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Assessing short-term economic consequences of cow-calf contact systems in dairy production using a stochastic partial budgeting approach

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Introduction: While early separation of dairy calves after birth has been debated from an ethical and animal welfare lens, the economic evidence surrounding alternative cow-calf contact (CCC) systems is scarce.

Methods: To address this knowledge gap, we assessed the economic consequences of CCC systems using data from the Agriwise database as well as parameters from published literature in a stochastic partial budget model. The implementation of CCC is very diverse between farms, so in our study we therefore selected a limited number of CCC systems to assess. The examined CCC systems were: (i) dam rearing with limited contact at milking (15 minutes twice a day for 115 days) with no manual milk feeding; (ii) dam rearing with 21-day full contact, after which calves are manually fed 8 kg of whole milk for 94 days; and (iii) mixed calf rearing with using both dams and foster cows with full contact; calves are initially kept with their dams and then moved to foster cows at 9 days of age.

Results: We found that adoption of CCC systems was associated with decreases in contribution margins in the range of 1 to 5.4%, as compared to a rearing system where the calves were separated from their dams after one day and were manually fed 8 kg of milk for 12 weeks. These results illustrated that the costs associated with CCC systems may be fairly high under certain circumstances and may prohibit farmers from adopting this practice. Sensitivity analysis suggested that differences in milk sales, assumptions on changes in labor requirements, and changes in daily calf weight gain depending on CCC system were the main variables that governed the net impact on the contribution margins.

Discussion: We did not include building costs in the analyses assuming that barn structures may not change in the short-term. The study focused only on short-term pecuniary associations between changes in CCC systems and contribution margins. To strengthen the economic decision-making around CCC systems, future research should consider non-monetary impacts of different CCC systems, as well as long-term economic impacts of these production strategies.

KEYWORDS

dairy farming, milk production, organic farming, calf rearing, animal welfare

1 Introduction

Public concern for the quality of life of farm animals has received much attention in recent years (Ellis et al., 2009; Ahmed et al., 2020). In the dairy sector specifically, lack of cow-calf contact (CCC) after birth is one of the more contentious practices, which is generally controversial for the public (Busch et al., 2017; Placzek et al., 2021; Sirovica et al., 2022). Notably, both consumers and dairy farmers have shown a heightened interest in systems that facilitate prolonged contact between cows and calves during the early stages of life.

A CCC system is any type of housing or management system that enable dairy calves to interact with either their biological dam or a foster cow during the suckling period (Sirovnik et al., 2020). These CCC systems can vary considerably in terms of the type and duration of physical contact allowed between dams and calves (reviewed by Johnsen et al., 2016). In a recent survey conducted by Eriksson et al. (2022), which targeted European dairy farmers implementing CCC practices, it was shown that CCC systems are employed across farms of varying sizes and with different housing systems. The authors reported that the most frequently used CCC systems included part-time CCC, where the calves were allowed to suckle their dams for restricted periods during the day (most commonly around milking), and mixed CCC systems, where calves could suckle both their dams and foster cows, either consecutively or concurrently (if kept in mixed groups). It was also common to let the calf suckle the dam for a period after calving, followed by artificial rearing. Additionally, systems allowing half-day CCC, either during the day or night, were also practiced on a low number of farms.

Separating cow and calf during the first day and rearing the calf artificially is, however, the most common calf rearing strategy used in intensive dairy production. One frequently stated reason for employing early separation is that this strategy results in a higher amount of saleable milk, which in turn increases farm profit (Barth, 2020; Nicolao et al., 2022; Wenker et al., 2022). Thus, understanding the costs and benefits of different CCC systems is of utmost importance, if the dairy sector is going to be able to move towards a production system that aligns better with the expression of natural behavior of the animals and current societal values in an informed way.

To assess the short-term economic impacts of CCC systems, we employ stochastic partial budgeting (as in e.g. Alvåsen et al., 2017; Jerlström et al., 2022; Owusu-Sekyere et al., 2023). Partial budgeting is a financial tool used to assess the costs and benefits associated with a specific change in an individual enterprise within the business operation, compared to the enterprise baseline. This tool specifically focuses on the implications of the intended change in a business operation by comparing the benefits and costs resulting from implementing the alternative, with respect to the current practice (Dhoubhadel and Stockton, 2010). By introducing informed uncertainty (stochasticity), based on previous information about the evaluated variables, this approach not only provides a point estimate of the effect that the change has on the contribution margin but also capture the uncertainty of the estimate. A subsequent sensitivity analysis provides information on the most important parameters that govern the cost-benefit relationship. This approach has previously been used to conduct cost-benefit analysis for several animal welfare improvement strategies in varied contexts (Ahmed et al., 2020; Leger et al., 2021; Jerlström et al., 2022).

Research in the field of the economics of farm animal welfare has yielded a complex picture of the impact of welfare enhancements on farm profitability, with both positive and negative consequences being documented (e.g. Jensen et al., 2008; Stott et al., 2012; Henningsen et al., 2018; Ahmed et al., 2020). For dairy farms, the literature is scarce but a relationship between animal health indicators (e.g. mastitis, lameness, metabolic disorders, digestive disorders, and reproductive disorders) and technical efficiency has resulted in somewhat conflicting findings (Lawson et al., 2004a; Lawson et al., 2004b; Barnes et al., 2011; Hansson et al., 2011; Tremetsberger et al., 2019). A review by af Sandeberg et al. (2023) highlighted the lack of research on health and welfare aspects that goes beyond the most important production diseases and linking these aspects to the economic and non-monetary benefits of improving dairy cattle welfare.

A competitive dairy sector requires that farms are not only economically viable, but also aligned with the animal welfare standards requested by society and consumers. However, there is lack of knowledge regarding the economic viability and practical feasibility of CCC systems in dairy production. Regarding the economic aspects of CCC systems, Knierim et al. (2020) laid out a conceptual framework for assessing the socio-economic consequences associated with various CCC systems. In their work, Knierim et al. (2020) itemized factors that should be taken into account in such evaluations. They concluded that a substantial degree of variability exists within rearing systems and specific farm conditions, and that an intricate interplay of numerous influential factors further complicates the assessment. Moreover, using a deterministic linear programming model, Asheim et al. (2016) found positive economic effects of longer suckling periods in dairy-beef dual purpose systems due to better calf health and higher calf weight at weaning. Our work extends that of Asheim et al. (2016) and Knierim et al. (2020) by using an analysis method allowing both deterministic and stochastic elements.

