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Structural Change in Livestock Farming: Research from Finland and the other Baltic littoral countries

Doctoral Dissertation

Olli Niskanen

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Academic dissertation

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Abstract

Olli Niskanen, Natural Resources Institute Finland (Luke)

Livestock production has been shifting towards larger production units, with the number of small livestock farms rapidly decreasing as a result. This dissertation examines the impact of this structural change in Finland and Northern Europe as it affects agricultural land use. The work comprises three substudies as well an introductory synopsis. It contributes to the literature through insights into the possible side-effects of the structural development studied, which highlights issues that deserve special attention.

In most instances, efforts to achieve economies of size account for past and ongoing growth in farm size: Farms seek possibilities to gain efficiency and productivity in order to keep their viability in the face of growing production costs. In the case of Finnish dairy farms, increased productivity is mostly attributable to advances in technology. Average technical efficiency has increased but only slightly; more importantly, a higher share of the total production volume is produced with higher technical efficiency. One factor affecting the technical efficiency of dairy farms is parcel structure, that is, the size of and distance to field parcels. Improving parcel structure would thus be an appropriate measure in the effort to improve technical efficiency.

One alternative to high-intensity production that has been put forward is a strategy based on low input use. In the northern European context, clover-grass-based forages are suitable for sustainable low-input or organic dairying. They are advantageous in that they require less nitrogen fertilization than pure hay grasses yet provide a higher protein content for livestock. While any incentive to cultivate clover-grass was found to be highly dependent on the price of nitrogen, increasing the yield of clover-grasses (i.e., decreasing the gap in yield vis-à-vis intensive grass production) would also effectively promote clover cultivation. Significantly, this would not entail additional costs for milk producers or society, a finding arguing for encouraging the development of clover varieties and cultivation practices. Yet, the potential for clover-grass was found to be limited due to the excessive quantity of manure nitrogen at average dairy farm stocking rates.

As livestock farms that continue to operate are growing larger and housing more animals, effects can be expected where the use of manure is concerned. The crux of the issue is the nutrient composition of manure: By the year 2030, farms housing more than 500 livestock units will likely produce more than two-thirds of all manure phosphorus, whereas the proportion in 2010 was one-third. This development would induce a need for growing farms to acquire 4.9 million hectares of land from exiting farms in order to meet the current manure spreading requirements. This shift represents 64% of the total area available for spreading in 2010 and 15% of the total utilized agricultural area of the regions studied.

The results suggest that despite it being economically justified to seek economies of size in agriculture, contrasting and/or countervailing tendencies can be identified that are related to land management. These tendencies 1) reduce efficiency, 2) limit cultivation opportunities and 3) lead to the concentration of nutrients on fewer farms. Structural development – livestock farms becoming larger – creates pressure to develop new nutrient solutions. An awareness of these issues is crucial when agri-environmental policies are developed. The present research indicates that it is justified to promote land-use efficiency in livestock farming through farm consolidation programs and by promoting cooperation between farmers. It is also advisable to enact manure nutrient regulation in the supranational context.

Keywords: agriculture, structural change, livestock farms, efficiency, intensity, agglomeration

Tiivistelmä

Olli Niskanen, Luonnonvarakeskus (Luke)

Kotieläintuotannon rakennekehitys on edennyt nopeasti kohti suurempaa tilakokoa. Tässä työssä tarkastellaan kehityksen vaikutuksia Suomessa ja osin Pohjois-Euroopassa maatalousmaan käytön näkökulmasta. Tutkimus täydentää olemassa olevaa tutkimuskirjallisuutta tuomalla tietoa rakennekehityksen mukanaan tuomista kitkakohdista maankäyttöön liittyen ja nostaa esiin eräitä kohtia, jotka ansaitsevat erityistä huomiota.

Rakennekehityksen taustalla on monia tekijöitä. Taloudellisesti olennaisin tekijä on tuotantokustannusten suhde tuotannon laajuuteen. Kuten kaikessa yritystoiminnassa, myös kotieläintuotannossa elinkelpoisuuden säilyttämiseksi on jatkuva paine pyrkiä tuottavuuden kasvattamiseen ja siten tuotantokustannusten hillitsemiseen. Usein keskeinen yksikkökustannusten alentamisen keino on tuotannon laajuuden kasvattaminen. Essee I tarkasteli maitotilojen tehokkuutta stokastisen tuotantorintamamallin avulla. Vuotuinen tekninen kehitys oli 1,4 % ja tekninen tehokkuus suhteessa parhaiden tilojen muodostamaan rintamaan koko tarkastelujaksolla keskimäärin 79 %. Tarkasteltaessa tuotantomäärän ja tehokkuuden suhdetta, havaittiin että suhteellisesti entistä suurempi osa maidosta tuotettiin kaikkein tehokkaimmassa maidontuottajajoukossa, kun vertailtiin tutkimusjakson alkua ja loppua. Painotettu keskietäisyys peltoihin sekä peltojen koko vaikuttivat merkitsevästi tehokkuuteen. Näin ollen, tilusjärjestelyissä sekä lohkojen etäisyyden vähentämisellä (lohkojen vaihdot) että lohkokoon kasvattamisella (lohkojen yhdistämiset) voidaan saavuttaa merkittäviä hyötyjä tuotannon tehostumisen kautta.

Vaihtoehtona tavanomaiselle, intensiiviselle panoskäytölle perustuvalle kotieläintaloudelle on esitetty matalan panoskäytön strategiaa, jossa pyritään vähentämään ostopanosten käyttöä ja hyödyntämään vahvemmin luonnon omia prosesseja. Pohjois-Eurooppaan soveltuva esimerkki voisi olla biologisen typensidonnan vahvempi hyödyntäminen nurmentuotannossa apilanurmia viljelemällä. Apilan typensidonnan hyödyntäminen edellyttää melko alhaista lannoitetypen käyttöä. Tällöin odotettavissa on yleensä intensiivistä nurmea alhaisempi satotaso, mutta sadon valkuaispitoisuus voi olla hyvällä tasolla. Näiden perusoletusten vallitessa, erilaisia keinoja kannustaa tiloja matalampaan panoskäyttöön apilanurmien hyödyntämisen avulla tarkasteltiin Suomen maataloutta kuvaavan DREMFIA-sektorimallin avulla. Tarkastellut vaihtoehdot, kuten viljelyn tuet ja viljelykustannusten madaltaminen vaikuttivat vain vähän tuotantoa lisäävästi. Typpilannoitteiden korkeampi hinta lisäsi apilan viljelyä merkittävästi, mutta vaikutti lisäkustannuksena maatalouden kannattavuutta alentavasti. Neutraalein tapa tukea apilanurmia on satotason kehittäminen. Havaittiin myös, että tavanomaisessa maidontuotannossa kotieläinten lannan typpeä muodostuu suhteessa pinta-alaan niin paljon, että sen käyttö tasaisesti viljelyssä voi alkaa rajoittamaan apilan menestymistä nurmiseoksissa. Matala panoskäyttö tässä suhteessa edellyttää siis myös keskimääräistä suurempaa peltoalaa tai vähintäänkin lannan hyödyntämisen suunnittelua niin, että apilanurmille levitettävä lantamäärä pysyy riittävän alhaisena.

