Social Welfare and the Selection of the Optimum Hog Slaughter Weight in Quebec

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What is the optimum slaughter weight? It depends from whose perspective. A dynamic systems model is built to analyze the welfare impact of alternative animal genetics, feeding program, feed quality and slaughter weight on producers, processors and the environment. The unique systems approach analyzes eight possible welfare rules and a corresponding harm function to assess animal performance within a multistakeholder context. The model results show there are significant tradeoff problems among producers, processors and the environment. The model highlights how the definition of animal performance needs to be revisited, as it has different meaning to different stakeholders in society. While performance historically was synonymous with production efficiency, with new social and political concerns, this interpretation is not universal. The model demonstrates greater complexities by broadening the set of affected parties.

Quel est le poids d'abattage optimal? Cela dépend du point de vue adopté. Une modélisation à base de systèmes dynamiques est construite afin d'analyser l'impact de méthodes alternatives en matière de génétique animale, de programme alimentaire, de qualité de l'aliment et du poids à l'abattage, sur les producteurs, les transformateurs et sur l'environnement. L'approche unique par systèmes analyse huit règles possibles concernant le bien-être social ainsi qu'une fonction correspondante aux nuisances associées pour mesurer la performance animale dans le contexte où plusieurs parties prenantes sont présentes. Les résultats du modèle mettent en avant des problèmes de compromis significatifs parmi les producteurs, les transformateurs et pour l'environnement. Le modèle souligne combien la définition de la performance animale a besoin d'être revue et corrigée étant donnée que les différentes parties concernées dans la société la perçoivent différemment. Alors que, historiquement, performance était synonyme d'efficacité de la production, avec les nouvelles préoccupations sociales et politiques, la définition de « performance » n'est plus universelle. Le modèle présenté ici illustre une plus grande complexité en augmentant l'ensemble des parties concernées.

INTRODUCTION AND LITERATURE REVIEW

Background

The question addressed in this paper is: What is the optimum slaughter weight for hogs raised in Québec? What is the optimum slaughter weight for the swine industry? It depends from whose perspective. It is generally assumed that the producers would like to market lighter animals, as the last pound of muscle gain is extremely expensive. Processors on the other hand, assuming an optimum level of lean mass, would prefer a heavier animal that lowers their cost per kilogram of processed meat. A third stakeholder not conventionally included in such problems is the environment. Hog manure — and in particular its components, nitrogen (N) and phosphorus (P) — are discommodities when these are goods produced in excess of what the market for disposal will bear. With the overproduction of such goods, society prefers less to more. Thus, from an environmental standpoint, preferences would be, *ceteris paribus*, lighter slaughter weights. The logic being that the younger (lighter) the animal, the smaller the quantity of manure produced over its lifetime.

While research has been conducted on the economics of swine production, previous research has used a production economics (single-equation) and a static approach using either mathematical programming, a single-equation regression model, or a singular functional form (i.e., exponential function) attempting to econometrically fit the growth of a pig (Giudice et al; Sonka et al; Boland et al 1993). Chavas et al and Boland et al (1996) recognize the dynamic nature of the swine growth problem. While the Chavas model, employing optimal control theory, had a high degree of fit, there is still a question about the robustness of such a model or even the modeling approach (see Koong et al; France and Thornley; Pomar, for a discussion of this issue). As the Chavas model is an empirical model and is a function of three variables — feed protein, feed energy and metabolic weight — it is limited to the range of the experimental conditions used to estimate the model parameters. Even Chavas et al cautioned the reader about the limited ability to extrapolate with their model. Though the dynamic production model gives a more accurate representation of biological responses to production inputs relative to the static model, for tractability, it is forced to utilize a relatively simple set of relationships.

The Boland 1996 model is deterministic, estimating feed intake as a function of body weight, live weight as a function of feed intake, and leanness and fat deposition as a function of live weight. The leanness and fat estimates are based on a 1932 (Huxley) "allometric" equation that fit a double-log, single-variable equation of leanness or fat as a function of live weight. The model, while tractable, ignores the underlying physiological systems driving growth.

In our research, instead of attempting to adapt a complex process such as animal growth, to an econometric methodology, we want to harness a more sophisticated mechanistic[1] model called PorcExpert[2] for use in our economic analysis.[3] PorcExpert simulates the biological processes and therefore can be used over a larger range of situations (Pomar et al) allowing us to explore the frontiers of our problem.[4] Also because PorcExpert includes provisions for animal and precise dietary characterization, it can be used to simulate the effect of different diets and feeding programs on several pig genetic stocks. This results in output that is much richer in its description of the growth of the animal, especially as it relates to questions of environmental impact. Animal growth is modeled as a complex system, so instead of simply reporting weight changes, much more detailed physiological responses are generated: lean deposition, fat deposition, nitrogen and phosphorus excretion.

Whereas PorcExpert is excellent as a source of data pertaining to changing management practices, it lacked an economic interface to assess welfare outcomes. Therefore, we realize that in order to answer the empirical question about slaughter weights an overlay model needs to be developed. Using system dynamics we built PorcSim to take the swine production data from PorcExpert and integrate it into a welfare model reflecting the producers' problem (max profit), the processor's problem (max profit), and the environmental problem (min cost[5]). The use of system dynamics, which is discussed in more detail in the Methodology section, allows us to develop an enhanced empirical approach to the study of the economics of swine production.

Public policy questions affecting individual stakeholders in different ways are common in agriculture as sectoral welfare issues or public goods are often involved. They are particularly challenging when heterogeneous stakeholders reflect fundamental differences, i.e., the environment and farmer welfare. Determining what maximizes society's welfare can involve conflict not only over defining the maximum, but also over the positive and negative impacts. This implies that a systems approach[6] would be valuable in policy analysis. Systems dynamics is a theory of the structure of dynamic systems, a methodology for analyzing the behavior of such systems, and a vehicle for evaluating alternative policies designed to improve system behavior (Lyneis). Additionally, agricultural research is unique in that policy questions often involve both biological systems and social systems. While agricultural research training is disciplinary in nature, separating the natural and social sciences, the reality of decision making in the policy arena requires that the sciences be integrated. To study this phenomenon, this research takes a unique approach and employs a multidisciplinary dynamic systems model to study a practical policy question involving the Québec swine industry. Our approach departs from previous work in this area that analyzed the problem from a static disciplinary and single-equation econometric framework.