The objective of the present study was to evaluate the short-term economic consequences of three CCC systems used on European farms, by simulating the costs and benefits in each scenario using a partial budget approach. The findings can serve as a basis for further research on whole-farm economic consequences of CCC systems and to guide stakeholders in making informed decisions.

2 Materials and methods

2.1 Farm simulation model

A farm simulation model for an organic dairy herd was constructed in Microsoft Excel 2016 (Microsoft, Redmond, WA, USA). This model was used to evaluate the economic impact of different CCC scenarios on a yearly basis using stochastic partial budget models.

A generic organic farm with 41 cows (including 8 dry cows) of dual-purpose breed, producing 7000 kg ECM per cow and year, was used to evaluate different CCC rearing scenarios against a baseline scenario of separating cows and calves after one day. The CCC scenarios were created based on the most common CCC strategies identified by Eriksson et al. (2022), who performed interviews with CCC farmers from Austria, France, Germany, Italy, Sweden and Switzerland. These quantitative interviews showed that the period cows and calves were kept together varied between 7 and 305 days (Q1 = 50, median= 90, Q3 = 150), that CCC was practised in a large variety of housing and management systems and that calves could be reared together with their dam, with foster cows, or using a combination of the two systems. The majority of farmers in the survey by Eriksson et al. (2022) had organic production and the number of adult dairy cows per farm was centered around the average herd size in each country, except for Italy and Sweden where the participating farmers had a smaller herd size than the national average.

The baseline and the three alternative CCC scenarios are described in Table 1 and their evaluated parameters are provided in Table 2.

Baseline Scenario: Organic herd practicing early separation from the mother during the first day after calving. Calves were manually fed 8 liters (Kalvportalen, 2021) of whole milk for 12 weeks according to EU regulations (Commission Regulation EC 889/2008).

Scenario 1: Dam rearing with contact at milking (15 minutes twice a day for 115 days). There was no manual milk feeding and the median amount of suckled milk per calf per day was 5.1 kg.

Scenario 2: Dam rearing with full contact for initial 21 days, after which calves are manually fed 8 liters of whole milk for 94 days.

Scenario 3: Mixed rearing with 24 hours contact; calves are initially kept with their dams (median milk intake of 10.9 kg/day) and then moved to foster cows at 9 days (survey median) of age (where median milk intake is 8.5 kg/day for 106 days).

Considering the above mentioned scenarios, the stochastic partial budget model for each of the scenarios was built using economic data from a Swedish livestock production database (Agriwise, 2020) and reported values of relevant biological parameters from the literature, complemented with survey data (Eriksson et al., 2022) and input from two Swedish farmers who had experience of separating cows and calves at different ages. The partial budgeting framework allowed us to isolate the effects of the different calf rearing strategies on the farm contribution margin by only focusing on the economic parameters likely to differ between

TABLE 1 Description of scenarios[1] used to evaluate economic consequences of CCC systems.

Parameters	Baseline	Scenario 1	Scenario 2	Scenario 3
Suckled dam (days)	1	115	21	9
Suckled foster (days)	0	0	0	106
Manual milk feeding (days)	90	0	94	0
Manually fed milk (kg/d)	8	0	8	0
Suckled milk (kg/d)	0	5.1 (Range: 3-10)	10.9 (Range: 9.2-12)	Dam: 10.9 (Range: 9.2-12) Foster: 8.5 (Range: 7.0-10)
Daily weight gain (g/day)	900	700	1100 for 21 days, then 900.	1100 for first 9 days, then 950

[1]Scenario 1: Dam rearing with limited contact at milking (15 minutes twice a day for 115 days) with no manual feeding; Scenario 2: Dam rearing with 21-day full contact, after which calves are manually fed 8 kg of whole milk for 94 days; and Scenario 3: Mixed calf rearing with using both dams and foster cows with full contact; calves are initially kept with their dams and then moved to foster cows at 9 days of age.

TABLE 2 Overview of input variables used in the partial budget model for Scenario 1 (S1; dam rearing with limited contact at milking twice per day), Scenario 2 (S2; Dam rearing with 21-day full contact, after which calves are manually fed 8 kg of whole milk for 94 days) and Scenario 3 (S3; mixed rearing with 24 hours contact; calves initially kept with their dams and then moved to foster cows at 9 days).

Parameter	Scenario	Value	Source	Type	Distribution
Calf herd size	All	35	Eriksson et al. (2022)	Deterministic	–
Suckling dam	S1	115 d	Eriksson et al. (2022)	Deterministic	–
	S2	21 d	Eriksson et al. (2022)	Deterministic	–
	S3	9 d	Eriksson et al. (2022)	Deterministic	–
Suckling foster	S3	106 d	Eriksson et al. (2022)	Deterministic	–
Manual feeding	S2	94 d	Eriksson et al. (2022)	Deterministic	–
Milk intake per calf suckling dam	S1	5.1 kg/d	Interviews with Swedish farmers	Stochastic	Triangular (3.0, 5.1, 10)
	S2, S3	10.9 kg/d	Interviews with Swedish farmers	Stochastic	Triangular (9.2, 10.9, 12)
Milk intake by calf suckling foster cow	S3	8.5 kg/d		Stochastic	Triangular (7.0, 8.5, 10.0)
Milk intake per calf when manually fed	S2	8 kg/d	Kalvportalen (2021)	Deterministic	–
Additional daily gain[1]	S1	-0.2 kg/d	Gelsinger et al. (2016)	Stochastic	Triangular (-0.1, -0.2, -0.3)
	S2, S3	+0.2 kg/d	Interviews with Swedish farmers; Kalvportalen (2021)	Stochastic	Triangular (0.1, 0.2, 0.3)
	S3	+0.05 kg/d for foster days	Kalvportalen (2021)	Stochastic	Triangular (0.03, 0.05, 0.07)
Change in mortality rate	S1	+1.7%	Svensson et al. (2006)	Stochastic	Triangular (0.011, 0.017, 0.024)
	S2, S3	-1.7%	Svensson et al. (2006)	Stochastic	Triangular (-0.011, -0.017, -0.024)
Change in feed intake	S1	+10%	Interviews with Swedish farmers	Stochastic	Triangular (0.0925, 0.10, 0.1075)
	S2, S3	-10%	Interviews with Swedish farmers	Stochastic	Triangular (-0.0925, -0.10, -0.1075)
Revenue per Calf	All	237 €	Agriwise (2020)	Deterministic	–
Concentrate	All	0.29 €/kg	Agriwise (2020)	Stochastic	Triangular (0.25, 0.29, 0.33)
Silage	All	0.12 €/kg	Agriwise (2020)	Stochastic	Triangular (0.094, 0.125, 0.141)
Milk price	All	0.44 €/kg	Agriwise (2020)	Stochastic	Triangular (0.43, 0.44, 0.46)
Meat price	All	3.37 €/kg	HK Scan (2021)	Stochastic	Triangular (3.225, 3.391, 3.5)

