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On the use of opportunity costs in deriving the economic value of herd life

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Abstract

This paper presents the economic perspectives applied when either using or not using opportunity costs of postponed replacement in deriving the economic value of herd life. Results show the equivalence of the rescaling method and the correction for opportunity costs. In economic terms, using rescaling or correction for opportunity costs forces the value of genetic improvement to change from revenues of increased output to reduction of costs per unit of (fixed) ouput. Under the zero profit theory, the economic value of herd life is equal when either using or not using correction for opportunity costs. In deriving economic values to define breeding goals, the choice of a method and price parameters will have to depend on foreseen future production circumstances for the system under study.

Keywords: *economic value, opportunity costs, productive life.*

Introduction

Van Arendonk (1991) introduced the use of 'opportunity costs' of postponed replacement in deriving the economic value of herd life. Opportunity costs are the average revenues minus costs per day of productive life (first calving to culling) per cow in the herd. In the study by van Arendonk (1991), ignoring opportunity costs led to a large overestimation of the economic value of herd life (260% with the interest of profitability per cow per lifetime). Since, several studies have been performed to derive the economic value of herd life either using or not using correction for opportunity costs (Allaire and Gibson, 1992; de Haan *et al.*, 1992; Cassell *et al.*, 1993; Harris and Freeman, 1993; Reinsch, 1993; Böbner, 1994; Stott, 1994; Veerkamp *et al.*, 1995; Visscher and Goddard, 1995; Weigel *et al.*, 1995). These studies include both data evaluation (positive approach) and data simulation (systems analysis or normative approach).

To elucidate an apparent discussion point, this paper compares the economic perspectives applied when either using or not using opportunity costs in deriving the economic value of herd life.

Concepts

Opportunity costs

In a herd with constant size, a cow should be kept as long as her expected marginal profit (per unit of time) is higher than the expected average profit during a replacing heifer's life (Renkema and Stelwagen, 1979). In other words, the input of a limited number of production factors should be applied in the most profitable manner. In the case of limited housing, the decision is either to house the present cow or to house a replacing heifer. The *additional* (future) profit (per unit of time) of housing the present cow is given by the margin between the profit of the present cow (per unit of time over her expected remaining herd life till optimal time of replacement) and the profit of the replacing heifer (per unit of time over her expected full herd life till optimal time of replacement). So, the additional profit is given by the profit of extending the herd life of the present cow minus the profit of the alternative use, which is keeping a replacement heifer. In economic terms, this means that the costs of extending the herd life of the present cow are given by the profit of the (best) alternative use, which is keeping a replacement heifer. The profit of the (best) alternative use is also referred to as 'opportunity costs'. This principle used in optimizing replacement decisions can also be applied to determine the economic value of (genetically extending) herd life.

Profit equations

Profit equations are used to derive economic values for milk production level and herd life. Time unit 'lifetime' is used to denote the productive period of an animal, from the moment she enters the herd as a replacement heifer at first calving until the moment she is culled from the herd. The animal characteristic 'herd life' directly determines the lifetime. The animal unit is 'cow', referring to an animal with full lifetime period in herd. The number of animals in the herd at one time (Nc) is the number of cows times their lifetime period [cow.lifetime]. To evaluate the number of cows in a herd, a period should be considered. On a yearly basis, the unit 'cow' would relate to the number of heifers entering the herd.

Van Arendonk (1991) defined the profitability over the lifetime of an individual cow i (PRTOT), the opportunity costs (OPCOST) as the average PRTOT divided by the average herd life, and profit per day of herd life (PPD)

$$\mathrm{PRTOT}_i = (a + b.\mathrm{MILK}_i).\mathrm{HERDLI}_i - \mathrm{COWF} \quad \text{[Dfl per cow per lifetime]} \qquad (1)$$

$$\begin{aligned}\mathrm{OPCOST} &= \mathrm{PRTOT}_{av} / \mathrm{HERDLI}_{av} \quad \text{[Dfl per cow per day]}\\ &= \{(a + b.\mathrm{MILK}_{av}).\mathrm{HERDLI}_{av} - \mathrm{COWF}\}/\mathrm{HERDLI}_{av}\\ &= a + b.\mathrm{MILK}_{av} - \mathrm{COWF}/\mathrm{HERDLI}_{av} \qquad (2)\end{aligned}$$