Kotieläintilojen lukumäärän vähentyminen ja toisaalta jatkavien tilojen koon kasvu aiheuttavat myös lannan ravinteiden keskittymistä harvemmille tiloille. Tutkimuksen kolmannessa esseessä tarkasteltiin kuinka lannan ravinteet jakaantuvat erikokoisille tiloille kahdeksassa eri Itämeren rannikkovaltiossa. Tutkimuksessa rakennettiin kotieläintalouden rakennekehitystä kuvaava Markovin ketju -malli, jonka avulla tehtiin projektio tulevasta rakennekehityksestä aina vuoteen 2030 asti. Tulosten mukaan vuoteen 2030 mennessä yli 500 eläinyksikön kokoluokan tilat tuottavat yli kaksi kolmasosaa kaikesta lannan fosforista, kun vuonna 2010 vastaava osuus oli noin kolmannes lannan kokonaisfosforista. Kehityksen myötä kasvavat tilat joutuvat hankkimaan 4,9 miljoonaa hehtaaria lannanlevitysalaa. Tämä muutos edustaa 64 prosenttia vuoden 2010 kokonaislevityspinta-alasta ja 15 prosenttia tutkittujen alueiden kokonaispeltopinta-alasta. Olisi tärkeää, että ravinteiden käytön ohjaus toimisi eri maissa yhteneväisin perustein, jotta tuotanto ei pitkällä aikavälillä keskittyisi maihin, joissa rajoitukset ovat väljimmät.

Tuloksiin perustuen voidaan todeta, että vaikka maatilojen koon kasvattaminen on taloudellisesti perusteltua, rakennekehitys aiheuttaa maankäyttöön liittyen myös ristiriitaisia vaikutuksia. Näistä olennaisimmat voidaan tiivistää kolmeen kohtaan. Tilakoon kasvattaminen: 1) tilusrakenteen kustannuksella voi heikentää tuotannon tehokkuutta, 2) voi rajoittaa matalan panoskäytön viljelymahdollisuuksia ja 3) johtaa ravinteiden keskittymiseen entistä harvemmille tiloille ja luo siten painetta kehittää uusia ratkaisuja ravinteiden käyttöön. Nämä seikat on syytä huomioida maatalouden ympäristöpolitiikkaa kehitettäessä. On perusteltua edistää maankäytön tehokkuutta tilusjärjestelyiden avulla ja edistämällä viljelijöiden välistä yhteistyötä. Lannan ravinteiden käyttöä on syytä tarkastella eri maissa yhteneväisin perustein.

Asiasanat: maatalous, rakennemuutos, kotieläintalous, tuottavuus, tehokkuus, intensiteetti, agglomeraatio

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Säyneinen, 30 July 2020

Olli Niskanen

List of original articles

This synopsis is a summary of the following articles, which are referred to in the text as Essay I, Essay II, and Essay III. They are reprinted here with the permission of the publishers.

I. Niskanen, O. and Heikkilä A.-M. 2015. The Impact of Parcel Structure on the Efficiency of Finnish Dairy Farms. Agricultural and Resource Economics Review, 44, 65–77. https://doi.org/10.1017/S1068280500004627

II. Lehtonen, H. and Niskanen, O. 2016. Promoting clover-grass: Implications for agricultural land use in Finland. Land Use Policy, 59, 310–319. https://doi.org/10.1016/j.landusepol.2016.09.005

III. Niskanen, O., Iho, A. and Kalliovirta, L. 2019. Scenario for structural development of livestock production in the Baltic littoral countries. Agricultural Systems, 179, 102771. https://doi.org/10.1016/j.agsy.2019.102771

Author's contribution:

In Essay I, Olli Niskanen was the leading author. He developed the original idea, constructed the data set and carried out empirical estimations. The literature review was completed and the article finalized collaboratively with Anna-Maija Heikkilä. In Essay II, Olli Niskanen was the contributing author, working with Heikki Lehtonen on the original idea, the literature review, and finalization of the manuscript. Olli Niskanen constructed the data set on clover cultivation. Heikki Lehtonen was responsible for the model calibration and writing up the results. In Essay III, Olli Niskanen was the leading author. He developed the original idea and constructed the data set. Leena Kalliovirta helped with the estimations. The literature was reviewed and article finalized jointly with Antti Iho.

Contents

1. Introduction

Agriculture, like all other industries, is constantly evolving. Many of the major changes in the sector reflect demographic trends such as urbanization and the decrease of rural populations, who previously made their living directly from agriculture. The roots of this development lie in advances in technology and growth in productivity, which together have freed up agricultural labor to work in other industries. This evolution over time is called structural change.

Throughout the world, farms and family farms include large-scale enterprises as well as medium-sized and small operations. Farmers may be specialized in agriculture, with this then providing a substantial share of their total income. Alternatively, they may draw on diverse sources of income or rely primarily on off-farm income (Lowder et al., 2016). Such heterogeneity is found in European agriculture, Finland being no exception.

It is often claimed that large farms perform better economically than small ones, which means that the former will evolve while the latter will eventually disappear and make room for those remaining to expand (Balmann et al., 2006; Bartolini and Biaggi, 2013). However, more attention has been given recently to the social and ecological consequences of a development that might induce contrasting and/or countervailing tendencies (van de Ploeg et al., 2016; de Roest et al., 2018).

Each continent, country, and region has its own distinctive farm structure, which is a product of natural conditions, history, and active policies designed to regulate or foster structural development. This dissertation focuses on the evolution of farm structure in northern Europe and on the development of the livestock sector in particular. While the industry has undergone rapid changes on many fronts, most of the labor input and market return in the sector are related to livestock farming (Latukka, 2019; Mäkinen, 2019). Its salience can also be seen in the intensifying debate on issues such as animal welfare, nutrient and climate emissions, and human diet.

