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Conservation of a native dairy cattle breed through terminal crossbreeding with commercial dairy breeds

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ABSTRACT
Farmers play a key role in conserving native livestock breeds, but without economic support, farms with native breeds may not be viable. We hypothesized that terminal crossbreeding can improve herd economy and decrease the economic support needed from society. Three scenarios were simulated using SimHerd Crossbred: a herd of purebred Swedish Polled Cattle, a herd of purebred Swedish Red, and a herd of 75% Swedish Polled Cattle and 25% F1 crossbreds. The results showed annual contribution margin per cow in the herd can be increased by €181 by crossbreeding compared with pure-breeding with the native breed, giving a 13.6% growth in contribution margin. However, the needed cost in subsidies paid by the government will remain unchanged if the population size of the native breed is to be maintained. Combining a crossbreeding strategy with the marketing of niche products may facilitate the conservation of native cattle.

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Introduction

Over the last few decades, increasing numbers of native cattle breeds all over the world have become endangered, mainly as a consequence of high production demands favouring a few high-performance breeds (Bett et al,. 2013; Upadhyay et al,. 2019) and increasing possibilities to specialize and intensify farming systems. This has led to a loss of genetic diversity, which is a concern, because such diversity may be needed if we are to overcome potential lack of genetic variation (Bett et al., 2013). Furthermore, global climate changes may cause a need for aptitudes specific to some native breeds (FAO, 2015).

Like several other European governments, the Swedish government has initiated a national action plan for animal genetic resources (Swedish Board of Agriculture, 2009) based on global action plans: the Convention on Biological Diversity (UN, 1992), signed in 1993, and FAO's 'Global Plan of Action for Animal Genetic Resources' in the Interlaken Declaration (FAO, 2007), adopted in 2007. The Aichi Target 13 for year 2020in the Convention on Biological Diversity's Strategic Plan for Biodiversity 2011–2020 is that the genetic diversity of domesticated animals is maintained, and 'strategies have been developed and implemented for minimizing genetic erosion and safeguarding their genetic diversity' (CBD, 2020). The main objectives of the national action plan are the conservation and sustainable utilization of domestic animal species native to the country. The Swedish government took responsibility for these objectives when they adopted the global action plans. However, other stakeholders – farmers, breeding organizations, dairies, retailers, etc. – need to be involved as well for the plan to be successful (Oldenbroek & Gandini, 2007; Wurzinger et al., 2011).

Of the nine native Swedish cattle breeds, the Swedish Polled Cattle (*Svensk Kullig Boskap*, **SKB**) is examined in the present study, using it as a model for any European native dairy cattle breed. The SKB breed was created in 1938 by merging the herd books of Swedish Mountain Cattle (*Fjällras*) and Swedish Red Poll (*Rödkulla*) (Johansson et al., 2020). The population of SKB has decreased since the 1970s when changes in the structure of the agricultural sector caused larger but fewer herds, a trend that is ongoing to this day. In 2017, only 735 SKB cows were milk-recorded, as compared with 10 379 in 1970 (Växa Sverige, 2018a). The total number of SKB

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Table 1. Phenotypic breed estimates[a] of Swedish Polled Cattle (SKB; n = 248) and Swedish Red (SR; n = 35 860) kept in an organic production system, and heterosis estimates in crosses between the breeds for production, risk of diseases, fertility, and mortality used in the model

	SKB	SR	Heterosis[b], %
305-d kg ECM, 1st parity	5 309	7 595	+3%
305-d kg ECM, 2nd parity	6 114	8 772	+3%
305-d kg ECM, later parities	6 811	9 087	+3%
Mastitis, %	16.9	9.8	0%
Hoof-related diseases, %	11.5	13.2	−10%
Other diseases, %	10.9	5.6	−10%
Dystocia	3.4	2.3	−7%
Cow mortality	4.5	3.5	−10%
Calf mortality (incl. stillbirth)	13.3	4.5	−12%
Young stock mortality	0.8	4.0	−12%
Conception rate, cows	0.40	0.45	+10%
Age at 1st service, months	17.6	17.9	-
Calving – 1st AI, days	102	93	-

ECM = Energy-corrected milk
[a]Data from the Swedish milk recording scheme from organic herds
[b]Based on Jönsson (2015). All estimates are favourable and based on crossbreds between Swedish Holstein and Swedish Red.

animals in Sweden (including males and young stock) was 2 663 by the end of 2018 (Swedish Board of Agriculture, 2018). Owing to its relatively low milk yield (Table 1) according to the Swedish standards, SKB is not able to compete economically with the two most popular commercial Swedish dairy breeds: Swedish Red (**SR**) and Swedish Holstein. Today, most milk-recorded SKB cows are kept at low proportions (<10%) in mixed herds with SR and/or Holstein cows, as shown in a study of organic production by Bieber et al., (2019). Those farmers who manage to keep mainly SKB cows are often found to have taken specific measures to be competitive on the dairy market, e.g. the promotion of local products, such as cheese, ice cream, and yoghurt, with an added value (Ortman, 2015). However, subsidies for conservation activities are still necessary to keep the farms viable. These subsidies are funded by the government, creating an expense for society. The level of subsidy for native breeds is currently approximately €140 per adult cow per year (Swedish Board of Agriculture, 2019).

