	0.26	1.46
Diversification	1.34	0.37	1.00	1.20	2.98
Income Range (0-11)	7.52	2.48	0	8	11
Corn Required (Bushels)	65,032	132,013	6.50	30,870	3,280,639
Corn Yield (Bushels/Acre)	147.03	18.98	0.00	150.50	185.00
Machinery Repair (C$)	19,294	28,542	0.00	10,374	441,736
Total Farmland (Acres)	309.80	447.57	0.00	189.00	17,634.00
Sold Crop Acre	166.50	319.76	0.00	73.00	17,434.00
Rent (C$)	39,884	133,084	0.00	6,027	3,593,806
Feed Pasture (Acres)	2.06	14.49	0.00	0.00	346.00
Feed Expense (C$)	421,147	1,091,437	0.00	157,388	33,629,042
Soybean Acre	85.68	143.79	0.00	35.00	2,740.00
Wheat Acre	39.32	85.77	0.00	0.00	1,970.00
Prime Rate (%)	4.19	1.18	2.40	4.42	6.10
XR Jan	1.19	0.16	0.99	1.18	1.54
XR Feb	1.19	0.16	0.99	1.17	1.51
XR Mar	1.18	0.15	0.98	1.17	1.48
XR Apr	1.18	0.15	0.96	1.14	1.46
XR May	1.16	0.15	0.97	1.11	1.38
XR Jun	1.15	0.13	0.98	1.11	1.36
XR Jul	1.15	0.13	0.96	1.12	1.38
XR Aug	1.15	0.13	0.98	1.09	1.40
XR Sep	1.13	0.12	0.98	1.10	1.36
XR Oct	1.13	0.11	0.98	1.13	1.32
XR Nov	1.13	0.11	0.97	1.14	1.31
XR Dec	1.14	0.10	0.99	1.15	1.31

Table 3. Log-log OLS Estimation Results for the Boundaries of Swine Farms: Mean, Median and Minimum Price during Harvest Season as Cost of Homegrown Corn

	Dependent variable: farm boundaries		
	Mean	Median	Min
	(1)	(2)	(3)
Mean C Buy	0.524*** (0.128)	0.179*** (0.068)	0.334*** (0.093)
Var C Buy	0.107*** (0.023)	0.121*** (0.022)	0.136*** (0.021)
Mean C Make	−0.508*** (0.126)	−0.188*** (0.067)	−0.233*** (0.064)
Var C Make	−0.092** (0.037)	−0.093** (0.039)	−0.204*** (0.038)
Diversification	−0.145*** (0.037)	−0.143*** (0.037)	−0.144*** (0.037)
Corn Required	−0.049*** (0.003)	−0.049*** (0.003)	−0.049*** (0.003)
Corn Yield	0.136*** (0.021)	0.149*** (0.020)	0.141*** (0.021)
Machinery Repair	0.002* (0.001)	0.002* (0.001)	0.002* (0.001)
Total Farmland	0.083*** (0.002)	0.083*** (0.002)	0.083*** (0.002)
Sold Crop Acre	−0.054*** (0.003)	−0.054*** (0.003)	−0.054*** (0.003)
Rent	0.005*** (0.001)	0.005*** (0.001)	0.005*** (0.001)
Feed Pasture	−0.019*** (0.004)	−0.019*** (0.004)	−0.020*** (0.004)
Feed Expense	−0.004** (0.002)	−0.004** (0.002)	−0.004** (0.002)
Soybean Acre	0.029*** (0.003)	0.029*** (0.003)	0.029*** (0.003)
Wheat Acre	−0.008*** (0.002)	−0.008*** (0.002)	−0.007*** (0.002)
Prime Rate	0.055** (0.025)	0.072*** (0.025)	0.110*** (0.023)
Constant	−0.046 (0.135)	−0.038 (0.140)	−0.290** (0.136)
Operation	Yes	Yes	Yes
County	Yes	Yes	Yes
Observations	10,897	10,897	10,897
R^2	0.345	0.345	0.345