This dissertation seeks to improve our understanding of the implications of the structural change that has occurred in livestock production in recent decades and is likely to continue in the near future. Focusing on the structure of agricultural production and, in particular, land use, the work puts forward the reasons why structural change continues. This synopsis is structured as follows. The introduction continues by reviewing the concept of structural change, introducing the underlying economic theory and defining the drivers of such development. Since most of the research is directly related to Finland, the introduction ends with a brief overview of recent Finnish history. This provides context explaining the current farm structure and framing the research questions. Chapter 2 continues with a detailed account of the subject matter of the dissertation and presents summaries of the methods, objectives, and results of the essays. The discussion and conclusions are presented in Chapters 3 and 4, respectively.

1.1. Concept of structural change

Structural change is a normal part of economic development and business renewal. When technologies, consumer preferences, and economic conditions change, new production opportunities will emerge and replace less productive ones. Over time, industries adapt to accommodate these changes (Hallam, 1991). This is a continuous process in the economy, with some jobs disappearing, especially in traditional industries, and new ones generated at the same time in new and/or growing sectors.

The "structure of agriculture" subsumes a number of indicators, such as 1) farm size distribution; 2) technologies, production types, and systems; 3) labor force characteristics; 4) ownership and financial arrangements, including tenancy; and 5) inter- and intra-sector linkages, including contract production and integration in production organizations (Boehlje, 1992). Changes in these can be considered structural changes (Saint-Cyr, 2016).

As is the case in the economy at large, the structure of agricultural production is constantly changing. However, some peculiarities of agricultural production distinguish structural change in the sector from that in others, examples being its dependence on biological processes, which results in a low rate of return on capital, and strong political guidance (Hyvärinen, 2016).

Historically, the greatest changes in agricultural production have been sparked by innovation and technological development, particularly where these have increased labor productivity. This may involve the same labor units producing more agricultural output or the same production being achieved with less labor. Often technological development takes the form of substituting labor input with capital input. In past decades, capital productivity has shown an overall decreasing trend, indicating that investments in machinery, buildings, and the like have played a major role in achieving output growth and in the substitution of labor (European Commission, 2016).

Traditionally, agriculture in western countries has operated in the form of family farms. Accordingly, the reduction of labor input has been directly reflected as a decrease in the number of farms and the expansion of those farms that continue to operate. This development has freed up agricultural workers to meet other needs of society and thus supported industrialization and urbanization.

The adaptive capacity of agriculture depends on the capital and knowledge invested in farming. In many cases, crop farmers have an opportunity to adjust their cultivation plans annually depending on expected market demand. Farm-level adjustments sum up to the sector level and, in the end, trends become visible in the national- or higher-level balances, grain production being a case in point. The slowest adaptability within agriculture is in sectors where production cycles are perennial, such as breeding of dairy cows. In such instances, volumes of livestock production are steadier, and trends can only be discerned in the long term.

In northern countries, agricultural buildings represent a significant share of the capital investments in animal production, whereby structural change largely depends on the need to build facilities. Livestock buildings are typically suitable only for their primary purpose. When the life cycle of buildings is coming to an end, the question becomes whether to continue production in the same production line, change it, or exit production completely. As a building's "expiry date" is not exact, farms can often extend its lifetime up to other tipping points of the farm life cycle, such as generational shifts. One exception is when political decisions prohibit certain modes of production, such as the EU-level ban on conventional battery cages for laying hens in 2012.

Changes in farm structure are the result of entry, growth, and exit decisions by the many operating and potential farm households (Flaten, 2002). A change in structure may also be prompted by productivity growth and production decisions on individual farms. Typically, the primary purpose of farming is to provide a living for the farm's owners, but the reasons for farming are often other than purely economic ones (Peltomaa, 2012). This being the case, a democratic society cannot determine the structure of production (Flaten, 2002). Notwithstanding, the direction of structural change has been affected by various policies, such as production quotas and investment subsidies. Structural changes may affect the viability of the sector as a whole and have social, economic, and environmental consequences at the local, regional, national, and even higher levels (Flaten, 2002). This dissertation analyses some of these effects.

1.2. Theoretical background

The most common definition for agricultural structural change, and probably the most visible change to those outside of the sector, is the change in the farm size distribution, that is, an increase in average farm size. The most frequently analyzed characteristics of production technology - and also the most common explanations of why farms are growing - relate to concepts of economies of scale and economies of size. By way of illustration, let us assume a production function:

$$y = f(x_1, x_2, \dots, x_n) = f(\boldsymbol{x}), \tag{1}$$

where y is output and $\boldsymbol{x}$ is the vector of inputs $(x_1, \dots, x_n)$. Increasing all inputs simultaneously by equal proportions will show how scaling up inputs affects output. A key measure here is elasticity of scale, which indicates how equal relative changes in inputs are reflected in the relative change in output while the technology remains the same. In the present case, elasticity of scale can be represented as the sum of the output elasticities of each input:

$$e = \sum \frac{\partial f}{\partial x_i} \frac{x_i}{y} = \sum \frac{MP_i}{AP_i}, \tag{2}$$

where e is elasticity of scale, $\frac{\partial f}{\partial x_i}$ is the marginal product (MP) of input x_i, and $\frac{x_i}{y}$ is the inverse of the average product (AP) of x_i. If e is less than one, then returns to scale are decreasing; if it is equal to one, the technology has constant returns on scale; and if it is higher than one, the technology shows increasing returns on scale (Chambers, 1988; Hallam, 1991).

The benefits of economies of size can be defined using the concept of cost elasticity $n(w, y)$, which is defined as the first derivative of the cost function with respect to output

y (marginal cost MC) divided by the average cost (AC) at given output y, where the input price w is given and the cost function is represented by c:

$$n(w, y) = \frac{\partial c(w,y)/\partial y}{c(w,y)/y} = \frac{MC}{AC} \tag{3}$$

If $n(w, y) > 1$, smaller production of y results in a lower unit cost, and if $n(w, y) < 1$, cost advantages may be gained with larger production. As mentioned, elasticity of size, $\in^* (w, y)$, is the reciprocal of cost elasticity, $1/n(w, y)$ (or AC/MC), and thus a farm exhibits increasing economies of size when $\in^* (w, y) > 1$ and decreasing economies of size when $\in^* (w, y) < 1$. When size elasticity is equal to one, average cost is at its lowest point (Chambers, 1988; Hallam, 1991).

The benefits of economies of size are closely linked to the economies of scale represented by the production function, but the two concepts must nevertheless be distinguished. Economies of size describe the change in costs as a farm moves through cost-minimization points when expanding production, while in the case of economies of scale, the use of all inputs is expanded by the same proportion. These expansion paths are, by definition, different (except in the special case where the production function is said to be homothetic; Chambers, 1988).

