From research to farm: *ex ante* evaluation of strategic deworming in pig finishing

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ABSTRACT: This paper upgrades generic and partial information from parasitological research for farm-specific decision support, using two methods from managerial sciences: partial budgeting and frontier analysis. The analysis focuses on strategic deworming in pig finishing and assesses both effects on economic performance and nutrient efficiency. The application of partial budgeting and frontier analysis is based on a production-theoretical system analysis which is necessary to integrate parasitological research results to assess aggregate economic and environmental impacts. Results show that both statistically significant and insignificant parasitological research results have to be taken into account. Partial budgeting and frontier analysis appear to be complementary methods: partial budgeting yields more discriminatory and communicative results, while frontier methods provide additional diagnostics through exploring optimization possibilities and economic-environmental trade-offs. Strategic deworming results in a win-win effect on economic and environmental performances. Gross margin increases with 3 to 12 € per average present finisher per year, depending on the cyclic pig price conditions. The impact on the nutrient balance ranges from +0.2 to –0.5 kg nitrogen per average present finisher per year. The observed efficiency improvements are mainly technical and further economic and environmental optimizations can be achieved through input re-allocation. A user-friendly spreadsheet is provided to translate the generic experimental information to farm-specific conditions.

Keywords: partial budgeting; frontier analysis; pig finishing; strategic deworming

Endoparasites in livestock cause discomfort, physical damage and economic losses (Stewart and Hale, 1988; Corwin, 1997; Vercruysse and Dorny, 1999; Jaeger et al., 2005; Kemper and Henze, 2009). Many efforts are made by scientists and veterinary pharmaceutical companies to develop anti-parasitic products and/or strategies (e.g. Murrell, 1986; Roepstorff and Jorsal, 1989; Roepstorff and Nansen, 1994; Williams, 1997; Nansen and Roepstorff, 1999; Vercruysse and Dorny, 1999; Joachim et al., 2001; Beloeil et al., 2003; Jaeger et al., 2005; Kemper and Henze, 2009). In order to get adopted by farmers, these strategies must guarantee net improvements in economic farm results. As long as parasitological research outcomes demonstrate significant improvements in key performance indicators such as productivity, quality or mortality, traditional techniques like partial budgeting (see e.g. Dijkhuizen and Morris, 1997) suffice for aggregating these outcomes to assess net economic effects and for extrapolating results to a larger set of farms. In its most simple form, aggregation and extrapolation can even be done with rough back-of-the-envelope simulations.

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Unfortunately, multiple factors may hamper easy transformation of parasitological research outcomes to relevant decision support information. First, outcomes may be incomplete and isolated from real-life or farm-specific conditions. This is particularly the case when research concerns complex (and mostly preventive) whole-farm strategies instead of simple (and mostly curative) products or technologies that can easily be tested in field trials with enough replicates. Second, production activities within the targeted livestock sector may already be highly optimized while economic margins are low. Consequently, research outcomes may only concern minor and even insignificant productivity gains, while the impact on economic margins may be more substantial. Third, as sustainability becomes more important, multiple criteria are at stake and have to be taken into account when aggregating and extrapolating research outcomes.

These factors specifically apply to strategic deworming (SDW) with flubendazole (Flubenol® Janssen Animal Health) in pig finishing (see JAH (2004) for a description of the technique). First, there is the research complexity problem. Field experiments face the problems of cross contamination in a blinded control treatment trial and the impact of historical contamination of the premises (see for example Hale et al., 1985). These problems may influence the variability between field experiments, which finally attenuates the statistical validity test (Kanora, 2009). Research outcomes must also be completed with real farm data to serve as a source of information. Second, pig finishing is already highly optimized and economic margins are low. Small changes in revenues or costs have a substantial impact on economic margins due to a leverage effect: in current Flemish conditions, for example, a 1% change in revenues results in an increase of the gross margin by 4% (Lauwers et al., 2009). Third, from a sustainability perspective, SDW should not only aim at increasing animal comfort and product quality but also at improving economic and environmental farm outcomes.

