

Replacement decisions on Finnish dairy farms

– toward better economic performance
with novel technology and
sustainable herds

Doctoral Dissertation

Anna-Maija Heikkilä



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Abstract

Competitive milk production in the northern parts of Europe and on relatively small dairy farms is challenging. The objective of this thesis was to find expedients that would improve the economic performance of Finnish dairy farms and, thus, their competitiveness on the market. Means under examination were related to replacement: replacement of old technology with novel technology and replacement of an existing cow with a new one. The theory of optimal behavior formed the basis for the methods used in solving the research problems. Empirical data originated from the Farm Accountancy Data Network (FADN) and from the Finnish dairy herd recording system.

The switch from labor-intensive tied-housing technology to capital-intensive loose-housing technology was examined using standard and random effect probit models, and with a model where the sequences of interrelated choice probabilities were estimated with Geweke-Hajivassiliou-Keane simulation technique (GHK probit model). The results of all models indicated that the young age of a farmer, a high rate of investment allowance, considerable building capital, and large dairy capacity have a positive effect on the changeover to loose-housing technology. The random effect and GHK probit models, which also control

for farmer-specific individual effects, suggested that these effects are significant determinants of the switch. The GHK probit model also controlled for serial correlation of period-by-period choices. The results indicated that positive revenue shocks encourage the replacement of old technology with new technology whereas negative revenue shocks retard or delay it. Likelihood of the switch to loose-housing technology decreases very elastically with respect to the increasing investment price.

The adoption of an automatic milking system was investigated as a means to improve the productivity growth of dairy farms. First, the discrete choice between conventional milking systems and automatic milking systems was modeled. Second, technology-specific production functions were estimated to derive the growth rate of total factor productivity and its components. The two-stage estimation method was applied to cater for the sample selection bias caused by the endogenous technology choice. Total factor productivity growth increased on those farms that switched from conventional milking systems to automatic milking systems. The change was linked to overall improvements in production technology and an expansion in herd size. The adoption of robotic milking intensified the positive

development on large farms. The direct effect was linked to beneficial technological change but automation may also contribute to improved productivity growth by solving problems related to the availability of skilled labor force. Thus, automatic milking opens access to larger herd size which is a premise for improving productivity growth in the Finnish dairy sector.

The optimal replacement of a dairy cow was investigated by applying the methods of dynamic programming. First, the optimum at lactation level was sought. The results suggested that only the oldest cows with low milk production capacity should be disposed intentionally. The optimal replacement rules were similar for healthy and diseased cows indicating that the treatment of diseases is more profitable than replacing a diseased cow with a first-lactating cow. Second, dynamic programming was applied to determine the costs of clinical mastitis with a special focus on the costs of premature culling of mastitic cows. In this model, the interval between the two successive stages was one month which enabled more detailed modeling than examination at lactation level. In spite of the high costs of clinical mastitis, the results recommended treating mastitic cows and keeping them in most cases until their fifth lactation. A cheaper (20%) heifer advanced the optimum to the previous lactation and a more expensive (+20%) heifer postponed it to the following lactation. Within a breed, the net present value of a cow was increasing with her milk production capacity but, when comparing Ayrshire and Holstein-Friesian breeds, Holstein-Friesians lose the advantage of their higher milk yield because of their shorter herd life and higher risk of diseases.

A linear programming model was built for examining the optimal choices between conventional insemination, insemination with sex-sorted sperm, and the use of conventional or sex-selected embryo transfer. The optimal outcome was a mixture of

available technologies. All cows of the herd were inseminated with conventional semen whereas, in some inseminations of heifers, it was optimal to use sex-sorted semen. The number of cows donating unselected embryos was at the upper constraint of the model whereas no embryo recipients existed in the optimal herd. Combining embryo production and sex-selection was economically justified for heifers only. In practice, the optimal insemination strategy is herd-specific depending on the production capacity of the cows and the technical success of each reproductive technology in the herd.

In conclusion, by prolonging the herd life of dairy cows, dairy farmers can improve the economic performance of milk production. Therefore, farmers' awareness about the real costs of premature culling and the gains that can be achieved by treating a diseased cow must be improved. Optimizing tools, based on farm-specific input data, are needed for determining the optimal replacement decisions and, hence, the optimal reproduction policy. Planned production of replacement heifers contributes to the target of improved sustainability of the herd. Changes in the milk price have a considerable income effect on dairy farms. Carrying out the optimal management decisions is only able to relieve the effects of unfavorable price changes. To ensure the continuation of milk production in Finland, investment allowances are needed to boost up investments on those farms which have potential for developing their production to meet the future challenges. Investments in technology appropriate for large farms improve productivity growth and, thus, the prospects of dairy farms to survive in the long run. However, a human cannot be replaced by technology, not even by novel technology.

Key words:

housing system, milking system, longevity, reproduction, productivity, optimization

Suomalaisen lypsykarjatilän uudistuspäätökset

– kestäväällä karjalla ja uudella teknologialla
kohti parempaa taloudellista tulosta

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Tiivistelmä

Kilpailukykyinen maidontuotanto Pohjois-Euroopassa ja verrattain pienillä lypsykarjatilajoilla on haasteellista. Tämän tutkimuksen tarkoituksena oli löytää keinoja, jotka parantaisivat suomalaisten lypsykarjatilajojen taloudellista tulosta ja siten niiden kilpailukykyä markkinoilla. Tutkimuksen kohteena olivat tuotantoteknologian ja karjan uudistaminen. Optimoinnin teoria muodosti pohjan tutkimusongelmien ratkaisussa sovelletuille menetelmille. Tutkimuksessa käytetyt tila- ja lehmäkohtaiset aineistot kerättiin suomalaisilta kannattavuuskirjanpitotiloilta ja lypsykarjojen tuotosseurannasta.

Todennäköisyys siirtyä työvaltaisesta parsinavetteknologiasta pääomavaltaiseen pihattoteknologiaan mallinnettiin kolmen erilaisen probit-mallin avulla. Kaikki mallit osoittivat, että nuori viljelijä, korkea investointiavustus, huomattava rakensuspääoma ja suuri olemassa oleva maidon tuotantokapasiteetti vaikuttivat positiivisesti pihattoteknologian käyttöönottoon. Myös viljelijäkohtaiset tekijät vaikuttivat tähän merkittävästi. Positiiviset tuottohokit rohkaisivat siirtymään uuteen teknologiaan, kun taas negatiiviset shokit jarruttivat tai viivästyttivät sitä. Todennäköisyys korvata vanha teknologia uudella muut-

tui hyvin joustavasti investoinnin hinnan muuttuessa.

Pihattoteknologiaan siirtyminen mahdollistaa lypsyjärjestelmän automatisoinnin. Perinteisen lypsyjärjestelmän korvaamista automaattisella tarkasteltiin keinona parantaa lypsykarjatilajojen tuottavuuskehitystä. Kaksivaiheinen estimointimenetelmä sisälsi teknologiavalinnan mallinnuksen perinteisen lypsyt ja automaattilypsyt välillä sekä teknologiakohtaisten tuotantofunktioiden estimoinnin. Kokonaistuottavuuden muutos ja sen komponentit johdettiin estimoiduista tuotantofunktioista. Kokonaistuottavuuden kasvu parani tiloilla, jotka siirtyivät perinteisestä lypsystä automaattilypsyyteen. Muutos kytkeytyi samanaikaisesti tapahtuneeseen tilakoon kasvuun ja tilan muun tuotantoteknologian uudistamiseen. Aineiston suurimmilla tiloilla automaattilypsyyteen siirtyminen vahvisti positiivista tuottavuuskehitystä. Välitön vaikutus oli teknisen muutoksen ansiota mutta lypsyt automatisointi voi edesauttaa tuottavuuskehitystä myös ratkaisemalla työvoiman saatavuuteen liittyviä ongelmia. Siten se osaltaan mahdollistaa yrityskoon kasvattamisen, joka on edellytys suomalaisen lypsykarjatilajojen tuottavuuskehityksen parantamiselle.

Lypsylehmän uudistaminen optimoitiin dynaamisen ohjelmoinnin avulla. Optimi määritettiin aluksi lypsykauden tasolla. Tulokset osoittivat, että vain vanhimmat, heikkotuotoksiset lehmät kannattaa poistaa karjasta harkinnanvaraisesti. Optimisäännot olivat samat sekä terveille että sairastaville lehmille, mikä osoitti sairaan lehmän hoitamisen olevan kannattavampaa kuin sen korvaaminen ensimmäistä lypsykauttaan lypsävällä lehmällä. Seuraavaksi dynaamista ohjelmointia sovellettiin näkyvän utaretulehduksen kustannusten määrittämiseen. Erityisenä tarkastelun kohteena olivat tulehduslehmän ennenaikaisesta poistosta aiheutuvat kustannukset. Tässä mallissa tarkasteluperiodin pituus oli yksi kuukausi, mikä mahdollisti yksityiskohtaisemman mallinnoituksen kuin tarkastelu lypsykausittain. Suurista utaretulehduksen aiheuttamista taloudellisista menetyksistä huolimatta malli suositti tulehduksen hoitamista ja lehmien pitämistä karjassa useimmiten viidennelle lypsykaudelle asti. Edullisempi uudistushieho (-20%) siirsi optimin edelliselle lypsykaudelle ja vastaavasti kalliimpi uudistushieho (+20 %) seuraavalle lypsykaudelle. Rodun sisällä lypsylehmän nettonykyarvo oli sitä parempi, mitä korkeampi oli lehmän tuotoskyky. Ayrshire- ja holstein-früsiläislehmien vertailu osoitti, että holstein-früsiläislehmät menettivät korkeamman tuotoksen tuoman taloudellisen edun lyhyemmän tuotantoajan ja suuremman sairastuvuusriskin takia.