The Québec Swine Industry

This question concerning the optimum slaughter weight is partially moot if an open exchange system exists between producers and processors. In such a market, processors, utilizing their own grids, independently coordinate the transaction with the suppliers of animals. This grid balances the needs of producers, by providing monetary incentives (premia) to supply animals bearing characteristics desired by particular processors, with those of the processors who assess discounts for light animals. The environmental issues of discommodity production are not explicitly incorporated into such proprietary pricing grids. Alternatively, the issue of an optimal slaughter weight for the entire industry is pertinent in markets, such as in Québec, where pooling across all producers occurs.

In Québec, the swine farm marketing system at the producer–processor interface level is based on collective action (Québec Federation of Pork Producers). Initiated in 1989, an electronic auction, operated by the producers' association, was established in the province to market approximately 28% of the daily volume of hogs. The remaining 72% is assigned to the processors based on historical volume (Québec Federation of Pork Producers). A government agency, the Régie des Marchés Agricoles et Alimentaires du Québec (Québec Office of Agricultural and Feed Markets) is the third-party body supervising the joint conventions outlining the marketing mechanism for the province. Unlike marketing in the United States, government facilitation is an important mechanism of the marketing process in Québec. Additionally, a fourth body is involved in the process, a provincial pork industry roundtable, le Table Filière Porcine.[7] This group is made up of over 30 stakeholders of the swine industry representing the interests of producers, processors, government, research and universities

(Table Filière Porcine). It is here that the strategic planning and coordination throughout the swine industry takes place.[8] Thus policy is conducted by means of group action at the producer and processor levels through their own advocacy groups, in partnership with government through the Régie des Marchés Agricoles et Alimentaires du Québec, and then at the industry level with the Table Filière Porcine. From this process has emerged not only an industry-wide pricing grid but also a system that actively analyzes optimum management and marketing strategies, optimum swine input usage involving feed, feed delivery systems and genetics. It is from this policy environment that the question concerning the optimum slaughter weight emerges.

Problem Description

There are three stakeholders characterized in the model: the producers, the processors, and those interests representing the environment. Each stakeholder group has its own net return function. For producers and processors, the assumption is that their objective can be defined as a profit-maximization problem, whereas the environment stakeholders' objective is modeled as a problem of cost (discommodity) minimization. The problem is dynamic as well, as the producer is optimizing throughout on a fixed set of assets and discounting future revenue streams.

In the model, the most important decision variables, from the producers' perspective, are those related to the choice of **animal genetics**, **feeding program** and **feed quality**. The management variables in the model are animal phenotype (three types), feed delivery/phase system (four types), and feed quality (two types).[9] Thus there are 24 ($3 \times 4 \times 2$) different management combinations (regimes) in the simulation that can be employed by the producers. Each of the regimes is evaluated, in terms of its welfare impact, for each of the three stakeholders at each of the 50 slaughter weights between 81 kg and 130 kg. The results form a response surface comprising 3600 (1200×3 stakeholders) unique points, each representing a NPV (net present value) of returns, a measure of stakeholder welfare. Each welfare outcome for the three stakeholders is then aggregated to generate a surface of 1200 societal welfare outcomes. For example, at a high slaughter weight, say, 125 kg, and under a certain management regime, say, 1–1–1,[10] the model estimates the NPV of such a regime on each of the three stakeholders. The interaction between the varying slaughter weights, management regimes, and stakeholder welfare functions results in a surface populated by 3600 stakeholder welfare outcomes; 1200 for each of the three stakeholders. It is this surface that is analyzed to determine the relationship between management regime, slaughter weight, and stakeholder (societal) welfare.

METHODOLOGY

In order to meet the above objectives an economic model, PorcSim, was built using system dynamics and linked to the already existing biometric model, PorcExpert, developed by Pomar. The joining of the two models addressed two limitations of previous approaches to analyzing the economics of swine growth: the lack of an economic interface on the biometric model (Pomar) and the limited nature of animal performance data found in econometric models of swine growth (i.e., Sonka et al; Giudice et al; Chavas et al; Boland et al 1993).

PorcExpert is a deterministic, dynamic and mechanistic model of pig growth (Pomar et al). The growth cycle is modeled utilizing an integrated set of equations attempting to capture the behavior of the body's various systems. As with actual growth, inputs are demanded in the form of nutrients and outputs are generated in terms of animal performance and waste production. The model then is set within an exogenous set of factors such as the environment (i.e., air temperature), genetics (phenotype) as well as feed and feeding regime. This set of exogenous factors affects a set of unique performance estimates describing an animal's growth over time. The animal performance data are then uploaded using Visual Basic® into a system dynamics model, PorcSim, which is described below. PorcSim[11] serves to link the physiological data with an integrated set of economic welfare equations reflecting three key stakeholders in the swine industry: producers, processors and the environment (Fig. 1). This system model is based on the theory of system dynamics developed by J. W. Forrester in 1950s and refined over the past 40 years (Forrester; Legasto et al).

The Model

It is assumed that producers and processors are profit maximizers and that the environment is a "cost minimizer."[12] The producers' profit function is modeled as the net present value of the returns from finishing, on a per unit (pig) basis. The processors' profit and the environmental costs are also calculated on a net present value per unit basis. Thus, the optimum slaughter weight can be defined as a unique value that maximizes the joint welfare function of the three stakeholders (Eq. 1).

$$SW^* = \mathrm{Max}\left\{NPV\,^*_{producer},\ NPV\,^*_{processor},\ NPV\,^*_{environment}\right\} \tag{1}$$

where * = the industry's defined optimum slaughter weight. Following Chavas et al, the market value of a particular animal to the producer at a particular point in time is:

$$\begin{gathered} NPV\ \ Producer = MAX\ \ F_p = \sum_j^{\infty} \pi_p e^{-rT=} \\ \frac{1}{1-e^{-rT}}\left[\int_0^T [-c_t u_t] e^{-rt} dt + P_T X_T e^{-rt} - I\right. \end{gathered} \tag{2}$$

where:
subscript p = producer
P = a variable that varies according to carcass weight and lean yield and is drawn from the 1996 Québec price grid
X = the carcass lean yield
c = a vector of the variable costs
u = a vector of variable inputs
T = the terminal period
I = the fixed costs
r = the discount rate.