The objective of this paper is to provide a method to valorise parasitological research information for farm decision support. The method is based on production theory and uses two techniques from managerial sciences: partial budgeting and frontier analysis. Research outcomes on SDW with flubendazole in pig finishing are used as a typical case of the from-research-to-farm extrapolation problem. Both economic outcomes and nutrient emission, being the most important environmental outcome in pig finishing, are assessed to serve as aggregate decision support information.

MATERIAL AND METHODS

Parasitological research results

Ascaris suum or large roundworm is one of the most important internal parasites in pigs worldwide (Hale et al., 1985; Urquhart et al., 1999; Wagner and Polley, 1997; Helwigh et al., 1999; Joachim et al., 2001; Caballero-Hernandez et al., 2004). SDW aims at minimizing physical and economic impacts of this parasite. Physical damage encompasses liver white spots, pleurisies and perforations of the gut wall (Hale et al., 1985; Murrell, 1986; van Wagenberg et al., 2009) and increased susceptibility to respiratory diseases (Bouwkamp et al., 2006). Daily weight gain decreases (Forsum et al., 1981; Hale et al., 1985; van Wagenberg et al., 2009) and feed absorption by the parasite deprives the host of nutrients (Stephenson et al., 1980; Hale et al., 1985; van Wagenberg et al., 2009). SDW improves the health status of the pigs and reduces liver rejections in the slaughterhouse (Van Meirhaeghe and Maes, 1996). Mortality and medication costs are reduced, homogeneity, lean meat percentage and carcass quality are improved. Average daily weight gain increases and feed conversion decreases (Kanora et al., 2004; Kanora, 2009).

Table 1 presents average results from three *in situ* experiments, in which SDW with flubendazole is applied. Historical pre-treatment data are compared with SDW trial data. For the first experiment, observations are available at allotment level: 31 pre-treatment cases can be compared with 25 SDW trial cases. Differences are tested with the nonparametric Wilcoxon two sample test. SDW has a positive effect on feed conversion, average daily weight gain and mortality. Only the latter effect is statistically significant. The first experiment also shows that SDW does not have a significant effect on medication costs.

SDW also improves carcass quality, resulting in a higher carcass value. Unfortunately, the three *in situ* experiments do not provide data on improved carcass quality. However, Kanora et al. (2004) provide average figures (Table 2) on the percentage of carcasses selected under the best lean meat classes (S, E and U) for the pre-treatment and the SDW case.

Table 1. Parasitological research results (source: Jansen Animal Health, Belgium)

Experiment No.	Key performance indicator	Pre-treatment	SDW trial	Absolute difference	*P*-value
1	feed conversion (kg feed/kg weight gain)	2.96	2.95	–0.01	0.83
	average daily weight gain (kg/day)	0.643	0.658	0.015	0.065
	mortality rate (%)	5.95	4.32	–1.63	0.0042
	medication costs (euro/APF)	3.47	3.37	–0.10	0.70
2	feed conversion (kg feed/kg weight gain)	2.98	2.88	–0.10	N.R.
	average daily weight gain (kg/day)	0.700	0.715	0.015	
	mortality rate (%)	6.89	6.82	–0.07	
3	feed conversion (kg feed/kg weight gain)	3.05	2.94	–0.11	N.R.
	average daily weight gain (kg/day)	0.772	0.787	0.015	
	mortality rate (%)	4.64	3.58	–1.06	

SDW = strategic deworming; APF = average present finisher; N.R. = not registered

Sample of pig-finishing farms

A sample of 117 farms, representative of the Flemish pig-finishing sector, is extracted from the Farm Accountancy Data Network (FADN). Data are pooled for three consecutive years (2001–2003) to reduce possible measurement errors. Table 3 presents the main zootechnical, economic and environmental key performance indicators, calculated from the detailed registrations.

Production-theoretical framework

In order to assess aggregate economic and environmental effects of SDW, we use basic production-economic theory. Central is the production function, which describes the technical relationship between inputs (X_i, X_j) and outputs (Y) of a production process. In the short run, the production capacity is fixed and limits the production process.