$$\begin{aligned}\mathrm{PPD}_i &= \mathrm{PRTOT}_i/\mathrm{HERDLI}_i \quad \text{[Dfl per cow per day]}\\ &= \{(a + b.\mathrm{MILK}_i).\mathrm{HERDLI}_i - \mathrm{COWF}\} / \mathrm{HERDLI}_i\\ &= a + b.\mathrm{MILK}_i - \mathrm{COWF}/\mathrm{HERDLI}_i \qquad (3)\end{aligned}$$

where, MILK_i [kg per cow per day] and HERDLI_i (days per lifetime) are variable milk production and herd life, a [Dfl per cow per day] and b [Dfl per kg] are constants representing costs per day of herd life and variable returns minus costs per kg of milk, COWF are (fixed) net replacement costs [Dfl per cow per lifetime], and MILK_{av} and HERDLI_{av} are (weighted) average MILK_i and HERDLI_i.

Profitability over the lifetime of an individual cow corrected for opportunity costs is then equal to

$$\begin{aligned}\mathrm{PROFOP}_i &= \mathrm{PRTOT}_i - \mathrm{HERDLI}_i.\mathrm{OPCOST} \quad \text{[Dfl per cow per lifetime]}\\ &= (a + b.\mathrm{MILK}_i).\mathrm{HERDLI}_i - \mathrm{COWF} - \mathrm{HERDLI}_i.\{a + b.\mathrm{MILK}_{av} - \mathrm{COWF}/\mathrm{HERDLI}_{av}\}\\ &= \{b.(\mathrm{MILK}_i - \mathrm{MILK}_{av}) + \mathrm{COWF}/\mathrm{HERDLI}_{av}\}.\mathrm{HERDLI}_i - \mathrm{COWF} \qquad (4).\end{aligned}$$

Profit at herd level can be calculated as PRTOT_i multiplied by the number of animals in the herd at one time (Nc, i.e. cows with a full lifetime in the herd [cow.lifetime]), but with a correction for the costs fixed (independent from herd size) at herd level (HERDF)

$$\mathrm{PROF}_h = \mathrm{Nc}.\{(a + b.\ \mathrm{MILK}_i).\mathrm{HERDLI}_i - \mathrm{COWF}\} - \mathrm{HERDF} \quad \text{[Dfl]} \qquad (5).$$

This profit is over a (not specified) time period corresponding to the time period used in defining Nc. If Nc is defined on a yearly basis, i.e. as the number of heifers entering the herd per year, PROF_h would be Dfl per year. In equation (5), MILK_i and HERDLI_i are assumed to be equal for all cows. Note, that profit at herd level corrected for opportunity costs is (by definition) zero, when ignoring HERDF.

Table 1 *Economic values of milk production (MILK) and herd life (HERDLI) when considering different interests of selection and using partial differentiation of profit equations: profitability per cow over her lifetime (PRTOT; equation (1)), profitability per cow over her lifetime when correcting for opportunity costs of disposed replacement (PROFOP; equation (4)), and profitability per cow per day of herd life (PPD; equation (3))*

Interest	Trait [unit] MILK	HERDLI
PROTOT	$b.\mathrm{HERDLI}_{av}$ [(Dfl per cow per lifetime) per (kg/day)]	$a + b.\mathrm{MILK}_{av}$ [(Dfl per cow per lifetime) per (day per lifetime)] = [Dfl per cow per day]
PROFOP	$b.\mathrm{HERDLI}_{av}$ [(Dfl per cow per lifetime) per (kg/day)]	$\mathrm{COWF}/\mathrm{HERDLI}_{av}$ [(Dfl per cow per lifetime) per (day per lifetime)] = [Dfl per cow per day]
PPD	b [(Dfl per cow per day) per (kg/day)] = [Dfl per cow per kg]	$\mathrm{COWF}/\mathrm{HERDLI}_{av}^2$ [(Dfl per cow per day) per (day per lifetime)] = [Dfl per cow per lifetime per day^2]