In agricultural production, inputs are rarely changed in the same proportions, especially in the complex case of farm enlargement. As agriculture in the short term typically involves high fixed input costs, such as buildings, economies of size usually result from spreading fixed costs over larger output until the capacity is fully utilized. Economies of size can also occur when a farm is able to obtain volume discounts on inputs such as fertilizers (Moore, 1959; Hallam, 1991). Inputs can often substitute for one other, depending on their price and availability. The typical example is the input substitution between capital and labor (e.g. Pietola and Heikkilä, 2005), which (together with technological change) may allow a labor-constrained family farm to sustain larger production.

A production function represents the maximum output attainable from a given set of inputs. Similarly, a cost function represents the minimum cost given input prices and output, and a profit function the maximal profit given input and output prices (Coelli, 1995). The upper bound of a production function is called the production frontier. Farms that operate on that frontier are perfectly efficient, those running beneath it not fully efficient. Efficiency can be defined as the difference between the actual production and optimal feasible production of the utilized technology (Färe et al., 1985). Productivity improvements can be achieved by improving the state of the technology through investments in new technology. This is commonly referred to as technological change and can be represented by an upward shift in the production frontier. Alternatively, one can implement procedures to utilize the existing resources more efficiently. This would be represented by farms operating closer to the existing frontier (Coelli, 1995).

Economies of size can be divided into internal and external with respect to effects (Hallam, 1991). Internal economies of size describe cost advantages (or disadvantages) due to conditions internal to the farm, such as efficiency of production, while external economies of size describe cost advantages (or disadvantages) based on larger production in a sector or region. External economies of size can arise from synergies of cooperation, while external disadvantages can result from excessively harsh competition for agricultural land or inefficient use of nutrients from manure due to an unduly high stocking density in the area. Significantly, agriculture is a sector in which both internal and external economies of size may be present (Klasen et al., 2016).

1.3. Drivers of structural change

The structural change of livestock production follows a similar pattern in most industrialized countries. Zimmermann et al. (2009) list the interlinked drivers of the process: 1) technology, 2) off-farm employment, 3) public programs and policy, 4) human capital, 5) demographics, 6) market structure, 7) social setting, and 8) the economic environment; the last can be regarded as the sum of the others.

In livestock production, item 1 applies to economies of size and the growth of labor productivity associated with technological development. Technological change, in turn, is prompted by the development of best practices, which make frontier shifts possible. Those who are first to adopt new technology reap the greatest benefits from increased productivity. They will gain from the first-mover advantage as long as output prices remain largely unchanged. As more and more farms adopt the technology, the prices of farm commodities will fall and competition increase; this in turn will force others to adopt the new technology or exit the industry, thus triggering structural adjustments (Zimmermann et al., 2009; Harrington and Reinsel, 1995).

Item 2 reflects the opportunity cost of labor. As opportunity costs rise due to higher wages outside agriculture, farmers tend to leave the sector until wages equalize (Hallam, 1991). The increase in opportunity costs also induces technological change that replaces labor input. Off-farm employment (i.e., pluri-activity) is one farming strategy to maintain small-scale farming, the assumption being that the off-farm income will complement the household’s income (Goddard et al., 1993).

Structural development in the European Union (EU) has been steered by a variety of policies (Item 3). Support for investment in agriculture has been a permanent element of the Common Agricultural Policy (CAP) since the mid-1960s (Smit et al., 2015). Today, most rural investment in the EU is promoted through different forms of investment support for rural development programs (RDP) (European Commission, 2015).

Item 4 refers to managerial skills. Education and advisory services contribute to these skills, which make it possible to run ever-larger and more complex farm operations (Goddard et al., 1993). Regional knowhow and spillover effects in livestock production also fall into this category.

Item 5 is largely a function of farmers’ age: the average age of European farmers is on the rise as there are ever-fewer entrants to the sector. The European Commission has recognized this problem and developed support measures for young farmers. Item 6 primarily reflects the liberalization of trade, which has increased competition in domestic, EU and world markets, but it also includes the effects of cooperative policies, such as the “same price for all” policy regardless of farm size.

Item 7 typically captures the role of family farms. Boehlje (1992) has posited the motivations for maintaining family farm-based agriculture. In societal perspective, the maintenance of such a structure is important for efficient production, community viability, and food supply. From the individual perspective, the motivations primarily relate to the independent lifestyle, family bonding, and social relationships involved.

It is important to highlight that an increase in size is not the only development strategy farms adopt. In Western Europe, other typical strategies for coping with economic challenges include intensification (within a given set of resources, which means increasing technical efficiency), product specialization (such as shifting to organic production), pluriactivity (engaging in non-agricultural business activities) and low-cost or low-input farming (minimizing the use of purchased inputs) (van der Ploeg et al., 2016).

1.4. Structural change in Finnish agriculture

Finnish agriculture is largely based on family farms. Today's farm structure is the result of long historical development, as it is in any country. Some basic features developed when Finnish society was predominantly agrarian, and these are still recognizable. In the early days of independence, the Government issued the Decree on the Redemption of Leased Areas (1918), which granted tenant farmers the right to buy the land that they had previously rented. This resulted in the creation of some 47,000 new farms and 46,000 housing plots. Other significant settlement laws were enacted in 1924 and later, during the Second World War (comprising the Winter War 1939–1940, Continuation War 1941–1944, and Lapland War 1944–1945), in order to provide resettlement and living opportunities for Finnish citizens evacuated from areas lost in the conflicts. This saw the creation of about 30,000 new farms ranging in size from 6 to 15 hectares. An additional 15,000 such farms with between 2 and 6 hectares of arable land were established later (Virtanen and Halme, 1983). Many of these farms increased their cultivated area by clearing new fields. With these developments, the number of individual farms and the amount of agricultural land reached its peak towards the late 1960s (Figure 1).