Note: Asterisks ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table 4. OLS Estimation Results Using Monthly US/CAD Exchange Rates to Estimate Means and Variances of Prices for Bought and Homegrown Corn

	Dependent variable			
	Mean C Buy	*Var C Buy*	*Mean C Make*	*Var C Make*
	(1)	(2)	(3)	(4)
XR Jan	20.562***	−7.373***	−1.073***	18.648***
	(0.376)	(0.097)	(0.411)	(0.095)
XR Feb	−116.474***	−55.367***	−80.919***	−78.854***
	(0.782)	(0.202)	(0.855)	(0.198)
XR Mar	375.663***	306.092***	366.707***	182.880***
	(1.300)	(0.336)	(1.421)	(0.329)
XR Apr	−413.326***	−334.977***	−403.421***	−190.094***
	(1.444)	(0.373)	(1.579)	(0.365)
XR May	42.086***	−6.825***	−15.421***	45.768***
	(0.981)	(0.253)	(1.072)	(0.248)
XR Jun	172.972***	166.150***	228.227***	49.074***
	(0.940)	(0.243)	(1.028)	(0.238)
XR Jul	−94.266***	−72.501***	−114.131***	−33.562***
	(0.375)	(0.097)	(0.410)	(0.095)
XR Aug	126.039***	122.706***	148.079***	58.702***
	(0.489)	(0.126)	(0.534)	(0.124)
XR Sep	−53.754***	−84.123***	−62.924***	−26.386***
	(0.444)	(0.115)	(0.485)	(0.112)
XR Oct	−244.187***	−165.064***	−248.597***	−114.512***
	(0.574)	(0.148)	(0.627)	(0.145)
XR Nov	230.600***	167.011***	230.768***	109.429***
	(0.614)	(0.158)	(0.671)	(0.155)
Constant	−93.598***	−75.591***	−96.896***	−43.696***
	(0.306)	(0.079)	(0.334)	(0.077)
Observations	10,897	10,897	10,897	10,897
R^2	0.969	0.996	0.965	0.989

Note: Asterisks ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table 5. 2SLS Estimation Results for the Boundaries of Swine Farms

	Dependent variable: farm boundaries
Mean C Buy	0.641*** (0.155)
Var C Buy	0.188*** (0.038)
Mean C Make	−0.582*** (0.155)
Var C Make	−0.207*** (0.067)
Diversification	−0.145*** (0.037)
Corn Required	−0.049*** (0.003)
Corn Yield	0.138*** (0.021)
Machinery Repair	0.002* (0.001)
Total Farmland	0.083*** (0.002)
Sold Crop Acre	−0.054*** (0.003)
Rent	0.005*** (0.001)
Feed Pasture	−0.019*** (0.004)
Feed Expense	−0.004** (0.002)
Soybean Acre	0.029*** (0.003)
Wheat Acre	−0.008*** (0.002)
Prime Rate	0.071*** (0.026)
Constant	−0.132 (0.142)
Operation	Yes
County	Yes
Observations	10,897
R^2	0.345

Note: Asterisks ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table 6. Robustness Check: County-level Data