Economic values from partial differentiation
Using partial differentiation of equations (1), (3), and (4), van Arendonk (1991) derived economic values of MILK and HERDLI. Results are in Table 1, where the economic value of MILK is evaluated on herd average for herd life, and the economic value for HERDLI is evaluated at the herd average for milk production level. [Note the error in Table 5 by van Arendonk (1991) with respect to the (relative) economic value of HERDLI when using the PPD interest — see also the economic value of HERDLI by van Arendonk and Brascamp (1990) when using the product profitability interest.] The equivalence of the economic values of both MILK and HERDLI as obtained by partial differentiation when either taking the interest (or objective) of PROFOP or PPD is obvious; the difference is just the scaling factor 1/$HERDLI_{av}$. The economic value of MILK is equal when taking the PRTOT or PROFOP interest. However, a difference in the economic value of HERDLI seems to occur between the interest PRTOT *versus* the interest PROFOP.

Economic values from partial budgeting
Economic values can also be derived using partial budgeting, starting from equation (5): profitability of the herd is compared before and after genetic improvement of MILK or HERDLI, expressed per cow (with a full lifetime in herd) before genetic improvement. When deriving economic values (EV), the level of genetic improvement (δMILK or δHERDLI) will usually be one unit, i.e. 1 kg/day and 1 day per lifetime.

$$\begin{aligned} EV &= 1/Nc_1.(PROF_{h2} - PROF_{h1}) \\ &\quad \text{[Dfl per cow per lifetime per (unit genetic improvement)]} \\ &= 1/Nc_1.[Nc_2.\{(a + b.MILK_{i2}).HERDLI_{i2} - COWF\} - HERDF \\ &\quad - Nc_1.\{(a + b.MILK_{i1}).HERDLI_{i1} - COWF\} - HERDF] \\ &= 1/Nc_1.[Nc_1.\{(a + b.MILK_{i2}).HERDLI_{i2} - COWF\} \\ &\quad + \delta Nc\{(a + b.MILK_{i2}).HERDLI_{i2} - COWF\} \\ &\quad - Nc_1.\{(a + b.MILK_{i1}).HERDLI_{i1} - COWF\}] \\ &= \delta Nc/Nc_1.\{(a + b.MILK_{i2}).HERDLI_{i2} - COWF\} \\ &\quad + (a + b.MILK_{i2}).HERDLI_{i2} - COWF \\ &\quad - (a + b.MILK_{i1}).HERDLI_{i1} + COWF \end{aligned}$$

where subscripts 1 and 2 denote the situation before and after genetic improvement of milk, respectively, and δ denotes the change between both situations. Final rewriting gives

$$\begin{aligned} EV &= \delta Nc/Nc_1.\{(a + b.MILK_{i2}).HERDLI_{i2} - COWF\} \\ &\quad + (a + b.MILK_{i1}).\delta HERDLI + b.HERDLI_{i1}.\delta MILK \\ &\quad + b.\delta MILK.\delta HERDLI \\ &\quad \text{[Dfl per cow per lifetime per (unit genetic improvement)]} \qquad (6). \end{aligned}$$

When independently changing genetic merit of breeding goal traits, which is assumed in deriving economic values, the fourth term of equation (6) will always be zero ($b.\delta MILK.\delta HERDLI = 0$, as either δMILK or δHERDLI is zero).

According to equation (6), the economic value of a trait is given by the change in profit per (present) cow over her lifetime, taking into account a possible change in number of cows (with full lifetime in herd) (Groen, 1989). Apart from assuming a fixed number of cows at herd level, also other bases of evaluation can be used (e.g. Smith *et al.*, 1986; Groen, 1989), such as fixed output in terms of kg milk produced per herd, or a fixed input in terms of herd total for number of days in herd summed over cows (i.e. Nc_1 multiplied by $HERDLI_1$, [cow.days]). The latter case would represent a restriction on housing. The base of evaluation determines the value of δNc (Groen, 1989). A fixed milk output (kg quota, over a not specified time period) at herd level results in:

$$Nc = quota/MILK_i.HERDLI_i$$

or

$$Nc_1.MILK_1.HERDLI_1 = Nc_2.MILK_2.HERDLI_2.$$

When rewriting $Nc_2 = Nc_1 + \delta Nc$ this leads to

$$\delta Nc / Nc_1 = -(MILK_1.\delta HERDLI + HERDLI_2.\delta MILK)/(MILK_2.HERDLI_2). \qquad (7a).$$