Table 2. Carcasses selected under SEU classes (%) (source: Kanora et al., 2004)

Classification	Pre-treatment	SDW trial
S	10.94	9.48
E	61.42	67.36
U	23.54	22.04
Total	95.90	98.88

SDW = strategic deworming

In the long run, also the production capacity can be considered as a variable input:

$Y = f(X_i|X_j)$ in the short run with variable inputs X_i and fixed inputs X_j

$Y = f(X_i, X_j)$ in the long run with variable inputs X_i, X_j

When prices of inputs (P_{Xi}, P_{Xj}) and outputs (P_Y) are known, profit (Π) can be calculated as:

$\Pi = P_Y \times Y - P_{Xi} \times X_i - P_{Yj} \times X_j$

Along the production function, profit can be maximized through selecting the optimal input-output combination, given their prices.

In the case of SDW, as in most other decision problems related to animal health control, the short run formulation of the production function is sufficient. The output consists of kg marketable pig. The main variable inputs are feed and piglets, while the fixed input consists of the number of pig places. The finishing activity takes about 140 days, thus each pig place can be occupied by more than one piglet per year to finish as a marketable pig. Rotations (= number of start-ups per year) can be seen as an input factor instead of the mere piglet input. The rotation price then consists of the piglet price and the other costs linked to the starting-up process.

In the short run, profit can be maximized given the number of pig places, which is the capacity constraint. Profit maximization then comes down to seeking an optimal combination of feed and rotations to produce a given amount of marketable big. This optimization coincides with a maximization of the gross margin (revenues minus variable costs). In practice, substitution between feed and rotations can be reduced to a change in delivery weight of the finished pig.

The pig place is the limiting factor, but in practice a real occupied pig place is more useful. The real occupied pig place becomes operational through the concept of average present finisher (APF), which is a pig place corrected for the actual occupation. The number of APF is easily monitored in most current accounting systems.

In order to valorise the parasitological research results, the challenge now becomes to link the traditional key performance indicators (feed conversion, average daily weight gain, mortality rate) with production-theoretical key performance indicators (inputs and output). This linkage allows for combining synergetic and counteracting effects on traditional key performance indicators to calculate aggregate effects. Moreover, it prevents a simple adding-up of positive and negative effects which would be erroneous because double counting or correlations would not be controlled for. Also the improvement in carcass value has to be related to an improvement in output price. Linking traditional to production-theoretical key performance indicators results in a qualitative production-theoretical impact matrix with the traditional key performance indicators as row entrants and production-theoretical performance indicators as column entrants.

Partial budgeting

Starting from the assessed production-theoretical key performance indicators, partial budgeting is applied to calculate the economic effects of SDW. A partial budget only takes into account the cost and revenue components that change due to a minor adjustment in the management. The net effect is the difference between aggregate positive and negative economic effects (Dalsted and Gutierrez, 1992). In this paper, the change in gross margin is calculated.

The partial budgeting method is extended to account also for the change in environmental outcome due to SDW. Based on the materials balance principle (Lauwers, 2009), the nutrient balance is calculated as the amount of nitrogen entering through inputs minus the amount leaving through marketable output. Nitrogen content data from literature are linked to input and output quantities.

The changes in economic and environmental outcomes can be combined to assess the difference in eco-efficiency. Eco-efficiency can be defined as the ratio between an economic outcome, to be maximized, and an environmental pollution outcome, to be minimized (Huppes and Ishikawa, 2005). In this paper, eco-efficiency is calculated by dividing gross margin by the nitrogen balance.

Frontier analysis

Also frontier methods can be used to valorise the parasitological research results, starting from the assessed production-theoretical key performance indicators. Frontier methods, issued from original work by Farrell (1957), aim at identifying inefficiency levels by comparing actual to optimal performance levels. Input oriented technical efficiency reflects the ability of using minimal amounts of input(s) to obtain (a) given amount of output(s). Output oriented technical efficiency reflects the ability to produce maximal amounts of output(s) with (a) given amount of input(s). Cost allocative efficiency reflects the ability to use inputs in cost minimizing proportions, given their respective prices and the production technology. Input oriented technical and cost allocative efficiency can be combined to provide a measure for cost efficiency.

