Economically optimal pig delivery scheduling and the design of meat pricing schemes when pig group is heterogeneous

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Abstract

This paper represents a model for optimizing the timing of delivery of pigs to the slaughterhouse when the pig group is heterogeneous. We examine the value of having the option to split deliveries into two or more days, and management and income implications of different meat pricing schemes. These schemes penalize producers delivering heavier or lighter carcasses than some specified weight range, and reward for delivering low-fat carcasses. Different feeding regimes and genetic lines are considered. Weight-based pricing has large impact on the optimal harvest weight. It is optimal to harvest the fastest growing pigs before they suffer price discount due to heavy carcass, whereas pigs with the poorest daily gain are harvested at a much lower weight. Results suggest that the utilization rate of facility capacity is important for the timing of delivery of the least productive pigs. The benefits from the split harvest are approximately €5 per pig space unit per year.

Keywords: Dynamic optimization, stochasticity, growth model, heterogeneous herd

1. Introduction

Heterogeneity of pigs can have important implications in animal production (cf. Pomar et al., 2003). Studies suggest that it is not economically optimal to harvest all pigs in a group at the same live weight or date (cf. Kure, 1997; Boys et al., 2007) nor to maximise the average daily gain of pigs (cf. Boland et al., 1999; Jean dit Bailleul et al., 2000; Niemi, 2006). For instance, if a group of heterogeneous pigs is harvested using the all-in-all-out (AIAO) principle, slaughterhouse price lists imply that both the heaviest and the lightest pigs in the group may suffer price discounts due to their weight. Producers can mitigate these discounts by splitting the timing of harvest ('split harvest') so that pigs in the group are shipped to the slaughterhouse at multiple dates.

Meat pricing schemes are an important tool for meat processors to control pig producers' behaviour. Processors can provide producers with incentives to deliver carcasses, which are lean and show small variation in weight. Hence, the processor's problem is to design pricing schemes which promote desired carcass quality and schedule deliveries to the slaughterhouse efficiently without excessive costs and quality premiums. However, getting the potential of pricing mechanism fully realized requires that processor takes into account that producers optimize management according to the scheme.

Besides meat pricing scheme offered by slaughterhouse, genetic line used by individual pig producers is an important determinant for economically optimal timing of harvest. Getting the productive potential of different genetic lines fully realized requires that all pig management practices are optimized conditional on the genetic line and in accordance with the meat processor's requirements regarding carcass quality. Even if the link between the genetics and management practices is acknowledged, most studies examine pig production using traditional techniques. These techniques do not quite reveal the true potential of genetic lines nor do they lead to management recommendations that would realize the full value of genetic lines. There are two major reasons for this. First, critical management practices are usually fixed across heterogeneous pig group. Second and even more important, the concept of optimization often focuses on biological results rather than on truly economic concepts, such as maximising the return on capital that is decisive for the competitiveness of pork production. Moreover, studies generally examine feeding and harvest timing separately although they, as shown by Chavas et al. (1985) are linked to each others. In this study we examine both decisions simultaneously.

This study analyses pig producer's behaviour under different slaughterhouse meat pricing strategies. The goal of is to examine (1) how producers using different genetic lines respond to price schemes offered to them and (2) how much producer can benefit from more precise 'split harvest' technology in comparison to AIAO technology in a heterogeneous pig group. The problem is analysed numerically using a structural-form dynamic optimization model, which maximises the return on capital invested in the pig space facility for a given genetic line and meat pricing scheme.

2 Optimization model

Economic optimization model includes a biological growth model, which explicitly takes into account the quantity and protein content of feed given to pigs and the pig's genetic line. The model optimizes when the harvest of pigs in a heterogeneous pig group occurs. It also chooses from different feeding regimes the one that maximises return on pig space unit. The timing of harvest is adjusted according to the observable state of the group of pigs (cf. the Bellman's principle of optimality (Bellman 1957)). Hence, it impacts the timing of harvest whether the pigs turn out to be poorly productive or highly productive type and how many pigs have already been harvested from the group.