Optimaalinen valinta erilaisten karjan lisääntymisvaihtoehtojen välillä määritettiin lineaarisella ohjelmoinnilla. Valittavina olivat siemennys tavanomaisella tai sukupuolilajittelulla siemenellä sekä tavanomaisen tai sukupuolilajittelun alkion huuhtelu tai siirto. Tulos oli käytettävissä olevien vaihtoehtojen yhdistelmä. Kaikki lehmät siemennettiin perinteisellä siemenellä mutta osa hiehoista lajitellulla siemenellä. Lajittelemattomia alkioita tuottavien lehmien määrä oli mallin sallimassa enimmäismäärässä. Alkiotuotannon ja sukupuol-

lilajittelun yhdistäminen oli taloudellisesti kannattavaa vain hiehoilla. Käytännössä optimaalinen karjan lisääminen on karjakohtainen ratkaisu, johon vaikuttavat muun muassa uudistuseläinten tuottamiseen soveltuvien lehmien määrä ja vaihtoehtojen teknologioiden tekninen onnistuminen kyseisessä karjassa.

Tarkastellut uudistus päätökset osoittavat, että karjan tuotantoa pidentämällä maidontuottajat voivat parantaa tuotannon taloudellista tulosta. Sen vuoksi tuottajien tietämystä lehmien ennenaikaisten poistojen kustannuksista ja taloudellisesta hyödyistä, joka on saavutettavissa sairastuneitten lehmien hoidosta, tulisi lisätä. Tätä varten tulisi kehittää tilakohtaista aineistoa käyttäviä laskentatyökaluja, joilla voitaisiin optimoida sekä lehmien poistoajan kohtaa että uudistuseläinten tuottamista. Suunnitelmallinen hiehoikasvatus ehkäisee omalta osaltaan lehmien ennenaikaisia poistoja. Maidon hinnanmuutoksilla on huomattavat tulovaikutukset lypsykarjatiloilta. Epäedullisten hintamuutosten vaikutuksia ei voida optimaalisilla uudistus päätöksillä kumota, ainoastaan lieventää. Maidontuotannon jatkuvuuden turvaamiseksi Suomessa tarvitaan investointitukia edesauttamaan investointeja tiloilla, joilla on potentiaalia kohdata edessä olevat haasteet. Investoinnit suurille tiloille soveltuvaan teknologiaan parantavat tuotavuuskehitystä ja siten edellytyksiä kannattavaan maidontuotantoon. Tuotantorakenteen muuttuessa on kuitenkin huomattava, etteivät ihmiset ole kokonaan korvattavissa teknologialla, eivät edes uudella teknologialla.

Avainsanat:

tuotantoteknologia, lypsyjärjestelmä, kestävyys, lisääntyminen, tuottavuus, optimointi

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There are many ways to accomplish a doctoral dissertation. My way has been a long one, having included both active and non-active periods. My first tutor at the University of Helsinki, Professor Viljo Rynnänen, piqued my interest in agricultural economics and encouraged me to engage in postgraduate studies. I still value highly his cordial way of taking care of his students. His replacement, Professor Matti Ylätaalo, firmly but kindly prodded me to complete my studies. Eventually, I accomplished my doctoral dissertation Professor John Sumelius being professor in charge. My warm thanks go to both Professor Ylätaalo and Professor Sumelius for their advice and assistance in many issues crucial to finishing the task.

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Inkoo, 27 June 2013

Anna-Maija Heikkilä

List of original articles

This thesis is a summary of and a discussion on the following articles which are referred to in the text by their Roman numerals:

I **Pietola, K. & Heikkilä, A.-M. 2005.** Switching toward capital-intensive technologies in Finnish dairy farms. *Agricultural Economics* 33: 381–387. doi: 10.1111/j.1574- 0864.2005.00078.x. (© 2005 International Association of Agricultural Economists. Published by John Wiley & Sons, Inc.)

II **Heikkilä, A.-M., Nousiainen, J.I. & Jauhiainen, L. 2008.** Optimal replacement policy and economic value of dairy cows with diverse health status and production capacity. *Journal of Dairy Science* 91: 2342–2352. doi: 10.3168/jds.2007-0736. (© 2008 American Dairy Science Association. Published by Elsevier Inc.)

III **Heikkilä, A.-M., Nousiainen, J.I. & Pyörälä, S. 2012.** Costs of clinical mastitis with special reference to premature culling. *Journal of Dairy Science* 95: 139–150. doi: 10.3168/jds.2011- 4321. (© 2012 American Dairy Science Association. Published by Elsevier Inc.)

IV **Heikkilä, A.-M. & Peippo, J. 2012.** Optimal utilization of modern reproduction technologies to maximize the gross margin of milk production. *Animal Reproduction Science* 132: 129–138. doi: 10.1016/j.anireprosci.2012.05.004. (© 2012 Elsevier B.V.)

V **Heikkilä, A.-M. & Myyrä, S. 2013.** Adoption of automatic milking system and its impact on productivity growth of dairy farms. Manuscript submitted to *Agricultural Economics*.

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Authors' contribution

Article I is an outcome from the collaboration of Dr Pietola and Ms Heikkilä. Ms Heikkilä collected and organized the data and built two of the models presented in the paper (standard probit, random effect probit). Dr Pietola developed the third model (GHK probit). Both authors contributed to and collaborated in writing the article.

Article II was developed in a joint research project in which longevity of dairy cows was investigated from different perspectives. Ms Heikkilä designed and programmed the model, collected the economic data and instructed Mr Nousiainen in producing the biological input parameters for the model. Mr Jauhiainen was responsible for the statistical analyses of the biological data. Mr Nousiainen and Mr Jauhiainen drafted the description of the parameters that they produced. Ms Heikkilä was responsible for the rest of the text and for finishing the paper following the suggestions by its reviewers.

In Article III, the model of Article II was further developed at the request of Finnish veterinarians in a joint research project of MTT Agrifood Research Finland and the University of Helsinki. Ms Heikkilä was responsible for the economic data and programming. Mr Nousiainen collected and organized the biological data by the orders of Ms Heikkilä. Professor Pyörälä contributed as a specialist in veterinary questions. Ms Heikkilä reported the research and revised the text according to the comments by the co-authors and the reviewers of the manuscript.

The model presented in Article IV is a continuation for a research project in which the novel techniques of reproduction were investigated as biological and technical issues. Ms Heikkilä recognized the need of economic research, designed and programmed the model as well as collected the economic input data for it. Dr Peippo collected the biological input parameters requested by Ms Heikkilä. Dr Peippo contributed to the manuscript in sections being her expertise area. Ms Heikkilä was, nevertheless, mainly responsible for the text and its revisions suggested by the reviewers.

Article V is based on investigation made for a joint European research project, Factor Markets. Ms Heikkilä planned the implementation of the study, collected and organized the data for it as well as programmed the models. Professor Myyrä contributed to the modeling with advice and proposals for improvement. Both authors contributed to producing the text but Ms Heikkilä had the main responsibility for it.

In Articles II, III and IV, Ms Heikkilä was the only economist among the authors. She was in charge for building the bio-economic models, conditional on biological parametrization. She was alone responsible for carrying out the economic analyses in the papers.

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1 Introduction

1.1 Background

At the end of 2012, the number of dairy farms in Finland was less than 4% of the top number of 247,000 at the beginning of the 1960s. Milk production in 2012 was, however, nearly 60% of the top production of 3.714 million kg in 1964. The number of dairy cows was at its highest in 1963, 1.187 million cows; in 2012, the number was 283,600 cows (Hyvärilä, 2008; Tike, 2013). Despite this pronounced decrease in the number of milk producers and dairy cows, milk production is still the most important production line in Finland measured as a share of the gross return of agriculture. Nevertheless, the years of overproduction problems are history. Today, Finnish milk production does not cover domestic consumption (Niemi and Ahlstedt, 2012).

Finland is not the only European country where a heavy structural change has taken place in milk production (Table 1). The total number of dairy farms has decreased and the average herd size increased. In Estonia and in the Czech Republic, the

development has been different from the general trend. Among the countries listed in Table 1, the change has been the most rapid in Denmark and Hungary but Sweden and Finland are close to them when both the number of dairy farms and the average herd size are taken into account. Regardless of the rather quick structural change in the Finnish milk sector, dairy farms are still small in comparison with many other European countries and intensive milk producers. In the Netherlands, for example, the average herd size is about threefold compared with Finland. According to the share of milk produced on farms with more than 50 cows, Austria and Switzerland are in the category of their own. In Finland, the share is clearly greater in comparison with these mountain regions but much smaller than in most European countries (Table 1). At the end of 2012, the average herd size in Finland reached the threshold of 30 dairy cows. The number of dairy farms with more than 100 dairy cows was 213 in May 2012 (TIKE, 2013).

Table 1. Structure of dairy farms in selected European countries in 2010 (Source: IFCN, 2003, 2011)

Country	Number of dairy farms, 1,000	Decrease since 2001, %	Average herd size, number of cows	Change since 2001, %	Share of milk produced in herds > 50 cows, %
Austria	40	43	13	53	7
Belgium	11	35	44	26	59
The Czech Republic	2	20	161	-15	98
Denmark	4	59	140	115	97
Estonia	3	0	28	-18	90
Finland	11	50	26	63	26
France	77	36	47	31	53
Germany	92	29	46	31	64
Hungary	12	63	21	75	74*
Ireland	18	42	61	65	95
The Netherlands	20	29	75	36	88
Sweden	6	45	61	65	74
Switzerland	27	43	21	40	10

*2007

Table 2. Number of dairy farms that received investment aid for cowshed construction (new, extension, renovation) in 2001–2011 (Source: Finnish Ministry of Agriculture and Forestry)

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Total	431	341	329	271	441	389	412	117	217	157	172
Loose-housing system, warm	109	103	118	103	176	194	222	112	125	95	91
Loose housing system, cold	17	24	25	18	44	29	35	13	26	23	48
Tied-housing system	305	214	186	150	221	166	155	52	60	39	33
Cows/cowshed	32	36	39	41	43	51	51	63	75	71	74

Due to the small herd size, traditional and labor-intensive production technology has been persistent in Finland. At the beginning of the 21st century, many dairy farms still invested in the tied-housing system (Table 2). By 2011, the emphasis of investments had shifted to modern loose-housing systems (Table 2) and the number of cattle places in those systems had reached the number of stanchion-tied stables (Tike, 2013). The total number of investments has varied over the years but the trend is decreasing similar to the total number of dairy farms. The terms of investment aid are a key reason for the annual variation as very few investments are realized without any subsidy. As a counterbalance to the decreasing number of investments, the size of facilities has increased rapidly during the last ten years (Table 2). A current investment typically doubles or even triples the original farm size measured by livestock numbers (Pyykkönen et al., 2013).