Coelli et al. (2007) also propose an environmental efficiency measure that can be decomposed into input oriented technical and, in this case, environmental allocative efficiency. Environmental allocative efficiency refers to the ability to use inputs in a combination that minimizes the nutrient balance.

To calculate efficiency scores, literature distinguishes between nonparametric data envelopment analysis (DEA) and parametric stochastic frontier analysis (SFA). We use the latter. SFA was originally and independently described by Aigner et al. (1977) and Meeusen and van den Broeck (1977), and fits a parametric production function to given data, specifying a two-part error term that accounts for both random error and the degree of technical inefficiency. Detailed reviews of SFA can be found in Greene (1993), Coelli et al. (2005), and, Kumbhakar and Lovell (2000).

The functional form of the production function needs to be specified by the researcher. Here, the Cobb-Douglas functional form is selected because it allows for deriving analytically the so-called dual cost function, representing minimum costs as a

Table 3. Descriptive statistics for a sample of 117 pig farms from FADN containing pooled data for the period 2001 to 2003

Key performance indicator	Average	Standard deviation	Minimum	Maximum	Median
Feed conversion (kg feed/kg weight gain)	3.06	0.18	2.69	3.60	3.04
Average daily weight gain (kg/day)	0.593	0.050	0.471	0.743	0.590
Mortality rate (%)	4.30	1.8	0.91	8.88	4.05
Slaughter pig price (euro/kg)	1.13	0.043	0.94	1.24	1.13
Feed price (euro/kg)	0.189	0.012	0.145	0.246	0.188
Gross margin (euro/APF/year)	62.8	21	11.3	113	61.0
Nitrogen excretion (kg/APF/year)	11.0	0.95	8.9	13.9	11.0
Eco-efficiency (euro/kg)	5.79	2.0	0.818	10.2	5.69

APF = average present finisher

function of output level and input prices. Bravo-Ureta and Rieger (1991) and Sharma et al. (1999) provide applications of assessing technical and cost efficiencies, using a Cobb-Douglas production function. In our research, this procedure is extended to derive also a dual environmental function, representing minimum nitrogen uptake as a function of output and nitrogen content of the inputs. Based on the dual cost and environmental functions, cost and environmental efficiencies are assessed. Allocative efficiencies are calculated residually. All efficiency scores vary between 0 and 1, 0 being totally inefficient and 1 being fully efficient.

SFA is applied on a cross-section sample of 177 cases: the FADN sample of 117 farms is combined with:

– 31 historical pre-treatment cases and 25 SDW trial cases from experiment 1;
– one pre-treatment case and one SDW trial case from experiment 2;
– one pre-treatment case and one SDW case from experiment 3.

User-friendly spreadsheet

The qualitative production-theoretical impact matrix, partial budgeting and frontier analysis are incorporated into a user-friendly spreadsheet. Together with this paper, the spreadsheet can be freely downloaded from the website of the Biomedical Technology, Epidemiology and Food Safety Global Network CENTAUR (http://centaur.vri.cz, From research to farm: *ex ante* evaluation of strategic deworming in pig finishing 2010-09-29). The Excel spreadsheet consists of four worksheets. Three worksheets allow for analyzing parasitological research results of SDW, while a fourth worksheet allows for linking SDW effects to individual farm data in order to provide farm-specific advice on the impact of SDW. The fourth worksheet can be used separately from the other worksheets.

To analyze parasitological research results of SDW, the spreadsheet user has to introduce values of traditional key performance indicators (feed conversion, mortality rate, average daily weight gain etc.) before and after SDW into the worksheet 'production-theoretical impacts'. Traditional key performance indicators are then transformed into production-theoretical key performance indicators (inputs, outputs etc.). The worksheets 'partial budgeting' and 'frontier analysis' use the production-theoretical key performance indicators to assess economic and environmental effects of SDW with the respective methods. Moreover, the worksheet 'frontier analysis' presents additional improvement margins that can be obtained before and after SDW through optimizing cost allocative efficiency.