With increasing MILK at constant HERDLI, equation (7a) reduces to

$$\delta Nc/Nc_1 = -\delta MILK/MILK_2, \qquad (7b),$$

and with increasing HERDLI at constant MILK, equation (7a) reduces to

$$\delta Nc/Nc_1 = -\delta HERDLI/HERDLI_2 \qquad (7c).$$

Equation (7c) is also valid with increasing HERDLI at the base of a fixed input of a herd total for days in herd.

Using the above equations, economic values at herd profit interest and at different evaluation bases are derived and summarized in Table 2. The economic value of MILK is changed when applying a fixed herd output of milk (FIXED MILK) instead of applying a base of fixed number of cows (FIXED COWS) or a fixed input for number of days in herd summed over cows (FIXED DAYS). Applying FIXED MILK or FIXED DAYS results in the same economic value of HERDLI but a different value is found for FIXED COWS.

Table 2 *Economic values of milk production (MILK) and herd life (HERDLI) when considering a herd profit interest of selection and different bases of evaluation, and using partial budgeting of herd profit† (equation (5)): FIXED COWS = fixed number of cows in the herd; FIXED MILK = fixed herd output of milk; FIXED DAYS = fixed herd total for days in herd (from equations (6) and (7))*

	Trait	
Base	MILK [(Dfl per cow per lifetime) per (kg/day)]	HERDLI [(Dfl per cow per lifetime) per (day per lifetime)]
FIXED COWS	$\{b.\text{HERDLI}_{av}\}$	$\{a + b.\text{MILK}_{av}\}$
FIXED MILK	$\{(\text{COWF} - a.\text{HERDLI}_{av})/\text{MILK}_{i2}\}$	$\{\text{COWF}/\text{HERDLI}_{i2}\}$
FIXED DAYS	$\{b.\text{HERDLI}_{av}\}$	$\{\text{COWF}/\text{HERDLI}_{i2}\}$

† Assuming the change for the trait of interest to be one unit, i.e. 1 kg/day and 1 day per lifetime.

Discussion

Equivalences of perspectives

By comparing Tables 1 and 2 some equivalences between perspectives become clear. First, economic values of both MILK and HERDLI with a fixed number of cows and herd profit interest are equal to economic values assuming the PRTOT interest. Secondly, the economic value of HERDLI at the base of fixed input of a total for days in herd (summed over cows) and herd profit interest is equal to economic value of HERDLI assuming the PROFOP interest. In other words, using a correction for opportunity costs when deriving the economic value of HERDLI (van Arendonk, 1991) is equivalent to rescaling (Smith *et al.*, 1986) to a fixed herd total for days in herd. As the economic value of MILK is not influenced by rescaling to a fixed herd total for days in herd, the observed equivalence also holds for the economic value of MILK. This equivalence of using opportunity costs and rescaling was not fully recognized in the literature. In their derivations, van Arendonk and Brascamp (1990) showed that the economic values from PROFOP were those when size was rescaled to a fixed number of cows, whereas those obtained from PRTOT were those for a fixed number of heifers entering the herd. They implicitly defined the number of cows as the herd total for days in herd and the number of heifers entering the herd as the number of cows with a full lifetime in herd.

From Table 1 and Table 2 it becomes clear that the relative economic value of HERDLI and MILK are equal for PPD, PROFOP and rescaling to a fixed output in terms of a herd total for days in milk.

