An Incomplete Contracts Model of Dairy Enterprise Organization

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Abstract

An empirical incomplete contracts approach is used to analyze optimal integration schemes in a Minnesota dairy farm supply chain that transfers feed and manure. The results show that the forage enterprise is the constraining factor. The preferred ownership structure is for a forage producer to own cropping and dairy assets.

Introduction

The dairy industry in Minnesota is characterized by a large number of relatively small farms, and is undergoing rapid changes in structure. Many small Minnesota dairy farms have left the industry in recent years. The rate of exodus has thus far exceeded growth in larger farms, causing decreases in total milk production. This is of particular significance as the US dairy industry orients itself toward more milk and dairy product production in California and the West, and processing facilities in the Upper Midwest face increased competition. As a strategy to improve its competitiveness, the dairy industry in Minnesota has encouraged investments in new facilities that can take advantage of size economies and increase milk volumes available for processing. Other sectors of agriculture, notably small grains, have been suggested as potential sources of new investment capital for the dairy industry. In some key dairy regions, such as West-Central Minnesota, dairy farms are closely interspersed with farms producing cash grains, predominantly corn and soybeans.

For the most part, dairy farms in Minnesota individually coordinate most of the production activities involved in producing milk. However, as farms restructure and specialize, a dairy farm supply chain has emerged with primary forage and small grain production activities as its origin and milk at the farmgate as its terminus. This supply chain is still developing; among the issues of interest is the structure of ownership and integration of the activities in the supply chain and the relation of size economies to correspondence between activities in the chain. Two of the key links in this supply chain are feed production and milking/herd maintenance.

This paper provides an empirical analysis of ownership and organization in a dairy farm supply chain. An empirical model of a dairy farm supply chain is developed to determine the limiting activities and optimal organization. Based on this model, ownership of activities in the supply chain is investigated using an incomplete contracts model. The results identify the optimal organization and ownership structure in a Minnesota dairy farm supply chain.

The Incomplete Contracts Approach

The incomplete contracts model evaluates efficient levels of integration between trading partners (the *make-or buy* decision); alternatively, it can be thought of as an analytical framework for mergers and acquisitions. In the model, parties to a transaction are assumed to be boundedly rational in the sense that not all contingencies can be planned for at the time a contract is written; some aspects are left open. The principal determinants of the model are the opportunity costs of idiosyncratic assets in the trading arrangement. There are quasi-rents associated with idiosyncratic assets that can be the subject of opportunism from parties in a trading relationship-this is referred to as the *holdup* problem in the industrial organization literature (Williamson, 1985). The allocation of residual control rights (ownership) can be used to control the holdup problem; however, alternative ownership structures can cause incentive (agency) problems. The incomplete contracts model evaluates ownership structures based on level of surplus generated.

Conceptual Model

The model presented here is an extended version of the general model developed by Hart (1995). There is an upstream firm (a crop producer) and a downstream firm (a dairy producer). The dairy producer purchases feed ingredients and must dispose of manure. The crop producer sells feed ingredients and must obtain fertilizer. The two parties set about a specialized relationship in which they exchange feed ingredients and manure. This relationship is characterized by boundedly rational agents and goods that are idiosyncratic in nature. There are uncertain aspects of the relationship between the crop producer and dairy producer that are difficult to formalize or anticipate in a contract. Feed ingredients are available from the central spot market; however, market prices may not reflect the value owing to scale economies in the dairy operation and uncertainty in feed quality and response of cows to feed due to weather. It is difficult to make long-term binding commitments to transfer manure, because manure regulations are liable to change in ways that cannot be anticipated *a priori*. Manure is an unpriced good (or bad), and manure disposal involves transaction costs in establishing agreements to convey manure and in searching for suitable cropland[3].

There are three time periods. In the initial period, the crop producer supplements its complement of small grain production assets by making investments in forage equipment *e*. In the second period, the dairy producer observes the investment by the crop producer and makes investments in dairy cows and facilities, *i*[4]. These investments are at least partially idiosyncratic, owing to location. In the final period, the conditions underlying the unspecified aspects of the relationship are revealed, and the parties make trading decisions. Let the revenue of the dairy producer be R(*i*) if it trades with the crop producer. If the crop producer trades with the dairy producer, its costs are C(e). The crop producer produces, and the dairy producer consumes, feed grains and forages *q*. If *p* is the feed transfer price, then the *ex post* earnings for the two parties (if they trade) are

$$pq(e) - C(q(e)) \tag{1}$$

$$R(q(i)) - pq(i) \tag{2}$$

and the total earnings from the joint relationship if they trade in feed (so $q(i) = q(e)$) are

[3] For example, the Minnesota Pollution Control Agency requires detailed nutrient management plans and aerial photos of land manure is to be applied on; lenders may also require that land for manure disposal be available long term.