Each step (slaughter weight) serves as a terminal point. The model moves through time: the animal grows, the carcass develops, waste is produced, and costs are incurred. Then at each of the 50 terminal points, an economic assessment is made, resulting in a statement of stakeholder and joint welfare.

The objection function for the producer is then to maximize profits over an infinite planning horizon (Eq. 3). One feature of this approach to the producers' problem is that the economic determination of optimal hog inventory flow-through is endogenous. Though environmental interests might prefer lighter animals, this may or may not be compatible with that of producers or processors. While greater throughput may make sense from an NPV standpoint, the price grid penalizes light animals. In this way, PorcSim reflects consumer demand without explicitly modeling the consumer's problem. Demand preferences and elasticity are captured indirectly in the price grid and through the representation of the producers' and processors' problems. Similarly, the present values of the environmental cost and processors' profit over an infinite planning horizon, *NPVenvironment* and *NPVprocessor*, are defined as:

$$NPV\ Processor = MAX\ F_s = \sum_{j=0}^{\infty} \pi_s e^{-rT=} \left(Ps_T Xs_T - Cs_T \right) * e^{-rT} / \left(1 - e^{-rT} \right) \tag{3}$$

$$NPV\ Environment = Max\ F_e = \sum_{j}^{\infty} \pi_e e^{-rT} = \frac{1}{1 - e^{-rT}} \left[\int_0^T \left[-E_t u_t \right] e^{-rT} dt \right] \tag{4}$$

where, for the processor (subscript *s*):
Ps = the wholesale price of processed pork
Cs = the producer price of pork plus a processing cost per unit
Xs = the yield of processed pork from the hog with the carcass weight X_T at time *T*.

For the environment (subscript *e*), there is no terminal value, only the integral of the net environmental costs over time. As is done with costs in the producers' problem, *E* = the costs and *u* = the units. The NPV calculation is a function of:

- the fertilizer value of N and P
- the costs of manure handling
- the cost to society of N and P.

Industry cost averages of handling manure are subtracted from 1997 fertilizer wholesale prices to arrive at the net value of a unit of N and a unit of P. Estimates of the gross cost to society are extrapolated from a sample of 1996–98 bonding rates (*Feedstuffs* 1996a; 1996a; 1996a; 1997; 1998). The use of insurance bonds emerged as communities were growing in conflict with large confined animal feeding operations and their manure management practices. In practice, some communities required hog producers to post bonds in the event of a manure spill as one prerequisite for licensing. The money was set aside to be used for cleanup and reclamation. The rates were set either per hog or per unit of animal weight. An average of these rates, \$0.001/g of nitrogen and \$0.0015/g of phosphorus produced, is used. The net fertilizer value of nitrogen (\$0.0002/g) and phosphorous (\$0.0001/g) is subtracted from the bonding rate to arrive at a net cost to society of each nutrient. The cost to society of N and P is then multiplied by the excrement quantity of N and P at each slaughter weight under each of the 24 scenarios.

The system is then set into motion by summing Eqs. 3 to 5. The stakeholder and social welfare impacts of the three different swine phenotypes, four different feeding phases, and two different feed qualities are analyzed. The three phenotypes drive the model through a minor cost difference between the phenotypes, but more significantly by affecting animal performance. The phenotypes, expressed through the biometric data, are differentiated in terms of voluntary feed intake and lean yield deposition under varying field conditions. The high phenotype animals (type 3) achieve the highest growth rates under the most advanced feeding, management, and herd health programs. The lowest phenotype (type 1) have low growth rates under a poor environment. The type 2 phenotype is the modal, or typical, phenotype for Québec.

Four different phase feeding systems are used. They are directly entered into the producers' NPV calculation as a fixed[13] cost per unit, ranging \$0.42–0.79. They also drive the model through their effect on animal performance. One-phase animals are on the same ration for the entire growing period. Two-phase two animals have two different diets, changing over at 50 kg. Three-phase animals change diets at 45 and 75 kg. Four-phase animals change diets at 40, 70 and 100 kg. The two-phase system is assumed to be typical for Québec.

The final decision variable studied in the model is feed quality. There are two feed qualities: high (reduced-crude protein, amino acid-supplemented diets) and low (standard least- cost-diets). Feed quality affects the model through the producers' profit function as well as the biometric data. Low-quality feed is based on the least-cost ration, thus is less expensive., while the high-quality feed is balanced for amino acid profile and produces better animal performance (Jean-dit-Bailleul et al). The least-cost ration approach is assumed to be representative of a typical Québec feeding regime.

In summary, PorcSim analyzes each of the linear combinations of three different phenotypes, four different feeding phases and two different feed qualities. These nine different management states are arranged into 24 different regimes (Table 1). Thus a 111 regime comprises the low phenotype, a single-phase feeding system, and a least-cost ration. The management regime 112 reflects the same phenotype and feeding phase, but the higher-quality ration is used. Among the 24 different management regimes, regime 221, comprising the middle (2) phenotype, two-phase feeding (2) and low-quality feed (1) is the base regime representing current practices in Québec. PorcSim then generates the 3600 data points (24 regimes $\times$ 3 stakeholders $\times$ 50 slaughter weights), which are spreadsheet-ready for the welfare analysis using Excel®.

RESULTS AND ANALYSIS

As mentioned above, net present value calculations are performed for the three stakeholder groups. The results pertain to the net present value of the net contribution each animal unit would contribute. For the producers and processors, this is generally a positive value, whereas for the environment group, this is always negative.[14] This calculation is made for each of the stakeholder groups at each of the 50 possible slaughter weights. The analytical task of this research is to evaluate the producers' management regime (#1 to #24) that optimizes the industry model. The results and analysis section is divided into three parts. The first part serves to dimentionalize the results on an industry as well as stakeholder level. The second section addresses the question of maximizing the joint welfare of the three stakeholder groups. The final

Table 1. Management regimes for analysis

Number	Regime (221 = typical)	Phenotype 1 = poor 2 = typical 3 = high	Feeding phase 1 2 = typical 3 and 4	Feed quality 1 = typical 2 = high
1	111	1	1	1
2	112	1	1	2
3	121	1	2	1
4	122	1	2	2
5	131	1	3	1
6	132	1	3	2
7	141	1	4	1
8	142	1	4	2
9	211	2	1	1
10	212	2	1	2
11	221	2	2	1
12	222	2	2	2
13	231	2	3	1
14	232	2	3	2
15	241	2	4	1
16	242	2	4	2
17	311	3	1	1
18	312	3	1	2
19	321	3	2	1
20	322	3	2	2
21	331	3	3	1
22	332	3	3	2
23	341	3	4	1
24	342	3	4	2

section focuses on the determination of the optimum slaughter weight using the harm function that describes the marginal effect to stakeholder welfare from a unit change in slaughter weight.