[1]Daily gain assumed to be 900 g/day at the baseline (Kalvportalen, 2021).

the rearing strategies. The contribution margin describes the difference between the revenue generated by a specific change and the variable costs associated with that change within a farm business. Contribution margin is a key component in partial budgeting, aiding in the evaluation of short-term financial decisions and their potential impact on a farm's overall profitability. The models included both deterministic and stochastic parameters. The decision to keep a variable deterministic or stochastic came from the nature of the parameter. For example, parameters such as prices or milk intake of calves can show considerable variation and therefore are considered stochastic. This stochasticity is introduced to take into account the uncertainty around the true value of a parameter, such that the estimation procedure generates results with a distribution, representing the uncertainty in results (Liang et al., 2017). However, the number of days associated with a certain scenario or number of calves on the farm were kept as deterministic parameters.

A sensitivity analysis of the impact of the stochastic parameters on net change in contribution margin was performed using the @Risk (Palisade, Ithaca, NY) add-in in Microsoft Excel with 5000 iterations using Latin Hypercube sampling to ensure replicable results across simulations. Tornado diagrams with regression coefficients were prepared, in which @Risk ran a multiple regression analysis using one observation per iteration with the outcome of interest and the simulated values of the stochastic variables as independent variables. The length of the bars in these plots represent the importance of variables that drive changes in net contribution margin in the three scenarios. Furthermore, a t-test was used to compare differences in contribution margin between the scenarios and the baseline.

In the sections below, we provide the modelling assumptions related to each of the above scenarios as well as information on the deterministic and stochastic input variables, the estimated parameters and their associated distributions of the stochastic variables, and from which information sources values for these parameters were identified.

Input variables, units, and distributions for all the scenarios are given in Table 2. For each of the alternative CCC scenarios, we assumed that the costs associated with changes in building structure were negligible, at least in the short term (following Ahmed et al., 2020). It was further assumed that each typical farm had 35 calves along with 41 cows (with 8 dry cows).

In a partial budget framework, the benefits and costs are estimated using the following equation:

$$Net\ change = (increased\ revenue + reduced\ cost) - (increased\ cost + reduced\ revenue) \quad (1)$$

2.2 Scenario 1: Dam rearing with limited contact at milking (15 minutes twice a day for 115 days)

Input parameters, units and distributions are given in Table 2. In this scenario, there was no manual milk feeding and the median amount of suckled milk per calf per day was 5.1 kg. We used equation (1) and inserted the following elements:

$$\begin{aligned} &Increased\ revenue \\ &= number\ of\ calves \times additional\ daily\ weight\ gain \times price\ of\ meat \times 90\ days \\ &+ number\ of\ calves \times additional\ leftover\ milk \times price\ of\ milk \times 90\ days \end{aligned} \quad (2)$$

and where *additional leftover milk = (8 - milk intake per calf).*

The increased revenue measure has two components and whether these components are positive or negative depends on whether the calf suckled more or less milk and if the calves have lower or higher daily weight gain compared to the baseline. The increase in revenue due to an increase in additional daily weight gain (A-DG) is positive according to the estimated milk intake suggested by Gelsinger et al. (2016) only if *milk intake per calf* is greater than baseline scenario of 8 liter/day. It is zero if milk consumed is comparable (from 6 to 8 liter per day) to the baseline. If *milk intake per calf* is less than 6 liter/day, we assume the A-DG is negative and thus this number becomes a decrease in revenue. The increase in revenue applies directly to male calves since they are generally sold to beef fattening units. On many dairy farms, male calves are moved to a fatting unit, but in the scenarios used in this study all calves were reared on the fictive farm during the whole milk feeding period. However, for female calves that may be kept on the farm as replacement heifers, the increase in weight and the associated value assigned using equation (2) captures the indirect positive effects of this weight gain, which may include better health, stronger immune system and improved fertility in later life.

Similarly, the second component related to milk sales is positive if *milk intake per calf* is less than the baseline scenario, illustrating that there is more milk left over for sales compared to the baseline, thus increasing revenue. However, this measure becomes negative when milk intake per calf goes beyond 8 liter/day, illustrating that now the farm has less milk available for sale to the market. Consequently, this measure can be thought of as increase or decrease in revenue depending on the value of *milk intake per calf*.

Apart from these two components, there is also an reduction in milk revenue that comes from the additional 25 days of keeping the calves on milk feed (in the baseline scenario calves are fed milk for 90 days). Thus, this reduction in revenue can be estimated as:

$$Reduced\ revenue = number\ of\ calves \times milk\ intake\ per\ calf \times price\ of\ milk \times 25\ days \quad (3)$$

Apart from the changes in revenue, another part we account for is related to increased costs in this scenario, where:

$$\begin{aligned} Increased\ cost = number\ of\ calves \times (&increase\ in\ feed\ intake \times price\ of\ feed \times number\ of\ days \\ &+ increase\ in\ mortality\ rate \times revenue\ per\ calf) \end{aligned} \quad (4)$$

Under the assumption that the calves are drinking less milk than the baseline, they will compensate the reduced energy intake from milk with higher feed intake (silage and concentrate), thus the feed costs would go up. We assume that the feed intake would be 10% higher for calves in this scenario as compared to the baseline. Secondly, the reduced milk intake per calf per day is assumed to have a negative effect on calf health and increase mortality. This impact is captured by a 1.7% increase in mortality rates for this scenario as compared to the baseline (Svensson et al., 2006) multiplied by the average revenue per calf as obtained from the Agriwise (2020) data.