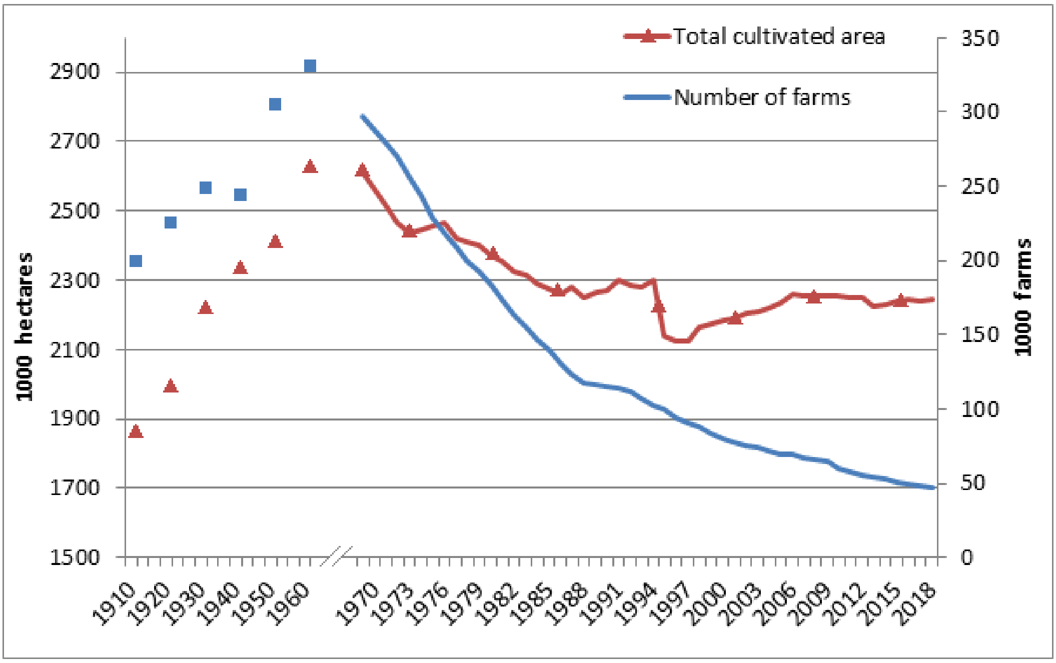

Figure 1. Total cultivated agricultural area and number of farms in Finland in the period 1910-2018 (Luke 2019; own elaboration).

During the same period, the productivity of agriculture rose as a result of considerable progress in technology, such as increased availability of artificial fertilizers and advances in animal breeding. In the mid-1950s overproduction started to become prevalent (Kettunen, 1972). Agricultural policy had to offer measures to curb production through both price policy and direct restraints. Production was controlled with quantitative restrictions, with both compulsory and voluntary programs in place for the purpose. Among the mandatory measures for curtailing production were dual milk and egg pricing systems and set-aside requirements. Milk quotas were first introduced in 1993, and after 1995, when Finland joined the EU, farmers were able to buy and sell their quotas rather freely. However, investing in and expanding milk production was only possible if a sufficient number of quotas had been purchased. This practice was in place until 2013. Thereafter, a milk quota was no longer a prerequisite for receiving an investment subsidy, and in 2015 the quota system was abolished completely. Currently, there are only few direct policy-related limitations[1] on the growth of farms, which means that in principle farms can grow as long as environmental and regulatory constraints are met.

[1] For example, the Act on National Aid for Agriculture and Horticulture (1559/2001) and national regulation based on Regulation 1305/2013 of the European Parliament limit the maximum amount of support a farmer may receive.

2. Subject matter of the dissertation

Land is the fundamental input of agriculture and thus is the productive input that most often limits farm development (Bartolini and Viaggi, 2013). This dissertation considers the relationship between structural change in livestock farming and land use from three different perspectives. Essays I and II focus on the Finnish context, while Essay III broadens the perspective to include the other seven Baltic littoral countries. Essays I and II concentrate mainly on dairy production, whereas Essay III considers all livestock sectors. Each of the essays also utilizes different methods and data sets (Table 1). The following sections (2.1–2.3) provide short summaries of each essay in the dissertation and the main findings of the research.

Table 1. Descriptions of the studies.

Study	Land perspective	Production line(s)	Aggregation level and region	Method
I	The effect of land fragmentation on farm technical efficiency	Dairy farms	Farm level, Finland	Stochastic Production Frontier Analysis
II	Land use of low-input roughage production	Dairy farms, all farms	Sector level, Finland	Partial equilibrium modeling
III	Changing land demand as manure spreading area	Livestock farms	Sector level, eight Baltic littoral countries	Markov Chain modeling

2.1. The impact of parcel structure on the efficiency of Finnish dairy farms

Milk production is characterized by a close link to arable farmland, not only because a certain minimum area is required for manure spreading, but also because land is needed to produce feed for animals. Farms usually produce most of their own feed; in milk production self-sufficiency in roughage is typically the minimum requirement (Sipiläinen and Ryhänen, 2005).

The distinctive feature of Finnish agriculture is its fragmented farm structure, which is a consequence of historical and geographical circumstances. When the availability of land is limited, farms need to acquire land when it can be had within a feasible distance; yet the distances to available land are often not optimal. The research question addressed in Essay I is whether a farm's structure causes a measurable impairment of its technical efficiency and, if a farm ceases operating, how much technical efficiency is lost due to the presumptive fragmentation that ensues. Fragmentation of land also has a bearing on the climate effects of livestock production and for this reason as well merits particular attention.

The study used farm-level micro data to empirically measure the technical efficiency lost due to land fragmentation. The data were provided by Finnish Farm Accountancy Data Network (FADN) and supplemented with field plot data (IACS data) on each farm. The research period covered the years 2000 to 2009. The data formed an unbalanced panel with 568 individual farms and 3,329 observations. The data were analyzed using Stochastic Production Frontier Analysis (SFA), as suggested by Battese and Coelli (1995). As the farm-level data is protected by the privacy policy of FADN, the data were merged by the statistics team of the Finnish Natural Resources Institute to ensure that the farm locations and identification data were hidden from the researchers.

Productivity growth can be observed as an improvement of the input-output relationship. The two recognized main sources of such growth are technological change (shift of the production frontier) and technical efficiency (catching up with the frontier) (Coelli, 1995). For example, productivity has improved on Finnish dairy farms mostly due to technical change, the increase being approximately 1.4% per year for the study period 2000–2009. The average technical efficiency score of Finnish dairy farms was 79%, which suggests that it may be possible to increase milk production by using the same level of inputs and existing technologies more efficiently. Technical efficiency has increased 0.2% per year. Milk production of farms was cross-tabulated with farms' efficiency scores, which revealed that production had shifted towards the farm class with the highest technical efficiency (farms with a TE score >90%) over time. This category produced 27% of the total milk produced in the year 2000, while its share in 2009 was 38%. The share of milk production on less efficient farms declined over the same period, suggesting that structural development drives production towards technically more efficient units.

A dairy farm's parcel structure, that is, the size of field parcels and distance to them, is a key determinant of its technical efficiency. Thus, improving parcel structure is one means to increasing technical efficiency. The average-farm approach was used to simulate and visualize the effect of parcel distance and parcel size on the technical efficiency of the farm with the estimated coefficients. Our variation of the parcel size from 50% to 200% caused the TE of the average farm to vary over a range from 0.72 to 0.85. When distance to parcels was varied over the same 50% to 200% range, the TE varied from 0.84 to 0.71. The conclusion to be drawn here is that efforts to improve a farm's parcel structure are justified as a means to improve its efficiency.