Latvala and Pyykkönen (2008) investigated technology choices and investment plans in Finnish animal husbandry. The data were collected by an inquiry in 2006. At that time, the most common milking system on dairy farms was a pipeline milking machine with the share of 75%. The share of modern milking systems, like milking parlors and automatic milking systems (AMS) was about 12%. The rest of the farms still used old technology, such as bucket milking machines. Since that,

the number of AMS has increased rapidly. When investing in a new construction with a loose-housing system, about 60% of farms also invest in AMS or at least in premises for it (Karttunen and Lätti, 2009). At the end of 2012, the total number of dairy farms with AMS was 717, corresponding to 7.7% of all dairy farms (Figure 1). Latvala and Pyykkönen (2008) reported the share of AMS being only 0.4% in 2006.

More than 70% of dairy herds and 80% of dairy cows belonged to the Finnish dairy herd recording system in 2011 (ProAgria, 2012). The system produces a considerable amount of cow- and herd-specific information about Finnish milk production. Based on the statistics of that recording system, the longevity development of Finnish dairy cows has been worrying: the average culling age is today almost two years less than in 1969. A rapid drop took place at the beginning of the 1990s when the criteria for milk quality were tightened significantly. The decreasing trend stabilized for about ten years at the end of the 1990s. In 2008, the trend at last turned slightly upwards (Figure 2). The short production life of a dairy cow is a multifaceted problem on Finnish dairy farms. Its economic consequence is a combination of increased costs and lost returns and, therefore, difficult to perceive.

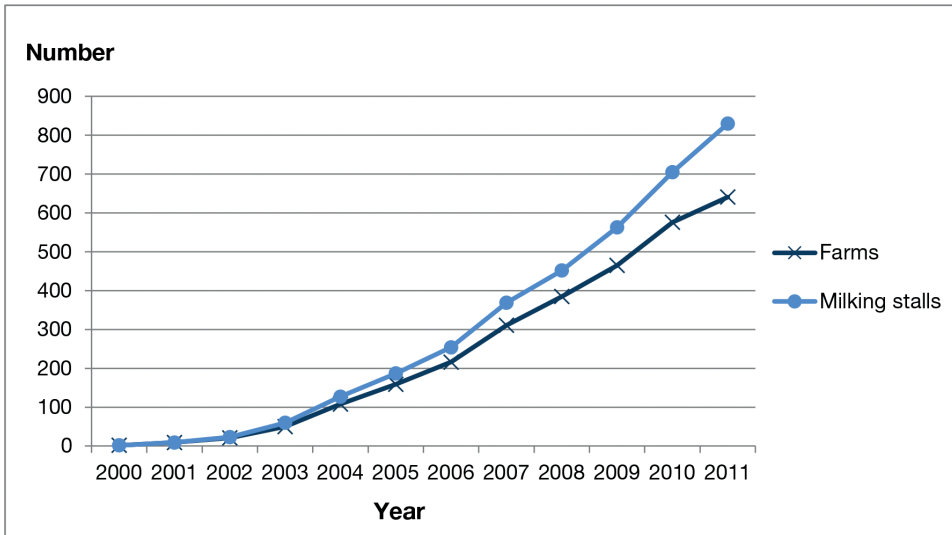


Figure 1. Number of farms having automatic milking system and number of automatic milking stalls in Finland in 2000–2012 (Source: E. Manninen, Valio, Finland)

The reasons for disposing of a cow from the herd are registered into the dairy herd recording system. From year to year, the main reasons have been mastitis and fertility problems. Nousiainen (2006), who investigated the insemination and treatment history of cows together with reported culling reasons, concluded that both reasons caused more than 20% of all cullings. To avoid excess costs related to

premature cullings, dairy farmers should have more information about the optimal treatment and replacement strategy of diseased cows. Moreover, they need tools for optimizing the use of available breeding technologies to produce a sufficient, but not excess, number of replacement heifers and to make the best possible profit taking into consideration the time effect that is related to poor fertility.

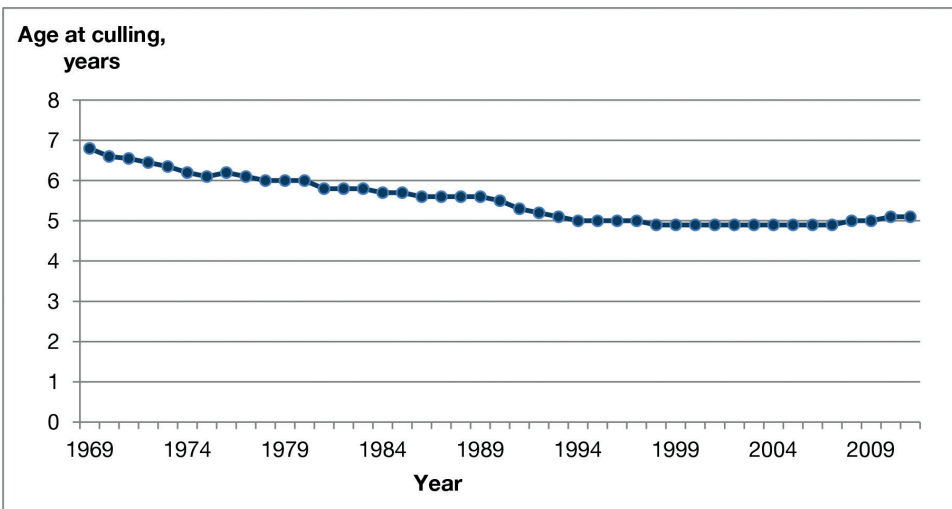


Figure 2. Average culling age of dairy cows in Finnish dairy herd recording system in 1969–2011 (Source: Association of ProAgria Centres)

Serious contagious diseases of cattle are very rare or non-existent in Finland. However, the prevalence of some less serious but harmful diseases has increased along current technologies and increasing herd sizes. Contagious hoof diseases are an example of these. Ringworm caused by *Trichophyton verrucosum* is diagnosed in 20–30 new herds per year. *Mycoplasma bovis* is the most recent problem on cattle farms. To avoid its spread, animal transfers between herds should be avoided in regions where the pathogen has been found. A new phenomenon is also that mastitis caused by *Streptococcus agalactiae* has become more common again. This disease has been observed especially in large herds with loose-housing technology (ETT, 2013). In herds having robotic milking, increased somatic cell counts have been measured compared with the concentrations of herds having non-robotic milking systems (Maitohygienialiitto, 2013).

Profitability of dairy farms has been rather stable in comparison with the other production lines of Finnish agriculture (MTT, 2013). Stability is usually a positive feature but, when the level of profitability is low, stability has a negative undertone.

In the time period from 2000 to 2011, the mean of profitability ratio was 0.57, the annual minimum being 0.47 and the maximum 0.68 (Figure 3). Thus, dairy farmers reach typically only around a half of the standardized wage claim and the standardized interest claim that have been stated for their own work and their own capital. Profitable milk production in Finland is expected to become even more challenging due to the changes in the milk quota system of the European Union (EU) after the year 2015.

This thesis examines the economics of Finnish dairy farms and, more precisely, the possibilities to improve their economic performance by optimal management decisions and reasonable technology choices. It consists of five separate articles and their summary. The specific research problems of the articles are all related to replacement: replacement of old technology with modern technology (Articles I and V) and replacement of an old or a diseased cow with a young one (Articles II and III). Article IV discusses both replacement targets, herd and technology, as it concerns the utilization of novel technology in the production of young cows.

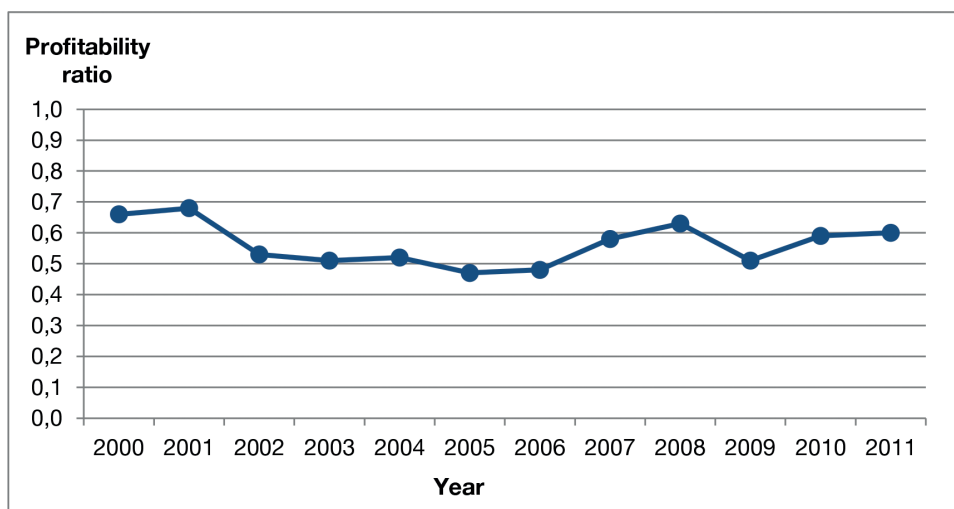


Figure 3. Profitability on Finnish dairy farms in 2000–2011 (Source: MTT, 2013)

1.2 Framework

Economic decision-makers assume that the decisions they make lead to the best outcome in a given situation. The decision-making process, by which the 'best solutions' are found, applies the principles of the optimization theory. The rules of optimization form the foundation for the theories of consumer choice, production, input usage, and profit maximization. These rules of optimization are pervasive throughout the study of economics and are essential for understanding the behavior of economic decision-makers (e.g. Dixit, 1990; Maurice and Thomas, 1995).

Optimizing behavior involves the maximization or minimization of an objective function. For a manager of a firm, the objective function is usually profit, which is to be maximized, or the cost, which is to be minimized. For a consumer, the objective function is satisfaction derived from the consumption of goods, which is to be maximized (e.g. Dixit, 1990; Maurice and Thomas, 1995).

In this thesis, a dairy farmer is the economic decision-maker who aims at maximizing his utility or profit by making optimal decisions. Decisions concern both technology and management choices but, still, they are based on optimizing behavior. Articles II, III and IV concerned typical optimization problems where the profit is maximized. In Articles I and V, the discrete choice between two technologies was estimated assuming that the choice is based on the maximization of expected benefits.