Use of saved production factors

Brascamp *et al.* (1985) denoted that economic values from different perspectives will be equivalent when assuming 'zero profit' of the farm. Applying this zero profit theory to equation (5) gives

$$\text{Nc}.\{(a + b.\text{MILK}_i).\text{HERDLI}_i - \text{COWF}\} = 0$$
$$=> a + b.\text{MILK}_i = \text{COWF}/\text{HERDLI}_i.$$

which is equivalent to

$$(\text{COWF} - a.\text{HERDLI}_i) \;/\; \text{MILK}_i = b.\text{HERDLI}.$$

Substituting these equations in Tables 1 and 2 shows that under the zero profit theory economic values for both MILK and HERDLI with the interests of PRTOT and PROFOP (Table 1) and, thus also, on base of FIXED COWS, FIXED MILK and FIXED DAYS (Table 2) are equal. Above equations ignore costs which are fixed on a herd basis; the denoted equivalence under zero profit does not hold if these costs exist. Brascamp *et al.* (1985) suggested that costs fixed at herd level should be considered as part of 'zero' profit. Smith *et al.* (1986) suggested that fixed costs on a herd basis should be considered as variable per unit product, as they are supposed to be variable in the long term.

Fully to understand the impact of this equivalence, two aspects have to be explained: the principles underlying the zero-profit and the essence of technical development.

The zero-profit theory of Brascamp *et al.* (1985) is also called 'normal-profit' theory and this name in fact better denotes its underlying principles: the producer obtains normal, in the long term socially accepted, returns from his input of production factors (Stonier and Hague, 1964). Thus, with normal profit, revenues of a farm will equal costs and profit will be zero. As explained when denoting the origin of using opportunity costs, the costs of input of production factors are the returns from the (best) alternative use. Therefore, a crucial assumption for the normal or zero profit theory is that returns from the input of production factors for alternative uses are equal. Note that with normal profit the opportunity costs will be zero.

Improvement of genetic merit is an area of technical development in animal production (Willer, 1967). The essence of technical development is improvement of efficiency of a production system: saving inputs of production factors per unit product and/or a change towards use of cheaper production factors. Saved production factors can either be used in the system where they are saved from (and thus expand product output of this system) or can be transferred to another system (via the market) (Willer, 1967). Applying this to the economic values, we see that with a fixed number of cows (FIXED COWS), the economic value of MILK originates from marginal revenues of increased selling of milk over the lifetime. Fixing the total days in milk at herd level (FIXED DAYS) will not influence the economic value of MILK. So, with FIXED COWS and FIXED DAYS saved production factors are used to expend product output of the system. However, with a fixed milk output at herd level (FIXED MILK), the situation changes as an increased milk production per lifetime reduces the number of cows with a full lifetime in the herd. The economic value of increased genetic merit for MILK now originates from reducing costs of production that are fixed per lifetime, both rearing costs and maintenance costs. In fact, a reduction in costs assumes an alternative use of saved production factors: they are either to be sold at the market or they are not to be bought from the market. With a fixed number of cows (FIXED COWS) the economic value of HERDLI originates from average revenues of selling milk over the additional days in the herd. Fixing both herd milk output and herd total for days in herd prohibits increased selling of milk, and the economic value of HERDLI now originates from reducing costs.

Concluding, different perspectives assume different alternative uses of production factors saved by genetic improvement. If these alternative uses give the same returns (normal profit), the economic values will be equal for all perspectives. If the price assumptions applied in deriving economic value do represent different returns from alternative uses of saved production factors, then economic values will not be equal when derived from different perspectives. A statement, such as that of van Arendonk (1991), that ignoring opportunity costs gives an overestimation cannot be generalized but is valid only given price parameters applied.