In this scenario, we assume no changes in *reduced cost*, and so only increases and reductions in revenue and increases in costs are taken into account in the analysis.

2.3 Scenario 2: Dam rearing with full contact for initial 21 days, after which calves are manually fed 8 kg of whole milk for 94 days

Input parameters, units, and distributions are given in Table 2. Once again, we are using a partial budget framework, hence we still use equation (1), but the elements included in it are changed according to the scenario. In this case, the increase in revenue primarily comes from higher A-DG due to increased milk intake per calf during the first 21 days of life. Thus:

$$\begin{aligned} &Increased\ \ revenue \\ &\quad = number\ \ of\ \ calves\ \ \text{x}\ \ A \\ &\qquad - DG\ \ \text{x}\ \ price\ \ of\ \ meat\ \ \text{x}\ \ 21\ \ days \end{aligned} \tag{5}$$

We assume that the A-DG happens according to the estimate suggested by Kalvportalen (2021), given that *milk intake per calf* is greater than the baseline scenario of 8 liter/day.

Next, we examine how this scenario reduces revenue from milk (1) during the first 21 days of life when the calves have full day contact with the dam (first half of equation 6), and (2) during the additional 25 days of artificial milk feeding beyond the baseline 90-day period (second half of Eq 6). Thus, this reduction in revenue can be estimated as:

$$\begin{aligned} &Reduced\ revenue \\ &\quad = number\ \ of\ \ calves\ \text{x}\ additional\ milk\ allowance \\ &\qquad \text{x}\ price\ of\ \ milk\ \text{x}\ 21\ days \\ &\quad + number\ \ of\ \ calves\ \text{x}\ milk\ intake\ per\ calf \\ &\qquad \text{x}\ price\ of\ \ milk\ \text{x}\ 21\ days \end{aligned} \tag{6}$$

Apart from the increases and reductions in revenue, we also estimate the reduced costs associated with scenario 2, where:

$$\begin{aligned} &Reduced\ cost \\ &\quad = number\ \ of\ \ calves\ \ \text{x}\ (decrease\ \ in\ \ feed\ \ intake \\ &\qquad \text{x}\ \ price\ \ of\ \ feed\ \ \text{x}\ \ (21 + 25)\ \ days \\ &\quad + decreased\ in\ mortality\ rate\ \text{x}\ revenue\ per\ calf \end{aligned} \tag{7}$$

Given that calves are drinking more milk than the baseline, they will have a lower feed intake (silage and concentrate), thus the feed costs would go down. We assume that the feed intake would be 10% lower for calves in this scenario compared to the baseline, both during the initial 21 days when they can suckle freely and during the last 25 days of the milk feeding period when the baseline has no milk provision. As the increased milk intake per calf per day can help improve calf health and decrease mortality, this is captured by assuming a 1.7% decrease in mortality rates compared to the baseline (Svensson et al., 2006).

In this scenario, we assume no changes in *increased cost*, so only increases and reductions in revenue and reductions in costs are taken into account.

2.4 Scenario 3: Mixed rearing with 24 hours contact; calves are initially kept with their dams and then moved to foster cows at 9 days of age

Input parameters, units, and distributions are given in Table 2. We still use equation (1), but the elements included in it are changed according to the scenario. In this scenario, the increase in revenue primarily comes from increased A-DG due to increased milk intake per calf during (1) the first 9 days of life when they can suckle the dam freely (median milk intake 10.9 kg/day; A-DG assumed to be +0.2 kg/day compared to baseline if milk intake per calf is greater than 8 litres/day), and (2) during the rest of the contact period (106 additional days) when multiple calves suckle the same foster cow (median milk intake 8.5 kg/day; A-DG assumed to be +0.05 kg/day), according to the estimate suggested by Kalvportalen (2021). This is shown in equation (8) below:

$$\begin{aligned} &Increased\ revenue \\ &\quad = number\ \ of\ \ calves\ \text{x}\ price\ \ of\ \ meat\ \ \text{x}\ \ (A \\ &\qquad - DG_{9\ days}\ \ \text{x}\ \ 9\ \ days + \ \ A - DG_{106\ days}\ \ \text{x}\ \ 106\ \ days) \end{aligned} \tag{8}$$

Next, we examine how this scenario can reduce milk revenues during the first 9 days of life, during the 81 days comparable with the baseline, and during the additional 25 days of artificial milk feeding beyond the 90-day baseline period. As milk intake is greater than the baseline during the first 9 days when the calves can suckle freely from the dam, this means that some milk sales are foregone during this period, which is reflected in the first part of equation 9. The second half of the equation estimates the milk sales forgone during the 81 comparable days if milk intake per calf is greater than 8 kg/day and the third part shows the reduced revenues due to the additional 25 days of milk feeding, when the baseline calves are already weaned. Thus, this reduction in revenue can be estimated as:

$$\begin{aligned} &Reduced\ revenue = \\ &number\ \ of\ \ calves\ \text{x}\ additional\ milk\ allowance\ \text{x}\ price\ \ of\ \ milk\ \text{x}\ 9\ days \\ &+\ number\ \ of\ \ calves\ \text{x}\ additional\ milk\ allowance\ \text{x}\ price\ \ of\ \ milk \\ &(if\ \ milk\ intake > 8)\ \text{x}\ 81\ days \\ &+\ number\ \ of\ \ calves\ \text{x}\ milk\ intake\ per\ calf \\ &\text{x}\ price\ \ of\ \ milk\ \text{x}\ 25\ days \end{aligned} \tag{9}$$