As optimization is a predominant theme in economic analysis, the classical calculus methods and the more recent techniques of mathematical programming occupy an important place in the economists' tool kit. Some tools are applicable only to static optimization problems where the solution sought usually consists of a single optimal

magnitude for every choice variable. In contrast, the solution of a dynamic optimization problem takes the form of an optimal time path for every choice variable today, tomorrow, and so forth, until the end of the planning period (e.g. Chiang, 1992).

1.3 Objectives

An overall objective of this thesis was to find technology choices and management practices that would improve the economic performance of Finnish dairy farms and, thus, their competitiveness on the market. The approach was empirical, aiming to produce practical recommendations for dairy farmers, advisers and administrative decision-makers. Moreover, the purpose was to develop tools for solving optimization problems that dairy farmers are confronted with. Each of the five articles contributed to achieving the objective through a specific target of its own.

The goal in Article I was to estimate the factors affecting a dairy farmer's choice between tied-housing and loose-housing technology. Identifying these factors helps to promote switching to loose-housing technology and, consequently, to less labor-intensive technology that may in the long run be more competitive than the traditional technology. The aforementioned target was set when the research started in 2003. Today, switching to loose-housing technology has also become a question of animal welfare which, in turn, is linked to the longevity of dairy cows, a topic examined in Articles II and III.

The purpose of Article II was to find an optimal replacement policy for dairy cows with diverse health status and production capacity. Moreover, the objective was to investigate the difference in economic value between dairy cow breeds and between single cows within the breeds.

The target of Article III was to estimate the total costs of clinical mastitis. Information about the real costs of mastitis is needed for producing correct economic incentives to prevent the disease. A special concern was the cost due to premature culling of mastitic cows. The optimal replacement time was estimated for a reference and, thus, the article produced more detailed information about optimal culling of mastitic cows than Article II where diseased cows were investigated as a whole.

As the replacement of dairy cows requires producing young animals to substitute the disposed ones, animal reproduction is linked to the problematics of replacement. In Article IV, the target was to optimize the use of different reproductive technologies of dairy cows. A special focus was modern technologies, such as embryo transfer and gender pre-selection. The optimal solution

had to produce enough replacement animals for the herd assumed to have 60 dairy cows and an alternating replacement rate.

When a dairy farm switches from tied-housing technology to loose-housing technology, the number of variant milking technologies grows. In Article V, the aim was to reveal how the switch from conventional milking systems (CMS) to automatic milking systems (AMS) affects the productivity growth of dairy farms i.e. whether the ongoing technological change could meet the expectations set for it in improving productivity development. The two-stage estimation method applied in Article V also required modeling the choice between the two milking technologies. Thus, Article V, like Article I, generated estimates for the factors affecting a dairy farmer's investment decisions.

2 Materials and methods

Both econometric methods and mathematical programming were used for solving the research problems of the five articles. Econometric methods were used in modeling the technology choice of a dairy farmer and the productivity growth of dairy farms (Article I and V) whereas mathematical programming was applied in solving the management problems of a single dairy cow or the whole dairy herd (Articles II, III and IV).

The discrete choice between tied-housing technology and loose-housing technology, conditional on farm characteristics and economic environment, was first estimated using a standard probit model. The standard probit model, however, neglects farmer-specific individual effects, and the specification does not control for serial

correlation of period-by-period choices. The second specification was a random effect probit model that also controls for the farmer-specific effects which may cause persistence in choices. Serial correlation can, in turn, be significant in the continuation region if the next period choices are affected by the past revenue shocks (Pakes, 1986). The third model specification used in the work controls for both serial correlation and farmer-specific effects by simulating the sequence of interrelated choice probabilities utilizing Geweke–Hajivassiliou–Keane (GHK) simulation technique (Eckstein and Wolpin, 1989; Keane, 1993; McFadden, 1989; Pakes and Pollard, 1989). The standard probit and the random effect probit models were estimated using LIMDEP software and the GHK probit model using GAUSS software.

The replacement of a dairy cow was optimized applying dynamic programming (Kennedy, 1986), a mathematical technique that is based on Bellman's principle of optimality (Bellman, 1957). The work takes into consideration the genetic production capacity of a cow, the uncertainty related to it, and the risk of animal diseases. The model also produces the expected net present value of a cow and, thus, enables the evaluation of different production and health traits of the cow. The two dominating breeds in Finnish dairy herds, Ayrshire and Holstein-Friesian, were analyzed separately. The optimal decision rules were solved numerically with a policy iteration technique (Bertsekas, 2001) using the *CompEcon* Toolbox of MATLAB software.

Dynamic programming was also applied in estimating the costs of clinical mastitis. A special focus was on the cost due to premature culling of mastitic cows. This model was based on the model already presented in Article II but it was tailored to cows having clinical mastitis. The interval between two successive stages was shorter, one month, while in Article II, it was a calving interval. The optimal replacement time of healthy and mastitic cows was determined as well as the expected net present value of healthy cows and cows having their first or repeated cases of clinical mastitis. Costs of mastitis were determined as a difference between these values similar to the method that De Vries (2006) applied in determining the economic value of pregnancy in dairy cattle. The algorithm of the model was programmed using MATLAB software and solved similar to the model of Article II.

A linear programming model (Hazell and Norton, 1986) was built for optimizing the choices between conventional insemination, insemination with sex-sorted sperm and the use of conventional or sex-selected embryo transfer. Embryo transfer was examined from the viewpoint of an

embryo donor and an embryo recipient. Optimization was made by maximizing the margin on the building and machinery costs. The model was solved using the large-scale algorithm of the Optimization Toolbox of MATLAB software.

A two-stage estimation method proposed by Heckman (1979) was applied in Article V for estimating the productivity growth of dairy farms having CMS vs. AMS. First, the discrete choice between the milking systems was modeled using a logit model. The model generated inverse Mills ratio which was further utilized in productivity analysis for correcting the selection bias caused by the endogenous technology choice. Second, technology-specific production functions, having the form of an extended Cobb-Douglas function, were estimated. Using the estimation results, output elasticities with respect to different inputs, returns to scale, technological change, and total factor productivity growth were derived (e.g. Kumbhakar et al., 1999). The logit model was estimated using LIMDEP software and the production functions using SAS software.

Farm- and cow-specific empirical data for all articles were mainly collected from Finnish dairy farms. In Articles I and V, the farm data came from dairy farms in the Farm Accountancy Data Network (FADN). In Articles II, III and IV, the data originated from the Finnish dairy herd recording system kept up by the member organizations of ProAgria. These recording systems include information about milk yields, veterinary treatments, inseminations, disposals from the herd, and culling reasons, among others. Some model parameters were derived from the previous studies. Data concerning the economic environment, such as input and output prices, were collected from Finnish official statistics. A detailed description of the datasets is presented in each article.

3 Results and discussion

This chapter summarizes and discusses the results as well as considers the confluences of the five articles. In the general discussion, the results are examined with respect to the overall objective of the thesis. Finally, requirements for future research are presented.

3.1 Replacement of tied-housing technology with loose-housing technology

The switch from tied-housing technology to loose-housing technology was estimated using three different probit models: standard, random effect and GHK probit. The results of all estimated models indicated that the young age of a farmer, a high rate of investment allowance, considerable building capital, and large size, measured as dairy capacity units, have a positive effect on the switch, whereas land area and milk price have no effect. The significance level of the parameters varied slightly between the models. The analysis of the random effect model suggested that the individual effects are significant determinants of the switch. The results of the GHK probit model indicated that both serial correlation in the errors and farmer-specific effects are important factors affecting the changeover. Positive revenue shocks encourage the replacement of old technology with new technology whereas negative revenue shocks retard or delay it.

Elasticity estimates for the models suggest that the likelihood of shifting to loose-housing technology decreases very elastically with respect to an increase in the investment price. The increase may be due to a rise in the building costs or a decline in the investment allowance. Existing building capital encourages even more to

invest in capital-intensive technologies, and farms with large capacity in the existing dairy production are most likely to adopt new technology.

The results of the factors having a significant effect on the investments in new technology were expected. An unexpected result was that the output price was not among those factors. The past revenue shocks are likely to dominate the output price effect. The result may also be an indication of a poor degree of variability in the price data over the study period. Overall, predicting the irreversible investments and discrete technology choices is difficult as the past revenue shocks and the farm-specific persistence are dominant determinants in these decisions. Variation in farmers' risk-attitude may be one reason for the farm-specific differences in the investment behavior (Dixit and Pindyck, 1994; Lagerkvist, 2005).

The results support the view that too small a capacity in current dairy operations constraints the farmers' access to modern capital-intensive technology. The farmers are forced to make investments step by step and, therefore, may be stacked by traditional technology. These farms cannot get full benefits from the capital-intensive, large-scale technologies. Gradual investing and increasing the size of the dairy capacity may have had positive consequences as well. For instance, the incurring of debts is not such a problem on Finnish dairy farms as it is on Danish dairy farms (Myyrä et al., 2011). Moreover, a rapid growth in the farm capacity often causes problems to increasing the herd size at the same rate. Consequently, the profitability of production does not match the expectations set for the investment. This has happened e.g. on farms having invested in AMS (Heikkilä et al., 2010).

During the past few years, sincere interest in the welfare of farm animals has increased. At the same time, there has been a move toward more welfare-friendly housing systems, such as loose housings for dairy cows (Johnsen et al., 2001). TGI 200 is an example of methods developed for on-farm welfare assessment and comparison of farms. The maximum score achievable is pre-defined by the housing system: the more restrictive it is the lower the maximum that can be obtained in the assessment is. A maximum of 200 points can be obtained in loose-housing systems with access to pasture. In Switzerland, dairy farmers receive financial support from the government if their housing systems or management procedures are considered welfare-friendly (e.g. they involve a loose-housing system, regular grazing or outdoor exercise) (Johnsen et al., 2001).

