Bioeconomic model for best slaughter endpoint for maximum profit*

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Introduction
As feedlots are used to finish more cattle, improved strategies evolve. One of the most important management questions once cattle are in the feedlot is “How long to feed them to maximize profit?” However, complex interaction between type of cattle, market demand and price, ownership of the feedlot and/or the cattle, and application of marketing and management tools make profit prediction difficult. Addressing these interactions requires proper application of economic principles, identifying the relevant biology of the animals being fed, and tools such as bioeconomic models to estimate animal performance. When used properly to answer the appropriate question, these tools provide insight into improved management of feedlot cattle.

Economic Considerations
One of the basic principles of microeconomics is profit maximization. However, for the feedlot case one needs to determine who is trying to maximize profit on a pen of cattle—the owner of the cattle or the feedlot. If the feedlot also owns the cattle, there are different constraints and objectives than if the cattle are owned, or partly owned by another person. Also, whether a pen of cattle can be replaced with another, as opposed to one pen per year or period, makes a difference.

In the case of an owner independent of the feedlot, and assuming this person’s capital is not limited by a particular pen of cattle, the profit maximizing strategy is to feed the pen of cattle until the costs for that day exceed the pen’s gain in value, that is, the marginal net revenue becomes negative. Hence, the cattle are fed until the feed and other costs for the last day exceed that day’s cattle gain multiplied by the cattle’s value per unit weight. Special attention is warranted in this scenario with discounts in cattle price for increasing carcass weight or decreasing yields, as this decrease in the pen’s value may be sudden. For this reason the more variable the cattle in a particular pen, the shorter is the optimum feeding period for profit maximization (Smith et al., 1988).

In the case of a feedlot owning the cattle, and recognizing that the feedlot’s profit maximizing objective is to make money on the pens over time, not just for any particular pen of cattle, then the economic principle is to feed cattle until their marginal net revenue (daily increase in value minus daily cost) no longer exceeds the average daily net revenue for an average animal in a pen in the feedlot. Average daily net revenue is the profit for an animal divided by the number of days that animal was in the feedlot. As long as the average net revenue is positive (the feedlot is making a profit on the cattle, as well as on the feedlot enterprise), cattle owned by the feedlot will be fed fewer days than those owned by others. Again, as in the case above, more variable cattle will be fed fewer days than more uniform ones, but this is less important in the feedlot owning the cattle scenario since the shorter days on feed reduce the chance of discounts.

There are two exceptions or alternatives in the above scenarios. If the cattle owner cannot

*Conferencia presentada durante el 34º Congreso Argentino de Producción Animal - 1º Joint Meeting ASAS-AAPA. 4 al 7 de octubre de 2011, Mar del Plata, Argentina.
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feed additional cattle until a pen of cattle is sold, then the objective is profit maximization over time, not for a pen of particular pen of cattle. Therefore, their cattle should be fed as in the case of the feedlot owning the cattle above. If the feedlot owns the cattle, and for some reason cannot use the pen again after the cattle are sold/removed (often in case where only one set of cattle are fed in each physical pen annually), then their profit maximization objective is as first scenario above where the cattle are owned independently of the feedlot—indeed the cattle profit is then independent of the feedlot profit. The above depends on the marginal net revenues as cattle progress in a feeding period. Note that in the early days after a pen of cattle is put on feed, their total value is less than the money invested and the early feed and processing costs (which would result in negative returns if sold at that point). However, the marginal net revenue is usually positive—the value of their daily gain exceeds the daily feed cost. Hence profits are increasing, or losses decreasing. If this is not the case, and marginal returns are negative, prolonging the feeding period increases the loss, and the cattle should be sold. This is not unusual for chronically sick individuals. Even for well animals, a pen of cattle can loose money if fed to the proper endpoint—it is just that they will loose less money if fed to that endpoint.

Marketing is a major consideration—that is the relative difference between the price paid for cattle and that for which they are sold. In the case of an independent owner, it is often the difference between profit and loss, independent of the discussion above on proper time of marketing the animals. For the feedlot owning the cattle (or the capital limited outside owner), it is more interesting. Since the optimal feeding strategy is to feed until marginal net revenue decreases to average daily revenue for typical pens in the feedlot, the average daily revenue is important—and depends more on the difference between the prices paid and received for cattle. If the feedlot does an exceptionally good job of buying cattle low and selling them high, then the average daily revenue is high, and cattle are fed shorter times. In fact, if it is quite high days on feed approaches zero, and the feedlot simply becomes a holding pen for cattle being transferred in ownership—a cattle broker’s location. Understanding how a feedlot’s average daily net revenue may change over time is thus important to optimizing profit for cattle owned by that feedlot. Thus if average daily net revenue is projected to decrease in the coming months after a set of cattle may be sold (incoming cattle prices too high, market cattle prices declining, feed prices increasing), the argument is to feed the cattle longer.