	Dependent variable: farm boundaries					
	Mn-Mn	Mn-Md	Md-Mn	Md-Md	Min-Mn	Min-Md
	(1)	(2)	(3)	(4)	(5)	(6)
Mean C Buy	0.721***	1.030***	0.348***	0.556***	0.706***	1.071***
	(0.255)	(0.346)	(0.135)	(0.178)	(0.190)	(0.263)
Var C Buy	0.104**	0.226***	0.123***	0.246***	0.127***	0.257***
	(0.048)	(0.064)	(0.047)	(0.064)	(0.045)	(0.061)
Mean C Make	−0.492**	−0.623*	−0.133	−0.175	−0.370***	−0.513***
	(0.250)	(0.337)	(0.137)	(0.183)	(0.136)	(0.188)
Var C Make	−0.216***	−0.366***	−0.228***	−0.375***	−0.354***	−0.555***
	(0.071)	(0.092)	(0.075)	(0.099)	(0.074)	(0.101)
Diversification	−0.184	−0.016	−0.173	−0.015	−0.182	−0.011
	(0.123)	(0.134)	(0.124)	(0.134)	(0.123)	(0.133)
Corn Required	−0.161***	−0.194***	−0.160***	−0.192***	−0.161***	−0.195***
	(0.013)	(0.015)	(0.013)	(0.015)	(0.013)	(0.015)
Machinery Repair	0.003	0.004	0.003	0.004	0.003	0.005
	(0.006)	(0.008)	(0.006)	(0.008)	(0.006)	(0.008)
Total Farmland	0.202***	0.184***	0.202***	0.183***	0.202***	0.183***
	(0.012)	(0.016)	(0.012)	(0.016)	(0.012)	(0.016)
Sold Crop Acre	−0.059***	−0.026***	−0.060***	−0.025***	−0.059***	−0.026***
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
Rent	−0.001	0.004	−0.0005	0.004	−0.001	0.004
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Feed Pasture	−0.034***	−0.025**	−0.034***	−0.026**	−0.034***	−0.026**
	(0.006)	(0.010)	(0.006)	(0.011)	(0.006)	(0.010)
Feed Expense	0.008	0.013	0.008	0.013	0.008	0.014
	(0.008)	(0.009)	(0.008)	(0.009)	(0.008)	(0.009)
Soybean Acre	0.001	−0.003	0.001	−0.003	0.001	−0.003
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Wheat Acre	−0.006	−0.001	−0.006	−0.001	−0.006	−0.001
	(0.004)	(0.005)	(0.004)	(0.005)	(0.004)	(0.005)
Prime Rate	0.073	0.186***	0.095*	0.210***	0.131***	0.265***
	(0.051)	(0.066)	(0.050)	(0.065)	(0.047)	(0.064)
Constant	0.826***	0.479*	0.809***	0.475*	0.522**	0.054
	(0.207)	(0.258)	(0.217)	(0.271)	(0.215)	(0.280)
Operation Fixed	Yes	Yes	Yes	Yes	Yes	Yes
Observations	852	596	852	596	852	596
R^2	0.570	0.469	0.569	0.467	0.572	0.473

Note: The word before hyphen represents whether the mean (Mn), median (Md) or minimum (Min) corn price during harvest season is used to represent the cost of homegrown corn. The word after hyphen represents whether the farm-level data are aggregated into county-level by mean or median. Asterisks ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table 7. Log-log OLS Estimation Results for the Boundaries of Swine Farms: Robustness Check on Risk Attitude

	Dependent variable: farm boundaries			
	(1)	(2)	(3)	(4)
Mean C Buy	0.524*** (0.128)	0.516*** (0.128)	0.003 (0.208)	−0.078 (0.209)
Var C Buy	0.107*** (0.023)	0.118*** (0.022)	0.096*** (0.037)	0.134*** (0.036)
Mean C Make	−0.508*** (0.126)	−0.491*** (0.126)	−0.002 (0.195)	0.074 (0.197)
Var C Make	−0.092** (0.037)	−0.102*** (0.037)	−0.091* (0.055)	−0.117** (0.055)
Diversification	0.145*** (0.037)		0.511*** (0.073)	
Income		0.032*** (0.007)		0.030*** (0.010)
Corn Required	−0.049*** (0.003)	−0.052*** (0.003)	−0.058*** (0.007)	−0.073*** (0.007)
Corn Yield	0.136*** (0.021)	0.138*** (0.021)	0.317*** (0.057)	0.334*** (0.058)
Machinery Repair	0.002* (0.001)	0.003** (0.001)	0.003* (0.002)	0.004* (0.002)
Total Farmland	0.083*** (0.002)	0.085*** (0.002)	0.079*** (0.003)	0.080*** (0.003)
Sold Crop Acre	−0.054*** (0.003)	−0.052*** (0.003)	−0.063*** (0.004)	−0.054*** (0.004)
Rent	0.005*** (0.001)	0.005*** (0.001)	0.003*** (0.001)	0.004*** (0.001)
Feed Pasture	−0.019*** (0.004)	−0.018*** (0.004)	0.010 (0.011)	0.013 (0.012)
Feed Expense	−0.004** (0.002)	−0.004** (0.002)	−0.009** (0.004)	−0.010** (0.004)
Soybean Acre	0.029*** (0.003)	0.030*** (0.003)	0.038*** (0.004)	0.038*** (0.004)
Wheat Acre	−0.008*** (0.002)	−0.006*** (0.002)	−0.001 (0.003)	0.002 (0.003)
Prime Rate	0.055** (0.025)	0.059** (0.025)	0.057 (0.040)	0.067* (0.040)
Constant	−0.046 (0.135)	−0.110 (0.134)	−0.821*** (0.285)	−1.033*** (0.285)
Operation	Yes	Yes	Yes	Yes
County	Yes	Yes	Yes	Yes
Observations	10,897	10,897	2,736	2,736
R^2	0.345	0.346	0.480	0.472