On organic and ecological farms, the housing system is regulated at EU level. According to the EC directive 1804/1999, which came into force in August 2000, cows housed in tied systems have to be exercised. After December 2010, all dairy cows must be kept in some kind of a loose-housing system (EC directive 1804/1999). Keeping cows in tied housings is still allowed in cases of small farms if there is no possibility to keep the cows in groups suitable for their special needs. However in such cases, the cows must have access to regular exercise (EC directive 1804/1999) (EFSA, 2009).

The influence of the housing system on animal health has often been investigated while examining the pros and cons of organic production (e.g. Hovi et al., 2003). Sundrum (2001) found that locomotion and social behavior improve and prevalence of several diseases decreases in loose-housing systems compared to stanchion barns. Some studies have had their focus expressly in the housing system. Their results indicate that loose housing has positive effects on the health and welfare of

dairy cows (Krohn and Munksgaard, 1993; Krohn, 1994; Weary and Taszkun, 2000). However, realization of these positive effects requires proficient management and appropriate constructional choices as well. In loose-housing systems, direct control of roughage or total mixed ration intake is very rare at individual cow level. Careful inspection of animals and planning of their feeding is therefore necessary in order to provide a balanced diet for each individual cow (EFSA, 2009). Also, the number of animals should be in a proper relation to the available space for feeding (Huzzey et al., 2006). The capacity of the milking system should be in line with the herd size to avoid too long a waiting time for the access to the milking parlor or milking robot (EFSA, 2009).

Cows kept in tie-stalls always have access to a resting area and competition for feed is rather limited. However, tie-stalls impair cow welfare by preventing the cow from moving freely and locomotion is usually limited for a long period, often for the whole winter season. Furthermore, tethering restricts cows in their activity of self-maintenance and prevents most social behavior. Social behavior, however, includes also aggression and, most often, there is some competition for resources, such as feed and resting areas, in the loose-housing system.

Overall, the comparison of animal welfare in different housing systems is complicated because a large number of specific features of the housing, such as bedding material and design of the resting and feeding areas, can affect the welfare (EFSA, 2009). Thus, a mere loose-housing system does not guarantee animal welfare and, consequently, it does not necessarily help in prolonging the herd life of dairy cows, which was indicated to be worth seeking (Articles II and III).

3.2 Replacement of conventional milking system with automatic milking system

In Article V, total factor productivity (TFP) growth was compared on dairy farms having conventional milking systems (CMS) and on dairy farms that switched to automatic milking system (AMS). To correct for the sample selection bias caused by the endogenous technology choice, the choice between the milking systems was also modeled. The measures of productivity growth were generated from technology-specific production functions. After the estimation, the results were classified by herd size to separate the technology effect from the size effect and by prevailing milking system to compare the productivity development before and after the switch to AMS.

Investment allowances, milk yield per cow and economic size of the farm had a positive and significant effect on the probability to switch to AMS. Prices of machinery and family labor input per cow had a significant but negative effect. The regional dummy variables indicated a significant increase in the switching probability when moving toward the northern regions of Finland. Around the sample means, the estimated probability to stay in CMS was 93.8% and the probability to switch to AMS correspondingly 6.2%.

The technology choice model generated inverse Mills ratio which served as an explanatory variable in the productivity analysis to correct for the selection bias. The Cobb-Douglas production functions extended with the time trend variable were estimated to derive the total factor productivity growth and its components. The coefficient of the inverse Mills ratio was significant in each of the technology-specific functions indicating the presence of sample selection bias and, thus, the relevance of the applied two-stage estimation method.

Due to the form of the production function, output elasticities with respect to variable inputs varied over time but not across farms. Returns to scale, the sum of output elasticities of inputs, was 0.96 for farms that stayed in CMS and 0.92 for farms that switched to AMS. Both rates expressed decreasing returns to scale. Technological change (TC) means a shift of the production function as the result of introducing new and more productive technology over a period of years. As cross-term parameters between trend and input variables were included in the production function, the function allowed technological change to be farm-specific. The production functions indicated a higher rate of technological change for farms that switched to AMS compared with farms that stayed in CMS, the rates being 2.4% and 1.5% per year, respectively. Total factor productivity being dependent on the scale effect and technological change was 2.1% per year for farms that switched to AMS and 1.5% per year for farms that stayed in CMS.

On large farms (more than 60 dairy cows), TFP growth was more rapid on farms that switched to AMS than on farms that stayed in CMS. There was no difference in the rate of TFP growth between the farm categories on small- and medium-size farms. On small farms (less than 25 dairy cows), the result was self-evident as all farms while being small had CMS. When the results of the farms that changed their milking technology were categorized by the prevailing milking system, they indicated more rapid TFP growth after the switch from CMS to AMS than before it. TC was the main cause for the development.

Factors quite similar to the ones that affected the switch from CMS to AMS (Article V) were found to affect the switch from tied-housing technology to loose-housing technology (Article I). That is not surprising because an investment in a new milking system often takes place

concurrently with a building investment, not as a distinct machinery investment. Both Article I and Article V indicated that the net cost and the existing farm size affect the investment decisions. In article V, the data was not modeled as a panel data and, therefore, the model did not estimate the unobserved farmer-specific effects. However, the regressors of the model give an idea about strategy differentiation between farms. Some farmers have decided to go for large herd size and more mechanized production, others have decided to take a more conservative investment strategy.

Technological change and farm size are linked to each other so that it is difficult to separate their impacts (Ryhänen, 1994). In Article V, the separation was carried out by comparing the outcomes of the productivity analysis between farms having an equal herd size category but diverse milking systems. The results indicated that adoption of AMS positively affects the rate of TFP growth of large dairy farms. The poorer results of the medium-size farms with AMS may indicate that the transition period with problems in the introduction of the new production and management system is still ongoing. Another possible and obvious reason is too small herd sizes for AMS (Rotz et al., 2003; Castro et al., 2012). The third reason for the result may be in the recent investments, i.e. only a few depreciations were made from the capital values of buildings and machinery. These reasons may also reduce the economic result of large farms which may be expected to be even better in the course of time.

Heikkilä (2012) compared profitability between AMS farms and CMS farms over the period from 2005 to 2010. All Finnish FADN farms with AMS and the largest farms with loose housing and CMS were included in the sample in that study. Differences in key economic figures between the milking systems were analyzed using statistical tests. Factors

affecting profitability were defined by regression models. At the beginning of the research period, severe profitability problems existed on the farms that invested in AMS. By the end of the period, the differences in profitability between AMS farms and CMS farms diminished even though the sample included new farms having made recent investments. There was some annual variation in the results but, as expected, capital costs per cow were higher on AMS farms and labor costs per cow were higher on CMS farms. Milk yield was higher on AMS farms compared with CMS farms in the last two years of the research period ($p = 0.04$ in 2010). A regression model estimated for the year 2010 indicated that milk yield per cow and milk price (including subsidy) had a significant positive effect on profitability whereas total depreciations per cow and labor input per cow had a significant negative effect. The total capacity of milk production did not affect profitability. The effect of the milking system on profitability was significant only in the first few years of the research period (Heikkilä, 2012).

Utilizing the same database, the findings of Article V have similarities with the results of Heikkilä (2012) who concluded that the high capital costs and the underutilization of robot capacity decrease the profitability of milk production for a few years after the robot investment. High capital costs are not avoidable in investments in AMS but more attention should be paid to the transfer to the new milking system to avoid unnecessary expenses. Careful plans on how to increase the number of cows to the intended herd size should be included in the investment scheme. Utilization of novel reproduction technologies is a worthy means in the enlargement process.

Ryhänen (1994) estimated the annual technological change of Finnish dairy farms having been 1.3% in 1965–1991. The rate indicates a major contribution of the technological progress to the

productivity growth. Sipiläinen (2008) referred to the importance of technological change on the productivity development on Finnish dairy farms in the 1990s. Myyrä et al. (2009) made corresponding observations from Finnish grain farms. The results of Article V are in line with those results; productivity growth in Finnish agriculture is due to technological progress. Productivity growth, in turn, is an essential prerequisite for positive development of competitiveness. In Finland, growth is especially important because the level of productivity e.g. on Danish dairy farms is 20% to 30% higher than the one on Finnish dairy farms (Sipiläinen et al., 2008).

In Article V, the evaluation of AMS was made on the basis of monetary input and output values. However, those values reflect the success of the production process on the farm. As follows, pros and cons of AMS are briefly presented from the viewpoints that have been discussed in Articles II, III and IV.

AMS like all milking systems and milking routines affect udder health and, thus, e.g. incidence of mastitis in the herd. Cows are generally milked more frequently in AMS than in CMS, and milking is quarter-based instead of udder-based. Despite these improvements in the milking process, the udder health of cows has not improved along the switch to AMS. This phenomenon has been verified in several studies comparing udder health between herds having AMS vs. CMS or comparing udder health before and after the introduction of AMS in the same herds. The problems may be related to the transition period from one milking system to another, but failures in mastitis detection and milking hygiene pose a permanent risk for udder health. These risk factors can partly be controlled by management actions taken by the farmer, but AMS also needs further technical development. To maintain good udder health in AMS, the

barn must be properly designed to keep the cows clean and the cow traffic flowing. Milking frequency must be maintained for every cow according to its stage of lactation and milk production. Careful observation of the cows and knowledge of how to utilize all data gathered from the system are also important (Hovinen and Pyörälä, 2011).

AMS is not only a milking system but a system that has potential to be a useful tool in the overall herd management. Automatic sensors provide possibilities for monitoring milk production, udder health, reproductive status etc. A farm manager, who takes advantage of these features of AMS, is able to detect small changes in an individual cow or within a herd in an early stage to take necessary measures for preventing major problems from occurring (Jacobs and Siegford, 2012). The detection techniques are various. For example, the detection of subclinical and clinical mastitis may be based on electrical conductivity of milk, milk color, somatic cell count of milk, or multivariate methods where the detection model combines several different parameters to reveal the disease (Hovinen and Pyörälä, 2011). Interpreting the results of mastitis detection to an operator-friendly alert is a challenging task which still requires development to meet the farmer-specific requirements for the system (Hovinen and Pyörälä, 2011; Mollenhorst et al., 2012). The alerting system must also meet the targets to decrease the use of antibiotics as a cure for mastitis rather than lower the threshold of using them.