[4] The order of moves in the investment "game" derives from the empirical finding in the empirical analysis that investments by the crop producer are the limiting factor in the system.

$$R(q(i)) - pq(i) + pq(e) - C(q(e)) = R(q(i)) - C(q(e)) \quad (3)$$

However, due to the presence of uncertainty and quasi-rents, the trading relationship may break down after the investments have been made. For example, the dairy producer may act opportunistically by insisting on renegotiating terms just as the crop producer is harvesting the crop. In anticipation of this possibility, agents consider the value of their idiosyncratic investments in other uses. The value of specialized assets in the next best use is dependent on the other assets an agent owns. For example, even if the crop producer and dairy producer are ultimately unable to trade in feed, the dairy producer may be able to derive benefits from the crop's land if it owns the crop assets that it could not if it did not retain residual control to the crop assets. In making investment decisions, the two parties consider their payoffs if the specialized relationship fails and they are forced to trade on the spot market; the structure of ownership generally affects these decisions.

Let $\bar{c}(q(e);A)$ be the cost function of the crop producer if it does not trade with the dairy producer, given ownership of assets A. Let $r(q(i);A)$ be the revenue of the dairy producer if it does not trade with the crop producer. Ownership schedule A^2 means that the crop producer owns both crop and dairy assets, A^1 means the crop producer owns the crop assets and the dairy producer owns the dairy assets, and A^0 means the dairy producer owns the dairy assets and the cropping assets. Regardless of ownership structure, the operator of the crop enterprise chooses *e* and the operator of the dairy enterprise chooses *i*. If trade does not occur between the two firms, the crop producer sells forage and feed grains at price $\bar{p}$ on the central spot market. In the absence of trade with the crop producer, the dairy producer purchases its feed ingredients from the central spot market at price p^{*}[5]. Thus, the total surplus if the relationship breaks down is

$$r(q(i);A) - p^{*}q(i) + \overline{p}q(e) - \overline{c}(q(e);A) \quad (4)$$

where $q(i) = q(e) = q$, but $q(i)$ is obtained from the spot market and $q(e)$ is sold to the spot market. Due to the idiosyncratic nature of the relationship, the benefit of investment is greatest under trade or under the highest level of integration if the relationship falters. This is also true at the margin;

$$\overline{c}'(dq/de;A^{0}) \geq \overline{c}'(dq/de;A^{1}) \geq \overline{c}'(dq/de;A^{2}) > C'(dq/de) \quad (5)$$

$$R'(dq/di) > r'(dq/di;A^{0}) \geq r'(dq/di;A^{1}) \geq r'(dq/di;A^{2})$$

Also, for all *e* and *i* and all possible values of A there are always *ex post* gains from trade;

$$R(q(i)) – C(q(e)) > r(q(i);A) - p^{*}q(i) + \overline{p}q(e) - \overline{c}(q(e);A) \geq 0 \quad (6)$$

In the final period, all uncertainties are revealed, and the gains from trade are realized. These gains are allocated through bargaining. *Ex post*, the Nash equilibrium bargaining solution is to split the gains from trade evenly[6]. The *ex post* payoff is such that each party's gain under trade is equal to its gain if the relation breaks down plus its share of the total gains from trade;

$$\pi^{C} = pq(e) - C(q(e)) = \overline{p}q(e) - \overline{c}(q(e);A) + ½ \{[R(q(i)) – C(q(e))] – [r(q(i);A) - p^{*}q(i) + \overline{p}q(e) - \overline{c}(q(e);A)]\}; \text{ and}$$

$$\pi^{D} = R(q(i)) – pq(i) = r(q(i);A) - p^{*}q(i) + ½ \{[R(q(i)) – C(q(e))] – [r(q(i);A) - p^{*}q(i) + \overline{p}q(e) - \overline{c}(q(e);A)]\} \quad (7)$$

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[5] If the parties trade on the central spot market, they must pay transportation costs such that $p^{*} = p^{o} + t$ and $\overline{p} = p^{o} - t$, where t is the per unit basis and p^{o} is the spot market price

[6] The Nash allocation of any fixed amount is a 50/50 split if both parties must give consent.