The worksheet 'individual farm effect' combines efficiency changes due to SDW to farm-specific data, in order to assess ex ante farm-specific impacts of SDW. The user has to introduce both efficiency changes due to SDW, which can be assessed previously in the worksheet 'frontier analysis', and values of farm-specific key performance indicators before SDW. If the user does not dispose of experimental data on SDW, the worksheet 'individual farm effect' can be applied separately by introducing farm-specific key performance indicators and combining them with efficiency changes due to SDW that are presented in this paper.

RESULTS

Qualitative production-theoretical impact matrix

Table 4 presents a qualitative production-theoretical impact matrix, linking the parasitological research results to changes in production-theoretical key performance indicators. Increasing average daily weight gain results in more rotations within a given time span. More rotations imply that more inputs are used and more output is produced. However, more rotations also imply that the sum of non-occupancy time between rotations increases. Hence, a higher average daily weight gain reduces the number of APFs. A lower mortality rate results in more slaughter pigs within a given finishing period. At the same time, more feed is used and the number of APF increases. A better feed conversion leads to less feed use within a given finishing period. Lower medication costs result in a lower price per rotation. Finally, the output price rises due to an improved carcass quality.

Partial budgeting

The partial budgeting results for the three SDW experiments are expressed per APF per year (Table 5). Similar to the statistical analysis for the parasitological research results, the nonparametric Wilcoxon two sample test is used for experiment 1.

SDW causes revenues to increase: the lower mortality rate and higher average daily weight gain result in more pigs that can be finished within a given time period. Moreover, the improved carcass quality results in a higher price per kg marketable pig. Variable costs remain almost constant, except for experiment 1. The variable costs increase for experiment 1 is less straightforward since average daily weight gain, feed conversion and mortality improve. The explanation lies in the synergetic and counteracting driving factors that affect both the costs itself and the expression per APF per year. Indeed, a better feed conversion leads to less feed costs. However, a lower mortality means that more pigs are finished, so feed costs increase. An improved average daily weight gain means more rotations within a given time period, which implies higher costs for piglets. Note that also the number of APF is affected. A lower mortality rate increases the number of APF while an increased average daily weight gain has the opposite effect: more rotations within a given time period means that the total amount of time that a compartment is not occupied between rotations increases.

Gross margin, calculated as revenues minus variable costs, increases with 5 to 11 € per APF per year (+7% to +11%). This is mainly due to higher revenues, since costs hardly change. The gross margin increase is statistically significant at the 10% level.

The change in nitrogen balance can also be explained by synergetic and counteracting driving factors. The nitrogen balance decreases with a better feed conversion. However, when more pigs are finished due to a lower mortality, more feed is consumed. The balance also increases with an improved average daily weight gain because more piglets are started up within a given time period. For experiments 2 and 3, the improved nitrogen balance reinforces the increase of gross margin, leading to a pronounced improvement of eco-efficiency (+12% and +16%). For field experiment 1, the increased nitrogen balance counteracts the improved gross margin, resulting in a less pronounced increase of eco-efficiency (+5%).

Table 4. Effect of a change in traditional key performance indicators on production-theoretical key performance indicators

	Kg marketable pig (Y)	Feed (X_1)	Rotations (X_2)	APF (X_3)	Pig price (P_Y)	Rotation price (P_{X2})
Feed conversion ↓	/	↓	/	/	/	/
Average daily weight gain ↑	↑	↑	↑	↓	/	/
Mortality rate ↓	↑	↑	/	↑	/	/
Medication costs ↓	/	/	/	/	/	↓
Carcass value ↑	/	/	/	/	↑	/

Y = output; X = input; P = price; APF = average present finisher

Table 5. Economic and environmental effects of SDW assessed with partial budgeting

