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Aligning Incentives for Contract Dairy Heifer Growth

Nicole J. Olynk and Christopher A. Wolf

As dairy farms grow and specialize in milking cows, raising replacement heifers is increasingly outsourced. Perhaps the largest challenge of outsourcing the heifer enterprise involves quality, measured as milk production potential, and the possibility for moral hazard due to hidden action on the part of the custom heifer grower. A principal-agent framework was used to elicit contract terms to provide incentives for the heifer grower to achieve desired growth rates, and enable the return of the heifer to the dairy farm on an accelerated time frame, without sacrificing quality. To mitigate incentive asymmetries, bonuses and deductions are proposed.

Key Words: contracts, heifer growth, moral hazard, principal agent

Introduction

As dairy farms become larger, managers of farms specializing in milk production must assess their comparative advantages. Enterprises not directly resulting in milk sales (e.g., crop production for feed, heifer rearing, raising beef steers, custom harvest operations) are assessed in terms of the opportunity cost of maintaining these enterprises versus increasing milk cow numbers. Often, given management time, labor, and capital constraints, dairy operations outsource activities that were once managed and performed on-farm (Wolf, 2003). The cost associated with raising replacement heifers is the third largest expense on the dairy farm behind the cost of feed and labor (Harsh, Wolf, and Wittenberg, 2001). An increasingly common choice for dairy farms specializing in milking cows is to outsource the heifer enterprise to a custom grower. Custom heifer growers generally take a calf from the dairy farm within its first week of life and are responsible for that heifer until it is returned to the dairy farm just prior to calving.

In recent years, accelerated dairy heifer growth has received increased attention from researchers and commercial dairymen. The main driver behind accelerated heifer growth is the desire to have heifers achieve breeding size, and therefore calve and begin lactation, at a younger age. Entering the milking herd earlier decreases the time the heifer spends as a nonproductive asset. Accelerated heifer growth comes with the challenge of having the heifer reach breeding size, subject to maintaining appropriate body conditioning and achieving desired stature. A properly implemented accelerated heifer growth program requires intensive heifer management and increased attention to feed and labor costs.

Contracts are important in order to formalize agreements between the dairy farm and the heifer grower (Wolf, 2003). Endsley, Atkeson, and Nott (1996) recommended that a written

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contract be used to establish the management and economic conditions regarding the heifer growing agreement. A survey by Wolf (2003) found that 69% of custom dairy heifer growers used some form of written contract. Several payment schemes were utilized in these contracts. Nearly 52% of survey respondents charged daily fees to raise heifers and about 13% charged per pound fees based on heifer gain.

The daily charge contract, as it is generally written, is essentially a fixed-payment contract where custom growers receive a fixed payment for their services, regardless of performance.¹ Fixed-payment contracts are similar to fixed-wage contracts, in which there exist incentives for shirking, unless effort is monitored. The price per pound of gain method has similar incentive problems as it provides incentive for cheap weight gain, which may compromise the heifer quality. Given the nature of heifer rearing, close monitoring by the dairy farm is almost surely prohibitively expensive and defeats the dairy farm's goal in employing an outside agent to free management and labor time for more productive purposes. Underlying the hesitation of many dairy farm managers about using a custom grower is that the custom grower does not have the same incentives to produce optimal heifer quality in an efficient and timely fashion. The greatest challenge when contracting heifer growth revolves around the potential for moral hazard because of hidden action on the part of the custom heifer grower. We hypothesize that since aligning incentives for raising heifers is difficult, creating incentives for additional effort, expense, and care with accelerated growth requires a more complex contract design than is present in the industry today.

Imperfect or asymmetric information can have a great impact on individuals' behavior. Three main areas of focus under the umbrella of imperfect information include moral hazard, adverse selection, and signaling (Macho-Stadler and Perez-Castrillo, 2001). The economic theory underlying agents' behavior in situations involving imperfect information has evolved since Akerlof (1970) to include applications in various sectors of the agricultural and food production systems. Principal-agent frameworks have been used to assess impacts of various incentives offered by principals for food safety (Starbird, 2005), food quality control (King, Backus, and Gaag, 2007), traceability in beef cattle (Resende-Filho and Buhr, 2008), and moral hazard in livestock production contracts (Dubois and Vukina, 2004). King, Backus, and Gaag added reputation as an incentive mechanism. Resende-Filho and Buhr identified optimal traceability investment levels to overcome informational asymmetries and identified incentive mechanisms necessary to induce behaviors by risk-averse agents.