Note: Asterisks ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table 8. Log-log OLS Estimation Results for the Boundaries of Swine Farms: Robustness Check on Historical Data Used to Calculate Mean and Variance of Prices

	Dependent variable: farm boundaries		
	Main (last 4 years)	last 3 years	last 5 years
	(1)	(2)	(3)
Mean C Buy	0.524*** (0.128)	0.131** (0.065)	0.637*** (0.231)
Var C Buy	0.107*** (0.023)	0.090*** (0.015)	0.203*** (0.032)
Mean C Make	−0.508*** (0.126)	−0.219*** (0.057)	−0.534*** (0.176)
Var C Make	−0.092** (0.037)	−0.017 (0.025)	−0.224*** (0.055)
Diversification	0.145*** (0.037)	0.149*** (0.037)	0.139*** (0.037)
Corn Required	−0.049*** (0.003)	−0.048*** (0.003)	−0.049*** (0.003)
Corn Yield	0.136*** (0.021)	0.153*** (0.020)	0.123*** (0.021)
Machinery Repair	0.002* (0.001)	0.002* (0.001)	0.002* (0.001)
Total Farmland	0.083*** (0.002)	0.083*** (0.002)	0.083*** (0.002)
Sold Crop Acre	−0.054*** (0.003)	−0.054*** (0.003)	−0.054*** (0.003)
Rent	0.005*** (0.001)	0.005*** (0.001)	0.005*** (0.001)
Feed Pasture	−0.019*** (0.004)	−0.020*** (0.004)	−0.019*** (0.004)
Feed Expense	−0.004** (0.002)	−0.004** (0.002)	−0.004** (0.002)
Soybean Acre	0.029*** (0.003)	0.029*** (0.003)	0.030*** (0.003)
Wheat Acre	−0.008*** (0.002)	−0.008*** (0.002)	−0.008*** (0.002)
Prime Rate	0.055** (0.025)	0.009 (0.026)	0.133*** (0.023)
Constant	−0.046 (0.135)	0.176 (0.142)	−0.298* (0.163)
Operation	Yes	Yes	Yes
County	Yes	Yes	Yes
Observations	10,897	10,897	10,897
R^2	0.345	0.345	0.346

Note: Asterisks ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table 9. Log-log OLS Estimation Results for the Boundaries of Swine Farms: Robustness Check on the Length of Harvest Season