Experiment No.	Aggregate effect	Pre–treatment	SDW trial	Absolute difference	*P*-value
1	revenues (euro/APF/year)	319.0	327.9	8.8	0.033
	variable costs (euro/APF/year)	242.0	245.7	3.7	0.11
	gross margin (euro/APF/year)	77.0	82.2	5.1	0.081
	nitrogen balance (kg/APF/year)	11.3	11.5	0.2	0.26
	eco–efficiency (euro/kg)	6.86	7.20	0.34	0.34
2	revenues (euro/APF/year)	346.7	353.8	7.0	N.R.
	variable costs (euro/APF/year)	262.7	262.6	–0.2	
	gross margin (euro/APF/year)	84.0	91.2	7.2	
	nitrogen balance (kg/APF/year)	12.4	12.0	–0.4	
	eco–efficiency (euro/kg)	6.79	7.61	0.82	
3	revenues (euro/APF/year)	385.2	394.1	8.9	N.R.
	variable costs (euro/APF/year)	291.3	289.5	–1.8	
	gross margin (euro/APF/year)	94.0	104.6	10.6	
	nitrogen balance (kg/APF/year)	14.0	13.5	–0.5	
	eco–efficiency (euro/kg)	6.70	7.76	1.06	

SDW = strategic deworming; APF = average present finisher; N.R. = not registered

For experiment 1, above partial budgeting uses both statistically significant and insignificant parasitological research results. If only the statistically significant change in mortality ($P = 0.0042$) is included in the analysis, a gross margin increase of 2.9 € per APF per year ($P = 0.38$) is obtained, compared to the increase of 5.1 € per APF per year ($P = 0.081$) when all parasitological research results are included. This illustrates the necessity to include statistically significant and insignificant research results in the production-theory based partial budgeting.

The partial budgeting results also illustrate the leverage effects on the overall economic or environmental outcome. In experiment 1, for example, SDW causes revenues to increase with 2.8%, while variable costs increase with 1.5%. Since revenues increase more than variable costs and gross margin is defined as the difference between revenues and variable costs, the change in terms of percentage of the gross margin is more elevated (+6.8%). For experiments 2 and 3, the leverage effect is even more pronounced because revenues increase and variable costs decrease. Despite this leverage effect on the gross margin, the SDW impacts are only statistically significant at the 10% level. Apparently, the variation in zootechnical key performance indicators is also amplified when using them in the production-theoretical framework.

In order to see whether results are robust with respect to the well-known pig cycle, we perform a sensitivity analysis. We use pig prices that fluctuate with 10% to 20%. The absolute impact of SDW on the gross margin decreases and becomes statistically more insignificant when the pig price diminishes. The impact of SDW becomes only statistically significant (at the 5% level) when the pig price is 20% higher. Nevertheless, the more pronounced leverage effect causes the relative impact on the gross margin to be more elevated when the slaughter pig price is lower. A similar analysis, with a 10% to 30% variation in the feed price, shows that absolute impacts of SDW on the gross margin are more or less independent from the feed price level. Relative impacts become important in unfavourable markets conditions. This indicates that SDW can be an interesting option for both the risk-averse and the profit maximising farmer.

Frontier analysis

Applying SDW improves both input and output oriented technical efficiencies (Table 6). The effect is less pronounced for experiment 1 (+0.007 or +0.7%) and most pronounced for experiment 3 (+0.014 or +1.4%). In general, allocative efficiency levels hardly change. For experiments 2 and 3, cost

Table 6. Efficiency effects of SDW

Experiment No.	Efficiency type	Pre–treatment	SDW trial	Absolute difference	*P*-value
1	technical (input oriented)	0.966	0.974	0.007	0.41
	technical (output oriented)	0.967	0.974	0.007	0.41
	cost	0.959	0.965	0.006	0.54
	environmental	0.505	0.501	–0.004	0.29
	cost allocative	0.992	0.991	–0.001	0.32
	environmental allocative	0.522	0.515	–0.008	0.10
2	technical (input oriented)	0.968	0.979	0.011	N.R.
	technical (output oriented)	0.968	0.980	0.011	
	cost	0.960	0.973	0.013	
	environmental	0.504	0.511	0.007	
	cost allocative	0.991	0.993	0.002	
	environmental allocative	0.521	0.522	0.001	
3	technical (input oriented)	0.973	0.987	0.014	N.R.
	technical (output oriented)	0.973	0.987	0.014	
	cost	0.962	0.977	0.016	
	environmental	0.498	0.505	0.007	
	cost allocative	0.989	0.990	0.002	
	environmental allocative	0.512	0.512	0.000	

SDW = strategic deworming; N.R. = not registered

allocative efficiency slightly increases and strengthens the technical efficiency improvement, resulting in a more pronounced improvement of cost efficiency. For experiment 1, the environmental allocative efficiency decrease compensates the technical efficiency improvement and results in a decrease of environmental efficiency. None of the efficiency changes is statistically significant.