The objective of this research is to derive contracts that account for the monitoring problem in accelerated heifer growth through a custom grower and align custom grower and dairy farm manager incentives for adaptations to the two most common contracting schemes used in the industry. This research specifies a contract that aligns incentives for custom heifer raisers to perform accelerated heifer growth and monitor heifers adequately with respect to body condition score (BCS) in order to maximize potential performance.² The analysis extends current knowledge regarding contracting for farm inputs by identifying contract terms for growth time frame and BCS. A numerical solution is obtained for the extensions of the daily charge and price per pound contracting schemes, which include incentive mechanisms for accelerated growth.

¹ Within fixed-payment contracts, there is often a clause for death or loss of calves. Generally, some small calf mortality rate at the heifer grower is considered unavoidable. If this level of mortality is exceeded, there may be provision for shared liability for the loss of additional calves between the dairy farm and grower. Calf mortality aspects are not the focus of this analysis.

² Body condition scoring uses a scale from 1 to 5. Its purpose for dairy cattle is to assess conditioning. A body condition score of 1 indicates a very thin animal, while a body condition score of 5 indicates an extremely fat animal. Scoring standards exist within the industry, and many industry professionals (e.g., veterinarians) provide body condition scoring assistance.

Accelerated Heifer Growth

Definitions of desired body size for replacement heifers are necessary among commercial dairy farms in order to effectively evaluate replacement heifer management programs (Hoffman, 1997). The Subcommittee on Dairy Cattle Nutrition (National Research Council, 2001) describes target weights for breeding and calving as a percentage of mature size. Specifically, heifers enter puberty between 45% and 50% of their mature size, heifers should be pregnant by the time they reach 55% of mature size, and they are expected to calve for the first time at 82% of mature size. The mature size of a Holstein cow varies from 1,400 to 1,800 pounds.

The goal of accelerating heifer growth is to achieve an earlier age at first calving, necessitating that heifers achieve the target size for breeding at an earlier age. For example, a target age at first calving of 22 months requires that heifers conceive by 13 months of age. If the mature body weight of the cow was expected to be 1,600 pounds, target breeding weight at 55% of mature body weight is 880 pounds. To achieve a weight of 880 pounds at 13 months of age, a calf born at 90 pounds must gain an average of 1.98 pounds per day. That same heifer would need to gain an average of only 1.72 pounds per day to achieve breeding weight at 15 months of age. In accordance with the dairy science literature, throughout this analysis, heifers with an average daily gain at or above 1.98 pounds per day were considered to be on an accelerated growth time frame, while slower growth was considered nonaccelerated (Albeni et al., 2000; Wolf, Hadrach, and Vandehaar, 2006).

Challenges associated with accelerated heifer growth revolve mainly around the desire for heifers to reach breeding size at a faster rate, subject to maintaining appropriate body conditioning and achieving desired stature. If heifers are simply pushed to gain weight without carefully balanced diet nutrition for optimal growth rates, they may become overconditioned. Dairy science research suggests possible adverse effects of accelerated heifer growth include a decrease in subsequent milk production (see Mourits et al., 1997; Van Amburgh et al., 1998); higher probabilities of dystocia (difficulty) during calving, potentially leading to reduced milk yield (Dematawewa and Berger, 1997); and increased incidence of health concerns, metabolic disorders, and decreased fertility (Dematawewa and Berger). Thus, properly implemented accelerated heifer growth not only requires additional feed and labor but also increased management attention.

The dairy farmer desires adequate frame growth, rather than more inexpensively achieved weight gain in the form of body fat. It is less costly to achieve weight gain if heifers become overconditioned but do not have adequate frame size. Heifer BCS is used to assess heifer size and structure.³ Body condition scoring has a degree of subjectivity but can be performed by an outside party chosen and agreed upon by the dairy farm and custom grower. A third party for body condition scoring, for example, might be a veterinarian.⁴

The Principal-Agent Model

A dairy farmer (principal) is assumed to produce and sell milk as a primary source of farm income. The principal seeks to use contractual agreements with a custom grower (agent) to raise heifers. The dairy farm desires accelerated heifer growth to enable the return of the

³ Milk production and stature (e.g., hip height) bonuses were investigated as additional contract variables. Because results were insensitive to these bonuses, they were not included.

⁴ Given the ease with which third-party verification could be accomplished on most dairy farms, the added costs of third-party verification are ignored for this analysis.

heifer into the milking herd at an earlier age. The custom grower (agent) is assumed to minimize cost by raising heifers under a nonaccelerated time frame and put forth low effort unless appropriately compensated to put forth high effort.

The underlying incentives differ for the daily charge contract and the price per pound of weight gained contract. Using a daily charge contract, the custom heifer grower has incentive to keep the heifer longer to increase revenue. The main concern in the price per pound of gain contracts is that gaining body condition is achieved more cheaply than gaining stature. Thus, if a goal weight is the criterion, the grower may compromise feed quality and management to achieve the required gain.