	Dependent variable: farm boundaries			
	Main (Oct 15-Nov 15)	Oct 1-Nov 15	Oct 15-Nov 30	Oct 1-Dec 15
	(1)	(2)	(3)	(4)
Mean C Buy	0.524*** (0.128)	0.552*** (0.148)	0.546*** (0.120)	0.546*** (0.120)
Var C Buy	0.107*** (0.023)	0.119*** (0.027)	0.101*** (0.024)	0.101*** (0.024)
Mean C Make	−0.508*** (0.126)	−0.496*** (0.148)	−0.546*** (0.112)	−0.546*** (0.112)
Var C Make	−0.092** (0.037)	−0.113*** (0.042)	−0.090*** (0.034)	−0.090*** (0.034)
Diversification	0.145*** (0.037)	0.142*** (0.037)	0.145*** (0.037)	0.145*** (0.037)
Corn Required	−0.049*** (0.003)	−0.049*** (0.003)	−0.049*** (0.003)	−0.049*** (0.003)
Corn Yield	0.136*** (0.021)	0.134*** (0.021)	0.130*** (0.021)	0.130*** (0.021)
Machinery Repair	0.002* (0.001)	0.002* (0.001)	0.002* (0.001)	0.002* (0.001)
Total Farmland	0.083*** (0.002)	0.083*** (0.002)	0.083*** (0.002)	0.083*** (0.002)
Sold Crop Acre	−0.054*** (0.003)	−0.054*** (0.003)	−0.054*** (0.003)	−0.054*** (0.003)
Rent	0.005*** (0.001)	0.005*** (0.001)	0.005*** (0.001)	0.005*** (0.001)
Feed Pasture	−0.019*** (0.004)	−0.019*** (0.004)	−0.019*** (0.004)	−0.019*** (0.004)
Feed Expense	−0.004** (0.002)	−0.004** (0.002)	−0.004** (0.002)	−0.004** (0.002)
Soybean Acre	0.029*** (0.003)	0.029*** (0.003)	0.029*** (0.003)	0.029*** (0.003)
Wheat Acre	−0.008*** (0.002)	−0.008*** (0.002)	−0.008*** (0.002)	−0.008*** (0.002)
Prime Rate	0.055** (0.025)	0.066*** (0.025)	0.042* (0.025)	0.042* (0.025)
Constant	−0.046 (0.135)	−0.121 (0.137)	0.003 (0.129)	0.003 (0.129)
Operation	Yes	Yes	Yes	Yes
County	Yes	Yes	Yes	Yes
Observations	10,897	10,897	10,897	10,897
R^2	0.345	0.346	0.346	0.346

Note: Asterisks ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table 10. Log-log OLS Estimation Results of the Efficiency of Transaction-facilitating Mechanisms on Farm Boundary: Different Operation Type

	Dependent variable: farm boundaries			
	Main	Farrow-Finish	Mix	Farrow-Weaner
	(1)	(2)	(3)	(4)
Mean C Buy	0.524*** (0.128)	0.451** (0.207)	0.494** (0.203)	0.113 (0.356)
Var C Buy	0.107*** (0.023)	0.146*** (0.037)	0.094*** (0.035)	−0.00001 (0.054)
Mean C Make	−0.508*** (0.126)	−0.449** (0.202)	−0.455** (0.199)	0.003 (0.338)
Var C Make	−0.092** (0.037)	−0.115* (0.060)	−0.093 (0.057)	−0.073 (0.091)
Diversification	0.145*** (0.037)	0.039 (0.061)	0.104* (0.058)	0.021 (0.100)
Corn Required	−0.049*** (0.003)	−0.096*** (0.007)	−0.040*** (0.005)	−0.025*** (0.008)
Corn Yield	0.136*** (0.021)	0.189*** (0.034)	0.118*** (0.031)	0.123 (0.095)
Machinery Repair	0.002* (0.001)	0.011*** (0.003)	0.001 (0.002)	0.002 (0.002)
Total Farmland	0.083*** (0.002)	0.103*** (0.004)	0.085*** (0.004)	0.074*** (0.006)
Sold Crop Acre	−0.054*** (0.003)	−0.043*** (0.004)	−0.061*** (0.004)	−0.070*** (0.008)
Rent	0.005*** (0.001)	0.009*** (0.001)	0.003*** (0.001)	0.001 (0.001)
Feed Pasture	−0.019*** (0.004)	−0.013** (0.006)	−0.022*** (0.007)	0.004 (0.011)
Feed Expense	−0.004** (0.002)	−0.009*** (0.003)	−0.003 (0.003)	0.010* (0.005)
Soybean Acre	0.029*** (0.003)	0.019*** (0.004)	0.031*** (0.004)	0.050*** (0.008)
Wheat Acre	−0.008*** (0.002)	−0.008** (0.003)	−0.004 (0.003)	−0.003 (0.006)
Prime Rate	0.055** (0.025)	0.064 (0.041)	0.045 (0.039)	0.076 (0.060)
Constant	−0.046 (0.135)	0.157 (0.219)	−0.123 (0.198)	−0.047 (0.511)
County	Yes	Yes	Yes	Yes
Operation Type	Yes	No	No	No
Observations	10,897	4,824	3,711	783
R^2	0.345	0.307	0.334	0.475