where π is the *ex post* payoff, C denotes the crop producer and D denotes the dairy producer. Each party receives its opportunity cost ($r(q(i);A) - p^{*}q(i)$, $\bar{p}q(e) - \bar{c}(q(e);A)$) plus its share of the gains from trade[7]. The gains from trade are disbursed in the *ex post* transfer price p;

$$p = \bar{p} + [½ \{[R(q(i)) – (r(q(i);A) - p^{*}q(i))] - [\bar{p}q(e) - \bar{c}(q(e);A) - C(q(e))]\}]/q \qquad (8)$$

Equation 7 is a statement of *ex post* payoffs- investment costs are ignored (because they are already sunk). However, investment decisions are made *ex ante* in which investment costs matter. Assume that the cost of dairy investments i is normalized to be just i and that the cost of forage investments e is e. Then the relevant objective in choosing investment levels (i,e) is to maximize payoff net of investment cost;

$$\pi^{C} - e = \bar{p}q(e) - \bar{c}(q(e);A) + ½ \{[R(q(i)) – C(q(e))] – [r(q(i);A) - p^{*}q(i) + \bar{p}q(e) - \bar{c}(q(e);A)]\}- e$$

$$\pi^{D} - i = r(i;A) - p^{*}q(i) + ½ \{[R(q(i)) – C(q(e))] – [r(q(i);A) - p^{*}q(i) + \bar{p}q(e) - \bar{c}(q(e);A)]\}- i \quad (9)$$

Assuming concavity of the system in (8), the equilibrium is the set of first-order conditions

$$\pi'^{C} = ½\, C'(dq/de \mid i = i(e)) + ½\, \bar{c}'(dq/de \mid i = i(e);\, A) -1 = 0$$

$$\pi'^{D} = ½\, R'(dq/di \mid e) + ½\, r'(dq/di \mid e;\, A) - 1 = 0 \qquad (10)$$

Since equations (10) are interdependent, they must be solved using a backward induction process applied in two stage games of complete information. First order conditions (10) differ according to ownership structure A. There is a solution to Equations (9), (i*,e*), for A^2, A^1, and A^0.

There is also a theoretically optimal level of i and e that a central planner would choose by cooperatively maximizing *ex ante* gains from trade $R(q(i))-C(q(e))-i- e$. In general, the crop producer and dairy producer will individually choose i and e that differ from this optimal level.

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[7] Note that if we add the two lines in (7), we obtain

$R(i) - C(e) = r(i;A) - p^{*}q + \bar{p}q - \bar{c}(e;A) + \{[R(i) – C(e)] – [r(i;A) - p^{*}q + \bar{p}q - \bar{c}(e;A)]\}$, or $R(i) - C(e) - [r(i;A) - p^{*}q + \bar{p}q - \bar{c}(e;A)] = \{[R(i) – C(e)] – [r(i;A) - p^{*}q + \bar{p}q - \bar{c}(e;A)]\}$. In other words, (7) is an implication of the *ex post* Nash equilibrium split of the gains from trade.

However, alternative ownership structures may induce the parties to choose i and e that more closely approach the theoretical optimum. The “efficiency” of different ownership structures is compared using an *ex ante* surplus function, S(i,e;A);

$$S(i^{**},e^{**};A^{2}) = R(q(i^{**})) - i^{**} - C(q(e^{**})) - e^{**}$$

$$S(i^{*},e^{*};A^{1}) = R(q(i^{*})) - i^{*} - C(q(e^{*})) - e^{*} \qquad (11)$$

$$S(i^{o},e^{o},A^{0}) = R(q(i^{o})) - i^{o} - C(q(e^{o})) - e^{o}$$

The ownership structure that yields the greatest level of surplus in (11) is the preferred choice. The distribution of this surplus is not important- it can be adjusted with lump sum transfers that do not affect investment incentives.

Empirical Model

An empirical model of the dairy and crop activities was developed to determine the size economies and factors constraining the dairy farm supply chain as a whole. To simplify the system, the supply chain is constructed such that only the crop producer and dairy producer were involved. The crop producer produces feed ingredients and mixes them into feed; the dairy producer sells milk and calves and purchases all feed and replacement heifers. Manure can be transferred from the dairy to the crop operations.