Overview of the Stakeholder Positions

The current industry optimum slaughter weight, reflected in the pricing grid, ranges 102–115 kg depending on lean yield. Under the current (typical) Québec management regime (221), the PorcSim model estimates that the optimum slaughter weight for the producers is 97.8 kg, while processors prefer animals to weigh 115.2 kg, and society, from an environmental point of view, prefers the lightest/youngest animal possible, 81 kg. This is consistent with the current state of relations between the three stakeholders, whereby processors prefer, *ceteris paribus*, heavier animals, the producers slightly lighter animals, and society much less production of manure (lighter/younger animals).

Under the current regime of a moderate genetics, a two-phase feeding system and a low-quality ration (221), PorcSim estimates that producers, using their optimum slaughter weight are able to generate a lifetime discounted net return of $3,091 per production unit[15] (Table 2). If the industry slaughters 4,795,240 (1995 data) hogs per year (Lebeau et al), the NPV of producer returns is

Table 2. Net present value returns of the best, worst and current management regimes

Scenario	Producers	Regime	Difference[a]	Processors	Regime	Difference	Environment	Regime	Difference
Worst	\$2,490	131[b]	19.4%	\$28	141[e]	38.5%	(\$115)	311[f]	27.7%
Current (221)	\$3,091	221[c]	NA	\$45	221	NA	(\$90)	221	NA
Best	\$3,707	312[d]	19.9%	\$60	312	32.4%	(\$65)	142[g]	28.1%
Range	\$1,216			\$32			\$50		

[a]Compared with the base (current) case.
[b]131 = Low phenotype, three-phase feeding and a least-cost ration.
[c]221 = Typical phenotype, two-phase feeding and a least-cost ration.
[d]312 = High phenotype, single-phase feeding and an amino acid-balanced ration.
[e]141 = Low phenotype, four-phase feeding and a least-cost ration.
[f]311 = High phenotype, single-phase feeding and a least-cost ration.
[g]142 = Low phenotype, four-phase feeding and an amino acid-balanced ration.

$14.8 billion for the entire industry or $4.6 million per each of the 3200 (Lebeau et al) producers. The processors would generate a lifetime discounted net return of $45 per slaughtered animal, $218 million as an industry, and $22 million for each of the industry's ten (Lebeau et al) processors. In terms of the environmental cost, losses are a NPV of $90 per unit, $430 million in total, or $58 per citizen of Québec.[16]

The least advantageous management regime is 131 for the producers and 141 for processors (Table 2, row 1), which means, *ceteris paribus*, that higher-phase feeding levels adversely affect producers and processors. This is the result of four characteristics of the system being modeled. The first is biological: higher-phase feeding increases slightly fat deposition, thereby lowering lean yield. Second, the price grid employed by the industry is a discreet matrix; in borderline carcasses, slight changes in carcass weight or, in this case, lean yield can result in a movement to an entirely different (lower) cell in the grid. Third, PorcExpert and PorcSim are deterministic models; therefore there is no distribution around a mean carcass value, which would significantly moderate the impact of the discrete price grid. Finally, and related to the third reason, the model is modeling only one animal unit and thus assumes complete homogeneity.

The low phenotype, not the high phenotype, harms the environment more. If regime 311 (high genetics, single-phase feeding and low-quality feed) is implemented, the society, as measured by the externality costs of manure, will be worse off. Thus the first important contribution of the model is that there is embedded in the slaughter weight question a significant tradeoff problem and an ambiguous definition of animal performance.

If animal performance is to be measured by traditional measures, i.e., commodity-producing attributes, then the type 3 phenotype is preferred. If animal performance is to be defined as the joint production of commodities and discommodities, then the type 1 phenotype may be preferred.

Processors and producers can both agree on the optimum regime (312), as they would be better off than under the current regime (221) (Table 2, row 3). Alternatively, society would prefer the lower-quality genetics, regime 142, where it would be significantly better off than under the current regime. This is due principally to a 28.3% decrease in the amount of nitrogen and a 7.0% decrease in the amount of phosphorus produced. If nitrogen and phosphorous reduction is the primary goal of society, simply changing the management regime, as opposed to the slaughter weight, will have significant effects.

Welfare Analysis

The previous section demonstrated that managerial regime and indirectly, agricultural policy, affect not only the optimum slaughter weight but also the optimum regime for each of the stakeholders. To address the question of the optimum regime, indices are calculated for each of the 24 management scenarios (Table 3). The current regime, 221 (medium phenotype, two-phase feeding, and low-quality feed) is set equal to 100.

When considering the optimum management regime, and in turn the slaughter weight, it is important to ask who is to define the optimum. Using the following welfare approach, in an attempt to bring order to this difficult question, several alternatives are offered for what might be the optimum.

To embark on the process of welfare analysis, it is helpful to imagine that there is an omnipotent authority, a dictator, who selects the management regime. This certainly is an abstraction from the pluralistic approach used in Québec, but does reflect the

Table 3. Index values reflecting changing welfare due to changing management regime

Management regime[a]	Producer index	Processor index	Environment group index	Average index
111	82	75	93	83.32
112	86	80	106	90.75
121	83	77	110	90.18
122	84	80	134	99.41
131	81	75	113	89.40
132	86	79	139	101.29
141	82	62	114	85.56
142	86	79	139	101.20
211	99	105	84	95.75
212	100	106	96	100.40
221[b]	100	100	100	100.00
222	98	94	120	103.94
231	95	89	102	95.19
232	98	93	125	105.29
241	97	88	102	95.96
242	100	87	125	103.76
311	119	130	78	109.10
312	120	132	88	113.51
321	115	116	92	107.52
322	114	116	110	113.35
331	105	91	94	96.74
332	111	114	114	112.69
341	108	99	94	100.57
342	111	100	114	108.42

[a]Management regime:
Phenotype: 1 = poor; 2 = typical; 3 = high.
Feeding phase: 1; 2 = typical; 3 and 4.
Feed quality: 1 = typical/least-cost ration; 2 = high/ amino acid-balanced.
[b]Base case management regime, 221, equals 100.

universality of decisions too that is present in Québec with respect to swine policy. Employing this abstraction, the question is, What kind of "dictator" is present? Does the dictator prefer one stakeholder above all others or believe in Pareto optimality? Or are the worst off in society the main concern?