Note: Asterisks ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table 11. Placebo and Falsification Tests

	Dependent: farm boundaries		Dependent: Random Numbers
	Main	Placebo	Falsification
	(1)	(2)	(3)
Mean C Buy	0.524*** (0.128)	0.378 (0.274)	0.001 (0.005)
Var C Buy	−0.107*** (0.023)	−0.289 (0.269)	−0.001 (0.001)
Mean C Make	−0.508*** (0.126)	0.130 (0.273)	−0.001 (0.004)
Var C Make	−0.092** (0.037)	−0.451 (2.672)	0.001 (0.001)
Diversification	0.145*** (0.037)	0.167*** (0.036)	0.001 (0.001)
Corn Required	−0.049*** (0.003)	−0.046*** (0.003)	0.00002 (0.0001)
Corn Yield	0.136*** (0.021)	0.184*** (0.019)	0.0002 (0.001)
Machinery Repair	0.002* (0.001)	0.002* (0.001)	0.0001* (0.00004)
Total Farmland	0.083*** (0.002)	0.083*** (0.002)	−0.0001 (0.0001)
Sold Crop Acre	−0.054*** (0.003)	−0.054*** (0.003)	0.00004 (0.0001)
Rent	0.005*** (0.001)	0.005*** (0.001)	−0.00000 (0.00002)
Feed Pasture	−0.019*** (0.004)	−0.020*** (0.004)	−0.00000 (0.0001)
Feed Expense	−0.004** (0.002)	−0.005** (0.002)	−0.00003 (0.0001)
Soybean Acre	0.029*** (0.003)	0.029*** (0.003)	−0.0002* (0.0001)
Wheat Acre	−0.008*** (0.002)	−0.008*** (0.002)	−0.00001 (0.0001)
Prime Rate	0.055** (0.025)	−0.0002 (0.012)	−0.001 (0.001)
Constant	−0.046 (0.135)	2.187 (18.576)	4.620*** (0.005)
Operation	Yes	Yes	Yes
County	Yes	Yes	Yes
Observations	10,897	10,897	10,897
R^2	0.345	0.342	0.005

Note: Asterisks ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table 12. The Break-even Price, Average Price and Price in Harvest Season for Corn in Ontario, 2003-2015

Year	Break-even Price (CAD/Bu)		Average Price	Price in Harvest Season (CAD/Bu)		
	without Rent	with Rent	(Bu/Ac)	Mean	Median	Minimum
2003	2.91	3.56	3.18	3.27	3.42	2.64
2004	3.01	3.68	3.36	3.37	3.42	2.73
2005	2.64	3.27	3.48	3.30	3.42	2.39
2006	2.85	3.49	3.29	3.05	2.99	2.36
2007	3.24	3.98	3.09	2.91	2.98	2.36
2008	2.98	3.66	3.14	3.02	3.27	2.36
2009	3.52	4.31	3.54	3.41	3.52	2.34
2010	2.89	3.63	3.98	3.81	3.71	3.24
2011	3.29	4.20	4.30	4.17	4.10	3.44
2012	3.52	4.69	5.01	4.86	4.57	3.70
2013	3.42	4.72	5.40	5.59	6.08	3.89
2014	3.28	4.73	5.77	5.52	5.58	3.86
2015	3.22	4.68	5.94	5.34	4.46	3.86