Milking with AMS does not appear to affect most measures of reproductive success (Kruip et al., 2000, 2002). However, further research using longer trials is needed to confirm the current findings (Jacobs and Siegford, 2012). For two reasons, we may expect that AMS would improve success in reproductive management. First, automatic activity detection combined to AMS helps in

the timing of inseminations as increased activity is strongly correlated with low progesterone during estrus (Durkin, 2010). Second, the dairy farmer is supposed to have more time for visual monitoring of estrus as the robot takes care of milking. The benefits of this improvement would appear in ordinary animal reproduction but, particularly, when novel reproduction technologies are utilized because they require especially careful heat detection to be successful (Article IV).

Animal welfare has been compared in AMS vs. CMS with the help of physiological responses like heart rate and plasma adrenaline concentrations (e.g. Hopster et al., 2002; Hagen et al., 2004). The stress of cows has also been investigated by comparing behavioral responses between different robotic milking systems (Wenzel et al., 2003). However, these results do not give any idea about the long-term welfare effects which could reflect the economic result of milk production e.g. via longevity of dairy cows. Instead, the social hierarchy of dairy cows may have immediate negative effects on the milk production and udder health of low-ranking cows who are forced to visit AMS at times that are not preferred and who have to wait for the access to the robot for a longer time than high-ranked cows (Hopster et al., 2002; Halachmi, 2009). As a result, the milking intervals of low-ranking cows are irregular, which could impair milk production (e.g. Hogeveen et al., 2001) or have negative effects on somatic cell count (Kruip et al., 2002).

3.3 Optimal replacement of dairy cows

The replacement policy of Ayrshire and Holstein-Friesian dairy cows was optimized at lactation level in Article II. The main result was that only the oldest cows with low production capacity should be disposed intentionally. When the replacement policy was optimal, 19.4% of

an Ayrshire herd and 20.3% of a Holstein-Friesian herd were replaced annually. Most of the cows were disposed from the herd because of compelling reasons (defined in Article II). The share of these cullings, called involuntary, was 17.5% for Ayrshire cows and 18.9% for Holstein-Friesian cows. Derived from the average culling age and the average age at the first calving, the replacement rate in Finnish herds was about double, 34%, in 2010. Thus, nearly half of current disposals are based on dairy farmers' own consideration, not on serious problems in the animal's health.

The optimal replacement rules were similar for healthy and diseased cows indicating that the treatment of diseases is more profitable than replacing the diseased cow with a first-lactating cow. This slightly unexpected result is in line with the findings of Stott and Kennedy (1993) and Houben et al. (1994). The optimal replacement rate may differ according to local production conditions but the profitability of treating at least cows with high production capacity is a common feature in the results of the previous studies. Sensitivity analysis revealed the importance of the production capacity of a dairy cow very clearly in Article II. Voluntary replacement was the optimal decision for Ayrshire cows having 15% lower production capacity than the default production capacity regardless of parity.

As the costs of clinical mastitis were estimated using dynamic programming, a replacement model was also built in Article III. Conditional on optimal replacements, the average cost of clinical mastitis of an Ayrshire cow was €485 but the variation was high, from €209 to €1,006. The respective figures for Holstein-Friesian cows were €458 varying from €112 to €946. The costs were the highest when the occurrence of clinical mastitis was at a top yield phase. When the risk of culling due to mastitis was included in the model, the average cost of clinical mastitis was €596

and €623 for Ayrshires and Holstein-Friesians, respectively. Disposing of a young cow at the end of her first lactation month caused the highest costs. In spite of the high costs of clinical mastitis, the model recommended treating the mastitic cows and keeping them in most cases until their fifth lactation. A cheaper (-20%) heifer advanced the optimum to the previous lactation and a more expensive (+20%) heifer postponed it to the following lactation.

The optimal replacement points presented in Articles II and III are not equal; the optimums of Article II are later than those of Article III. A contrary result would have been expected because the model in Article II included the risk of all diseases but the model in Article III only the risk of clinical mastitis. The reason for the difference in optimums was searched from the distinct structure of the models. In the model of Article II, the cows were allowed to stay in the herd at maximum for ten lactations, whereas the availability of monthly data restricted the investigation into six lactations in Article III. However, tested using an equal constraint, the optimums in Article II were not on the fifth lactation like in Article III but on the sixth lactation when the replacement was forced. Thus, the other structural differences between the models cause the divergence in the results.

The essential deviations between the two models are in favor of the model of Article III. It considered the repeated cases of the disease whereas the repeatability of the diseases was not taken into account in Article II, i.e. in that model, the probability of diseases was the same for all cows despite their earlier diseases. Moreover, the length of a period was one month in Article III which enabled estimating production losses due to diseases more precisely than in the model at lactation level. Thus, Article II gave a rough conception about the need to lengthen the herd life of Finnish dairy cows but a more detailed model is necessary for

determining the optimum for a single dairy cow. The most detailed current models are based on daily data (Nielsen et al., 2010).

Both Articles II and III show that replacement decisions of dairy cows have economic importance in milk production. However, the decisions are often made in a non-programmed fashion and based partly on the intuition of the decision-maker (Lehenbauer et al., 1998). This may be one reason for the difference between current practices and optimal replacement decisions, besides the limitations of the replacement models presented in the discussion of Article III. The most important limitations are related to ignoring the spread dynamics of contagious diseases.

Preventing premature culling because of mastitis should naturally start from preventing mastitis. Hogeveen et al. (2011) evaluated the profitability of preventive measures of mastitis. Six out of 18 measures indicated positive net benefits (Hogeveen et al., 2011) but implementing recommended practices in mastitis management is often driven by factors that do not necessarily result in monetary returns (Kuiper et al., 2005).

Valeeva et al. (2007) found that factors internal to farm performance and an individual farmer provide more motivation than external factors related to the whole dairy sector. Furthermore, motivation to improve mastitis management differs across individual farmers. Kuiper et al. (2005) also found that many farmers think that their knowledge on existing management practices for controlling mastitis on the farm is good. Regardless of this, underestimation of the costs of mastitis is typical among dairy farmers (Huijps et al., 2008). A low adoption rate and a low level of compliance with advice given to the dairy farms for controlling mastitis suggest the presence of inertia. Farmers who already have implemented a specific

management measure are more likely to continue to do this than those who apply a different management regime, regardless of the availability of more effective or lower cost alternatives. Additionally, farmers are more sensitive to penalties than bonuses aimed at stimulating desired behavior (Huijps et al., 2010).

3.4 Optimal use of novel reproduction technologies

When the utilization of different reproductive technologies was optimized, the result was a mixture of available methods (Article IV). In the basic scenario, all cows in a herd were inseminated with conventional semen but heifers also with sex-sorted semen. The number of cows donating unselected embryos was at the upper constraint of the model whereas no embryo recipients were in the optimal herd. With the constraints and price relations of the basic scenario, combining embryo production and sex-selection was not economically justified. Without restrictions to any technology, all cows were donors of unselected embryos and all heifers were donors of sex-selected embryos. Production of crossbred calves was included in the optimal solution only in the scenario where dairy cows had equal milk yields. In practice, the optimal strategy is herd-specific depending, for example, on the production capacity of the cows and, thus, their appropriateness for the production of replacement heifers.

Because of the low conception rates with cows, sex-sorted semen is first of all used for heifers (Andersson et al., 2006). The results of Article IV are in line with this practice. The economic benefits did not outweigh the higher price of sex-sorted semen and the lower conception rate related to its use for cows. The price of sex-sorted semen was about 1.5-fold compared with unsorted semen and the conception rates were 30.2% with sex-sorted semen and 43.8%

with unsorted semen. The number of heifers inseminated with sex-sorted semen was dependent on the replacement rate of the herd. Increasing the use of sex-sorted semen was an efficient way to increase the number of female calves for the needs of replacement.

The results indicate that the donation of conventional embryos is very profitable. The reason is the proceeding of embryo technology as the profitability is highly dependent on the number of transferable embryos recovered. The mean number with cows in 2010 was as high as 12 transferrable embryos per recovery of which 49% were female embryos. With X-sorted semen, the yield was 4.5 embryos per recovery of which about 10% were undesired sex. Thus, it is possible to receive more female calves from good milk producers by using conventional semen rather than sex-sorted semen. After insemination with conventional semen, recovered embryos can be diagnosed for sex by an embryo biopsy. The method is efficient in sorting the sex but embryo viability may be compromised after the biopsy. The yield of female embryos in the model was set 10% lower than it would have been without sorting the embryos. Therefore, producing sex-selected embryos was not a competitive alternative in the optimal reproduction strategy.

The recipients of embryos were not included in the optimal solution. One reason for this result may be that the model does not capture the long-term effects of embryo transfer on the genetic progress of the herd. The high non-return rate and, as a result, the short calving interval did not bring sufficient economic benefits for the embryo recipients. This result means that all the embryos recovered should find recipients from other herds. If the supply of embryos exceeds their demand, a consequence on the market is a reduction in prices. The sensitivity analysis proved that embryo donors would, however, stay

in the optimal solution even after a distinct fall in the price of embryos.

In Article IV, the model was developed for a herd of 60 dairy cows. It is the minimum size for a single-stall AMS (Rotz et al., 2003) and the size to which the smallest farms often enlarge their production at the first stage. After that, the enlargements follow the capacity of an extra milking stall. Thus, the second step means doubling the number of dairy cows. The results of Article IV suggest that inseminations with sex-sorted sperm would be worthwhile also in the quick growing of the herd size as they were useful in covering the increased need for replacement heifers (Article IV).

3.5 General discussion

In this chapter, possibilities to improve the economic performance of Finnish dairy farms by the investigated management practices and the technology choices are evaluated. Moreover, measures that are needed to bring the results for everyday use are discussed.

3.5.1 Management decisions

Management decisions related to replacement and reproduction of dairy cows were investigated in Articles II, III and IV. In Article II, the weighted average of economic losses caused by animal diseases was estimated to be €400 per diseased cow regardless of her breed. The corresponding mean because of premature culling was far greater, about €1,300 for Ayrshires and €1,500 for Holstein-Friesians (2006 prices). The amount of losses due to premature culling is highly dependent on the age of the cow and on her production capacity. Aforesaid figures indicate that, in any case, it is profitable to prevent diseases which cause economic losses as such and, additionally, increase the risk of the even more expensive premature culling (Rajala and Gröhn, 1998; Bell et al., 2010).