Welfare Alternative #1

Pareto efficiency (optimality) is the notion that if a welfare-maximizing change is to occur, no agent or, in our case, no stakeholder can be made worse off (Varian). There are two components to this type of policy. The first is the maximization, in aggregate, across the three groups of welfare when moving from regime 221 to an alternative regime. The second component is that no group can be made worse off than their current position under a regime of 221. Using this decision rule, regime 322 (high-quality genetics, two-phase feeding and

Table 4. Stakeholder indices of eight alternative optima

Decision rule		Scenario[a]	Producers	Processors	Environment group	Average
Status quo	SQ	221	100	100	100	100
Pareto efficiency	PE	322	114	116	110	113
Potential Pareto efficiency	PPE	312	120	132	88	113
MaxiMin with PE	MMPE	332	114	114	111	113
MaxiMin	MM	332	114	114	111	113
Max producer	MProd	312	120	132	88	113
Max processor	MProc	312	120	132	88	113
Max environment	MEnv	142	86	79	139	101

[a]Scenarios:
Phenotype: 1 = poor; 2 = typical; 3 = high.
Feeding phase: 1; 2 = typical; 3 and 4.
Feed quality: 1 = typical/least-cost ration; 2 = high/ amino acid-balanced.

high-quality diet) yields the most benefits (based on NPV of returns) for society, improving the state of producers, processors and society (Table 4). No stakeholder is made worse off.

Welfare Alternative #2
Potential Pareto efficiency (PPE) is the notion that if a management change were to be implemented, the second component of the Pareto efficiency rule is not binding. Under PPE, it is assumed that the winners from the policy shift can compensate the losers. In the case of this model, the optimum under PPE is regime 312. Producers and processors gain, but society loses 12%. The logic here is that the producers and processors are able to compensate those environmentally concerned members of society for their losses.

Welfare Alternative #3
A third measure of welfare is MaxiMin under the condition of Pareto efficiency (MMPE). This policy rule focuses on the least well off in “society” (the three stakeholders). this is a “social justice” policy, whereby the dictator focuses on the most disadvantaged in society, trying to make them as well off as possible. There are two components to MMPE. The first is to make the worse off of the three as well off as possible. Second, because of the PE constraint, neither of the other two can be made worse off. Thus when changing the regime from 221, is there a regime that maximizes the third best while at the same time not forcing any of the stakeholders to fall below 100? Regime 332 has most total welfare generated, while at the same time the poorest member of society, the environment, has an index value of 111. In none of the other 23 scenarios does the poorest stakeholder have an index value greater than 111. In scenario 332, the minimum has been maximized.

Welfare Alternative #4
Under MM without Pareto efficiency (MM), stakeholders can be made worse off. The second rule of MMPE no longer holds. The results in this model, though, are the same, 332. A high

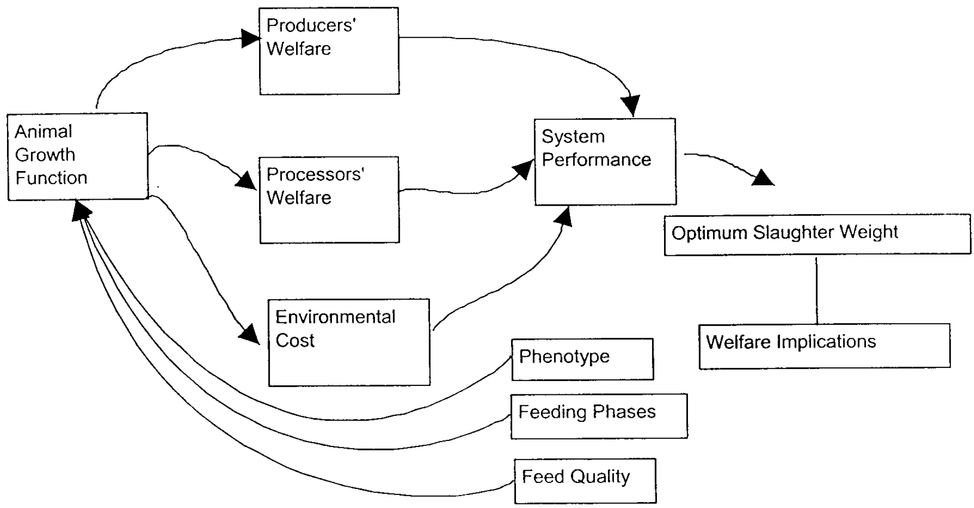

Figure 1. The model's structure.

level of genetics combined with three-phase feeding and a high-quality ration increases producers', processors' and environment groups' welfare. By improving the states of all three while maintaining similar improvements among the three stakeholders, MM is a most egalitarian strategy.

Welfare Alternatives #5 to #7

The final three dictator social welfare policies are based on the notion that there is a preferred stakeholder. This may result from lobbying, a strict class system, or simple preferences on the part of the dictator. The result, simply put, is that one group is preferred over the other two. If producers have political power, are effective lobbyists, or have captured the heart of the dictator,[17] their welfare will be maximized with a regime of 312. The same is true for the processors. Under such a regime, producers and processors would be better off, while the environment would be worse off. The environment, on the other hand, would prefer a scenario of 142. Under such a policy, it would be significantly better off, at the expense of producers and processors.

Selecting the Optimum Slaughter Weight

The above analysis demonstrates one application of a systems model such as PorcSim. While it could help policy makers address the distributional issues related to the slaughter weight question, an additional question remains. This is the question of political compromise and the selection of the actual industry slaughter weight.