2.2. Promoting clover-grass: implications for agricultural land use in Finland

One farm development strategy is to specialize in low-input production. Low-input dairy systems are primarily understood to differ from high-input dairying in terms of feed ration composition and feed production. In northern European dairy production, one applicable low-input production strategy is to cultivate legume-based grasslands. These may yield significant environmental benefits (Lüscher et al., 2014; Soussana et al., 2010) as well as offer farmers an option for increasing resilience to market changes by reducing the use of purchased inputs and thus production costs.

While structural change has increased stocking rates on continuing farms, average stocking rates are still at a reasonable level. Finnish dairy production is characterized by high production costs, which cause a competitive disadvantage. Essay II takes up the question of whether there are any alternatives to conventional, intensive production systems other than certified (and supported) organic production. This was investigated through a study on increasing clover cultivation in grass mixtures and thereby reducing the use of inorganic nitrogen input. The research questions were: (1) How can cultivation and use of clover-grasses as feed be promoted? (2) How much more land area could be allocated to clover-grass if clover-grass premiums were implemented, cost levels reduced, a fertilizer tax imposed, or clover-grass yields increased? (3) What kind of change in land use is implied if the area under clover-grass is increased, that is, for which crops would less land be used? (4) By how much can clover-grass production be increased, using reasonably inexpensive policies and other measures, without increasing the overall budget for agricultural support payments yet keeping dairy and cattle production economically viable?

The research employed the agricultural sector model DREMFIA (Dynamic Regional Sector Model of Finnish Agriculture; Lehtonen, 2001), which is a partial equilibrium model representing the Finnish agricultural sector. The model draws on price and policy scenarios to simulate competitive markets up to the year 2030. The selection of production activities (i.e., cultivation options) in the model was complemented by a new cultivar, clover-grass, which may produce a higher share of protein in the yield, but which produces lower total yield in high-input (nitrogen) production systems. As official data on clover cultivation are lacking, data for the study were compiled from various sources, such as grass silage analyses for dairy farms from Valio Ltd., certified clover seed production, seed import and export data from the Finnish Food Authority, and cultivation statistics compiled by Natural Resources Institute Finland.

Two price scenarios, that is, two baselines, were developed and evaluated using the sector model. These enabled assessment of the effectiveness of specific measures for promoting clover-grasses that have been put forward in the literature. The research analyzed land use and production effects of measures to promote clover-grass cultivation in forage production. The promotion methods were 1) reduced costs, 2) higher clover-grass yield levels, 3) premium payments (subsidies) for clover-grasses, and 4) fertilizer taxes (i.e. higher price of fertilizers).

All of the above methods could increase cultivation of clover-grass and its use as feed, especially in dairy production. The results suggest that premium payments for clover-grass areas or reduced costs may have little effect, whereas fertilizer taxes and higher yield levels of clover are more likely to result in significantly increased clover-grass production. The effectiveness of measures promoting cultivation of clover-grass is highly dependent on the prices of crop and livestock products as well as the cost of fertilizer. The main result related to structural change of agriculture is that the potential for increasing clover-grass is limited due to considerations such as manure spreading requirements. These result in increased marginal costs and decreased marginal benefits when the use of clover-grass as feed and its cultivation area are increased. In conventional production, an average stocking density (0.92 livestock units (LSU)/ha) results in a level of average nitrogen fertilization per hectare that is above the optimal level for clovers to succeed. Allocating adjunct nitrogen to some of the farm’s fields (under other crops) relieves the oversupply, but still exceeds the maximum allowed by the Nitrates Directive. For comparison, on organic dairy farms the stocking density was only 0.71 LSU/ha, which results in more suitable nitrogen fertilization. It was found that it would be difficult to increase the proportion of clover-grass on all grassland area in Finland to more than 30% from the current proportion of 15%.

An increase in average farm size, which decreases the unit cost of production, is undoubtedly needed in order to maintain the economic viability of dairy production in Finland. One problem, however, is that increased farm size often leads to an excessively high livestock density and, conversely, discourages low-input forage options such as clover-grasses. Cooperation between livestock and crop farms could offer a solution if cultivation of low-input forage is to be promoted.

2.3. Scenario for structural development of livestock production in the Baltic littoral countries

Recent decades have seen profound changes in the structure of livestock production in Europe and this development seems to be continuing apace. One consequence is that manure is being — and will be — produced on fewer but larger farms. Livestock farms often use imported feed to supplement feedstuff grown on the farm’s own fields. Indeed, more nutrients tend to be imported into intensive animal production areas in the form of animal feed than are exported from them in the form of end products. This may result in nutrient surpluses, which increase the risk of nutrient loading to surface and ground waters. The higher the number of production animals within a facility is, the greater the likelihood is of nutrients accumulating locally (Baerenklau et al., 2008; Innes, 2000). The total amount of nutrients in manure generated by the production animals may exceed the agronomic needs of the crops grown within an economically sensible distance of the animal facility. Where this is the case, livestock production may contribute to spatial accumulation of nutrients.

Essay III describes research investigating the magnitude of manure nutrient agglomeration due to structural change in the Baltic Sea region. The study 1) puts forward an estimate of the distribution of main manure nutrients between farms of different sizes, 2) estimates how this distribution will change in the near future, and 3) discusses the land use effects of this development. A Markov chain model was used that applies a stochastic approach estimating the probability that a farm will move among a set of discrete size classes (Zimmermann and Heckelei, 2012). Input data were from the Farm Structural Survey (FSS) of Eurostat and reflect the actual structural change in livestock farming between 2003 and 2013 in eight Baltic Sea littoral countries: Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland and Sweden. The estimated transition probabilities were used to predict future farm numbers over the course of the next decade, until 2030. Agricultural production was estimated separately from farm numbers using the CAPRI model (Common Agricultural Policy Regionalized Impact; Britz and Witzke, 2014), which provided the total number of production animals in 2030 regionally. The main result – estimates of the number of animals by farm size category – is combined with other data sources in order to visualize how this development will affect the volume of manure as well as the allocation of nitrogen and phosphorus between farms of different sizes. The results suggest that by the year 2030 farms housing more than 500 livestock units will produce more than two-thirds of all manure phosphorus, whereas the proportion in 2010 was one-third.

To study the interaction of land use and structural change, Farm Accountancy Data Network (FADN) data were used to estimate the connection between farm size and stocking density for ruminant and granivore farms. This information was used to estimate the land use effects of the estimated structural development, that is, to anticipate how land ownership and leasing are expected to change given the pace of animal facility growth. To illustrate the change, it was assumed that the Nitrates Directive limits the use of organic nitrogen of manure in all regions. Under such circumstances, growing farms will need to acquire, or make contracts for the use of, 4.9 million hectares from exiting farms or the open market in order to comply with manure spreading requirements. This shift will involve 64% of the total spreading area of 2010 and 15% of the total utilized agricultural area of the regions studied.