Potentially, one way to accommodate the conservation objectives, and to improve the SKB farms' economic sustainability, would be to crossbreed with a high-producing breed. Crossbreeding in dairy cattle has shown favourable effects, especially on functional traits and herd economy, connected with heterosis (Sørensen et al., 2008; Clasen et al., 2020). However, if heterosis is to raise profits, the breeds in the crossbreeding program must be economically similar and complement each other's strengths and weaknesses (Sørensen et al., 2008; Clasen et al., 2020), and this not the case with SKB and SR or Swedish Holstein. The purpose of crossbreeding between a native low-producing breed and a high-producing commercial breed is to gain from the superior milk production performance in the latter (Franklin, 1997) and possibly keep superior functional traits or alleles from the native breed. According to Poulsen et al. (2017), the allele for A2 protein could be an example of a favourable allele found in SKB. Although systematic crossbreeding that utilizes and conserves a native breed has been successful in a few situations (e.g. Lambert-Derkimba et al., 2019), crossbreeding as a conservation strategy is uncommon, as it may be incompatible with the conservation goals for the native breed. Uncontrolled crossbreeding has in some cases threatened the existence of the original breed, as happened with Flemish Red Cattle (Lauvie et al., 2008), or virtually wiped out the original genetics, as was seen with Swedish Lowland Cattle (Bett et al., 2013).

This study simulated the economic outcome of a terminal crossbreeding strategy (sustained crossing; FAO, 2010) using SKB as the example of a native breed crossed with SR as a highly productive breed. The aim was to evaluate how effective such a crossbreeding strategy is in increasing economic sustainability in SKB herds and thus potentially saving the SKB population in dairy production. Some of the potential consequences of the crossbreeding strategy at population-level will be discussed.

The study focuses on organic production. According to the vision of the International Federation of Organic Agriculture Movements, animals used in organic production should be adapted to local conditions and local breeds are preferable (IFOAM, 2014). Organic dairy production in Sweden has a higher proportion of SKB cows (1.2%) than conventional production (0.5%) (Ahlman, 2010), although there are almost five times more conventionally farmed SKB cows than organically farmed ones (Växa Sverige, 2018a).

We hypothesize that the simulated crossbreeding strategy improves production economy at herd level, and reduces the costs per animal for society associated with subsidies paid for conservation of the native breed.

Materials and methods

Herd scenarios

In an organic production system in Sweden, we specified three herd scenarios: purebred SKB alone, purebred SR alone, and two-breed terminal crossbreeding between SKB and SR (**XB**). The terminal crossbreeding implied that only purebred SKB were used as breeding candidates while F1 crossbreds of SR x SKB females were kept as production animals. The F1 crossbreds were bred using beef semen to produce beef x dairy crossbred calves. The terminal crossbreeding system was carried out within the herd, meaning that the simulated crossbreeding herds had both purebreds and crossbreds. We wanted to keep a surplus between one and three purebred heifers in each scenario to ensure they were economically comparable. To do that in the pure-breeding scenarios, we pre-adjusted the number of heifers by breeding some of the purebred cows to beef semen, in the simulation. This adjustment was done on the proportion of purebreds that would produce crossbred animals in the crossbreeding scenario. Considering the reproductive performance, cow longevity, and calf mortality in the simulated herd, 20% of the purebred SKB females were bred to an SR sire after the adjustment.

The three scenarios were simulated using a modified version of the existing SimHerd model, SimHerd Crossbred (Østergaard et al., 2018). SimHerd Crossbred is designed to simulate crossbreeding systems at herd level by tracing breed proportion and heterozygosity for each animal in the simulated herd. The mechanisms of the model are described in more detail in Clasen et al. (2020). The scenarios were simulated for 50 years to ensure that equilibrium was reached. The results in this study are averages of 1 000 replicates over the last 10 years (year 41–50). In practice, we do not expect such a long period to fully implement the crossbreeding strategy; 50 years were simulated because the transition period from pure-breeding to crossbreeding is not optimized in SimHerd Crossbred.

Input parameters

The simulated production system mimicked a Swedish organic production system. The simulated milk withdrawal period after antibiotic treatment was twice (two weeks) that in a conventional production system (European Union, 2018). The effects of other practices in organic production, such as grazing, feeding, health, and housing were reflected in the input parameters (Table 1), management decisions, and prices (Table 2) used.

The input parameters for the breed-specific traits were based on information from the Swedish milk recording scheme. Raw means of data held in the Swedish cattle database (organized by Växa Sverige) on cows with a calving event between 2011 and 2016 were used. The dataset consisted of 248 and 35 860 milk records from SKB and SR cows, respectively, all in organic production. Because there are no available studies on heterosis in SKB crosses, the estimates for direct heterosis effects were based on estimates found in SR x Swedish Holstein crosses (Jönsson, 2015). The breed differences and heterosis estimates for the most important traits are shown in Table 1 (Appendix 1 for the conventional production system).