Dairy Operations

The dairy operation is modeled as a mixed integer linear programming problem. The problem faced by the dairy producer is to choose a herd size, milking parlor configuration, feed ration, and number of building sites given limitations on the maximum daily hours of operation of the parlor, maximum number of production sites, and technology constraints. The dairy producer’s objective is to maximize earnings derived from milk and calf sales less annual facilities costs, feed costs, labor costs, herd replacement costs, manure disposal costs, and veterinary and miscellaneous costs. The model is constrained by technical parameters identifying milking parlor throughput, freestall, feed storage, manure storage, NRC nutrient requirements, and fixed constraints of no more than 21 daily hours of operation and 5 production sites. Integer constraints were placed on herd size, number of calves sold, the number of parlors of a given configuration, and the number of production sites. The key parameters of the model are identified in Table 1. Up to 3000 tons of dairy ration and soymeal can be purchased by the dairy. Milk revenues are based on 2000 cwt/cow/year and a price of $13.81/cwt. Facilities costs are the annuity value of the initial investment at a 9% interest rate.

Crop Operations

The crop investment problem is also conceived as a mixed integer linear programming problem. The crop producer chooses feed ingredients to produce, acreage to rent, and levels of investment in forage equipment. The model is constrained by the technology and integer constraints and by the number of skilled and unskilled workers available; one skilled worker and two unskilled workers are assumed[8]. The crop producer already has in place in equipment suitable for tillage, seeding, crop maintenance, and harvesting of grain crops; these services are valued at per-acre costs estimated by Lazarus (1998). Investments in forage equipment are broken into fixed (ownership) costs and variable costs. Fixed costs are taken as the annuity value purchase prices for machines at 9% over their useful life; fixed costs are measured in units of machines owned and constrained to be an integer. Variable costs are associated with fixed costs based on estimates of maximum acres per year for each machine (Table 1); variable costs generally decrease

[8] Following Lazarus (1998), only skilled workers can operate a forage harvester; skilled workers can also operate the same equipment as unskilled workers.

as machine capacity increases. Regardless of whether the dairy and crop trade, the crop producer can sell up to 1000 acres of cash crop corn and 1000 acres of cash crop soybeans. Feeds that are transferred to the dairy are ground and mixed by the crop producer at a cost of $8/ton.

Manure Disposal

Manure is stored in an earthen facility by the dairy producer for 365 days. It is applied on cropland based on the uptake of nutrient by corn, alfalfa, and soybeans and whether it is broadcast or incorporated[9]. There are transaction costs associated with securing land for manure disposal of an assumed $15/acre/year. The dairy producer bears the application cost; custom manure application rates assuming 2 miles transportation estimated by Lorimor (1998) for Iowa are used.

Ownership Scenarios

There are 3 ownership possibilities: Ownership of all assets by the crop producer (A^2), ownership of all assets by the dairy producer (A^0), or ownership of crop assets by the crop producer and ownership of dairy assets by the dairy producer (A^1). In each case, feed is transferred at cost with the transfer price determined *ex post*; if trade does not occur, each party pays a basis of $7.27/ton extrapolated from a survey by Lazarus (1999). Under A^2, the crop producer retains right of first refusal to the dairy's manure. There are no transaction costs if manure is applied to the crop producer's land, and additional land can be obtained to dispose of manure subject to transaction costs. Under A^0, the dairy retains residual claim to cropland for the purposes of manure disposal. No transaction costs are required in applying manure to the crop producer's land, but the dairy enterprise scales its operations in expectation of utilizing solely this acreage so no additional land is accessed for manure disposal. Under A^1, all manure applications entail transactions costs

[9] Nitrogen uptake rates: Corn 48 lbs/ac, Soybeans 220 lbs/ac, Alfalfa 100 lbs/ac. If manure is broadcast, approximately 15% of the nitrogen is lost to the atmosphere; if it is injected 2% is lost.

because the crop producer does not have residual rights to the manure and the dairy producer does not have residual rights to the cropland.

Empirical Analysis of Ownership Structure

As a base run against which to interpret the incomplete contract results, the central planner's problem was solved by choosing investment levels cooperatively under the imposition that trade will occur between dairy and crop. The results are presented in Table 1. The crop producer supplies corn silage, hay, and corn to the dairy producer. The factor limiting the scale of trade is the forage enterprise, specifically the capacity to cut hay. The dairy producer constructs 2 sites with 36 stall milking parlors. A total of 5174 acres are required to incorporate manure, requiring an additional 826 acres to be secured.