Two potential levels of effort put forth by the agent, a_i , comprise the action space: A = high effort and costs associated with accelerated heifer growth (a_1) or low effort and costs associated with nonaccelerated heifer rearing (a_2). The dairy farm cannot observe the effort level put forth by the custom grower, and can only effectively assess heifers when they are returned. Further, the outcome, measured in quality and timing of heifers returned to the dairy farm, is an imperfect indicator of custom grower effort level.

In order to align incentives, the contract grower and farmer must agree on the target BCS, against which heifer performance will be measured. Recommendations for BCS at calving range from 3.0 to 3.5 (Vandehaar, 2001). Following Sniffen and Ferguson (1991) throughout this analysis, the target BCS used for a heifer at calving is 3.5. The key aspect of the target is that values are set in advance of contract signing, and both the farmer and the grower acknowledge the standard.⁵ The heifer grower then decides whether to put forth high or low effort, knowing all of the probabilities associated with heifer states of nature under each effort level and related compensation.

Dairy Farmer Cost Minimization

Following standard assumptions, the principal (dairy farmer) is risk neutral while the agent (heifer grower) is risk averse. In order to calculate principal cost minimization, every possible "state of nature" in which the heifer could return from the custom heifer grower and its associated probability must be identified. Six discrete states of nature were identified to encompass all states in which the heifer may be returned. Agent effort level influences the probability that the heifer returns to the dairy farm in each of the states. Each state of nature is a combination of whether the heifer returned on an accelerated or nonaccelerated time frame and whether heifer BCS differed from the target. In terms of BCS, the heifer has the possibility of returning to the dairy farm: (a) deviating from the ideal BCS by one full score (or more) and incurring a deduction in the pay to the agent, (b) deviating a half of a score and incurring a deduction, or (c) returning with no deviation from the ideal score and incurring no deduction.⁶ The possible outcomes for time frame and BCS considered in this analysis and

⁵ In the event that several custom heifer raisers were employed by a single dairy farm (not the common arrangement), heifer rearing would be well-suited to aspects of tournament style contracts. Since heifers are coming from a single dairy farm, genetics of heifers sent to multiple growers are comparable. Further, heifers return to a single milking operation from the heifer raiser, so comparisons of performance once returning to the dairy farm are possible. Knoeber (1989) assessed the use of tournament contracts in broiler production, and determined that tournaments used in growing broilers are not intended to identify a winner or the most capable grower, but to provide incentives to growers. Knoeber highlights advantages to tournament contracts used in broiler production which are applicable to dairy heifer rearing, including that tournaments save monitoring and measuring costs because comparison to relative performance is allowed. Tournaments difference out the effects of common shocks which would be experienced by all raisers, allowing comparison to relative performance rather than the necessity to measure absolute performance.

⁶ Deductions for BCS deviation from optimal are symmetric; the amount of the deduction is the same whether the heifer is returned above or below the optimal BCS. Given the wide range of potentially negative consequences resulting from over- or underconditioning and the wide ranges of associated costs, a symmetric deduction scheme seems reasonable.

the possible effects on payment received by the heifer grower associated with each outcome under each of the contracting schemes investigated are presented in table 1.

Six possible states of nature were developed using probabilities associated with average daily gain and BCS outcomes, as presented in Van Amburgh et al. (1998), who report BCS and average daily gain outcomes from heifer feeding studies in which heifers were assigned to diets with energy treatments designed to elicit different rates of gain. Probabilities of deviations from optimal BCS and of achieving an accelerated time frame were calculated using the BCS outcomes presented in the feeding study from Van Amburgh et al. The variable $P_{G,j}$ represents the probability of each of the six states of nature. Three states exist for when the heifer achieves accelerated growth ($G = 1$) and three in which the heifer is returned on a nonaccelerated time frame ($G = 0$). Subscript j represents the possible deviation from the target BCS upon returning to the dairy farm. For example, $P_{1,(0.5)}$ is the probability that the heifer achieves accelerated growth and is returned to the home farm at a half-score deviation from the optimal BCS. The probabilities of the heifer being in each state of nature were estimated from average daily gain and BCS data provided for heifers with different growth rates in Van Amburgh et al., and are displayed in table 2. The interpretation of these probabilities is explained below.

The principal makes a payment to the custom heifer raiser $I_{G,j}$. When $G = 0$, the heifer is returned on a nonaccelerated time frame, which means the grower will face a deduction associated with failing to return the heifer on an accelerated time frame in the daily charge contract, and is still potentially subject to a deduction if the BCS deviates from the target. In the price per pound contract, when $G = 0$, the grower fails to obtain a bonus for returning the heifer on an accelerated time frame and faces possible deductions for BCS deviations. When $G = 1$, the heifer is returned on an accelerated time frame and, using the daily payment contract, does not face the time-frame deduction, although there is still a possible deduction for BCS deviation. When the heifer is returned on an accelerated time frame using the price per pound contract, the grower obtains a time-frame bonus, but faces a possible BCS deviation deduction.