Table 2. Assumed prices as of 2018 (Clasen et al., 2020) in € for milk production, slaughter value and live calves for organic production

Item	Price, €
Milk, per 1 000 kg ECM	484
Slaughter SKB cow, per kg live weight	1.16
Slaughter SR cow, per kg live weight	1.39
Slaughter SR x SKB cow, per kg live weight	1.29
SKB dairy bull calf, per head	10[a]
SR dairy bull calf, per head	225[a]
SR x SKB dairy bull calf, per head	117.5[a]
Beef x dairy bull calf, addition[b] per head	70
Beef x dairy heifer calf, addition per head	35

ECM = Energy-corrected milk; SKB = Swedish Polled Cattle; SR = Swedish Red
[a]Market price corrected for rearing costs
[b]Added to the price of a dairy calf

The essential price assumptions for these simulations are in Table 2 (Appendix 2 for the conventional production system). All other assumptions regarding prices and costs were identical to the assumptions in Clasen et al. (2020). The milk price per 1 000 kg energy corrected milk (**ECM**) was €1 higher for SR and €0.5 for F1 SKB x SR crosses relative to purebred SKB (not shown in table) as a result of differences in the fat and protein contents of the milk. All dairy bull calves and beef x dairy crossbred calves were sold as live calves for beef production after a two-week rearing period in the simulated herds. The value of purebred SR and beef cross calves was higher than purebred SKB calves because of the higher body weight (Växa Sverige, 2018b). The money received for the live calves was adjusted for the risk of calf mortality, milk feeding, and other costs associated with the rearing period because these costs were not considered for slaughter calves in SimHerd Crossbred.

We chose to simulate a herd size of 100 cows, as this is the number used in previous studies based on SimHerd Crossbred (Clasen et al., 2020). Because we did not include any costs that depend on the herd size, such as labour and buildings, the outcome per cow was expected to be the same regardless of herd size. Thus the results are scalable.

Sensitivity analyses

Some input variables, for example, economic values and breed variables, were fixed in our simulation study. In reality, they are fluctuating between countries, periods, and even herds, which means the total economic result likely fluctuates as well. Therefore, we analysed how sensitive the economic results were to changes in on three of the potentially most fluctuating variables: milk price, milk performance traits in the breeds crosses, and heterosis.

Marketing initiatives promoting the conservation of native breeds have been suggested, such as selling milk or cheese branded as a 'native breed product' for a higher price than conventional products (Swedish Board of Agriculture, 2009). This could lead to an increased milk price being paid, by the dairy plant, to farmers with a majority of the native breed on the farm. The first sensitivity analysis investigated the break-even in milk price that is necessary to pay SKB herds if they are to be economically competitive with purebred SR. The sensitivity analysis was based on the assumption that an additional premium is paid for the milk in herds with cows of a native breed including crossbreds.

The second sensitivity analysis investigated the effect of increasing differences in production level between the breeds on the economic difference between the scenarios. Owing to genetic improvements, SR has increased the 305-day ECM yield by approximately 100 kg per year since 1990, while over the same period the production level in SKB has been almost unchanged (Växa Sverige, 2018a). The analysis assumed an annual increase of 100 kg in 305-day ECM over 25 years for SR and no change in SKB. Changes in other traits were ignored, mainly because the trends for them are unknown in the SKB breed. Five simulations were made to represent the changes every 5 years.

Given the absence of heterosis estimates for crosses between SKB and SR, the assumed heterosis in the simulations may differ from the true heterosis for SKB-crosses. Heterosis estimates in crosses between native and modern breeds in other countries can also be different from our assumed estimates. Therefore, the third sensitivity analysis investigated the effect of changing heterosis on the economic difference between the scenarios. The effects analysed were heterosis estimates of −50%, +50%, and +100% relative to the default heterosis estimates based on crosses between SR and Swedish Holstein given in Table 1.

Results

Herd scenarios

The effect of applying crossbreeding to 20% of the purebred SKB cows was 25% F1 crossbred cows within the herd in the XB scenario (Table 3), primarily as a result of better fertility and less calf mortality. Thus, in a 100-cow herd, 75 of the milk-producing cows would be purebred SKB, and 25 would be F1 crosses. The major effects of terminal crossbreeding on herd dynamics were increased milk yield and a reduced number of young stock. The 305-day ECM production per cow increased by 348 kg relative to SKB. With the reduced calving interval (−4 days) and reduced calf mortality (−12%), the number of replacement heifers that should be raised in the herd was also reduced by approximately 12% in the XB scenario.