Fixed herd costs

In this study, as in van Arendonk (1991), fixed herd costs (not depending on the number of cows or product output per lifetime) were not included in the profitability per cow per lifetime (equation (1)), and therefore neither influenced profitability corrected for opportunity costs (equation (4)) nor profit per day of herd life (equation (3)). The fixed herd costs were considered in total herd profit (equation (5)) but did not enter into the economic values from partial budgeting (equation (6)). Van Arendonk and Brascamp (1990), however, did consider fixed herd costs and observed that these fixed herd costs do influence the economic value of HERDLI when derived from the perspective of product profitability and a fixed number of lifetimes. In terms of Table 1, the economic value of HERDLI with the PPD interest becomes (HERDF/Nc + COWF)/$HERDLI_{av}^2$. In other words, the economic value is increased by a term denoting the dilution of fixed herd costs over more days in herd and higher milk product output. This implies that the earlier denoted equivalence will only be valid under the condition of either ignoring fixed costs or expressing fixed costs as variable per unit of product (Smith *et al.*, 1986). Validity of this assumption is discussed by Groen *et al.* (1997).

Opportunity costs

When deriving economic values using the normative approach (for any trait) it is generally assumed that all cows in the herd are identical. Also the theory given in this paper assumes that all cows in the herd (either before or after genetic improvement) are identical. The interest of profit per day of herd life essentially assumes identical replacement. The definition of opportunity costs applied in this study (average profitability divided by average herd life) implicitly assumes identical replacement. However, this definition of opportunity costs can be adapted to reflect cases of non-identical replacement (profitability divided by the herd life of a genetically superior replacement heifer). So, when applying opportunity costs in deriving the economic value of HERDLI, it is still to be considered how to calculate these costs. Opportunity costs are the expected average profits during a replacing heifer's life. According to Renkema and Stelwagen (1979), the economic principle includes that opportunity costs are calculated assuming an optimum herd life for the replacing heifer. In other words, profit from the (best) alternative use is optimized. The bias in economic values from the assumption of identical replacement will depend on the (practical) difference in returns on (optimally) using production factors (or cost price per kg product) either from a 'better' cow or a 'worse' cow. This assessment is difficult, but worthwhile to reflect upon. When analysing realized data (positive approach) to derive economic values, opportunity costs from an optimum herd life vary among farms and it will be difficult to assess these costs (van Arendonk, 1991).

Rescaling

In deriving the economic value of traits, one will always have to define the 'boundaries' of the assumed production system — a base of evaluation or rescaling factor, e.g. in terms of a fixed number of animals, a fixed output of a product, or a fixed input of a production factor. A question that arises, especially in multiple product and production factor systems, is: which base of evaluation or rescaling factor is to be applied? According to Smith *et al.* (1986), 'any extra profit from genetic change that could also be obtained by altering the size or rescaling the operation should not be counted in assessing the value of genetic improvements'. Interpreting this as rescaling to profit of the herd (i.e. $PROF_{h2} = PROF_{h1}$) does not work, as this condition simply leads to zero economic values for all traits involved. Gibson (1989) and Groen (1989) considered multiple product and production factor situations and concluded that rescaling to a given product or production factor influences only the value of that product or production factor, according to the difference between market price and value of the product or production factor within the production system. The way of rescaling obviously influences the obtained economic values, unless assumed prices reflect the normal profit situation. Rescaling according to the practical situation under which farmers have to operate in future seems most reasonable, for example product output quota (Gibson, 1989; Groen, 1989), environmental legislation restricting nitrogen or phosphate output (Steverink *et al.*, 1994), or roughage input (Visscher *et al.*, 1994).

Conclusion

This paper shows the equivalence of the rescaling method (Smith *et al.*, 1986) and the correction for opportunity costs (van Arendonk, 1991). In terms of economics, using rescaling or correction for opportunity costs forces the economic value of genetic improvement to change from revenues of increased output to reduction of costs per unit of (fixed) ouput. Under the zero profit theory (Brascamp *et al.*, 1985), the economic value of herd life is equal when either using or not using correction for opportunity costs. This demonstrates that differences in the economic value of herd life when derived either with or without correction for opportunity costs depend fully on the assumed deviation from a zero profit situation, i.e. price parameters. Even without the assumption of zero profit, but applying the general rule of identical replacement, the interests of profit per day of herd life and profitability corrected for opportunity costs are the same.

It is important to realize that showing equivalence itself is not an argument for the choice of rescaling or correction for opportunity costs, or assuming zero profit. In deriving economic values to define breeding goals, the choice of a method and price parameters will have to depend on foreseen future production circumstances for the system under study.

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