Apart from the increases and reductions in revenue, we also estimate the reductions in costs associated with scenario 3, where:

$$\begin{aligned} &Reduced\ \ cost\ \ = \\ &\quad number\ \ of\ \ calves\ \ x\ \ (decrease\ \ in\ \ feed\ \ intake\ \ x\ \ price\ \ of\ \ feed\ \ x \\ &\quad (9\ +\ 25)\ \ days\ +\ decrease\ \ in\ \ mortality\ \ rate\ \ x\ \ revenue\ \ per\ \ calf) \end{aligned} \tag{10}$$

Given that calves are drinking more milk than the baseline during the first 9 and the last 25 days of the milk feeding period, they will consume less solid feed (silage and concentrate) during these periods, thus the feed costs will go down. We assume that the feed intake would be 10% lower compared to the baseline both for the first 9 days, as well as the last 25 days of the milk feeding period when the baseline has no milk provision. The increased milk intake per calf per day can help improve calf health and decrease mortality. This impact was captured by assuming a 1.7% decrease in mortality rate compared to the baseline (Svensson et al., 2006).

In this scenario, we assume no changes in *increased cost*, so only increases and reductions in revenue and reductions in costs are taken into account.

2.5 Analysis with labor costs

To estimate the effect of a potential need for an increase in working hours, we analysed the following two situations: i) a 1% increase in the labor effort required per cow in all CCC scenarios, and (ii) a 5% increase in the labor effort required per cow increased in all CCC scenarios. The average labor time required per cow in a dairy operation with 90 cows is about 22 hours per year (Agriwise, 2020). Assuming a similar labor time required for our smaller, generic organic dairy farm, a 1% increase in labor time would mean a labor time requirement of 22.2 hours per cow and year while a 5% increase would mean a labor time of 23.1 hours per cow and year. Average labor costs per hour are about €22 (Agriwise, 2020). This analysis allowed us to simulate the expected impact of increased labor requirements associated with CCC systems.

3 Results

3.1 Scenario 1: Dam rearing with 15 minutes contact at milking twice a day for 115 days

Results for Scenario 1 are provided in Table 3. Using equation (2), we estimate the effects of scenario 1 on milk sales as well as on additional weight gain (or loss) as compared to the baseline scenario. If milk intake of calves is less than 8 kg/day, this implies that there is leftover milk which can be sold and hence revenues can be increased by €3,203 (SD = 2,309), on average.[1] Similarly, we assume that if milk intake is greater than the baseline scenario, calves will gain additional weight per day according to the estimates reported in Gelsinger et al. (2016). However, we assume that the decrease in average daily weight gain only happens when there is a substantial reduction in milk allowance for calves as compared to the baseline, i.e., when milk allowance is less than 6 kg/day, a reduction in daily weight gain of 0.2 kg/day, on average, is modelled stochastically in our calculations. Given the distribution of milk allowance, it is more likely that a reduction in milk intake occurs for calves in this scenario. Therefore, the increase in revenues due to additional weight gain is €337 while reduction in revenues is €1,782.[2] It is worth noting that the standard deviations associated with each of these estimates is large because of the substantial variation in milk intake per calf.

In scenario 1, there is also an additional 25 days of milk provision as compared to the baseline. This reduction in revenue due to less saleable milk is estimated according to equation (3) and

TABLE 3 The effect of Scenario 1 (dam rearing with 15 min contact at milking twice a day), Scenario 2 (Dam rearing with 21-day full contact, after which calves are manually fed 8 kg of whole milk for 94 days) and Scenario 3 (mixed rearing with 24 hours contact; calves initially kept with their dams and then moved to foster cows at 9 days) on contribution margins compared to the baseline where calves are separated from the dam within the first day and are manually fed whole milk (Supplementary Table 1).

Variable	Value[1]		
	Scenario 1	Scenario 2	Scenario 3
Changes in revenues			
Increase in milk sales (in first 90 days, if milk intake< 8 kg/day)	3,203 (2,309)		
Milk sales foregone for the first 9 days			-373 (84)
Milk sales foregone for the first 21 days		-888 (180)	
Milk sales foregone in the 81 days			-686 (781)
Milk sales foregone for additional 25 days of milk provision	–2,232 (648)	-3,100 (43)	-3,315 (248)
Increase due to additional daily weight gain (if milk intake > 8 kg/day)	337 (1,000)	493 (104)	216 (43)[2] 66 (73)[3]
Decrease due to less weight gain (if milk intake< 6 kg/day)	–1,782 (1,673)		
Changes in costs			
Forage costs	–17 (1.4)	6 (0.57)	5 (0.42)
Concentrate costs	–69 (4.4)	13 (0.42)	10 (0.31)
Mortality costs	–145 (22.8)	36 (8.49)	94 (19)
Net change in contribution margin	–793 (1,404)	-3,432 (224)	-3,982 (800)

[1]Mean values in Euros. Standard deviations are reported in parentheses.
[2]For the first nine days.
[3]For the remaining 106 days.

comes out to be €2,232, on average.[3] Additionally, for the first 90 days when the milk intake per calf is lower than the baseline, the calves are assumed to rely more on forage and concentrate and thus the forage and concentrate consumption costs in the model have increased on average by €17 and €69, respectively.[4] Mortality costs

1 $Days \times (8 - milk\ intake\ per\ calf) \times price\ of\ milk \times number\ of\ calves = 90 \times (8 - milk\ intake\ per\ calf) \times price\ of\ milk \times 35$ where calf milk intake and price are stochastic variables imported from Table 2.

2 $Number\ of\ calves \times price\ of\ meat \times A-DG \times days = 35 \times price\ of\ meat \times A-DG \times 90$ where $A\text{-}DG > 0$ if milk intake per calf > 8 kg/d, and $A\text{-}DG < 0$ if milk intake per calf < 6 kg/d. *A-DG* and *price of meat* are stochastic variables imported from Table 2.

3 $Milk\ intake\ per\ calf \times number\ of\ calves \times price\ of\ milk \times 25\ Days$, data for variables imported from Table 2.