In analyzing alternative ownership structures, alternative forms of the mixed integer linear program embodying Equation (9) are solved. The objective function is thus a combination of earnings under trade and under no-trade. Because it is a two-stage game of complete information, an iterative solution procedure is used. Feasible combinations of investments are isolated from the crop producer's problem. These are iteratively substituted in the dairy producer's problem. The dairy investment level that maximizes the dairy producer's payoff given any feasible crop investment is the dairy producer's best response; combined with the corresponding crop investment this defines the equilibrium[10]. Table 1 summarizes the results of this procedure, where "crop own" is A^2, "contract" is A^1, and "dairy own" is A^0. The criterion function (11) is given by the central planner's payoffs in Table 1. Based on this specification of ownership scenarios, ownership of dairy and crop assets by the crop producer is optimal. Both A^2 and A^1 result in the

[10] Reaction functions are "substituted" in alternative payoffs functions by fixing their value with equality constraints

same allocation of manure nutrients and other resources; the difference in payoffs comes from a lower cost of transferring manure under A^2 relative to A^1. Although the investment levels are identical, solutions under A^2 and A^1 differ from the central planner's result due to differences in the allocation of hay cutting capacity. Under the cooperative solution, scarce hay cutting capacity is allocated away from haylage in favor of hay production. Only A^0 resulted in a significant alteration in investments due to a reduced herd size. Strict dependence of the dairy on owned crop assets to dispose of manure results in a smaller dairy herd, underutilized milking center facilities, and a misallocation of manure nutrients relative to the central planner's result. The transfer prices of feeds in all three scenarios are remarkably stable. In all cases, the transfer price is between the central spot market price and the spot market price delivered to the dairy.

VI Conclusions

This paper derives and illustrates the use of an incomplete contracts model to study integration in a dairy farm supply chain given technology and specification of objectives under alternative ownership schemes. The key determinants are the cost and productivity of dairy and crop investments and transaction costs in manure disposal. The results show that feed production is the limiting factor in the dairy farm supply chain. The ownership structure that generates the largest surplus is ownership of dairy and crop assets by the crop producer. This suggests that a source of future expansion in the West-Central Minnesota dairy industry may be the cash crop sector. Accurate estimates of manure transaction costs and improved information on cost and capacity of forage equipment will improve future research in dairy farm supply chain integration.

Table 1 Summary of Results and Significant Parameters

	Payoffs			**Herd**	**Milking Center**	**For Harv Sm 165 ac**	**For Harv Sm SP 305ac**	**For Harv Lg SP 458 ac**	**Rake 699 ac**
Price ($/yr)	**Central Planner ($)**	**Crop ($)**	**Dairy ($)**	401/cow	1643.20 per stall	6224	34,013	36,327	687
Base Run	1,411,566	352,420	1,0591,047	2462 hd	Two 2X18	0	0	1	3
Crop Own	1,381,527	314,959	1,066,568	2462 hd	2 2X18	0	0	1	3
Contract	1,325,260	323,508	1,001,753	2462 hd	2 2X18	0	0	1	3
Dairy Own	1,258,489	321,684	936,805	2203 hd	2 2X18	0	0	1	3

	Baler Sm Rnd 603 ac	**Baler Lg Rnd 804 ac**	**Baler Lg Sq 3258 ac**	**Haybine Sm 350 ac**	**Haybine Lg 465 ac**	**Haybine Lg SP 621ac**	**Crop Land Rent**	**20% Dairy Ration**	**48% Soy**
Price ($/yr)	3841	4489	13,443	3216	5160	16,706	45/ac	159/tn	159/tn
Base Run	0	0	1	0	0	3	4321 ac	1213 tn	3000 tn
Crop Own	0	0	1	0	0	3	4321 ac	934 tn	3000 tn
Contract	0	0	1	0	0	3	4321 ac	934 tn	3000 tn
Dairy Own	0	0	1	0	0	3	4321	0	2300 tn

	Manure Incorp	**Manure Broad**	**Corn Silage**		**Hay**		**Haylage**		**Corn Fed**		**Hay Sold**	**Soy Fed**	**Soy Sold**
Price ($/yr)	.007/gal	.011/gal	23.10/tn**		85/tn**		35.89/tn**		83.99/tn**		77.73/tn	197.65/tn**	190.38/tn
Transfer P			*p*($/tn)	*q*(tn)	*p*($/tn)	*q*(tn)	*p*($/tn)	*q*	*p*($/tn)	*q*(tn)			
Base Run	5147 ac	0	-	8001	-	6744	-	0	-	3575	0	0	1170 tn
Crop Own	5147 ac	0	24.17	8001	86.07	5086	36.96	4580	85.07	3575	0	0	1170 tn
Contract	5147 ac	0	24.17	8001	86.07	5086	36.96	4580	85.07	3575	0	0	1170 tn
Dairy Own	10 ac*	4311 ac*	24.19	8001	86.09	4835	36.98	4580	85.08	3575	251 tn	0	1170 tn

***Estimate**

****Central spot market prices; corn silage valued at 10 x shelled corn price, haylage value moisture adjusted from hay price**

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