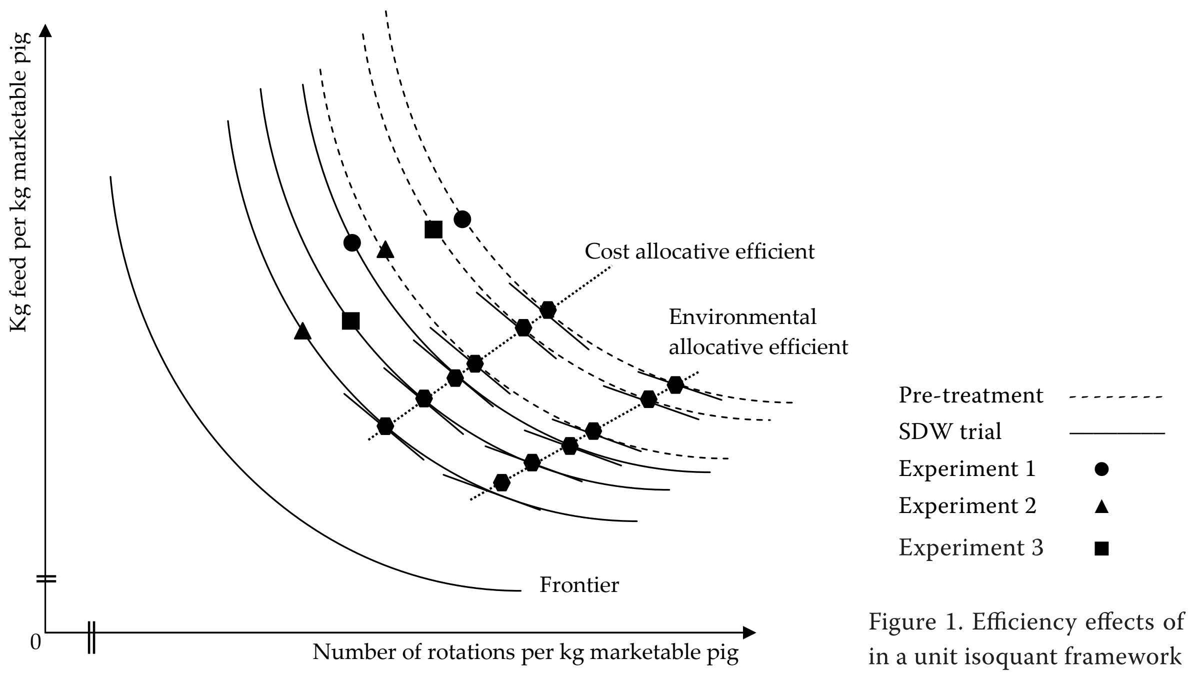

Figure 1. Efficiency effects of SDW in a unit isoquant framework

Figure 1 illustrates (for illustrative purposes, exact proportions are not respected) the SDW effects on average efficiency levels, using unit-isoquants. A unit-isoquant represents the input substitution possibilities per unit of output. The unit-isoquant that represents the frontier is located closest to the origin. Allocative efficient input combinations are found where isocost or isonutrient lines are tangent to the isoquant (Coelli et al., 2007).

SDW increases input oriented technical efficiency: the corresponding unit-isoquant shifts towards the frontier. The same amount of kg marketable pigs can be produced with less feed and rotations. The increase in input oriented technical efficiency is a straightforward consequence of improved feed conversion and mortality. For each experiment, more rotations and less feed have to be used per kg of marketable pig production in order to increase cost and environmental allocative efficiencies. Consequently, input substitution yields a positive trade-off between economic and environmental performance. Improving economic performance through using more rotations and less feed corresponds to increasing environmental performance.