Biological Constraints
The above economic discussion seems to ignore the resulting animal’s product and its growth. However, this is not the case because the animal’s value is quite dynamic, depending on carcass weight, quality, possible defects and other market factors; its profit also depends on efficiency of gain. These biological parameters are complex and have been the focus of much beef cattle research for over fifty years. Rather than summarize all the literature, an overview of the major factors affecting how animal value changes as feedlot animals approach slaughter endpoints follows. Carcass weight is a major driver of revenue, and animal value increases in direct proportion unless other factors interact to decrease value per unit carcass weight. Thus, in most analysis, feeding animals to heavier weights usually increases profit. Constraints due to excessive carcass size in slaughter plants, or undesirably large muscle cuts limit carcass size by decreasing value of the carcass. Increasing cost of gain as animals age also constrain carcass size, usually as a result of an increasing proportion of the feed being used for animal maintenance (related to body weight) instead of gain. Hyer et al. (1986) also showed that as steers reached or exceeded normal market weight, feed intake decreased, further exacerbating the above
effect of less feed available for gain. Carcass weight and the yield of retail cuts in the carcass change with increasing body weight, and result in value differences as well. Pricing cattle on a live weight basis requires consideration of the relative increase in carcass weight as a proportion of live weight. But pricing cattle on either a live weight or carcass weight basis must also consider the decrease in retail cut yield as carcass fatness increases. As animals finish in a feedlot fatness increases, so beef yield as a proportion of carcass decreases, particularly so for genetically fatter animals. In the US this is called Yield Grade, and steep discounts for animal with higher Yield Grades effectively limit time on feed.

Although Yield Grades, or carcass yield, become less desirable with time on feed, carcass quality, Quality Grade in the US, generally improve. Genetics and feeding strategy affect carcass quality with certain breeds (and sires) exhibiting greater marbling and other improved meat qualities. Steroid status of the animal often affects marbling, and interacts with age the animal enters the feedlot. Aggressive anabolic implant use earlier in life seems to decrease marbling; the younger the animal is when entering the feedlot enhances marbling. This probably depends on the endpoint at which marbling is measured—calves are often fed longer before slaughter at a lighter weight than yearling or older cattle. Backfat of calves reaches a given level at a lighter body weight than for older cattle, so they are often slaughtered younger and lighter, to avoid carcass yield discounts and possibly resulting in decreased total value due to lighter carcasses. Yearlings may be more profitable if the cost of gain is high, and the trend to feed these older cattle increases with feed and grain prices.

An interesting interaction between frame size (mature weight of the animal) and optimal feeding period exists, with larger frame cattle benefiting from earlier feedlot entry, or smaller frame cattle benefiting by being grown on forage diets or pastures before feedlot entry. On forage diets, backfat does not increase with body weight as it does on feedlot rations (Sainz et al., 1995), thus the smaller frame animal can be fed to larger, more profitable weights after a period of restricted growth on a lower energy diet. The NRC (2000) accounts for this using an equivalent weight concept, the weights at which different animals reaches 28% body fat. Thus, one makes an adjustment on body weight to account for different frame size and management effects.

**Useful Models**

There are multiple interacting factors that affect the dynamic costs and returns for the finishing beef animal. A method to integrate the biology of the animal, its management, and market prices is needed to project animal and carcass characteristics through time, and associated costs and potential revenue. While the NRC (2000) can be used to make point estimates of animal performance and a good spreadsheet implementation adequate for a budget projection, it is severely limited in evaluating and projecting animal compositional and value changes through time. More dynamic tools are needed, and in the past decade, the Cornell group has developed the Cornell Value Discovery System to assist in decisions for individual growing cattle management (Guirroy et al., 2001; Fox et al., 2004; Tedeschi et al., 2004). The Cornell Value Discovery System software provides the following: 1) predicted daily gain, incremental cost of gain, and days to finish while optimizing profits and marketing decisions while marketing within the window of acceptable carcass weights and composition; 2) predicted carcass composition during growth to avoid discounts for under- or overweight carcasses and excess backfat; and 3) allocates feed fed to pens to individual animals for the purposes of billing feed and predicting
incremental cost of gain, and providing information that can be used to select for feed efficiency and profitability.

Oltjen et al. (1986a) developed a similar system, the Davis Growth Model (DGM), and implemented it in ration formulation and profit projection software, TAURUS (Ahmadi et al., 1994; Dunbar et al., 1994) which shows the daily costs and returns throughout a feeding period. The DGM is based on general cell number and size mechanisms of growth to predict net protein synthesis. It is integrated into the same net energy system used in the Cornell System to estimate gain of fat and lean tissue. The model was evaluated first with respect to its ability to predict growth and composition of steers as affected by nutrition, initial condition, frame size, and use of growth-promotants. Using 2 independent data sets, the model predicted empty BW and fat content with standard deviations of predicted minus observed of 14 and 10 kg, respectively (Oltjen et al., 1986b). No systematic biases were evident with respect to composition, frame size, or energy intake. However, fat gain was underpredicted (p<0.01) at high feed energy concentrations.