The optimization problem regarding a group of heterogeneous pigs is:

$$(1) \qquad V_t(\mathbf{x}_t) = \max_{\mathbf{u}_t^{\text{feed}}} \left\{ \max_{\mathbf{u}_t^{\text{cull}}} \left\{ R_t(\mathbf{x}_t, \mathbf{u}_t^{\text{cull}}) + \beta E(V_{t+1}(\mathbf{x}_{t+1})) \right\} \right\} \text{ for } t = 1,..,T$$

subject to: $\mathbf{x}_{t+1} = g(\mathbf{x}_t, \mathbf{u}_t^{\text{cull}}, \mathbf{u}_t^{\text{feed}})$ (the pig growth model)

$\mathbf{x}_1$ and $V_{T+1}(\mathbf{x}_{T+1})$ given (initial state and terminal value given),

where V_t is the optimal value function normalised per pig space unit; $\mathbf{x}_t$ is the state vector; t is the time index (measured in days); $\mathbf{u}_t^{\text{cull}}$ is the control vector for the harvest timing of pig groups and $\mathbf{u}_t^{\text{feed}}$ is the feeding rule; $R_t(.)$ is the one-period return function; β is the discount factor; $E(.)$ is the expectations operator; $V_{t+1}(\mathbf{x}_{t+1})$ is the next-period value function; $g(.)$ is the pig growth model or the harvesting decision; $V_{T+1}(\mathbf{x}_{T+1})$ is the value of a per pig space unit after the terminal period T, and $\mathbf{x}_1$ is the state at the beginning of the planning horizon (set on average at 25 kg piglet). One-period returns are the net income from selling pigs to slaughterhouse plus related subsidies minus the purchase price of a piglet and the feed costs.

The state vector includes the weight measures of each individual pig in the group. The weights of individual pigs are distributed around the average pig. Live weight is represented as a function of the weight of fat (x_t^{fat}) and fat-free tissue (x_t^{lean}) in the pig. These components are used to determine the quality-adjusted market value of a carcass. The daily gain potential of each individual pig is represented using the Gompertz function, which has three important parameters: maturing rate (MR), adult weight of fat (MW^{fat}) and adult weight of fat-free tissue (MW^{lean}) (cf. Niemi, 2006). An increase any of these parameters implies that the pig's average daily gain potential increases. However, the dynamics of growth process imply that an increase in adult weight puts more emphasis on increasing weight gain of heavy pigs whereas an increase in the maturing rate increases the daily gain potential most significantly on pigs weighing 50-100 kg live weight (in our case) (see Emmans and Kyriazakis, 1999).

The control vector includes decision to harvest the pig and decisions how much feeds to give to the group of pigs. The decision to harvest a group of n pigs (e.g. a truck-load of pigs) is based on their live weight and age, which are observable data. Feeding pattern is chosen in the set of pre-defined feasible feeding policies. Producer supplies protein and energy to the pig by controlling the amounts of barley, soybean meal and a premix feed. For each pig, the transition equation for body component i is represented as the function of feed supply and genetic line using the growth model reported by Niemi (2006):

(2) $x_{t+1}^{\mathrm{i}} = f(x_t^{\mathrm{lean}}, x_t^{\mathrm{fat}}, u_t^{\mathrm{energy}}, u_t^{\mathrm{protein}}, u_t^{\mathrm{cull}})$, (nutrient supply limits growth)

subject to: $x_{t+1}^{\mathrm{i}} \leq f(x_t^{\mathrm{lean}}, x_t^{\mathrm{fat}}, \mathrm{MR}, \mathrm{MW}^{\mathrm{fat}}, \mathrm{MW}^{\mathrm{lean}})$ (genetic potential limits growth),

for i={lean,fat} and where the pig's growth potential is derivative of the Gompertz function.

Table 1 represents meat pricing schemes and market scenarios for which the value and management implications are studied. Market prices represent the Finnish pig meat market in 2005-2007. Moreover, two different genetic lines are examined in this study. 'Fatty genetic line' has a high daily gain potential but tendency to produce fatty carcasses, whereas 'lean genetic line' has lower daily gain potential but it produces low-fat carcasses (Table 2). Genetic line parameters were estimated in a dataset based on an animal experiment. The model is programmed in Matlab 7.6.

Table 1. Market prices scenarios and meat pricing schemes examined in the baseline scenario of this study and alternative values considered for each price parameter in other scenarios.

Item	Unit	Parameter values used in the analysis	
		Baseline scenario	Alternative scenario[1)]
Pig meat price[2)]	€ per t	133	
Lean price	€ per t	2	1
Weight discount	€ per t	2	1
Target range	min – max	75 - 90	80-90 kg or 80-95 kg
Piglet price	€ per piece	56	
Harvest premium[3)]	€ per carcass	16	0
Soybean meal price	€ per t	310	
Barley+premix price	€ per t	121	

1) Indicates parameter value examined besides the value used in the baseline scenario (ceteris paribus).
2) Pig meat price is adjusted for individual carcass as follows: Each percentage point below (above) 60% red meat in the carcass gives 'lean price' additional discount (bonus) to the per kg pig meat price. Each additional kg deviation of carcass weight from the upper or lower bound (whichever is closer) of the 'target range' gives 'weight discount' additional discount to the pig meat price.
3) Paid for carcasses heavier than 61 kg carcass weight upon harvest.