Table 3. Simulated herd dynamics at equilibrium in a herd of purebred Swedish Polled Cattle (SKB); a herd using a two-breed terminal crossbreeding system with SKB purebreds and 25% F1 Swedish Red x SKB crossbreds (XB); and a herd of purebred Swedish Red (SR), all in an organic production system

	SKB	SR	XB
Crossbred cows (%)	0	0	25
Replacement (%)	31.9	29.3	30.1
Replacement heifers in the herd/cow	0.81	0.74	0.72
Dairy bull calves sold/cow	0.37	0.37	0.33
Beef x dairy crosses sold/cow	0.14	0.28	0.23
305-d kg ECM yield (kg/cow)	5 743	8 433	6 091
Calving interval (days)	417	405	413
Conception rate (cows)	0.40	0.45	0.42
Disease treatments/cow	0.39	0.37	0.38
Cow mortality (%)	4.2	3.5	4.0
Calf mortality (incl. stillbirth) (%)	13.3	4.5	11.7
Young stock mortality (%)	1.1	4.1	1.2

As an effect of having 25% crossbreds in the herd, the total contribution margin per cow-year increased by €181 (+13.6%) in XB compared to SKB (Table 4). The increases were mainly due to increased income from milk production, increased income from the sale of live calves, and reduced costs associated with young stock. Income from milk production increased by 6.1% in XB in comparison with the purebred SKB herd, but the higher milk production also increased feed costs. The dairy bull calves and beef x dairy crossbred calves sold from the farm at the age of two weeks had on average a higher value in the crossbreeding scenario than in

Table 4. Simulated annual economic results (€/cow) in a herd of purebred Swedish Polled Cattle (SKB); a herd using a two-breed terminal crossbreeding system with SKB purebreds and 25% F1 Swedish Red x SKB crossbreds (XB); and a herd of purebred Swedish Red (SR), all in an organic production system

	SKB	SR	XB
Income			
Milk production	2 754	4 055	2 922
Slaughter cows	120	227	121
Live calves	13	157	29
Total income	2 887	4 469	3 073
Costs			
Feeding cows	943	1 369	992
Feeding young stock	308	273	275
Inseminations	48	44	46
Disease treatments	62	49	59
Other costs	192	182	186
Total costs	1 552	1 918	1 557
Total contribution margin	1 334	2 552	1 515
Difference to SKB		+1 218	+181

the SKB scenario as a result of the influence of SR and beef breed. This created higher income from the sale of live calves in the crossbreeding scenario.

Appendices 3 and 4 show results for the conventional production system. These are similar to those obtained in the organic production system; the crossbreeding scenario earned +€179 per cow-year relative to the SKB scenario. However, the relative gain was slightly larger (+16.1%), mainly as a result of the larger differences in milk yield between the breeds and lower prices in the conventional production system.

Sensitivity analyses

Figure 1 shows the effect of increasing the milk price for a herd that has at least some SKB cows, i.e. the SKB scenario and the crossbreeding scenario, compared to the SR scenario. The break-even in milk price cow-year was €696 per 1 000 kg ECM paid for milk originating from herds with SKB cows to obtain the same contribution margin per cow-year as SR. This corresponds to a 43.8% increase from the initial milk price (€484). In the XB scenario, the break-even was estimated at €656 (+35.6%) for XB to obtain the same contribution margin per cow-year as SR.

When the production level was increased due to genetic progress for SR but not for the SKB breed, the difference in production level between SKB and crossbreds of SKB and SR increased as well. This caused the total contribution margins per cow-year to increase in the XB scenario (Figure 2). From year 0 to year 25, the difference in total contribution margin per cow-year between SKB and XB increased from €186 to €307 (€4.8/year). Other traits were kept at a fixed level, and therefore there were no changes in other variables.

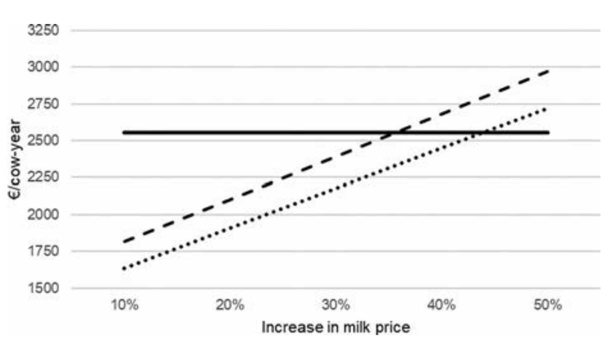

Figure 1. Effect of increasing milk price in a herd of purebred Swedish Polled Cattle (SKB; dotted line) and a herd using a two-breed terminal crossbreeding system with SKB purebreds and 25% F1 Swedish Red x SKB crossbreds (XB; dashed line) compared with a herd of purebred Swedish Red (solid line; no increase in milk price) in an organic production system with current milk price.