4 $(\Delta forage\ intake \times price\ of\ forage + \Delta concentrate\ intake \times price\ ofco\ ncentrate) \times 115 \times 35$, data for variables imported from Table 2.

have also been modelled to increase due to an on average lower milk allowance than the baseline, and come out to be €145.[5]

In total, the contribution margin goes down by €793 (SD = 1,404). However, this estimate is not statistically significant as there is a large standard deviation associated with the estimate, mainly due to the substantial variability in milk intake per calf. The €793 (SD=1,404) reduction in contribution margin is about 0.85% [793/92,330] of the annual contribution margin at the farm-level.[6] Our sensitivity analysis suggests that there may be some combination of values in the distributions of input variables that may result in positive profits (e.g., when the milk intake is comparable or greater than baseline, so that the negative effect of reduced daily weight gain is minimized). Furthermore, the tornado chart in Figure 1 shows that the leftover milk available for sales (which depends on the distribution of milk intake per calf modelled as a triangular distribution) is the primary driver of changes in contribution margins at the farm level, followed by additional suckling days and additional weight gain (or loss). Some stochastic variables have negligible effects, for example increase in feed intake and price of silage, and therefore the software does not report them in the tornado chart.

For scenario 1, after adjusting for labor costs, the decrease in contribution margin is between 1% to 2% of the contribution margin at the baseline, estimated as net change in contribution margin divided by total contribution margin at the baseline (Table 4).

3.2 Scenario 2: Dam rearing with full contact for initial 21 days, after which calves are manually milk fed 8 kg for 94 days

Results for Scenario 2 are provided in Table 3. Using equation 5, we estimated the effects on increased revenue due to additional weight gain as compared to the baseline. Due to this weight gain, we estimated that the revenues could be increased by €493, on average.[7] Using equation 6, we estimated the decrease in revenues due to increased milk provision to calves in the first 21 days of life, as well as during the last 25 days when the baseline calves were already weaned. This reduction in revenues was estimated as €888 and €3,100, respectively.[8]

On the cost side, for the first 21 days as well as the last 25 days in the milk feeding period, when the milk intake per calf was higher than the baseline, the calves were assumed to rely less on forage and concentrate and thus the forage and concentrate consumption costs in the model were decreased by on average €6 and €13, respectively. Mortality costs were also decreased due to higher milk intake compared to the baseline, and came out to be €36.

In total, the contribution margin decreased by €3,432 (SD = 224) which represents a reduction of 3.7% [3,432/92,330] of the yearly contribution margin at the farm-level. The difference in means t-test showed that the estimate was statistically different from the baseline (P< 0.01). The sensitivity analysis in Figure 2 shows that the AD-G due to higher milk intake and decreases in saleable milk are highly associated with changes in the contribution margin. Price of milk also appeared to be an important factor for changes in net contribution margin, while other evaluated factors had a negligible impact. For scenario 2, after adjusting for labor costs, the decrease in contribution margin is between 3.9% to 4.8% of the contribution margin at the baseline (Table 4).

3.3 Scenario 3: Dam rearing with 9-days full contact and then reared by foster cow

Results for Scenario 3 are provided in Table 3. Using equation 8, we estimated the effects on increase in revenues due to additional weight gain, as compared to the baseline. In this case, higher weight gain is assumed for two distinct production periods. First, the first 9 days of life, when the calves could suckle the dam freely; the increase in revenue for these 9 days is estimated to be on average €216. Second, the following 106 days in life, when multiple calves suckled the same foster cow; if milk intake is greater than 8 kg/day for the next 106 days, the increase in revenue due to A-DG is estimated to be €66, on average.[9]

Using equation 9, we estimated the reduction in revenues due to increased milk provision to calves in the first 9 days, the next 81 days that are comparable with the baseline if milk intake per calf is greater than 8 kg/day, as well as during the additional 25 days when the baseline calves were already weaned. This reduction in revenues was estimated as €373, €686, and €3,315, respectively.

On the cost side, for the first 9 days, as well as the last 25 days during the milk feeding period, when the milk intake per calf was higher than the baseline, the calves were assumed to rely less on forage and concentrate and thus the forage and concentrate costs in the model decreased on average by €5 and €10, respectively. Mortality costs were also decreased in this scenario due to an on average higher milk intake than the baseline, and came out to be €94. The reduced costs for feed and mortality were estimated according to equation 10.

In total, the contribution margin decreased by €3,982 (SD = 800). This reduction in contribution margin is about 4.3% [3,982/

5 *Increase in mortality rate* x *profit per calf*, data for variables imported from Table 2.

6 92,330 is the contribution margin in the baseline scenario developed in Appendix Table A1.

7 *Number of calves* x *price of meat* x $A-DG$ x 21 *days*, data for variables imported from Table 2.

8 *Number of calves* x 21 *days* x (*calf intake* – 8) x *price of milk* + *Milkintake per calf* x *number of calves* x *price of milk* x 25 *days*, with data for variables imported from Table 2.

9 *Increased income due to* $A-DG$ = *Number of calves* x *price of meat* x $A-DG$ x[9 *days* + (106 *days if milk intake* > 8)], with data imported from Table 2.

FIGURE 1
Tornado plot with regression coefficients showing determinants of a change in net contribution margin on a typical EU dairy farm for Scenario 1 (dam rearing with 15 min contact at milking twice a day).

TABLE 4 The effect of Scenario 1 (dam rearing with 15 min contact at milking twice a day), Scenario 2 (Dam rearing with 21-day full contact, after which calves are manually fed 8 kg of whole milk for 94 days) and Scenario 3 (mixed rearing with 24 hours contact; calves initially kept with their dams and then moved to foster cows at 9 days) on contribution margins adjusted for increases in labor requirement, compared to the baseline where calves are separated from their dams within the first day and are manually milk fed (Supplementary Table 1).

Variable	Value[1]		
	Scenario 1	Scenario 2	Scenario 3
Net change in contribution margin[2]	-793	-3,432	-3,982
Labor costs at 1%	-198	-198	-198
Labor costs at 5%	-992	-922	-992
Net change in contribution margin adjusted for labor costs at 1%	-991	-3,630	-4,180
Net change in contribution margin adjusted for labor costs at 5%	-1,785	-4,424	-4,974

[1]Mean values in Euros.
[2]When increase in labor costs are not assumed (as in Table 3).