Leaving the artificial notion, used above, of a policy dictator, this next section assumes that the stakeholders are sitting around the table having settled on a particular regime, i.e., 312. This is not such an abstraction, as the industry relies heavily for policy direction on the Table Filière Porcine, a pork industry roundtable of ~30 stakeholder groups in the province. Now their task is, by means of negotiation, to find a common point (slaughter weight). For

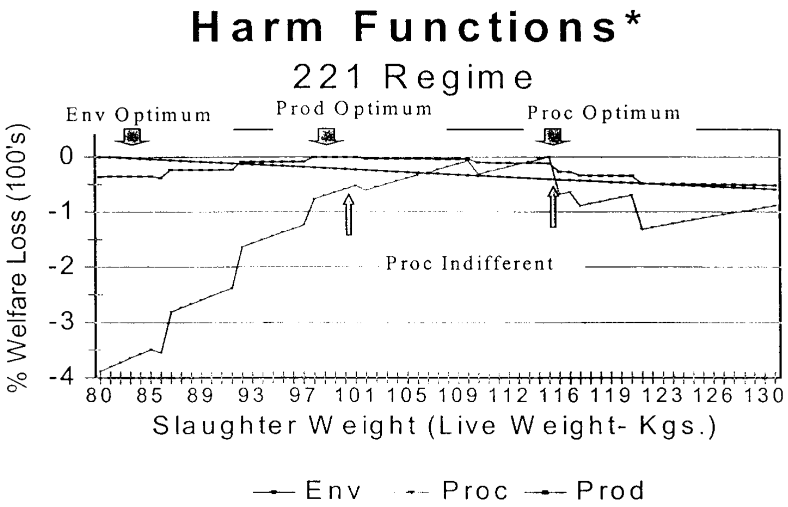

Figure 2. The harm function under a 221 regime
*First derivative of welfare functions with a change in slaughter weight.

example, the challenge remains that while producers and processors may prefer regime 312, producers would like to slaughter at 98 kg (live weight), processors would prefer 115 kg and the environment 81 kg. The following section, using a tool called the harm function, offers a strategy for arriving at a unique point.

The harm function is defined as:

$$Hi = f\left({\partial Wij} \big/ {\partial SWij \neq k*} \right) \tag{5}$$

where:
i = stakeholder groups [1, 2, 3]
W = welfare
j = feasible slaughter weights [$j$min...$j$max]
$k*$ = the optimal stakeholder slaughter weight
$j$min = the regime's minimum preferred slaughter weight
$j$max = the regime's maximum preferred slaughter weight.

The harm function traces out the marginal effects (detrimental) to a particular stakeholder group when it moves away from its preferred position. The welfare of stakeholder i declines at each slaughter weight (SW) step away from the stakeholder's optimum weight within a given regime. Figuratively, the harm function traces out the slope as welfare falls away from its peak. This slope or harm terrain will vary across all possible compromise slaughter weights. Currently the price grid in Québec is centered on a live weight range of 102–115 kg, depending on the lean yield. The following analyzes the four regime alternatives that are welfare maximizing (Table 4), as well as the status quo, to determine the optimal slaughter weight.

Strategy 1: Maintain Status Quo, 221

According to the model, if the industry decided to maintain the status quo and remain under the current regime of 221, producers would prefer to slaughter at 97.8 kg, processors at 115.2 and the environment at 81 kg. By tracing out each of the stakeholders' harm functions, it is evident that in the negotiation process some groups are hurt worse than others (Figure 2).

Low slaughter weights, while moderately affecting producers and the environment, dramatically affect the processors. A slaughter weight of 90 kg, for example, decreases the processors welfare by over 250%, while producers and the environment are harmed 23% and 10%, respectively.

By linearly aggregating the three functions, a PPE negotiation optimum can be reached. At the optimum point of 109 kg,[18] welfare losses are minimized to an average of 14.96% (Table 5, row 1). At this settlement point, producers would lose 4.03%, processors 7.72% and the environment 33.13%. Alternatively, using an MaxiMin (MM) approach to form a consensus, the optimum would be 106 kg (Table 5, row 2). At this slaughter weight, no stakeholder would be harmed more than 29.48% and the average loss would be 20.35%. The MM average loss is 36% higher than at the PPE slaughter weight, but the distribution of the harm is more equitable.

Strategy 2: Pareto Efficiency, 322

Under this policy directive no stakeholder can be made worse off by the regime shift. Under 322, producers would prefer to slaughter at 102.2 kg, processors at 115.5 kg and the environment at 80 kg. Under a 322 regime, a PPE consensus rule is optimized at 109 kg, where the average harm is minimized at 13.57% (Table 5, row 4). Under a MaxiMin rule, the weight is little changed, falling to 108 kg, and the average welfare loss would rise 13%. The largest loss under a MM slaughter weight in 322 regime would be suffered by the environment's loss of 25% from its preferred slaughter weight.

Strategy 3: Potential Pareto Efficiency, 312

The third policy alternative under study is 312, which meets the PPE decision rule and which also maximizes the producers' and processors' welfare. Using a PPE consensus rule and the appropriate harm function, the optimum slaughter weight for 312 is 109 kg (Table 5, row 7). When achieving such a consensus, the average welfare loss is 18%, with the environment losing 38%, producers 6% and processors 9%. Under the more equitable MM rule, the slaughter weight falls 3% to 106 kg. Under the MM consensus rule, processors give up the most, as their welfare falls by more than 200% to a loss from optimum of 31%, on par with the environment group's loss of 33%.

Strategy 4: MaxiMin

The fourth policy choice is regime 332 (Table 5, rows 10–12). This regime meets both the MM and MMPE criteria. The optimum slaughter weight under the PPE consensus rule is 109 kg. The stakeholders give up only 9% on average from their optimum. The environment gives up the most, 19%. Producers remain on their optimum and processors move 7% from their optimum choice. Under an MM consensus criterion, the optimum slaughter weight falls to 108 kg (1%). To achieve these small gains, processors pay a heavy price, as their deviation from their optimum rises 86%, while the environment, which, in this model, always gains from the MM criterion, improves by only 3%.