Changing the heterosis estimates had some effects on herd dynamics and herd performance, and a substantial effect on the total contribution margins in the XB scenario (Table 5). Doubling the heterosis allowed more crossbreds to be introduced into the herd: 27% relative to 25% in the initial scenarios (default heterosis estimates). This was mainly due to improvements in production, fertility and calf mortality, and a reduced replacement rate, thus fewer purebred cows were needed to ensure enough replacement heifers. The crossbred cows survived longer in the herd with higher heterosis estimates; thus the need for purebred cows to produce crossbred replacement heifers was reduced. Relative to the initial scenarios, the total contribution margin per cow-year increased €36 in XB when the heterosis estimates were doubled. Halving the heterosis estimates had the opposite effect, resulting in 24% crossbreds in XB, and fewer benefits in production and other traits, relative to the default scenario. The total contribution margin per cow-year was €20 less than the default scenario when heterosis was halved.

Discussion

The simulated crossbreeding scheme does not necessarily represent an optimal strategy for conserving a native breed and obtaining higher contribution margins from terminal crossbreeding with modern breeds. Nevertheless, it points to a potential economic way to conserve dairy herds with native breeds, and one that can benefit both farmers and society, if it is assumed that all animals on the farm include some native breed genes.

Financial subsidies were not included in the economic calculations, as the size of any such subsidy and the regulations under which it is offered may differ between countries and breeds. Currently, the Swedish regulations for endangered livestock breeds only allow subsidies for animals owned by farmers who follow breed-specific (pure-)breeding plans (Swedish Board of Agriculture, 2019). The purpose of this regulation is obviously to promote the pure-breeding of native breeds. However, the conservation of native breeds may be more attractive to farmers if it can be combined with higher contribution margins in alternative breeding strategies such as terminal crossbreeding with modern dairy breeds or beef breeds. Thus, the regulations governing subsidies may need to be changed to allow crossbreeding plans – at least, if it is confirmed that crossbreeding promotes the conservation of the breed.

Farmers play an important role in the conservation of dairy cattle. But if the economic benefit is too small, they might as well convert to SR or Holstein or another high-

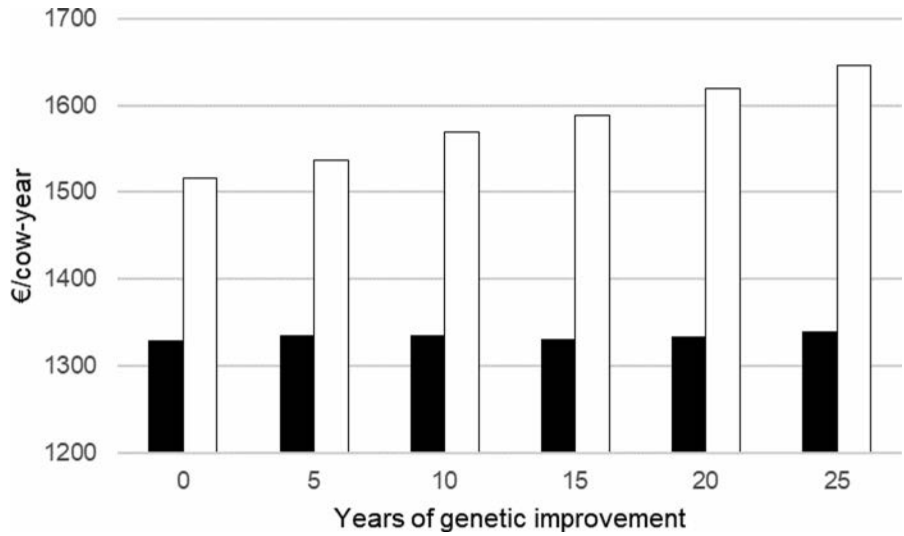

Figure 2. Effect on total contribution margin after 5, 10, 15, 20 and 25 years when 305-day kg ECM yield increases by 100 kg/year in the Swedish Red breed in a herd of purebred Swedish Polled Cattle (black bars) and a herd using a two-breed terminal crossbreeding system with SKB purebreds and 25% F1 Swedish Red x SKB crossbreds (white bars). All herds in an organic production system.

profit breed and phase out any native breed cows in the herd. The estimated herd contribution margin was €2 552 per cow-year for purebred SR which is €1 218 more than purebred SKB. This difference indicates the subsidy that will be needed from society for SKB to be economically competitive with SR herds, given the parameter inputs in our simulations. The difference in contribution margin between the SKB herd and the SR herd can be reduced to €1 037 by having 25% crossbreds in the SKB herd (XB). The farmer will still need economic support from society, but the ability to create higher profits from some of the cows may motivate more farmers to keep the native cows. However, if subsidies are paid only for purebred cows, the crossbred cows will be insufficiently profitable to cover the difference in subsidies between the SKB and XB herds needed to match the profit of a purebred SR cow. A mixed herd with purebred cows of SKB and SR, i.e. without any crossbreeding, would provide a higher contribution margin (+8%) than that obtained in the XB scenario if the proportion of SKB cows is the same. This is because the SR breed is economically superior to SR x SKB crossbreds, despite heterosis effects. However, such a mixed herd may present management challenges as a consequence of the large breed differences (e.g. cow size, energy requirements, and robustness under extensive conditions), which is why farmers may be reluctant to adopt this strategy and rather choose the XB scenario if they intend to include another breed in the herd.