The principal seeks to select daily charge for each day the heifer is under custom heifer grower care for accelerated heifer growth, BCS deviation deduction, and time-frame deduction. The principal's problem can be expressed as minimizing expected heifer rearing costs for a single heifer as follows:

$$(1) \quad \text{Min}_{d,\delta,\tau} EC_H = (\phi * d) - (|B - B_T| * \delta) + F - \tau,$$

where ϕ is number of days under the care of the heifer grower, d is price paid to the heifer grower per day the heifer is under the care of the heifer grower, B is the BCS of the heifer upon returning to the home farm, B_T is the target BCS, δ is the deduction per whole score of BCS difference from the target, F is the cost to the principal associated with not having the heifer returned to the dairy farm at the optimal time (which is assumed to be the accelerated time frame), and τ is the deduction incurred by the heifer grower for failing to return the heifer on an accelerated time frame.

Taking into account the probability of the heifer returning in each of the six predetermined states and payments which would be made to the grower contingent on those states of arrival, the second-best expected cost per heifer to the principal for heifer rearing is:

Table 1. Possible States of Nature and Heifer Grower Payment Effect

Contract Term	Possible States of Nature	Effect on Payment Received by Heifer Grower in Daily Charge Contract	Effect on Payment Received by Heifer Grower in Price per Pound Contract
Time Frame:	Nonaccelerated	Deduction	None
	Accelerated	None	Bonus
Body Condition Score (BCS):	No deviation from ideal (3.5)	None	None
	Deviation from ideal (> or < 3.5)	Deduction	Deduction

Table 2. Probability of Heifer Growth by State of Nature

		Time Frame					
		Nonaccelerated			Accelerated		
Deviation from Target BCS		1	0.5	0	1	0.5	0
Agent Action:	Low Effort Probability	0.00	0.10	0.71	0.00	0.02	0.17
	High Effort Probability	0.01	0.25	0.07	0.02	0.51	0.14

$$\begin{aligned}
 (2) \quad EC(I_{0,(1)}, \dots, I_{1,(0)}) &= (P_{0,(1)} * I_{0,(1)} * (F - \tau)) + (P_{0,(0.5)} * I_{0,(0.5)} * (F - \tau)) \\
 &+ (P_{0,(0)} * I_{0,(0)} * (F - \tau)) + (P_{1,(1)} * I_{1,(1)}) + (P_{1,(0.5)} * I_{1,(0.5)}) \\
 &+ (P_{1,(0)} * I_{1,(0)}).
 \end{aligned}$$

Note from the probabilities presented in table 2 that when the agent puts forth low effort and incurs the relatively lower costs associated with this action, the chance of having an accelerated heifer is 19%. When an agent puts forth high effort and incurs the associated costs, the probability that a heifer is returned on an accelerated time frame is 67%. Thus, even when high effort is put forth and the relatively high costs associated with this action are incurred by the agent, 33% of the time the heifer is returned on a nonaccelerated time frame. Further, even with high effort put forth by the custom heifer grower, it is possible for the heifer to have a BCS which differs significantly from the target BCS, resulting in a deduction. Disease, initial calf health, infertility, and heifer genetic potential may affect whether a heifer achieves targets. Although these factors may be outside the control of the grower, they further explain why agent effort is not perfectly reflected by heifer state.

Heifer Grower Expected Utility

The custom heifer grower’s utility function, U , is specified according to the formulation proposed by Grossman and Hart (1983, p. 10) and adapted by Resende-Filho and Buhr (2008):

$$(3) \quad U(I_{G,(j)}, a_i) = k(a_i)u(I_{G,(j)}) - d(a_i),$$

where $U(\cdot)$ is a von Neumann-Morgenstern utility function and $u(\cdot)$ is a Bernoulli utility function as defined by Mas-Collel, Whinston, and Green (1996, p. 184). Following Resende-Filho

and Buhr, we set $k(a_i) = e^{kc_a}$, $u(I_{G,(j)}) = -e^{k*I_{G,(j)}}$, and $d(a_i) = 0$. Adopting these conventions, the resulting von Neumann-Morgenstern utility function is $u(I_{G,(j)}, a_i) = -e^{-k(I_{G,(j)} - c_a)}$, with $k > 0$, where k is defined as the coefficient of constant risk aversion and c_a is the cost of taking action $a_i \in A$ (Resende-Filho and Buhr). Using this constant absolute risk aversion (CARA) utility function allows modeling of risk aversion, or increases in risk aversion, by altering the value of k .