*Table 2. Parameters maturing rate (*MR*), adult weight of fat (* MW^{fat} *) and adult weight of protein (* MW^{lean} *) for genetic lines examined in this study, corresponding average daily gain potential (*ADG*, kg live weight per day) and red meat percentage (*Lean %*) at 110 kg live weight.*

Genetic line	MR	MW^{lean}	MW^{fat}	ADG	Lean %
Lean	0.0132	35.5	52.0	0.945	61.6
Fatty	0.0142	33.0	64.0	1.017	58.7

3. Results

Results suggest that the optimal feeding pattern restricts the amount of energy and protein provided in the feed below the pigs' growth potential. There are differences in feeding patterns between genetic lines and between market scenarios. Differences are related to the heterogeneity of pig group and to the potential of a genetic line to deposit protein into the body, which causes lines to benefit differently from feeding patterns. Feeding differences between scenarios can be characterized as changes in the slope of feed inclusion curve (the amount of feed adjusted according to the pigs' live weight) and changes in the level of feed inclusion curve. Harvest dates and weights give some indication on the net effect. When the harvest date delays but harvest weight is unaffected, less feed in given to the pigs.

The model suggests that it is optimal to deliver heterogeneous pig group to the slaughterhouse using several shipments. The heaviest pigs are delivered just before they reach the upper bound of the target weight range. Thereafter, it is optimal to wait for one or more days before the next load of pigs reach the same delivery weight than already delivered pigs. Depending on the pricing scheme and genetic line, one or more groups can be delivered before the last load of pigs is delivered. The more pricing scheme penalizes pigs that do not meet specific weight, the more loads it is optimal to deliver.

Split harvest results in about one kilogram higher average carcass weight than AIAO. However, a higher harvest weight does not necessarily imply longer fattening period, because split harvest policy feeds pigs with more feed that AIAO policy. Higher harvest weight and an earlier harvest date for split harvest than AIAO occurs particularly when harvest premium is set zero in the model.

When utilizing split harvest, most scenarios report that about half of pigs are delivered in the last harvest date. Moreover, the slowest growing 10% of pigs are harvested before they reach the target weight range. An exception to this rule is when harvest premium is removed from the fatty genetic line. For instance, in the baseline scenario for fatty genetic line, pigs which have reached 89 kg carcass weight are delivered at days 92, 98, 101 and 104 (10% of pigs at each date). The remaining 60% are delivered at date 107 when their carcass weight is 73-89 kg.

According to the baseline scenario, producer benefits from the split harvest, when compared to AIAO, by about €5 per pig space unit per year. The benefit increases when target weight range becomes narrower, its location moves to reward for higher carcass weights, premium paid for lean carcasses decreases or harvest premium is removed from the model. In contrast to this, smaller penalty for carcass not meeting the target weight range and a low piglet price decreases the benefit from split harvest. These results are logical when taking into account biological dynamics in the growth model.

Variation in the individual pig's performance causes large variation in return on pig space unit. For instance, in the baseline scenario for fatty genetic line, the most productive 10 % of pigs yield 29 €/pig higher return on pig space unit that the least productive 10 % of pigs.

Genetic lines benefit differently from the meat pricing scheme, but differences between genetic lines in harvest weights are quite small (Table 3). In particular, lean genetic line benefits from the premium paid for lean carcasses. When lean price decreases from €2 to €1, the value of lean but slowly growing genetic line decreases by €4 per pig space unit per year whereas that of fatty genetic line can even increase a little because its growth rates can be high.

The target weight range has a strong impact on the optimal harvest weight. Narrow range of the target weight increases economic benefit from segregated timing of harvest and increases the number of days when pigs are delivered to the slaughterhouse. However, a narrower target weight range reduces return on pig space unit when compared to the baseline scenario. Result suggests that weight-based meat pricing is costly to producer as it puts weight on variation in carcass quality, and it is costly if it promotes too low harvest weights.