In light of these predictions, international nutrient policies should consider the evolution of farm structure in general and manure phosphorus agglomeration in particular. Also salient will be improved cooperation beyond the single-farm level to ensure the functionality of crop-livestock systems. What is more, agglomeration of manure may provide incentives to develop novel manure-processing technologies.

3. General discussion

The structural change of agriculture is an international phenomenon, but each country has its own national history, which is the underpinning of its present structure and point of departure for its path forward. The search for economies of size and lower unit costs explains the past and ongoing growth of farm size in most cases: Farms seek possibilities to gain efficiency and productivity in order to keep their viability in the face of increasing input prices. Generally speaking, agriculture has not been profitable, but heterogeneity of farms explains the phenomenon whereby some (most unprofitable) farms exit the sector and some continue by investing to achieve better profitability. This twofold development has been going on for decades.

Each farmer operates under local conditions in terms of agricultural land, the community of other farmers and conditions for selling and/or further processing agricultural products. The agricultural sector of a certain region may gain an advantage or suffer a disadvantage from economies of size, with a concomitant improvement or decline in its regional and international competitiveness. Economies of size in one country may be exploited to maximize domestic welfare, while economies of size in another country may be stifled, and the industry protected, to attain other social goals (Hallam, 1991). The latter was the case for decades in Finland: Structural development was essentially precluded by policy in order to control production volumes and maintain the viability of family farms. The resulting high production costs were offset by import tariffs and export subsidies (Kettunen and Niemi, 1994).

For the case of Finland, the shift towards free trade began in 1995 by joining the European single market. At the time, the country lagged behind its rivals in the pace of structural change and level of productivity. Since joining, total factor productivity (TFP) growth in Finland has been roughly comparable to that in Sweden, Denmark, and Germany, but as the country's starting position in productivity (and competitiveness) was weak, differences in TFP have largely persisted (Irz and Jansik, 2015). Closing the gap would require even faster growth, but any efforts to increase productivity face the challenges of natural conditions in the north. It is said that Finland is the northernmost country engaged in agriculture.

The reform of the Common Agricultural Policy in 2003 introduced decoupling of agricultural payments, which removed or markedly weakened the link between the receipt of a direct payment and the production of a specific product. Prior to this reform, farmers received a direct payment only if they produced the specific product with which the payment was associated (European Commission, 2017). This process was continued in the EU's CAP "health check" in 2009. The overall objective of decoupling has been to move the agricultural sector more towards the free market and to give farmers greater freedom to produce in keeping with market demand. However, the health check permitted member states to continue coupling some direct payments with production in order to support the production of certain products and thus avoid abandonment of farmland in vulnerable regions. This permission has been fully exploited in Finland to support livestock production and certain other agricultural activities.

Farming generally requires the possession of agricultural land. Accordingly, expanding farm size usually requires investing in land in one way or another. Having one's own agricultural land constitutes a significant farm asset but also requires high capital investment, while renting agricultural land represents a significant annual expense. Agricultural land prices vary regionally, but general speaking prices have increased over time in many EU countries.

As is the case with all asset prices, land prices eventually stabilized at a level reflecting a balance between supply and demand. High demand has raised prices especially in the most agglomerated agricultural regions. This can be observed in Finland, with land prices differing between eastern and western as well as northern and southern parts of the country. Land prices are higher in the regions of intensive livestock production than in the regions with fewer animals (Pyykkönen, 2006). However, agricultural policies also influence land prices. The capitalization of agricultural subsidies in land prices has been the subject of extensive empirical and theoretical research.

According to Ciaian et al. (2018), in the past century, decoupling of agricultural subsidies from products and coupling to land has increased capitalization and land prices and as a result generated capital gains for landowners. Capitalization and increased prices are holding back changes in land ownership and thus increasing expenses for farms planning to expand production. This conclusion is in line with Storm et al. (2014), who concluded, using Norwegian data, that higher direct payments for neighboring farms seem to decrease the probability of a particular farm surviving. The underlying logic put forward to explain this is that a farm is less able to compete when expanding its operations and faces limited growth prospects, whereby its chances of surviving decrease. Essay I suggests that reparcelling land and merging field plots could offer benefits for dairy farms that suffer from inefficiency caused by poor farm structure. Higher efficiency would result in better productivity and free up resources, especially hours of labor, for other activities on the farm.

Land prices also reduce possibilities to convert livestock production in the direction of less intensive production practices. As feeding of Finnish dairy cows (and cattle) is typically based on grass silage complemented by grain and rapeseed meal, possibilities for lower input use should mainly concern such facilities. Intensive grass silage production requires significant nitrogen fertilizer input, which in conventional production is mainly inorganic nitrogen supplemented with manure nutrients. Increasing milk production on farms undergoing structural change has led to higher livestock densities and thus higher (manure) N fertilization. Essay II discusses the possibilities to lower the use of the nitrogen by utilizing biological nitrogen fixation of clovers in roughage production. It was found that premium payments or reduced costs of clover-grass cultivation had small effects, whereas introduction of a fertilizer tax and higher yield levels boosted clover-grass production. High prices for protein feeds and fertilizers would also increase clover-grass areas.

As with every agricultural average, the averages used in the sector model mask a wide heterogeneity. However, in the present case it can be concluded that, on average, at current stocking rates the opportunities to use low-input cultivation practices such as clover-grass nitrogen fixation are limited due to the manure nitrogen surplus involved. The processing of manure in biogas production, for example, could offer a solution improving the transportability of manure; it would refine nitrogen use on clover-grasses to a level that would take advantage of clover's biological nitrogen fixation and increase feed protein content.

From the beginning, northern agriculture has largely been based on animal production, especially dairy cows. Animals have produced not only milk and meat for human consumption but also manure, which was essential for grain production before inorganic fertilizers became easily available. The disconnect between animal and crop production has allowed spatial segregation between the production lines. On the other hand, animal production is concentrated in certain areas where conditions are favorable – directly or relatively – if those areas are not particularly suitable for crop production. Today, in the European single market, production or certain parts of the production chain may cross national borders. The European CAPRI model is one of the best available tools for estimating changes in the volume of production. In livestock production, major changes take place through enlargement investments and/or the simultaneous closure of livestock farms. Depending on the total demand, less competitive regions will eventually reduce production over time while more competitive regions will be able to increase their production.