The principal-agent problem consists of the principal cost minimization subject to agent individual rationality and incentive compatibility constraints. The individual rationality constraint is necessary to ensure the participation of the agent (heifer grower) in the contractual agreement. In order for the agent to participate in the contractual agreement, expected utility obtained from participation must be greater than his or her reservation utility. The agent's reservation utility is the required returns to their productive factors (i.e., management, labor, and capital).

In the numerical example, the reservation utility is assumed to be that which could be obtained from the net revenue associated with growing heifers for another dairy farmer who contracts for conventional heifer growing services. The individual rationality constraint for a single heifer contract is denoted by:

$$(4) \quad IR = EU_{a_1} = \left[\begin{array}{l} \lambda * U[(\phi * d) - (|B - B_T| * \delta) - c_{a_1}] \\ + (1 - \lambda) * U[(\phi * d) - (|B - B_T| * \delta) - c_{a_1} - \tau] \end{array} \right] \geq EU(R),$$

where λ is the probability with which high effort on the part of the heifer grower is reflected in the outcome of the time frame of the heifer; c_{a_1} is the cost to the agent associated with action a_1 , which is to put forth high effort and incur the associated costs; and R is the reservation net return for the heifer grower. The probability with which the effort put forth by the heifer grower is accurately conveyed in heifer outcome λ is necessary due to the underlying biological, genetic, and other uncontrollable circumstances associated with the rearing of a heifer from birth to calving. Both the dairy farmer and the heifer grower recognize that the effort put forth will not be apparent in the output (in this case, the heifer upon her return to the dairy farm).

The incentive compatibility constraint assures that the custom heifer raiser has the incentive to put forth high effort with associated costs (a_1), rather than shirking and putting forth low effort, thus incurring relatively lower costs (a_2).⁷ The incentive compatibility constraint for a single heifer contract is expressed as:

$$(5) \quad IC = EU_{a_1} = \left[\begin{array}{l} \lambda * U[(\phi * d) - (|B - B_T| * \delta) - c_{a_1}] \\ + (1 - \lambda) * U[(\phi * d) - (|B - B_T| * \delta) - c_{a_1} - \tau] \end{array} \right] \geq$$

$$EU_{a_2} = \left[\begin{array}{l} \gamma * U[(\phi * d) - (|B - B_T| * \delta) - c_{a_2} - \tau] \\ + (1 - \gamma) * U[(\phi * d) - (|B - B_T| * \delta) - c_{a_2}] \end{array} \right],$$

⁷ Underlying this analysis, although not explicitly contained within the contract, are the issues of reputation, repeated interaction between the two contracting parties, and the amount of trust between the two parties. Assuring growers that good performance will be rewarded with repeat business will strengthen incentives for high effort (King, Backus, and Gaag, 2007).

where γ is the probability that low effort put forth by the heifer grower is reflected in the time-frame outcome of the heifer, and all other terms are as defined above.

Contract for Price per Pound of Weight Gain

While daily payment contracts are the most common, payment per pound of weight gain is also utilized by a segment of the industry. Examination of this contract allows us to elicit alternative terms for comparison. Using the same underlying theory and parameters as developed in the price per day contract described above, the price per pound of gain contract was assessed where the principal seeks to select price per pound for each pound of gain during which the heifer is under the care of the custom heifer grower for accelerated heifer growth, BCS deviation deduction, and time-frame bonus. The principal's problem can be expressed as minimizing expected heifer-rearing costs for a single heifer as:

$$(6) \quad \underset{p, \delta, \sigma}{\text{Min}} EC_H = (\eta * p) - (|B - B_T| * \delta) + F + \sigma,$$

where η is pounds of gain while under the care of the heifer grower, p is price paid to the heifer grower per pound of weight gain while under the care of the heifer grower, σ is the bonus paid to the heifer grower if the heifer is returned on an accelerated time frame, and the other terms are as defined in the previous contract.

Using the same custom grower utility function, the payment under this contract is determined by price per pound of weight gained, amount of weight gained, time frame for heifer return with associated bonus, and heifer BCS with associated deduction. The individual rationality constraint, altered from that presented above to incorporate the price per pound of gain rather than the price per day base contract, is specified as:

$$(7) \quad IR = EU_{a_1} = \left[\begin{array}{l} \lambda * U \left[(\eta * p) - (|B - B_T| * \delta) - c_{a_1} + \sigma \right] \\ + (1 - \lambda) * U \left[(\eta * p) - (|B - B_T| * \delta) - c_{a_1} \right] \end{array} \right] \geq EU(R),$$

where variables are as defined above.