The graphical representation helps to explain why SDW in experiment 1 causes both cost and environmental allocative efficiencies to diminish. The decreased mortality causes more feed to be used per rotation since more pigs are finished. Mortality also diminishes substantially in experiment 3. Here, allocative efficiencies do not decrease because the decreased mortality is compensated by an improved feed conversion. A better feed conversion results in less feed to be used per rotation if the slaughter weight remains unchanged.

Table 7 presents the additional income that can be gained through producing cost allocative efficient. In experiment 1, SDW causes the potential improvement margin to increase since cost allocative efficiency decreases. Cost allocative efficiency levels increase in the other experiments, resulting in decreased potential improvement margins.

Table 7. Improvement margins (€ per kg marketable pig) through optimizing cost allocative efficiency

Experiment No.	Pre-treatment	SDW trial
1	0.0069	0.0076
2	0.0073	0.0058
3	0.0097	0.0081

SDW = strategic deworming

Although frontier analysis has more diagnostic power than partial budgeting, results are less discriminatory. The efficiency scores do not change substantially due to SDW. This is mainly because frontier analysis only considers price (and nutrient content) proportions to detect allocative efficient combinations of inputs. Absolute price levels are not taken into account.

Upgrading results to farm-specific information

So far, a production-theoretical framework is constructed to aggregate parasitological research results on SDW. Based on the assessed changes in production-theoretical key performance indicators, partial budgeting and frontier analysis are used to obtain an improved diagnosis of economic and environmental effects. The question is now how these results can be extrapolated to practical situations. Can they be linked to individual farm data and allow for farm-specific advice?

To upgrade results for farm-specific decision support, we use frontier analysis in combination with partial budgeting. We start from both input and output oriented technical efficiency scores of each of the 117 farms of the FADN sample. Compared to this sample, the experimental pre-treatment data show already high efficiency scores. This might indicate that the experiments may be too optimistic and hampers a direct extrapolation of the efficiency scores obtained under SDW to a larger sample of real farms. However, since technical efficiency improvements due to SDW are rather robust for the three experiments, efficiency shifts are used for extrapolation purposes. For each of the 117 farms of the FADN data sample, the average relative input and output oriented technical efficiency improvements of the three experiments (respectively +1.12% and +1.11%) are applied. After these improvement are translated into new production-theoretical key performance indicators, partial budgeting is used for calculating the expected new economic outcome. For the worst performing farm, the gross margin improves from 9.7 € to 14.9 € per APF per year (+54%), while for the best performing, the gross margin increases from 115.7 € to 123.9 € per APF per year (+7.1%).

The developed user-friendly spreadsheet allows for linking efficiency changes due to SDW to farm-specific data, in order to assess ex ante farm-specific impacts of SDW.

DISCUSSION

This paper uses production theory and adopts methods from managerial sciences to upgrade partial information from parasitological research for farm-specific decision support. The particular case of SDW shows the indispensability of a coherent production-theoretical framework to integrate synergetic and counteracting parasitological research results. The framework consists of an appropriate definition of production-theoretical key performance indicators, a qualitative linking of traditional and production-theoretical key performance indicators and a quantitative translation of this link.

Having production-theoretical key performance indicators then enables an improved partial budgeting and frontier analysis, well-known in management sciences. Both methods appear to be very complementary. Frontier analysis provides a more powerful diagnosis through positioning farms in a larger sample, indicating optimization pathways and analyzing economic-environmental trade-offs. Partial budgeting yields more discriminatory and communicative results, but only provides a discrete outcome, without indicating further optimization possibilities. Optimization becomes of particular interest for farms when improvement margins are small and farm income is under pressure.

Application of the production-theoretical framework on SDW in pig finishing shows a win-win effect on economic and environmental performance. Positive effects are robust under varying market conditions. This is mainly due to technical efficiency improvements, which can be an important guideline for the individual farmer to translate generic experimental information to farm-specific conditions. Through the leverage effect, minor productivity changes due to SDW have an amplified impact on farm income. Spreadsheet models going beyond traditional partial budgeting may help the farm-specific translation from trial to farm.

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