92,330] of the yearly contribution margin at the farm-level. According to a difference in means t-test, this estimate is statistically significant (P< 0.01). The sensitivity analysis in Figure 3 shows that the additional milk provision during all three periods is the main determinant of change in the contribution margin at the farm-level. Other factors, e.g., decrease in mortality rates and stochasticity of prices play a negligible role. For scenario 3, after adjusting for labor costs, the decrease in contribution margin is between 4.5% to 5.4% of the contribution margin at the baseline.

4 Discussion

For the three CCC systems evaluated, which were the CCC systems identified in a recent survey conducted in six European countries (Eriksson et al., 2022), we found relatively small or moderate costs of CCC systems relative to the baseline. In the first scenario, where calves have contact with the dam only at milking (15 minutes twice a day for 115 days) and there was no manual milk feeding, the contribution margin was 0.85% lower than the baseline. The contact time of 15 minutes twice a day is consequential in the sense that it drives the amount of milk consumed by each calf (median of 5.1 kg/day). Broucek et al. (2020) reports a similar milk intake for calves sucking the dam for 30 minutes per day. This is, however, a relatively low milk intake as most countries recommend intakes between 6-8 liters per day, or 10-15% of the body weight (Code of Welfare, 2019; Kalvportalen, 2021). Other studies found milk intakes in restricted CCC systems of higher milk amounts per day (e.g. Ivemeyer et al., 2016: on average 10.4 kg/day between week of life 3-13) and median suckling durations of 12 minutes and 39 seconds in twice daily restricted CCC systems (Wildemann et al., 2020). Therefore, our scenario is based on a system with CCC after milking hypothesising that most of the milk is already milked within the milking parlor. Furthermore, if the contact time had been 30 minutes (i.e. 60 minutes per day), as done in Bieber et al. (2022) or allowing CCC before milking, the milk consumption would have been greater than our baseline and hence could have produced a positive economic results by reducing the loss in revenue due to the decrease in daily weight gain that was assumed in this scenario. However, the higher milk intake would simultaneously reduce income from milk sales, so the effects on the contribution margin remains unclear.

The second and third scenarios were associated with a respective 3.7 and 4.3% decrease in contribution margin, as compared to the baseline contribution margin presented in Appendix Table A1. While these estimates are statistically significant from baseline, we argue that it only has minor economic effects. Given that these reductions in contribution margins were small or moderate, they likely can be recovered if farmers are able to sell their milk at a premium. Indeed, recent literature has found significant increases in consumer willingness-to-pay for higher animal welfare in dairy products (Wolf and Tonsor, 2017; Yang and Renwick, 2019). Also, Eitelberg et al. (2022) suggests that personal values are relevant for willingness-to-pay for dairy products from CCC systems. However, we found

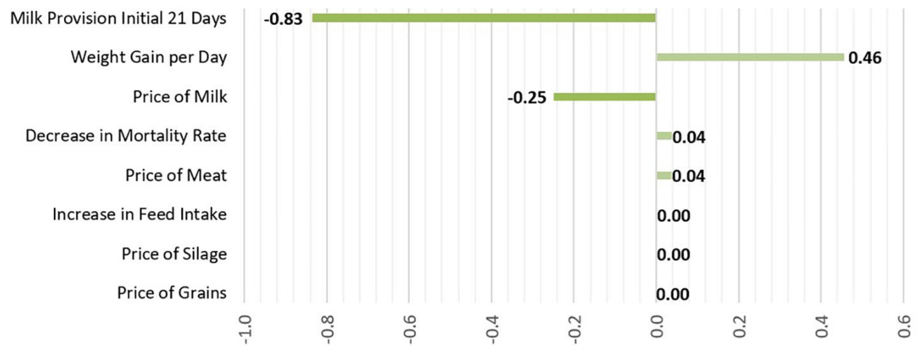

FIGURE 2
Tornado plot with regression coefficients showing determinants of a change in net contribution margin on a typical EU dairy farm for Scenario 2 (dam rearing with full day contact for the first 21 days followed by artificial rearing).

no study that estimated the price premiums consumers would be willing to pay for increased CCC and thus it is difficult to predict what exactly would be the price premium for this specific animal welfare attribute in the dairy sector. More broadly, studies have found negative consumer attitudes towards early cow-calf separation as it is deemed unnatural and a source of stress for the animals (Busch et al., 2017; Placzek et al., 2021). It is also important to keep in mind that the scenarios used in the present study might not fulfil the consumers' expectations of CCC and so there is a need to investigate their perceptions towards different CCC systems, including both those that allow full-time contact with the dam and alternative methods. The studied scenarios in the current study allows CCC, but still results in the separation of dam and calf after full-day contact for 9 or 21 days. This management would likely result in a very stressful event for both cows and calves, but especially for the dams because bonding has been developed and is then interrupted, which could be viewed as problematic by consumers. Moving the calf to either a foster cow or to an artificial milk feeder, may also be problematic in terms of adapting to the new feeding system. In addition, studies have shown that the dam spends more time socializing with her own calf than a foster cow does with an alien calf (Franz-Wippermann et al., 2022; Wieczorreck and Hillmann, 2022). This underlines the importance of focusing on the animal welfare outcomes of a practice rather than the intent (Taylor et al., 2023).