The incentive compatibility constraint for a single heifer's contract using a price per pound of gain based contract is given by:

$$(8) \quad IC = EU_{a_1} = \left[\begin{array}{l} \lambda * U \left[(\eta * p) - (|B - B_T| * \delta) - c_{a_1} + \sigma \right] \\ + (1 - \lambda) * U \left[(\eta * p) - (|B - B_T| * \delta) - c_{a_1} \right] \end{array} \right] \geq$$

$$EU_{a_2} = \left[\begin{array}{l} \gamma * U \left[(\eta * p) - (|B - B_T| * \delta) - c_{a_2} \right] \\ + (1 - \gamma) * U \left[(\eta * p) - (|B - B_T| * \delta) - c_{a_2} + \sigma \right] \end{array} \right].$$

Parameter Identification

Parameters for the numerical solution include costs associated with raising heifers using high effort (a_1), costs associated with raising heifers using low effort (a_2), reservation net revenue for the custom heifer grower (R), and the probabilities of a heifer arriving at the dairy farm in the six possible states of nature given each $a_i \in A$. Parameters identified for the numerical solution are summarized in table 3, and their derivations are described in detail below.

Table 3. Parameter Identification for Numerical Solution

Description of Parameter	Estimate
Heifer raising cost (high effort)	\$1,850
Heifer raising cost (low effort)	\$1,649
Expected net revenue of custom heifer raiser under a conventional time-frame contract (reservation net revenue)	\$1,825
Coefficient of absolute risk aversion	1.08
Income over feed cost for 81-day difference in time of return to milking herd	\$340.20

Costs associated with nonaccelerated or conventional heifer growth were taken from Huibregtse (2008) and adjusted to remove the value of the calf (\$500). This resulted in a non-accelerated heifer rearing cost of \$1,649, which was assigned as the cost associated with low effort (a_2). Costs for raising heifers in an accelerated time frame were estimated by increasing feed and labor costs according to discussion with industry professionals, resulting in costs of \$1,850 per heifer.

The reservation utility is the utility of the expected net revenue the custom heifer raiser would earn under a conventional time-frame contract. The expected net revenue of a custom heifer raiser will vary widely depending on costs, such as feed and labor. In a 2007 survey conducted by the University of Wisconsin, heifer raising costs were found to range from \$1,595 to \$2,935, including a \$500 value for the calf (Huibregtse, 2008). Assuming the custom heifer grower could receive \$2.50 per day to raise the heifer, the expected revenue of the grower would be \$1,825 for 24 months, which results in a net revenue to the grower of \$176 per heifer.⁸

Custom heifer growers are assumed to be averse to the risks associated with taking on accelerated heifer growth. Due to the uncertainty surrounding the income under these prescribed contracts with the inclusion of possible deductions for body condition score and uncertain time-frame bonuses, a coefficient of risk aversion was incorporated. Following Haubrich (1994, p. 264), a custom heifer grower with a net worth of \$932,753 and a coefficient of relative risk aversion equal to 1 (Hardaker et al., 2004, p. 109) has a coefficient of absolute risk aversion of 1.08.⁹

The cost to the dairy farm, F , associated with having a heifer returned to calve later than the optimal time of 22 months—which would require an average daily gain of 2 lbs./day (0.9 kg/day)—is income over variable costs (or net income over challenger cow) if the heifer had entered the milking herd at the optimal time rather than the later, nonaccelerated time period in which the heifer was returned. This cost to the dairy farm depends upon the specific situation, e.g., whether a stall is left empty for two months due to the heifer being returned late or a less profitable cow remains in the herd until the heifer is returned. In this analysis, a stall is assumed to be empty if the heifer was not returned. Income over feed costs was used to estimate the income over variable costs associated with that heifer, had the heifer entered the milking herd at 22 months. From Van Amburgh et al. (1998), the low-effort action yielded

⁸ The daily charge of \$2.50 per day for custom heifer rearing was assumed in order to account for the increased feed costs seen in recent years. Huibregtse (2008) cites costs at \$3.02 per day per heifer, although this figure included the \$500 value of the calf; the daily charge of \$2.50 falls within a reasonable range of daily charges, after removing the \$500 cost of the heifer calf.

⁹ The average net worth of dairy farms in the 2006 Michigan Dairy Farm Business Analysis Summary (Wittenberg and Wolf, 2007) of \$932,753 was used under the assumption that the net worth of a typical custom heifer grower is similar to that of a dairy farm operation. This assumption is supported by the fact that many custom growers are former dairy farmers (Wolf, 2003).

an average age at first calving of 22.6 months, and the high-effort action yielded an average age at first calving of 19.9 months. The 81-day average difference in age at first calving between these two actions was assumed to be the number of additional days the heifer could have spent in the milking herd if the heifer was returned on an accelerated time frame. Total feed costs were estimated at \$9/cwt of milk produced, and the milk price received was \$15/cwt, resulting in an income over feed cost of \$6/cwt. Assuming the heifer would have produced 70 pounds of milk per day for the 81 additional days in the milking herd, the total income over feed cost for the 81-day period is \$340.20. This value was used as the cost incurred by the principal if the heifer is returned on a conventional time frame.