Table 5. Selecting an optimum slaughter weight using consensus

Consensus rule: Regime[a]	Optimum weight	Difference	Average welfare Loss	Difference	Maximum welfare loss	Difference	Producer loss	Difference	Processor loss	Difference	Environment loss	Difference
	(kg)	(%)	(kg)	(%)	(kg)	(%)	(kg)	(%)	(kg)	(%)	(kg)	(%)
"Maintain status quo"												
PPE:221	109.4		15.0		33.1		4.0		7.7		33.1	
MM:221	106.4	–2.74	20.3	36.03	29.5	–11.02	3.6	–9.93	29.9	287.69	29.5	–10.9
"Pareto efficiency"												
PPE:322	108.9		13.6		25.7		2.6		18.7		25.7	
MM:322	108.0	–0.86	15.4	13.12	24.8	–3.55	2.7	1.15	12.4	–33.46	24.8	–3.5t
"Potential Pareto efficiency"												
PPE:312	109.1		17.6		37.6		5.8		9.4		37.6	
MM:312	105.5	–3.36	23.1	31.38	32.7	–13.03	5.6	–2.43	31.0	229.68	32.7	–13.03
"MaxiMin"												
PPE:332	109.4		8.8		19.0		0.0		7.4		19.0	
MM:332	108.5	–0.88	10.8	22.39	18.4	–3.11	0.1	0.00	13.8	86.27	18.4	–3.16
"Max environment"												
PPE:142	109.2		13.6		21.7		14.1		5.2		24.7	
MM:142	108.5	–0.57	15.0	9.75	21.3	–1.75	18.6	32.22	5.0	–3.08	21.3	–13.77

[a]Consensus rule: regime:
Phenotype: 1 = Poor; 2 = typical; 3 = high.
Feeding phase: 1; 2 = typical; 3 and 4.
Feed quality: 1 = typical/least-cost ration; 2 = high/ amino acid-balanced.

Strategy 5: Max Environment

The final policy alternative is 142 where the environment is the preferred stakeholder (Table 5, rows 13–15). Under this regime the optimum slaughter weight is 109 kg and the average welfare loss is 14%. In this world of compromise, the environment has to give up 22%, the producer 14% and the processor 5% to arrive at a single point. The MM consensus rule does not vary the outcome very much, reducing the optimum slaughter weight less than 1%. Average welfare losses rise 10%, with most of the burden falling to producers (+32%).

MODEL WEAKNESSES AND FUTURE RESEARCH

The purpose of this research project is to demonstrate, in an applied way, a multidisciplinary systems approach to policy analysis. Agriculture policy decisions are becoming more complex as they address greater numbers of stakeholders. Using a systems approach such as PorcSim is critical for success. We are able to:

- integrate a biometric model, PorcExpert, with an economic model, PorcSim
- represent three important stakeholder groups
- provide a tractable industry model.

The parsimony, though, comes at a cost. Two weaknesses of our approach need discussion and provide direction for further research in this area.[19] The first challenge is to more effectively capture the dynamic integration of supply and demand that result from changing market signals and available technologies. The second challenge is to more effectively capture and integrate the full environmental costs into a dynamic endogenous model.

Our model does not explicitly incorporate demand elasticities. Understanding how consumers will respond to decreasing supplies of meat due to environmental constraints is an important feature of a welfare approach. Our model implicitly models demand as inelastic by using the current price grid. Any substantive shift in quantity is met by a dramatic fall in value to the system and high harm values. A more advanced welfare analysis would effectively capture the tradeoff between demand for pork and N and P excreted by pigs; either through fewer days on feed (reduced manure quantity) or improved genetics and feed (improved manure quality).

For example, while environmental interests prefer lighter animals to heavier animals, lighter animals infer that more animals will be needed to meet market demand, negating any environmental benefits.[20] While the quantity of meat supplied is relatively constant across our response surface, the quantity of N and P produced per pound of pork carcass or per pound of lean meat varies significantly.

If demand were elastic and abatement were expensive, the supply curve would shift up and supply would fall. But if modeled dynamically, producers would start exploring novel genetic/management combinations and new supply responses. New price signals would entail new management practices. Because our model is mechanistic, based on data from current behavior, it is in this sense “static.” The data set used to calibrate the phenotypic response is based on a relevant range of current practices and animal responses, and is therefore constrained. The current price grid is two-dimensional: weight and leanness. Our animal growth data used to reflect phenotypic response emerge from a world of weight gain and muscle deposition. It is essential for comprehensive welfare analysis to understand how the supply function will shift when alternative genetics are employed and new phenotypic responses result from adjusted management practices.

One response to a tax on P would be for producers to feed low-phytate corn (supply affecting), which would reduce the excretion of phosphorous. While our model could easily add an additional feeding regime, the mechanistic component of the model cannot so easily adjust. The calibration of the model's growth parameters reflects phenotypic responses to a range of current feeding practices. To accurately model low-phytate feed, new databases of animal responses to such feed will be necessary to recalibrate the model. While the mechanistic approach can be very robust within a setting, its generalizability across settings is less effective.

A second limitation of our model, and an issue also critical to environmental systems modeling in general, is the issue of the demand for environmental abatement. What is the best way to model the "environmental problem"? What is the cost to society of one more unit of N or P in the form of swine manure? It is unlikely the valuation is linear or static.

To review, our modeling approach is deterministic, based on published bonding rates and the current fertilizer value of manure. Though the use of linear bonding rates in the industry is evident (see References), it is not clear if bonding rates effectively capture the full cost of the environmental damage. The bonding rates may be biased on the low side because they are designed to compensate for direct costs of cleanup, which is only one component of the environment impact. Therefore our use of these measures of environmental impact is less than perfect. More accurate would be estimates of both indirect and direct costs to the environment of swine manure. A fuller cost approach estimated through more sophisticated techniques, such as contingent valuation (see Braden and Kolstad 1991; Freeman 1993), would more effectively get the prices right. Finally, an important question is whether monetization is the correct approach. The objective of the environmental problem may not in fact be to minimize environmental costs, but to maximize environmental sustainability.[21]

CONCLUSION

The case example used in this paper concerns the Québec industry and its objective of selecting a socially optimum slaughter weight. The model results show there are significant tradeoff problems among producers, processors and the environment. The model highlights how the definition of animal performance needs to be revisited, as it has different meaning to different stakeholders in society. While performance historically was synonymous with production efficiency, with new social and political concerns, this interpretation is not universal. In the case of our model, we demonstrate the greater complexities by broadening the set of affected parties.