Although the DGM accounted for variations attributable to initial body composition and mature size, the model did not always yield acceptable estimates of fat gain. This was not unexpected, because fat accretion was computed after energy requirements for maintenance and protein gain were satisfied. Thus, any errors in estimates of maintenance or protein gain resulted in biased fat gain predictions. Garcia et al. (2007) compared the DGM with a dynamic French model (IGM) also developed to predict protein and fat deposition in growing cattle (Hoch and Agabriel, 2004). Both models gave accurate and precise predictions of body protein. They also performed well for prediction of body fat in continuously growing animals. However, DGM tended to underestimate body fat deposition during feed restriction periods. This suggests that DGM overestimated heat production during periods of low MEI. The IGM was not sensitive enough to MEI, because it overestimates body fat at low MEI and it underestimates body fat at high MEI. Also, IGM does not take into account ME concentration of the diet and thus did not simulate different growth trajectories for same MEI but different ME concentrations. These results suggest that model’s structure and equations for protein accretion in DGM and IGM are valid. These limitations require a focus on prediction of heat production during feed restriction periods for DGM, confirming the need for a variable maintenance component, and on mathematical formulation of feed energy utilization for fat synthesis for IGM to improve model sensitivity to MEI.

To improve the accuracy of the predictions of these systems, a more mechanistic approach is required to account for variable maintenance energy requirements and thus reduce the errors of the NRC (2000) and the Cornell System. Sainz and Bentley (1997) showed that the observed changes in maintenance energy expenditures were closely related to changes in visceral protein mass. A collaborative effort between scientists in New Zealand, Australia, and the United States developed a dynamic model of the visceral protein (v), muscle protein (m), and fat (f) pools (Soboleva et al., 1999). In the model, muscle and viscera each have an upper bound (m* and v*, respectively). For muscle, m* is genetically fixed, although the possibility of reaching this level depends on both the current intake (MEI) and nutritional history of the animal. However, v* is also affected by energy intake and depends on previous nutrition. Net energy for gain drives the growth of muscle and viscera. Heat production for maintenance depends on MEI and changes asymptotically to new levels when MEI changes resulting in a lag in change of maintenance requirements after intake changes. Additional information regarding kinetics of the growth model is given by Oltjen et al. (2000). The heat production per unit of protein mass of viscera is about 10 times that of muscle. Also, viscera responds faster than muscle to changing energy intake by the animal, but this change has some time lag.
Therefore, maintenance requirement becomes a dynamic variable depending on nutritional history as well as current energy intake. Thus, the static form of maintenance function used in traditional feeding systems is probably inappropriate, especially for dynamic situations. One of the advantages of the way the model is formulated is that the performance of different functions describing animal heat production can be investigated. That is, the fit of the model to data, using either traditional NE concepts and maintenance energy, or more general functions for HP, can be compared with choose the best functional description.

We have recently refined this prediction system for ruminant animal growth and composition. With a new equation for viscera, the multiple regression prediction of heat production using $m$, $v$, and their accretion (Oltjen and Sainz, 2001) is also improved, as is the prediction of body fatness. New additions refine predictions at levels of energy intake at or below maintenance. Although the model provides the structure for predicting composition of growing cattle, not all its parameters have been estimated and evaluated. Barioni et al. (2006) added the variable maintenance representation from the sheep model to the DGM for beef cattle. Fitting beef cattle growth data, variable instead of fixed maintenance requirements for each experimental group significantly improved the precision of the model for fat and RE, confirming the conclusions of Sainz et al. (1995) that previous nutrition had substantial effects on maintenance energy expenditures and indicates that variable maintenance can significantly improve model predictions.

McPhee et al. (2007a,b) has extended the DGM to 4 fat depots: intermuscular, intramuscular, subcutaneous, and visceral, again based on DNA and cell size concepts. Fat depot parameters were estimated, and no differences between implant status and frame size were detected. The model currently underpredicts fat in all 4 fat depots for finishing steers fed high concentrate diets, which suggests that a secondary phase of hyperplasia may be occurring, which is not represented in the DGM. Future efforts will incorporate these more refined estimates of carcass quality into value systems and profit projection.

Most recently, Barioni et al. (2009) designed a hybrid algorithm to efficiently find optimal solutions to the time on feed and feedlot rationing problem. The algorithm has, in an internal loop, a linear diet optimiser and, in an external loop, a non-linear evolutionary algorithm (Eiben and Smith, 2003) to maximize profit, constrained by capital and feed availability. The optimum slaughter time is calculated based on simulations with the Davis Growth Model. The DGM simulates the average growth and body composition of each group of cattle, but intra-group variation is unaccounted for at this stage. For each iteration of the non-linear algorithm, a new least cost diet is formulated with the constraints for diet formulation defined by the non-linear algorithm and optimum slaughter date is then defined by the DGM outputs for the diet and seasonal prices variation informed. Analyses of performance have shown that feeding period and optimum liveweight are strongly affected by the feeding cost in Brazil. For high grain prices, optimum strategies include buying heavier animals and having shorter feeding periods. Diets with minimum cost of gain were not always best because of beef prices seasonality. Results indicate that as important as having low cost of production is to provide liveweight gains that allow slaughter in periods of higher prices. The combination of a linear (simplex) and a non-linear (evolution strategy) and dynamic simulation of animal growth produced robust solutions for the problem of optimizing feedlot operations allowing the identification of more promising strategies.

References