Using the parameter values described above, we obtain numerical solutions to the principal-agent game using Microsoft Excel. The nonlinear program consisting of (a) the principal's cost-minimization problem, (b) the individual rationality constraint, and (c) the incentive compatibility constraint was solved numerically with Microsoft Excel Solver, which uses the Generalized Reduced Gradient (GRG2) nonlinear optimization code.

Scenarios and Results

The first-best scenario, which serves as a benchmark for comparison, is one in which the principal and agent have symmetric information. As noted in Grossman and Hart (1983, p. 38), for the agent utility function, $-e^{-k(I_{G,(j)}-c_a)}$, with terms defined as above, the reservation utility of the agent is $-e^{-k(R)}$, where R is the reservation net income. The cost of the first-best outcome is independent of k and is defined as $C_{FB}(R) = a_1 + R$. Thus, the cost to the dairy farmer associated with a first-best scenario is the sum of the cost to the agent of putting forth high effort and reservation net income. The second-best scenarios represent those in which the dairy farmer cannot accurately determine the effort level put forth by the custom heifer grower simply by observing heifer outcome.

Symmetric Information

The first-best dairy farmer contract cost for the daily charge contract and the per pound charge contract was \$2,026/heifer. Under symmetric information, the dairy farmer simply pays the custom heifer grower for costs incurred to perform high effort (\$1,850) and the additional net income to provide adequate return to unpaid factors (\$176). Because the first-best contract is a function of only the cost of the action (a_2) and the reservation net income, the cost is identical for both pricing systems.

Second-Best Scenarios

The alternative scenarios represent situations in which the principal cannot directly observe the effort level put forth by the agent, resulting in a second-best solution. The minimum cost to the dairy farm was the minimum cost associated with obtaining the expected outcomes from high effort by the agent. The price paid per day, body condition score deduction, and deduction for failing to return the heifer in the accelerated time frame were the terms of the daily charge contract. The expected minimum-cost contract to the dairy farm in the daily charge contract scheme, which elicits high effort on the part of the agent, was \$2,151. The

Table 4. Payment to Custom Heifer Grower and Cost to Dairy Farmer

	Time Frame					
	Nonaccelerated			Accelerated		
Deviation from Target BCS	1	0.5	0	1	0.5	0
Payment to Custom Heifer Grower:						
Daily Charge Contract	\$1,685	\$1,710	\$1,735	\$2,169	\$2,194	\$2,219
Payment per Pound Contract	\$1,536	\$1,631	\$1,726	\$2,111	\$2,206	\$2,301
Cost to Dairy Farmer:						
Daily Charge Contract	\$2,205	\$2,050	\$2,075	\$2,169	\$2,194	\$2,219
Payment per Pound Contract	\$1,876	\$1,971	\$2,066	\$2,111	\$2,206	\$2,301

price paid per day to achieve this minimum cost contract was \$3.65, the deduction per whole body condition score deviation was \$50, and the deduction for failing to meet the accelerated time frame was \$780.

When comparing the case of symmetric information or the cost to the dairy farmer of the first-best contract to the case of asymmetric information, the cost of asymmetric information in this analysis is \$125. In other words, the asymmetric information in this case costs the dairy farmer an additional \$125 per heifer.

While the expected cost to the dairy farmer to elicit high effort from custom heifer growers is \$2,151 per heifer, the actual cost to the dairy farmer (and pay to the custom grower) for each individual heifer received back from the custom heifer grower will differ depending on the state of nature in which the heifer is returned. Table 4 reports the payment to the custom heifer grower and cost to the dairy farmer for each possible state of nature in which the heifer could be returned to the dairy farm for the daily charge contracting scheme. For example, the payment to the heifer grower, given that a heifer arrives at the dairy farm prior to calving on a nonaccelerated time frame and deviating from the optimal body condition score by a half of a score, is \$1,710.

We solved for the price paid per pound, body condition score deduction, and bonus for returning the heifer in the accelerated time frame as contract terms of the price per pound contract. The expected minimum cost contract to the dairy farm in the price per pound contract scheme, which elicits high effort on the part of the agent, was \$2,145 per heifer. The cost per pound to achieve this minimum cost contract was \$1.37, the deduction per whole body condition score deviation was \$190, and the bonus for meeting the accelerated time frame was \$575.