Table 5. Effect of changing heterosis estimates on simulated herd dynamics at equilibrium in a herd using a two-breed terminal crossbreeding system with SKB purebreds and 25% F1 Swedish Red x SKB crossbreds (XB) compared to a herd of purebred Swedish Polled Cattle (SKB) in an organic production system

Change in heterosis	Default[a]	−50%	+50%	+100%
Crossbred cows (%)	25	24	26	27
Replacement (%)	30.1	30.4	29.8	29.3
305-d kg ECM yield (kg/cow)	6 091	6 054	6 134	6 156
Calving interval (days)	413	414	412	410
Calf mortality (incl. stillbirth) (%)	11.7	12.0	11.5	11.3
Total contribution margin	1 515	1 495	1 537	1 551
Rel. SKB	*+13.6%*	*−12.2%*	*+15.1%*	*+16.2%*

[a]Please see Table 1 for default heterosis estimates

In our simulations of the conventional production system, the crossbreeding scenario's economic gain in comparison to the SKB scenario (Appendix 4) was similar to the corresponding gain in organic production system. Thus, from an economic perspective, the consequences of crossbreeding between SKB and SR are similar regardless of the production system. However, that may not be the case in other countries or between other native and modern dairy breeds, and from the perspective of conserving the genetics of the native breeds, the production system does not matter. However, from the socio-economic perspective, the incentive of conserving the native breeds in organic rather than conventional systems is enhanced by the EU commitment to increase organic farming in Europe ('The European Green Deal'; European Commission, 2019).

The main characteristics of organic dairy production include pasture-based feeding and the utilization of local feed sources. This may benefit breeds that are adapted to these practices (IFOAM, 2018). Studies have suggested that local breeds or crossbreds, rather than modern high-producing breeds, are better suited to organic production (Ahlman, 2010; Bieber et al., 2019;

Rodríguez-Bermúdez et al., 2019). The studies point out that the high-producing breeds have been intensively selected under high-input production conditions, and have become less fit for organic conditions. Given this, having crossbreds and native breeds in the same herd may be preferable to keeping purebreds of both the native and modern breed in the same herd. Additionally, milk from native breeds in combination with grass-based diets shows favourable compositions of minerals and fatty acids (Poulsen et al., 2020).

Niche products from local breeds have been a major key in efforts to increase the population of endangered local breeds (e.g. Gandini et al., 2007). The first sensitivity analysis showed that the break-even in milk price that must be paid for herds to become economically competitive with SR is lower for XB (+35.6%) than SKB (+43.8%). This additional milk price could, for instance, be met through the marketing of niche products. In Sweden, there is no additional price paid by the large dairies, although some farmers of native breeds run on-farm dairies and manage to create a local market for the milk they produce. Milk from native Swedish cattle breeds has shown better properties for cheese and cream-based products, compared with high-yielding Swedish Red cows (Poulsen et al., 2017). In France, there is a large market for dairy products labelled PDO (Protected Designation of Origin; INAO, 2019), which is based on EU legislation on quality control for agricultural products (European Union, 2012;2013). For each specific product, there are regulations on the origin of the milk used to manufacture it. For example, some cheeses from the Normandy region, such as the *Livarot*, require milk from herds with 100% Normande cows, while the *Neufchâtel* cheese allows milk from herds having at least 60% Normande cows (the remainder may be crossbreds or other breeds), and the *Camembert de Normandie* and *Pont-l'Evêque cheeses* allow milk from herds having at least 50% Normande cows (Association de Gestion des ODG Laitiers Normands, 2020). The PDO incentive has turned out to be an effective motivation for farmers to keep local breeds, as they will then benefit from higher prices for their products (Verrier et al., 2005).

Where a specific (minimum) number of purebred native cows are maintained the cost of government subsidies for society should not change with crossbreeding. However, if dairy plants, retailers, and consumers were willing to pay more for products from herds in which purebred native cows are kept together with crossbred cows, economic support from the government directly to farmers could eventually be scaled down.

Milk yields from modern breeds in Sweden have increased substantially, which makes the native breeds even less competitive (Växa Sverige, 2018a). Faster improvement of modern breeds makes crossbreds with native breeds more profitable than the native breed, as was shown in the second sensitivity analysis (Figure 2). However, the sensitivity analysis here assumed that only milk yield improved genetically in the modern breed, and an almost linear relationship in total contribution margin per increase in milk yield emerged. Most breeding indices, such as the Nordic Total Merit Index (NTM; Sørensen et al., 2018) that is used in the selection of breeding candidates in Nordic dairy cattle, are constructed to improve all desired traits simultaneously. Given this, the sensitivity analysis may have underestimated the effects of other traits as well, such as improved fertility and health.