In Article III, the total costs of clinical mastitis, converted to figures per cow-year, were €121 for Ayrshires and €147 for Holstein-Friesians if the culling decisions were optimal. The respective figures were €155 and €191 when the current culling practice was included in the model (2009 prices). Thus, the cost effect of premature culling was +28% for Ayrshires and +30% for Holstein-Friesians. The results indicate that one way to reduce the costs due to clinical mastitis and, thus, to improve the economic performance of milk production is to increase the threshold of disposing a cow with clinical mastitis from the herd and to tend to optimal culling decisions. Preventing mastitis would, of course, give even more economic benefits than preventing only premature culling due to it. The amount of savings per herd can be assessed by the case-specific costs and the change in mastitis prevalence. In large herds, success in improving the mastitis situation means total savings of thousands of Euro per year.

Disposing a diseased cow from the herd may, however, be more profitable than keeping her in the herd if the disease is contagious. Models presented in Articles II and III ignored the spread dynamics of contagious diseases. This deficiency must be considered while making conclusions from the results. Repeated cases of clinical mastitis were taken into account in the model of Article III. The results were more or less surprising, even though, they were partly due to the aforementioned limitations of the model. The basic scenario of Article III also recommended treating the repeated cases of clinical mastitis and keeping the cows in the herd around as long as the healthy cows. However, the result was sensitive to price changes. A decrease in the heifer price and an increase in the milk price advanced the optimum culling time of cows with repetitive mastitis.

The need for veterinary treatments and the probability of involuntary culling were higher for Holstein-Friesian than for Ayrshire cows (Articles II and III). When clinical mastitis was the only disease in the model, the expected net present value of a cow was nearly equal for Ayrshire and for Holstein-Friesian cows (Article III). When all of the veterinary treatments were accounted (Article II), the respective value was slightly higher for Ayrshire than for Holstein-Friesian cows. Thus, the economic benefits of the higher milk yield of Holstein-Friesian cows compared with Ayrshire cows are eroded by the diseases and the short herd life of Holstein-Friesians. Within a breed, the net present value of a cow was increasing with her production capacity (Article II). Thus, high yields give better economic performance than low yields if they can be reached without an increase in the prevalence of diseases.

The modern reproduction technologies were included in the optimal combination of available technologies (Article IV). The result indicates that their utilization brought economic benefits in a herd of 60 dairy cows. Tested using conventional strategy (i.e. allowing insemination with unsorted milk breed semen only), the gross margin on the building and machinery costs was considerably lower than the margin in most of the scenarios of Article IV. However, the optimal strategy, like the margin, is very herd-specific. The appropriateness of diverse reproductive technologies depends on the number of cows whose calves would be desired or, correspondingly, undesired replacement heifers in the herd. Moreover, the economic result depends on the technical success of each reproductive technology in the herd.

The model in Article IV was a static one. It is obvious that enlarging herds would benefit of novel reproduction technologies even more. In that case, there is an extra indirect positive effect as the targeted herd

size can be reached more rapidly and, thus, the cost of empty capacity units can be reduced or totally avoided.

The sensitivity analysis revealed the importance of milk price for the net present value of a cow and her replacements (Articles II and III) and for the gross margin on machinery and building costs (Article IV). In spite of adjusting the replacement decisions optimal, the net present values were only about 60% of the original value after a decrease of 20% in the milk price (Article II). An equal decrease in the milk price did not change the optimal combination of different reproductive strategies but decreased the gross margin by 36%. These results indicate that optimal replacement decisions and breeding strategies are not very efficient tools against dramatic changes in the milk price. As the average net result of Finnish dairy farms is negative even with the current milk price (MTT, 2013), each measure diminishing the loss is worth introducing anyway.

The models presented in Articles II to IV were developed using MATLAB software which provides an efficient way for solving both dynamic and linear optimization models. However, these models do not totally correspond to the aim of this thesis to develop tools for solving farm-level management problems. The developed tools are working in scientific context but, to serve dairy farmers in their everyday work, more user-friendly models must be developed. Tool-boxes, which enable the use of farm-specific parameters and utilize software that veterinarians, advisers and farmers have easy access to, are one possibility. Another one is to build a web-based service where the users could load case-specific data and the optimization would take place on a server of the service holder which might be an advice organization or a dairy company, for example. The latter alternative would not require so much simplification of the models as the first one and would therefore

be preferred. The basic work made in this thesis gives an idea about the results on average level and helps in perceiving the variables that should be included in the practical applications. The model presented in Article IV is particularly valuable in this respect because no corresponding optimization model has been developed earlier.

3.5.2 Long-term technology choices

Articles I and V suggested that investment subsidies have a significant positive effect on investment likelihood on dairy farms. The statistics also indicate that very few investments in animal constructions are made without investment allowances. Pyykkönen et al. (2010) forecasted the structural change and the investments in Finnish agriculture in the period from 2010 to 2020. According to their estimation, there will be 240,000 dairy cows on around 5,000 dairy farms in 2020. It means that the number of dairy farms halves in ten years. This rapid change requires investments in order to maintain the production capacity. The total investment need in constructions for milk production was estimated to be €1.2 billion. This, together with the need to improve the competitiveness of Finnish dairy farms, emphasizes the need to support farmers' investments also in the future (Pyykkönen et al., 2010).

The need for investment allowances is apparent while comparing the building costs and the returns of an average dairy farm. Latvala and Pyykkönen (2010) investigated the construction costs of cattle farms through farm visits and interviews with farmers. Altogether 17 dairy farms were interviewed, out of them 6 farms had invested in AMS. After the investment, the size of the dairy farms varied from 50 to 175 milking cows. The total cost of the investment was on average €817,000 (min. €402,000, max. €1,358,000) excluding VAT. The mean was approximately

€10,000 per dairy cow capacity unit. AMS increased the cost by about €1,000 per unit. Technology for milking, feeding, and manure removal constituted around 40% of the total cost. Of those costs, milking systems had the biggest share the median being €87,000. The investments of the study were realized in the period from 2004 to 2008. Since 2005, the building costs of farm buildings have increased by 27% (Statistics Finland, 2013).

In 2011, the family farm income of dairy farms was €43,300, the entrepreneurial loss €30,600, the return to assets -1.4%, and the equity ratio 70.8% (MTT, 2013). Considering these figures and the building costs of a new, modern barn, it is evident that every dairy farm does not have prerequisites for such an investment. Possibilities to save beforehand for future investments are minimal if the family farm income is less than €50,000 per year. Incentives to invest in milk production may also be minor if both entrepreneurial profit and return to total assets are negative in the prevailing production. The investment should really improve profitability to be attractive. The equity ratio measures the solvency of agricultural holdings, i.e. the ability to withstand losses and to fulfill financial commitments in the long run. The ratio of 70.8% indicates good ability to take care of these obligations. Thus, on the average level, excessive indebtedness does not prevent from taking out a loan for an investment. However, paying back the loan takes a long time and requires long-term commitment as well as faith in success in volatile markets and under changing policy programs.

Those, who make the investment in a barn having a loose-housing system and AMS, can certainly expect benefits which compensate the high investment costs. Karttunen and Lähti (2009) presented some key figures from dairy farms having 40 to 70 dairy cows by milking systems. The difference in labor productivity

between farms having a pipeline milking system (tied housing, 49 cows) and farms having a milking parlor (loose housing, 51 cows) were marginal when measured as liters of milk per one working hour (112 l/h vs. 111 l/h). The corresponding figure for farms having AMS (loose housing, 57 cows) was better (160 l/h) but also the standard deviation was greater. The aforementioned figures do not indicate the superiority of the loose-housing system if milking takes place in a milking parlor but, with AMS, the production is more efficient.

The efficiency measure, liter per hour, is affected by both components of the measure, milk yield and labor input. Jacobs and Siegford (2012) concluded in their review article that AMS has potential to increase milk production by up to 12% and decrease labor by as much as 18%. Svennersten-Sjaunja and Pettersson (2008) presented that increased milk yield with AMS has been observed, but lack of increased production has also been reported from the field, probably due to less attention paid to the total management system. The data of Article V showed an increase of 6% in milk yield and a decrease of 53% in labor input per cow in the period from 2005 to 2010 but there was also a big difference in the size of the farms with different milking systems (32 cows on CMS farms, 68 cows on AMS farms). When only farms having at least 45 cows were considered (66 cows on CMS farms, 70 cows on AMS farms), the differences were less than 4% in milk yield and 24% in labor input in favor of AMS. Thus, it is obvious that AMS gives economic benefits in terms of labor saving at least in herd sizes that are prevalent in Finland. So far, the benefits of increased milk yields are not so evident. The reasons may lie in the transition periods when the whole management system, including feeding, has changed. Moreover, increasing herd size means an increasing number of young cows whose milk yields have not yet

reached the level of later lactations (Article II).

Another aspect related to labor is labor management. Hyde et al. (2007) brought up this viewpoint, i.e. what is the value of avoiding labor management while evaluating the profitability of robotic milking. They referred to the fact that robots do not get sick or get paid overtime. Robots certainly need service and repair every now and then but there seem to be no problems in their availability in Finland, though the distances between AMS farms may be long. Naturally, these services are not free.

A third aspect related to labor is its sufficiency. Availability of skillful farm workers is an increasing problem even in a country like Finland where, on the other hand, unemployment is more or less a permanent phenomenon (Statistics Finland, 2013). Attractiveness of the work on a dairy farm is also a problem concerning the farm family. It was surprising that the age of a farmer was not a significant determinant when the choice between CMS and AMS was modeled; its sign was even negative (Article V). The result may suggest that older farmers who are soon going to exit milk production try to make the farm more attractive for the next generation by investing in AMS. Being bound to the milking work twice a day for seven days a week seldom is a young person's dream.

Price of labor also affects the profitability of AMS. Labor costs are rather high in Finland but so are the purchasing cost of AMS. The price of family labor depends on the family members' alternative possibilities to use their labor input and is thus farm-specific. For current farmers, the alternatives seem to be scarce as they continue production even if they earn around half of the standardized wage claim which equals the average salary of an agricultural worker. However, a

dairy farmer has to weight labor costs vs. capital costs, taking into consideration the availability of labor and the value of avoiding labor management, while making the choice between CMS and AMS.