Comparing this contract to the first-best contract, the cost of asymmetric information is \$119 per heifer. While the expected cost to the dairy farmer is \$2,145 per heifer to elicit high effort from custom heifer growers (as with the daily payment contract), the actual cost to the dairy farmer for each individual heifer received back from the custom heifer grower will differ. Also displayed in table 4 are the payments to the custom heifer grower and cost to the dairy farmer for each possible state of nature under the price per pound contracting scheme. For example, the payment to the heifer grower, given that a heifer arrives at the dairy farm prior to calving on a nonaccelerated time frame and deviating from the optimal body condition score by a half of a score, is \$1,631.

Implications for Decision Making

The expected cost to the dairy farmer to elicit high effort by the custom heifer raiser under the daily charge contract was \$2,151, while the expected cost under the price per pound contract was \$2,145. For all practical purposes, the expected cost of high effort is identical under the two contracts. However, the range of possible payments to the heifer grower differs depending on the contracting scheme employed. Under the daily charge contract, the payments ranged from \$1,685 to \$2,219 depending on the state in which the heifer was returned. The price per pound contracting scheme had payments ranging from \$1,536 to \$2,301, a much larger span. In the states representing the worst outcomes, such as nonaccelerated and deviating from optimal BCS, the payment to the heifer grower did not cover the costs associated with the high effort action. In the best outcome states, states in which the heifer was accelerated and not deviating from optimal BCS, the payment to the heifer grower covered the costs associated with high effort and generated net profit for the custom grower.

The costs to the principal ranged from \$2,025 to \$2,219 in the daily charge contract and from \$1,876 to \$2,301 in the payment per pound contract. Given this range of possible costs to the principal in each contract, it is conceivable that a principal may have a preference for one contracting scheme over another, although the expected cost under each scheme is essentially identical. The principal may choose a contract specification based on the variability of possible outcomes. For example, if the principal wished to limit the range of the possible payments to be made, the daily charge contract would be chosen. Alternatively, the principal may be an optimist and seek to use the maximax decision criterion in which the best outcome in the best-case scenario is selected. In terms of principal cost, the best-case outcome is an accelerated heifer returned with no deviation from the optimal BCS; the principal would select the daily contract and incur costs of \$2,219 rather than \$2,301 under the gain-based contract.

In contrast, the principal could use the maximin criterion in which the best outcome given the worst-case scenario occurs. In this example, the principal would select the lowest cost under the case where the heifer is nonaccelerated and has the maximum deviation in BCS or a full point deviation in this analysis. Using the maximin criterion, the principal would select the gain contract and incur costs of \$1,876 rather than \$2,025 in the daily charge contract.

Another potential decision criterion the principal could use is the safety-first mechanism in which the dairy farm establishes a predetermined amount above which it cannot afford to pay for heifer rearing. In this case, the safety-first mechanism would only be effective in selecting between the two contracts if the predetermined maximum cost was between \$2,219 and \$2,301. If the predetermined costs were less than \$2,219, then neither contract would be acceptable under the safety-first criterion, because there is a positive probability of both contracts having the principal incur costs above the predetermined maximum cost. If the predetermined maximum cost was \$2,250, the principal would select the daily contract, because the gain contract has a positive probability of costing the principal \$2,301—which would deem the price per pound contract unacceptable under safety-first criteria. Finally, if the predetermined maximum cost were above \$2,301, the safety-first criterion would not aid in selecting between the two contracts because neither contract would have a positive probability of costs above the maximum level.

Conclusions

The topic of contracting with custom heifer growers for accelerated heifer growth is of increasing importance to dairy farms specializing in the milking herd enterprise. Increasing

contract use in production agriculture gives rise to concerns regarding incentive structures and eliciting effort when effort levels put forth are not perfectly communicated in the outcome. As individual agricultural producers become more specialized, there is a need for contracts to align incentives between parties. Beyond the purchase of inputs, contracting is becoming common for services such as manure application or harvesting and preparing feed for storage.

A principal-agent framework was used to elicit contract terms, which provide incentives for the custom heifer grower to put forth high effort toward performance of accelerated growth without heifers becoming overconditioned. The greatest potential challenge of contracting out the heifer raising enterprise of a dairy farm centers around the potential for a moral hazard problem because of hidden action on the part of the custom heifer grower.

In the price per day contract, comparing the case of symmetric information (or the cost to the dairy farmer of the first-best contract) to the case of asymmetric information, the cost of asymmetric information in this analysis was \$125 per heifer. The cost of asymmetric information in the case of the price per pound contract was \$119 per heifer. Given the costs associated with providing a contract with the incentives for accelerated growth at a custom heifer grower, the dairy farm manager must consider whether heifers can be raised on an accelerated growth program on-farm more efficiently. The need to pay an acceptable return, or one which is competitive with rival contracts, combined with the cost of asymmetric information, should be carefully considered in the decision of whether or not to outsource heifer rearing with accelerated growth.

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