Enlarging farms also produce more manure nutrients, which raises the question of their impact on nutrient recycling processes. Transportation costs largely explain why a farming system comprising 1000 facilities with 50 animals generates a different manure accumulation pattern than one comprising 50 facilities with 1000 animals. Essay III presents a model for estimating the development of production facilities and this development is linked to statistics on manure nutrients.

In the matrix of stationary transition probabilities utilized, the development of farm numbers is fixed. Accordingly, higher or lower demand for livestock products does not affect the number of farms, but it does affect the number of livestock in the largest size class. This is rationalized so that in circumstances of higher (or lower) demand of animal-based products, housing investments are made bigger (or smaller). It is also generally known that most investments are made by farms which are already large (e.g., Hyvärinen, 2016). At the farm level, the continuation of production is linked not only to market demand and prices but to many other issues as well, such as how close the farmer is to retirement age, interest in an agrarian lifestyle, and tradition.

Significant investment in production capacity is required to realize the projected scenario. Most countries support their rural investments via the "second pillar" of the CAP. For the eight countries considered in Essay III, the expected funds for rural development programs (RDPs) for investments total over 2.6 billion euros on 80,000 farms in the program period from 2014 to 2020. For example, Poland has ambitious investment targets in its RDP and has prepared to support over 42,000 farm investments in the period (European Commission, 2018). Other financial instruments are also available in the EU to improve access to investment capital (European Commission, 2019).

The estimated production would most likely require the investments suggested in the Essay III unless the CAPRI baseline over- or underestimates the long-term demand (and thus supply) of livestock products. Although a broad consortium of experts has helped to calibrate the equilibrium model parameters, CAPRI cannot account for unexpected changes in supply or demand. The obvious unexpected changes can be related to trade barriers or unexpected economic changes, such as a deep recession. Unpredictable changes in product demand may occur for example in outbreaks of animal diseases. It is also possible that recently introduced substitutes for animal proteins will take a larger share of the markets and fulfill a significant share of protein needs. Thus, the results put forward in Essay III are meant to make the expected development visible to policy makers, and not to be taken as absolute values.

At both the EU and national level, the future of agricultural policy is outlined primarily in terms of growing active farms. The future horizons of the farms are, however, polarized between specialization and diversification on the one hand, and between full- and part-time farming on the other (Peltomaa, 2015). This dissertation has focused on specialized and growing livestock farms, but agriculture is full of other stories as well. In the end, consumer demand determines how agriculture will evolve, for example where agricultural products and ecosystem services are concerned. However, rationalizing the production structure has many advantages both from the farmer's and society's perspectives.

The results suggest that although it is economically justified to achieve economies of size in agriculture, there are contrasting and/or countervailing tendencies related to land management that may 1) reduce efficiency, 2) limit cultivation opportunities, and 3) lead to nutrients being concentrated on fewer farms. As these issues are closely linked to manure utilization, solutions to improve the efficiency with which it is used are increasingly needed. These issues are important to be aware of when agri-environmental policies are developed. It is also important to promote land-use efficiency in livestock production by offering farmland consolidation programs and by promoting cooperation between farmers. Another lesson that emerges from Essay III is that international nutrient use policies should consider the evolution of farm structure when undertaking to relieve potentially rising agglomeration problems and to avoid concentration in regions where environmental constraints are fewest.

4. Conclusions

Livestock production has shifted towards larger units, with the number of small livestock farms rapidly decreasing. In most instances, efforts to achieve economies of size serve to account for the past and ongoing development of farm size growth: Farms seek possibilities to gain efficiency and productivity in order to keep their viability in the face of growing production costs.

Increased productivity on Finnish dairy farms is mostly attributable to advances in technology. Technical efficiency has increased but only slightly; more importantly, a higher share of the total production volume is produced with higher technical efficiency. One factor affecting the technical efficiency of dairy farms is parcel structure, that is, the size of and distance to field parcels. Improving parcel structure would thus be an appropriate measure in the effort to improve technical efficiency.

A low-input strategy has been put forward as an alternative to high-intensity production. In the northern European context, clover-based forages are suitable for sustainable low-input or organic dairying. They are advantageous in that they require less nitrogen fertilization than pure hay grasses yet provide higher protein content. Any incentive to cultivate clover-grass was found to be highly dependent on the price of nitrogen; however, increasing the yield of clover-grasses (i.e., decreasing the gap in yield vis-à-vis intensive grass production) would effectively promote clover cultivation without additional costs for milk producers or society. This finding constitutes an argument for encouraging the development of clover varieties and cultivation practices.

As continuing livestock farms are growing larger and housing more animals, effects can be expected where the use of manure is concerned. The crux of the issue is the nutrient composition of manure: by the year 2030 farms housing more than 500 livestock units are likely to produce more than two-thirds of all manure phosphorus, whereas the proportion in 2010 was one-third. This development would require growing farms to acquire land for manure spreading in proportion to their growth in order to avoid overfertilization. Cross-country restrictions on fertilization are an additional consideration here.

The main conclusion and thus contribution of this dissertation to the present literature on structural change is that despite it being economically justified to seek economies of size in agriculture, there are contrasting and/or countervailing tendencies which are related to land management. These tendencies may 1) reduce efficiency, 2) limit cultivation opportunities and 3) lead to nutrient concentration on fewer farms. Structural development – livestock farms becoming larger – creates pressure to develop new nutrient solutions. Yet measures to promote structural change in livestock production should not ignore land management issues, such as reparcelling. Technological solutions to manure management (e.g. separation) may aid in tempering what are problematic rising trends.

Some limitations of the component studies of this dissertation should be noted. Firstly, more sophisticated methods are in many ways available. In the case of Essay I, a more detailed production function could have been used and decomposition of the productivity growth could have been more detailed. In Essay III, the stationary Markov Chain model could have been replaced with a non-stationary one, which would have made it possible to examine alternative scenarios for future pathways. Had these methodological opportunities been exploited, the results would have been more reliable and accurate, but the main interpretations of the results would stand as presented here. In Essay II, the input data for establishing the baseline of current clover-grass cultivation in Finland were very limited and had to be estimated based on various sources. Again, having better data to begin with would not have produced a result changing the main interpretation regarding the effectiveness of promoting cultivation.

The studies suggest directions for further research. In addition to updating methods, as suggested in the previous paragraph, future work should examine structural change at the farm level: this focus would enable researchers to determine more detailed effects of agglomeration of animal farms. Among other things, the farm-level perspective would make it possible to study the economics of manure spreading with actual field plot data and to take neighboring effects into account. Such research could be implemented as a regional case study, but IACS (Integrated Administration and Control System) field plot data might enable large-scale assessments as well.

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