Other pros and cons of AMS discussed in Chapter 3.3 (i.e. milk quality, reproductive success, animal health and welfare) also have economic consequences in milk production. However, their realization is highly dependent on the overall success in designing the barn and managing the operations of the farm. Svennersten-Sjaunja and Pettersson (2008) supposed that, with proper management routines, it is possible to achieve a production level and animal well-being in AMS that are at least as good as in CMS. More empirical data is needed to acquire evidence whether the observed effects are really due to AMS and being permanent or only related to the transition period. Some measures, like the replacement rate, simply require a longer observation period for producing reliable estimates. The rate measured in the transition period may be biased because all existing cows are not appropriate for AMS and will therefore be disposed from the herd. In the long run, the requirements of AMS, at least for conformation traits, can be taken into account in animal breeding.

In Article V, milk production was described with a production function that expresses the relationship between the quantities of productive factors used and the amount of product obtained. Thus, the model captured all the effects that affected the success in the production process. As the product, i.e. milk, was expressed in monetary terms, its quality (fat and protein contents, hygienic quality) was also taken into account in the model.

The results indicated improved productivity growth on farms that switched to AMS compared with farms that stayed in CMS. The increased productivity growth was linked to the enlargement and the

overall organization and mechanization of milk production in large herds as the rate improved along with the herd size on farms with CMS as well. In large herds, loose-housing technology is dominating although the milking system may not be automatic. Thus, the results indicate that the switch to loose-housing technology is beneficial in terms of productivity growth but AMS intensifies the positive development on the farms having large enough herds to utilize the whole capacity of the robot.

Sipiläinen (2008) saw that technological change was an important component to improve the productivity growth of Finnish dairy farms in the 1990s but the scale effect was minor. Article V shows that the situation was similar at the beginning of the 21st century. A technological jump forward was needed to generate productivity growth, increasing the scale of production with existing technology did not produce such an improvement. A positive scale effect would be important in the future to generate even better productivity growth rates which are essential from the perspective of competitiveness. When prices have to be taken as given, like typically in agricultural production, productivity growth and the optimal allocation of inputs and outputs are ways in which farmers are able to improve their economic performance (Sipiläinen, 2008). Thus, improved productivity growth estimated in Article V substantially contributes to the efforts of improving the economic performance of Finnish dairy farms. However, both options for the improvement are at least to some extent related to the competence and education as well as the managerial skills of the farmer (Sipiläinen, 2008).

It is noteworthy that all three review articles about AMS also emphasize the role of the herd manager. Jacobs and Siegford (2012) finished their article with the remark that management continues

to play a huge role in the success or the failure of AMS. Svennersten-Sjaunja and Pettersson (2008) concluded from the literature that successful AMS depends on farm conditions and the knowledge and management skills of the herd manager. Further, humans can never be replaced with technical equipment; herd managers must supervise and manage the system. Hovinen and Pyörälä (2011, p. 547) expressed the same thing with the words: "Automatic' does not mean that the role of a competent herdsman is in any way diminished." The aforementioned views may be expanded to concern the modern reproduction technologies discussed in this thesis. Novel technology on dairy farms may be helpful and useful but, to be profit-making, it must be accompanied by a wise dairy farmer. Unfortunately, the estimation of the data of Article V as a panel data was not successful. Therefore, any exact estimate for the significance of the farmer-specific effect cannot be presented.

The investment decisions require exact profitability and liquidity calculations which should be as realistic as possible. The history of the farm concerned is the best source to set the expectations into the calculations; introduction of new technology does not change the ability of the herd manager to take care of his or her animals or manage the operations of the farm. Even though the results of Article V encourage for enlarging the herd size and investing in modern technology, these measures cannot be recommended for every farmer, and every farmer is not willing to take a risk that is related to the costly investment.

3.6 Future research

The reason for the difference between optimal and actual replacement decisions is a topic for further research targeting to diminish the economic losses caused by premature culling of dairy cows. In

this thesis, the costs of clinical mastitis were estimated in general. The economic effects of mastitis may, however, differ depending on the pathogen that caused mastitis (Halasa et al., 2009). Pathogen-specific costs would give more precise information for evaluating the profitability of preventive measures and for finding optimal management and replacement decisions. In the case of contagious-type mastitis, the spread of the disease should be taken into consideration in the economic models.

A single-year linear programming model is sufficient for identifying how to differentiate between breeding technologies within a herd. Further research is needed to develop dynamic models for capturing the effects of genetic progression and the stochastic nature of reproduction. When the inseminations are made with unsorted semen, a farmer never knows whether the calf to be born is female or male. A linear programming model cannot take into account this uncertainty which may play a role especially in small herds. A stochastic dynamic model is necessary for expanding herds as well. It is also possible to modify the herd-level model to optimize the breeding strategies in the whole dairy sector. The results would help setting the targets for the use of various reproductive technologies. For instance, the so-called milk-beef program, which is aimed to be resuscitated, would benefit from the sector level model.

The lengthening of the calving interval is a clear trend in Finnish dairy herds. The mean was 399 days in the herds that attended the milk recording system in 2003. In 2011, the mean was 417 days. It should be investigated whether prolonged calving intervals are economically justified as the milk yields have increased and the daily yields may still be rather high at the traditional end of the lactation period. The length of the calving interval could be optimized similar to the

optimization of the replacement time. The optimization could be combined to the cow-level optimization of the use of novel reproduction technologies. In this thesis, the optimization was made at herd level. The use of those technologies means a large variation in the calving interval as embryo production takes time and the non-return rate is lower when sex-sorted sperm is used in an insemination compared with inseminations with unsorted semen.

Feeding of dairy cows is among the management decisions that have a great economic importance in milk production. It was totally excluded from this thesis but it alone could be the subject of a study. Recent research in the field of animal sciences would provide improved possibilities to apply similar methods for optimizing the feeding as used in this thesis for optimizing the replacement decisions. An optimization model could be parameterized with the help of the knowledge gathered in numerous feeding experiments during the past few years and being collected together with meta-analyses (Huhtanen et al. 2009, 2011; Nousiainen et al., 2009). In economic research aiming

to support the management decisions of dairy farmers, it would be most important to utilize the existing data for optimizing the feeding of dairy cows as well.

Further research is needed to support dairy farmers in their farm enlargement endeavors. A special question of growing dairy farms is finding the optimal way to increase the number of dairy cows, considering the risk of diseases related to purchased animals. Pyykkönen et al. (2013) emphasized the need to find solutions how to organize the operations of an enlarged farm because running it solely on the labor input of the farm family is impossible. Which are the key operations that the farm family has to run by themselves? Are there operations that they can totally outsource? Are there operations that can be organized in cooperation with other farmers? These questions are relevant as the environmental regulations limit the possibilities to enlarge only the herd size without enlarging the arable area. Farms with AMS are still a target of interest because, so far, minor empirical data have limited the possibilities of investigation.

4 Conclusions

Economically optimal culling decisions would generate a considerably lower replacement rate for a herd than the rate of current herds. Therefore, the awareness of dairy farmers about the real costs of premature culling and the gain that can be reached by treating a diseased cow must be improved. Tools for this purpose should be based on farm-specific data to produce individual estimates for varying conditions. These calculations would also help in evaluating the profitability of preventive measures. Planned production of replacement heifers contributes to the target of increased herd life and is there-

fore advisable. The developed optimization models suggest that it is profitable to treat the diseased cow and keep her in the herd almost as long as the healthy cows. The optimal replacement point of healthy cows was at the end of their fifth lactation. Cows having low production capacity or a contagious disease may be exceptions from this rule.

The results of the embryo recovery technology have improved during the past few years. Consequently, it is profitable to favor embryo donors in a herd provided there is demand for the embryos recovered. The

demand may be scarce because receiving embryos is not as profitable as donating them. Combining sex selection and embryo production is competitive with the separate use of these technologies only with heifers. The sole use of sex-sorted semen, especially for heifers, is an efficient way to produce female calves with high expected value. However, cows and heifers inseminated with conventional semen still retain their position in a dairy herd. If there are cows whose calves are not wanted as replacement heifers, it is profitable to use beef breed semen for their insemination. In this way, it is possible to produce valuable calves for beef production and prevent the negative effect of surplus heifers. The optimal reproduction strategy is herd-specific depending e.g. on the production capacity of the cows. Tools for defining the optimum, based on farm-specific input data, are therefore needed for this purpose, like for determining the optimal replacement decisions.

Price changes in milk and production inputs cause considerable income effects on dairy farms. Management practices can only partially adjust to these changes, i.e. carrying out the optimal replacement policy and reproduction strategy cannot entirely cancel out the impacts of negative price changes. They may still relieve the effects of unfavorable price relations and support the strategic decisions made for improving the economic performance of milk production. Thus, the optimal practices are worth defining and, most importantly, implementing as well.

Investments in loose-housing technology that is used in large herds improve the productivity growth of dairy farms. The switch from CMS to AMS further improves the rate of productivity growth provided that the herd size matches the capacity of AMS. Automation may also solve the problems

related to the availability of labor force. Thus, it opens access to a herd size where improved productivity and, as a consequence, improved profitability and competitiveness can be reached. As nearly all AMS farms in Finland are recent adopters of the system, the results concerning their productivity development may reflect the situation of a transition period. Thus, the final conclusion on how much AMS could improve productivity development of Finnish dairy farms should wait until more empirical data is available from established AMS farms.

The investment decisions of dairy farmers respond very elastically to the rate of investment allowances. Farms with small capacity in their existing dairy operations may not have access to modern technologies even with the help of subsidies and they will exit production when current production technology comes to the end of its life. To ensure the continuation of milk production, investment allowances are needed to boost up investments on farms which have potential for developing their production to meet the future challenges. On low productivity areas, investments in technology appropriate for large farms improve productivity growth and, thus, possibilities of dairy farms to survive in the long term.

Novel technology enables efficient animal reproduction, provides relief for burdensome work, helps in detection of diseases, and gives possibilities for increasing the herd size as well as improving productivity development. Concurrently, contribution of a dairy farmer in managing and organizing large-scale operations becomes more and more important in achieving good economic performance. Therefore, a human cannot be replaced by technology, not even by novel technology.

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