The information on SKB in organic production was very limited in comparison with that available for SR. This is explained by the small SKB population size, and the fact that approximately 17% of the milk-recorded cows (across all breeds) are organic (Växa Sverige, 2018a). Bieber et al. (2019) also used a rather limited number of SKB cows in their study on German and Swedish breeds under organic conditions. The low number of records for SKB cows means that the relative breed differences shown in Table 1 may not show the true characteristics of the breed, especially for the health traits.

The heterosis estimates in Table 1 were based on SR x Swedish Holstein crosses (Jönsson, 2015) because, to our knowledge, heterosis has not been estimated in SKB crosses. Therefore, the values we used may not accurately reflect heterosis for SKB crosses. A recent study of the genomic relationships between Swedish cattle breeds suggests that SR and SH are genetically closer than are SKB and SR or Swedish Holstein (Upadhyay et al., 2019). Thus, the heterosis when SKB is crossed with SR could, theoretically, be larger than that involved in the crossing of SR and Swedish Holstein. Furthermore, the heterosis estimates between native breeds and modern breeds in other countries may be different. The third sensitivity analysis (Table 5) showed how the results changed with changing heterosis estimates. It implied that the greater the heterosis effect is, the larger the contribution margin obtained from crossbreeding will be as compared with pure-breeding. Nevertheless, the increase in contribution margin from doubling heterosis effects would still be insufficient to compare to purebred SR.

Bull calves of pure SKB are smaller and grow at a slower rate than the larger dairy breed calves and beef x dairy crosses (Växa Sverige, 2018b). They are therefore not very attractive to beef producers, hence the low value assumption. We did not simulate the alternative for farmers to keep the SKB males as steers and eventually sell them for slaughter at an older age. The number of dairy bull calves produced (both purebred and crosses) was slightly reduced when crossbreeding was introduced, while the number of beef x dairy crossbred calves increased as a result of the increased use of beef semen. The production of dairy bull calves can be minimized through the use of X-sorted sexed semen. Sexed semen is usually not available in native breeds, but sexed semen from modern breeds to produce crossbred heifers can make crossbreeding more efficient (van Arendonk, 2011), and would also lower the number of purebred cows needed in the herd, i.e. allow for more crossbreds. Beef semen was used in the purebred SKB scenario to reduce the surplus of replacement heifers. Production of beef x SKB calves is probably more beneficial than raising purebred SKB bulls and heifers for beef production unless there is a reasonable market to sell replacement heifers.

The number of young heifers needed to be raised as replacements decreased when crossbreeding was introduced. This not only reduces associated costs but also creates more free resources, such as labour time, stable space, and pasture space – resources that were not taken into account in the economic calculations. Such resources could, for instance, be used to increase the herd size or to raise slaughter calves instead of selling them. The simulated results are based on a 100-cow herd, but the economic figures are scalable to any herd size, because the costs of labour, buildings, equipment, etc. are not included in the calculations. However, most herds with native dairy cows are usually small, and one can question if the effect of having 25% crossbreds in a 30-cow herd really would remain the same as in a 100-cow herd. The effect of herd size was not studied in this simulation. If the benefits of crossbreeding are dependent on expanded herd size, they may be less obtainable for some farmers. Furthermore, to keep the current population size of SKB, today's SKB farmers will need to increase their herd sizes if a terminal crossbreeding scheme of the sort studied here is widely adopted. Alternatively, of course, more farms with SKB cows need to be established.

As a part of FAO's global plan of action on animal genetic resources, guidelines including issues such as for crossbreeding programs have already been published (FAO, 2010, 2012). However, before implementing a terminal crossbreeding strategy in a native dairy herd, the actual effects on the conservation of the breed in question should be investigated and a thorough breeding plan on population-level needs to be prepared. Improving herd economy might 'conserve the farm', but how many farms are needed to implement the crossbreeding for the actual breed to be conserved? According to Upadhyay et al., (2019), the SKB breed still has a high genetic diversity, which confirms the conclusion from Bett et al. (2013) that this breed is not at risk. Nevertheless, the population size of SKB is decreasing (Växa Sverige, 2018a), and in case crossbreeding is implemented, it is of high importance to develop a breeding plan that conserves the genetic diversity a nucleus of the breed. A control system for crossbreeding and conservation needs to be put in action, to avoid the risk of inappropriate crossbreeding practices that threaten the pure breed, as what happened to the Flemish Red Cattle (Lauvie et al., 2008) and the Swedish Lowland Cattle (Bett et al., 2013). Furthermore, the terminal crossbreeding strategy that we propose, requires a well-managed purebred population, which potentially benefits from playing a key role in a crossbreeding strategy (FAO, 2012). Additionally, the crossbred animals in this strategy are omitted from the breeding populations, which minimizes the risk of loss of valuable gene combinations unique to the native breed.