The scenarios used were the three most common strategies from the survey by Eriksson et al. (2022). The fourth most common strategy was slightly similar to scenario 3, as it also involved mixed rearing but instead of keeping the calves with the dam for 9 days, calves in this strategy were moved to foster cows at 4.5 days after birth. We reasoned that both of these scenarios were similar and that it was enough for this study to focus on the three most frequent CCC strategies. In Germany, the certification for CCC systems is defined as having contact time between cow and calf for a minimum of 3 months (IG kuhgebundene Kälberaufzucht, 2022). For future studies, it would however be interesting to include a gold standard representing full-day contact between cow and calf during the milk-feeding period to assess the economic effects of that CCC system. Furthermore, in the majority of conventional dairy farms across Europe, calves are typically nourished with milk replacer. In contrast, organic production recommendations advocate for feeding calves with maternal milk. If we were to introduce a scenario depicting conventional production involving immediate

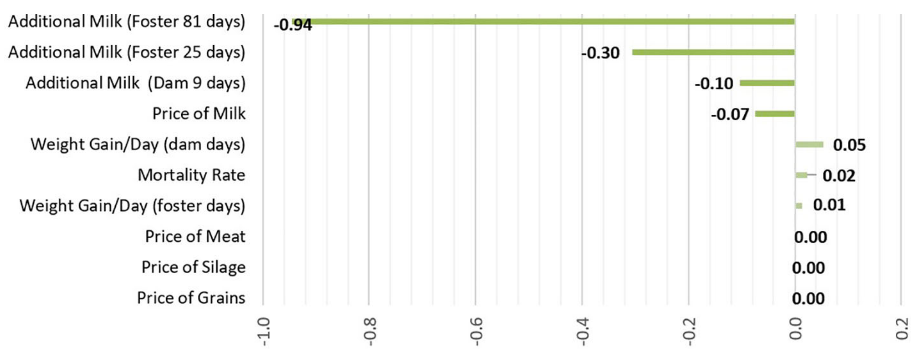

FIGURE 3
Tornado plot with regression coefficients showing determinants of a change in net contribution margin on a typical EU dairy farm for Scenario 3 (mixed rearing with 24 hours contact; calves are initially kept with their dams and then moved to foster cows at 9 days).

separation from the dam and the subsequent use of artificial milk replacers, it is likely that this would have increased the overall cost of the studied CCC scenarios.

Some studies have evaluated dairy farmers' drivers and barriers to applying prolonged CCC. Neave et al. (2022) reported that conventional farmers in New Zealand raised concerns of reduced animal welfare if cows and calves were to be kept together, for example increased risk of mastitis in the dam, inadequate colostrum intake for the calf, and increased stress for cow and calf from the delayed separation. However, the systematic review by Beaver et al. (2019) found no negative or positive effects of prolonged CCC on the health of calves and cows. A large proportion of the CCC farmers interviewed in the European survey study did not perceive any barriers for implementing CCC on their farms (Eriksson et al., 2022). As the latter study only included farmers that already practiced prolonged CCC, and hence likely supported this system, this could explain the differences in farmer perception compared to Neave et al. (2022). Among the barriers to implement CCC that were mentioned in the European survey study, inappropriate barn design was most frequently reported (Eriksson et al., 2022). This is similar to the findings by Vaarst et al. (2020), who found that improper calf housing when keeping cows and calves together, as well as slatted floors, were limiting factors for CCC rearing. In the present study, building costs were not included in the economic models. We have compared different types of calf rearing on the same fictive farm and hence we assume no major building costs in our scenarios. On real farms, however, it may be necessary to modify existing cow sheds in order to allow calves access to a creep area with separate provision of feed, water and protected lying places (Knierim et al., 2020). In terms of labor costs it is reasonable to think that the time needed to care for the calves is similar between the baseline scenario and the CCC scenarios, but that the work tasks differ. In the baseline scenario more time might be spent on feeding calves and cleaning calf feeders whilst in the CCC scenarios more time is needed on observing and socializing with the calves. In the study by Eriksson et al. (2022), the majority (77%) of 100 responding farmers with CCC systems, perceived that their CCC system required either equivalent or less time to complete daily tasks compared to an artificial rearing system. Also, 22% of the farmers thought that their CCC was more time consuming. To account for a potential increase in labor hours, we assumed that the labor requirements will go up by 1% or 5% as there are no available information of the effect of CCC systems on labor requirements. The analysis of labour costs show that indeed under certain circumstances, the decrease in contribution margins can be quite significant and cumbersome for the farm economy. However, it is also reasonable to believe that the work load will differ between the CCC systems. Future research should estimate more precise measures of labor requirements for CCC systems, which will lead to a more accurate economic analysis.

The sensitivity analyses for all scenarios suggest that changes in the amount of saleable milk (depending on milk intake of the calves) and changes in calf weight gain (with assumed downstream effect on health and mortality) compared to the baseline resulted in the largest changes in the contribution margins. In scenario 1, the calves consume less milk than the baseline, thus there is additional milk income from sale of milk, while in scenarios 2 and 3, calves consume more milk than the baseline, thus reducing milk sales in these scenarios. Unfortunately, there is limited literature available on the effects of different CCC systems, but we chose the best possible approximations available as well as using information from interviews with Swedish farmers. We also introduced relevant variability in variables (e.g., daily weight gain, mortality rate) to estimate the costs and benefits of CCC systems.

Our modelling highlights several limitations in the literature which future research should focus on alleviating. First, CCC systems may have positive long-term impact on an animal's growth rate, productivity and longevity (Meagher et al., 2019), however, evidence for this is inconsistent (Zipp and Knierim, 2020). Indeed, farmers perceive that CCC systems have lasting positive impacts on cows as well as calves (Eriksson et al., 2022). These aspects of different CCC systems are not taken into account and only a short-term profitability analysis is provided in our study. Long-term studies addressing the effects of dairy calf rearing with CCC are needed. Second, while most of the parameters used in the calculations are taken from peer-reviewed articles or published databases, some parameters are based on farmer opinions and thus these results should be interpreted with caution. Also, the parameters from Agriwise are based on Swedish data which will limit the generalizability of the results, e.g. both the amount of labor hours needed and the hourly wages can differ between countries. Third, the study only considers pecuniary impacts of CCC systems and does not consider animal welfare impacts or the 'soft values' associated with animal welfare provision in the modelling approach. In this sense, the costliness of CCC systems in our estimations may be overstated, as positive welfare impacts are not included in the estimation, predominantly because of the difficulty of assigning an economic value to such outcomes

We found that all CCC systems were costlier than the baseline and that the loss in contribution margin ranged between about 1 and 5% for different CCC systems. Future research should aim to fully understand the short and long-term relationships between CCC systems and animal welfare attributes such that these can be used to estimate the long-term economic consequences of CCC systems and strengthen economic decision-making related to CCC systems in the dairy sector.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Author contributions

KA, MH, and KB acquired funding. KA and HA conducted the data analyses and drafted the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fanim.2023.1197327/full#supplementary-material

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