For example, higher-phase feeding is not beneficial for producers nor processors because the cost-saving benefits are swamped by the lower degree of lean yield deposition. However, the real impact (negative) of phase feeding on production revenue may be lower than simulated because of the deterministic growth model used in this study and the discrete price grid matrix used by the industry. High-quality phenotypes, while providing producers and processors high returns, will only aggravate the manure management problem facing the industry. Clearly, moving away from a least-cost ration to an amino acid-balanced ration is beneficial for all concerned. Animal performance is better in terms of lean yield deposition and also reduces excretions of nitrogen and phosphorous.

Also important for policy makers are the decision rules necessary to allocate the benefits and costs across the affected parties. We offer eight such rules and empirically explore their impact. If all stakeholders are equally valued, then using a MaxiMin decision rule combined with a PPE consensus rule may be best for society. The optimum slaughter weight would remain unchanged from that currently being used, but the management regime would be significantly different, 332 versus 221. In terms of policy, the high-quality phenotype, three-phase feeding and amino acid-balanced ration formulation should be considered best management practices.

The model looks at one particular applied problem facing the industry. The approach, though, has many applications for policy makers. For example, while only 24 scenarios are analyzed, provided data are available, an almost infinite number of management regimes could be modeled. Also the model is well adapted to explore such questions as alternative pricing grids, the effect of exogenous input and out-price shocks, and sensitivity analysis.

Our approach demonstrates how modeling combined with a holistic framework can help policy makers work through a complex and seemingly intractable problem. Structural change in agriculture places increasing demands on the food supply chain. Optimizing performance is more complex, involving greater numbers of stakeholders with daunting temporal implications. Dynamic systems models, as shown here, can help managers and policy makers make sense of these complexities through exploration, learning and analysis.

NOTES

[1]A mechanistic model is a deductive model that attempts to capture the underlying physical and chemical relations (see Black; Whitmore). By capturing the underlying mechanisms of the (growth) process, flexibility is increased and better predictability is achieved (Baldwin).

[2]PorcExpert is the property of The Lennoxville Dairy and Swine Research and Development Centre (http://res2.agr.gc.ca/lennoxville/pages/pork_porc_e.htm) and was developed by Candido Pomar. A discussion of the features of PorcExpert can be found in Pomar et al 1991.

[3]See Boland et al (1996) for another bio-economic swine model.

[4]A mechanistic growth model estimates growth, body composition and nutrients excretion based on underlying biological processes. For example the linkages between nutrient intake and fat deposition are explicitly modeled. Alternatively, the econometric models bypass this relationship, focusing directly on growth and feed utilization as a function of time.

[5]For parsimony, the environmental problem is monetized. A valid criticism is that the environmental problem is not one of minimizing environmental bads but is better characterized as maximizing sustainability.

[6]Systems thinking is an approach elaborated by Forrester and Senge (Senge and Fulmer 1993), whereby managers think of outcomes as the result of complex systems; understanding the system with all its variables, interactions and feedback will reveal the true subtle interactions that drive the system. Thus it is tied closely to how we can effectively learn and manage an outcome by replacing traditional notions of linear and narrow cause-and-effect relationships with an appreciation of the breadth of the system.

[7]The Table Filière Porcine (TFP—Swine Industry Roundtable) was formed in 1990, emerging from an industry with a history of government involvement and industry coordination. The government legitimizes the TFP because it draws its direction with respect to policy and industry research. For example, the TFP in 1996 presented the industry with the task of managing its environmental impact. By first identifying such issues, then charting a set of tactics, the TFP is fundamentally maintaining the industry's competitiveness. Behind this authority is the commitment of the swine producer's federation (FPPQ), which controls the supply of hogs to industry. For research institutions to receive funding, they have to target TFP priorities and tactics. The final component is the feed and slaughter industries that realize their needs rank below those of the producers but are still given a strong voice at the TFP. The producers recognize, as do policy makers, that strong feed and slaughter industries are key for the competitiveness of the industry. That being said, vertical integration between hog production and slaughter is prohibited, packer concentration is taken very seriously, and the largest packer is closely linked to the province's largest agricultural cooperative.

[8]This is a legitimate body because it provides direction to the government on issues concerning the swine industry, it sets the research and development agenda for the province, and it is given the responsibility by the government for settling industry disputes. So when laws, grades, standards, procedures, etc., are established in the province related to the swine industry, the Table Filière Porcine has the responsibility and authority. Thus it is a gatekeeper for all policy pertaining to the industry.
[9]Phenotypes: 1 = low growth performance; 2 = typical; 3 = high growth performance. Feeding phases: 1, 2, 3, 4 diets. Feed rations: 1 = least-cost standard diet; 2 = reduced crude protein-amino acid-supplemented diet.
[10]Low growth performance, single-phase feeding, and a least-cost standard diet.
[11]The system dynamics development tool used is Powersim® (http://www.powersim.com/).
[12]While obviously the environment is not an economic agent, the environmental problem, as modeled in this research, is to minimize the effects of N and P. Less is preferred to more, and excess N and P are economic discommodities necessitating their minimization.
[13]Interviews with industry representatives indicated that the only variable costs differences between phase systems were feed-related due to ration changes. The remaining differences between phase systems related to differences in fixed investment.
[14]This is always negative because the bonding rates are greater than the fertilizer value when calculated on a per unit basis of N and P.
[15]Mentioned earlier, unit is a term preferred by industry and refers to a production slot. For simplicity, it can be thought of as a pig, though.
[16]Some 7.3 million according to the Ministry of Agriculture (MAPAQ).
[17]Not unreasonable when thinking about the agrarian tradition in North American agriculture.
[18]The 109 kg optimum also happens to be the midpoint optimum on the Québec grid.
[19]Special thanks go to anonymous Journal reviewers for raising these important issues.
[20]This raises an excellent issue for modelers who take a systems view. Historically, the price grid has driven optimal management practices. That is, the grid could be thought of as exogenous or at least endogenous but relatively static, and the industry focused on optimizing systems to perform in that world. In that world, environmental costs were not part of the pricing (grid) structure. As modelers, we can explore environmental issues associated with the current system (as we have done). Or is there greater value exploring completely new configurations where prices are either endogenous or where multiple radical pricing scenarios feedback into dynamic growth models.
[21]Special thanks to an anonymous Journal reviewer for raising this point.

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