Table 3. Optimal average harvest weight and date for an all-in-all-out (AIAO) operation, weight and date of the first harvested group (First), the last harvested group (Last), the average harvest date and weight (Mean) and the number of dates when pigs are delivered to slaughterhouse (Groups) in an operation, which can deliver pigs to slaughterhouse multiple dates, and estimated benefit from split timing of harvest (€/year/pig space unit) and the impact of pricing scheme on annual return on pig space unit for the two genetic lines evaluated in this study.

Scenario[1)]	Harvest dates[2)]				Harvest weights[3)]						
	AIAO	First	Mean	Last	AIAO	First	Mean	Last	Groups	Benefit[4)]	Return[5)]
a) Lean genetic line											
Baseline	106	95	108	112	84	89	86	74	6	5.0	0.0
No harvest premium	116	99	112	116	85	89	86	74	6	5.6	-42.5
Target range 80-90 kg	112	95	109	115	85	89	86	75	8	7.6	-1.8
Target range 80-95 kg	110	101	113	116	88	94	89	76	5	4.7	2.5
Weight discount €1	107	98	108	111	85	91	86	73	5	1.7	1.5
Lean price €1	104	94	107	111	83	89	86	73	6	5.3	-4.9
b) Fatty genetic line											
Baseline	102	92	104	107	84	89	85	73	5	4.6	0.0
No harvest premium	116	98	111	116	85	89	86	76	7	5.5	-43.0
Target range 80-90 kg	106	92	105	111	85	89	87	76	7	7.3	-1.7
Target range 80-95 kg	109	99	112	115	88	94	90	77	5	4.3	2.3
Weight discount €1	103	95	104	107	85	91	86	73	5	1.7	1.3
Lean price €1	97	87	99	102	84	89	86	74	6	4.9	0.8

1) Column indicates genetic line under investigation and which parameter value is adjusted when other parameter values have the same values as the baseline scenario (see Table 1).

2) The facility was populated with 25 kg piglets (average weight) on day 1.

3) kg carcass weight

4) Difference in the value of pig space unit between split harvest and AIAO. The value functions are evaluated for 25 kg piglet (t=1) and the difference is converted to € per pig space unit per year basis.

5) Difference in the value of pig space unit between the baseline scenario and alternative scenario.

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4. Discussion and conclusion

Bio-economic models are useful for determining the optimal delivery scheduling of heterogeneous pig group, because they can take into account both biological and economic aspects. Our results suggest the option to split the timing of harvest of a group of heterogeneous pigs into two or more dates offers economic benefits. However, there is a trade-off between the homogeneity of carcasses and the duration of period that the facility is utilised. In general, it is not optimal to wait that the lightest pigs in the group reach the upper (or even lower) bound of the target weight range, because these pigs are expected to have a poorer productive potential than the fast-growing pigs already delivered to slaughterhouse. These results are in line with previous studies (e.g. Kure, 1997; Boyd et al., 2007). Results also suggest that the benefits from split harvest timing increase when the profitability of production decreases. For instance, recent increase in production costs or decoupling of production subsidies in pig production in Finland has strengthened producer incentives for split harvest.

Producers still relying on a fixed harvest weight or the maximum daily gain assumption should reconsider their management policy. Results suggest that besides harvest timing, split harvest affects the optimal feeding regime when compared to AIAO policy. This emphasises the importance of studying feeding and harvest timing simultaneously. Increased feed quantity jointly with increased harvest weights suggests that split harvest can produce fattier carcasses than AIAO policy.

With regards to the feed-back loop to the meat processor's carcass delivery control problem, our analysis suggests that the meat pricing scheme has large impact on variation in carcass weights. This highlights the importance of determining the meat pricing scheme correctly. If the target weight range is too narrow or promotes too light carcasses, it reduces return on pig space unit and hence producer's incentives to produce, unless these effects are compensated by paying a higher base price for pig meat. Moreover, if the scheme penalizes heavily carcasses which do not meet the target weight, it can be costly to producers and still have only a small impact on variation in harvest weights. In contrast to this, high price premium paid for lean carcass benefits producer who has proper genetic material, and it can increase carcass leanness. Genetic line nevertheless has quite small impact on the optimal harvest weights.

Besides meat pricing, slaughterhouses can use piglet price and quantity bonuses to control harvest weights. If the number of shipments to the slaughterhouse is a problem e.g. due to transportation costs, the number of shipment dates can be reduced by widening the target range or offering a premium based on the number of shipments. If slaughterhouse wished to buy the maximum quantity of meat per year, it can promote this goal by reducing price discounts due to too heavy or light carcasses or premiums paid for lean carcasses, and by paying a harvest premium.

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