Using SKB as an example, this study shows improved herd contribution margins of 13.6% in a herd with 25% crossbreds between a native and modern breed, as compared with a herd with the native breed alone. However, a mixed herd containing purebred cows of SKB (75%) and SR (25%) and no crossbreeding would generate contribution margins 8% higher than those obtained in the corresponding XB scenario. Even though crossbreeding may not reduce the monetary cost per native breed cow to be carried by society, it could keep the farms viable, thus helping to succeed in conservation plans. From a societal perspective, not only the number of purebred native cows matters but also the number of farmers engaged in the conservation scheme. Crossbreeding alone cannot compensate for the economic gap between native and modern breeds. However, combining crossbreeding with other conservation incentives, such as marketing niche products, may improve the economic benefits of having native cows on the farm, meaning that eventually the economic support from society can be scaled down. This study only examines economic potentials, and further investigations of the genetic and conservation effects of this strategy are highly recommended before any such crossbreeding with native breeds is implemented. The conservation strategy presented in this study may apply to breeds of interest in other European countries. However, its benefits, when its application is extended in this way, may differ depending on the national prices and costs, differences between breeds, and heterosis expressed by crossbreds.

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Appendices

Appendix 1. Phenotypic breed estimates[a] of Swedish Polled Cattle (SKB) and Swedish Red (SR) kept in a conventional production system, and heterosis estimates in crosses between the breeds for production, risk of diseases, fertility, and mortality used in the model

	SKB	SR	Heterosis[b], %
305-d kg ECM, 1st parity	5 360	8 369	+3%
305-d kg ECM, 2nd parity	6 572	9 586	+3%
305-d kg ECM, later parities	6 856	9 873	+3%
Mastitis, %	8.1	7.8	-
Hoof-related diseases, %	11.1	16.8	−10%
Other diseases, %	2.6	2.1	−10%
Dystocia	6.4	4.6	−7%
Cow mortality	4.5	3.5	−10%
Calf mortality (incl. stillbirth)	8.8	5.3	−12%
Young stock mortality	0.8	4.1	−12%
Conception rate, cows	0.40	0.45	+10%
Age at 1st service, months	19.7	17.9	-
Calving − 1st AI, days	74	77	-

SKB = Swedish Polled Cattle; SR = Swedish Red; ECM = Energy-corrected milk
[a]Data from the Swedish milk recording scheme. The dataset consisted of 789 milk records from SKB cows and 440 924 milk records from SR cows
[b]Based on Jönsson (2015). All estimates are favorable.

Appendix 2. Assumed prices as of 2018 (Clasen et al., 2020) in € for milk production, slaughter value and live calves for conventional production

Item	Price, €
Milk, per 1,000 kg ECM	375
Slaughter SKB cow, per kg live weight	1.12
Slaughter SR cow, per kg live weight	1.35
Slaughter SR x SKB cow, per kg live weight	1.24
SKB dairy bull calf, per head	10[a]
SR dairy bull calf, per head	225[a]
SR x SKB dairy bull calf, per head	117.5[a]
Beef x dairy bull calf, addition[b] per head	70
Beef x dairy heifer calf, addition per head	35

ECM = Energy-corrected milk; SKB = Swedish Polled Cattle; SR = Swedish Red
[a]Market price corrected for rearing costs
[b]Added to the price of a dairy calf

Appendix 3. Simulated herd dynamics at equilibrium in a herd of purebred Swedish Polled Cattle (SKB); a herd using a two-breed terminal crossbreeding system with SKB purebreds and 25% F1 Swedish Red x SKB crossbreds (XB); and a herd of purebred Swedish Red (SR), all in a conventional production system

	SKB	SR	XB
Crossbred cows (%)	0	0	30
Replacement (%)	31.4	28.1	29.4
Replacement heifers in the herd/cow	0.75	0.69	0.67
Dairy bull calves sold/cow	0.36	0.35	0.33
Beef x dairy crosses sold/cow	0.22	0.32	0.29
305-d kg ECM yield (kg/cow)	6 124	9 205	6 624
Calving interval (days)	412	399	409
Conception rate (cows)	0.40	0.45	0.42
Disease treatments/cows	0.22	0.32	0.22
Cow mortality (%)	4.2	3.5	4.0
Calf mortality (incl. stillbirth) (%)	9.0	5.4	8.0
Young stock mortality (%)	1.1	3.9	1.3

Appendix 4. Simulated annual economic results (€/cow) in a herd of purebred Swedish Polled Cattle (SKB); a herd using a two-breed terminal crossbreeding system with SKB purebreds and 25% F1 Swedish Red x SKB crossbreds (XB); and a herd of purebred Swedish Red (SR), all in a conventional production system

	SKB	SR	XB
Income			
Milk production	2 292	3 441	2 479
Slaughter cows	73	209	71
Live calves	17	24	37
Total income	2 382	3 836	2 587
Costs			
Feeding cows	800	1 179	856
Feeding young stock	206	185	185
Inseminations	47	44	45
Disease treatments	31	28	30
Other costs	186	180	181
Total costs	1 271	1 615	1 296
Total profit	1 111	2 221	1 290
Difference to SKB		+1 110	+179