The hot and cold cow

– a stochastic production frontier analysis of the effect of temperature and income diversification in Swedish dairy farms.

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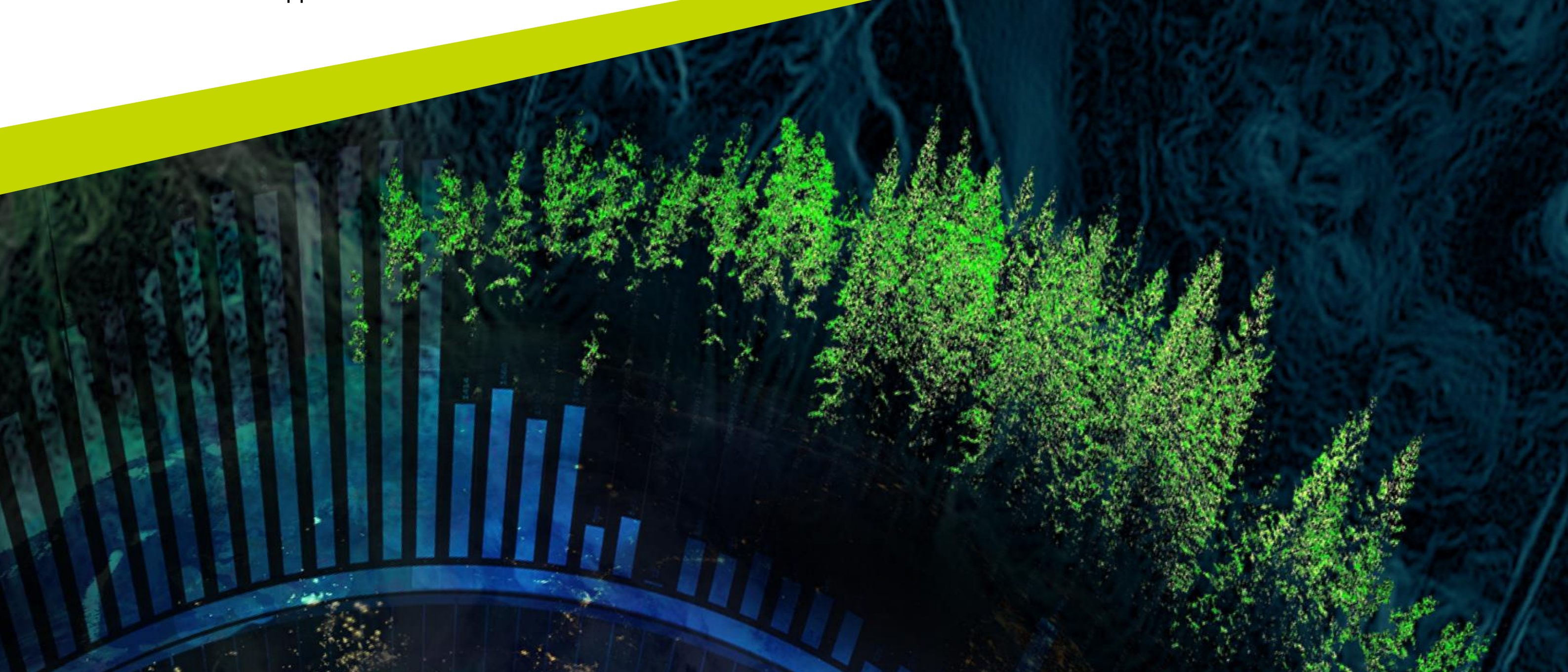

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Abstract

This thesis examines if Swedish dairy farms between 2005-2016, that diversify into unconventional income opportunities, can cushion a possible negative effect from increase in the mean temperature in Sweden. Dairy cows are sensitive to increases in temperature and could suffer from both heat and cold stress. This might cause effects on dairy production because the energy is diverted to maintain body temperature instead of producing milk.

According to IPCCs fifth assessment report (2014) there are evidence of an increasing global temperature. Between 1951-2012 the global mean surface temperature increased with 0.72°C. The warming has shown to have been largest in the Scandinavian areas. Diversification could work as an insurance for future changes in the environment. When a farm introduces new income sources into the business it could create a more stable stream of income. Dairy farms need to be able to survive in a changing environment and bringing diversification into the system may be a possible solution to secure framers income and availability to food.

This thesis contributes to the literature by incorporating income diversification and temperature to evaluate the effect on dairy farm productivity from an economic perspective. The method used to analyze is a Stochastic Frontier Analysis (SFA) for an unbalanced panel data of 684 dairy farms located all over Sweden. The model consists of 3947 observations and includes the variables temperature, Simpson's index of diversification and an interaction term between diversification index and temperature. The temperature data is divided into seasons of winter, spring, summer and autumn.

The results show that there are both negative and positive effects from increased mean temperature dependent on the season and an indication of a positive effect from income diversification on output. Further the interaction term displays a positive sign for spring and summer temperature which have a negative effect on output by themselves. This indicates that a negative impact from changes in temperature on dairy productivity could be reduced trough income diversification. Though, the results should be interpreted with caution because of weaknesses in the data.

Keywords: dairy farms, stochastic frontier, income diversification, diversification, Simpson's index, temperature

Sammanfattning

I denna avhandling undersöks om svenska mjölkgårdar mellan år 2005–2016, som diversifierar in i okonventionella inkomstmöjligheter, kan dämpa en eventuell negativ effekt från en ökning av medeltemperaturen i Sverige. Mjölkkor är känsliga för temperaturökningar och kan drabbas av stress från både värme och kyla. Detta kan orsaka effekter på mjölkproduktionen, eftersom energin används för att bibehålla kroppstemperaturen istället för att producera mjölk.

Enligt IPCC:s femte bedömningsrapport (2014) finns det tecken på en ökande global medeltemperatur. Mellan 1951–2012 ökade den globala medeltemperaturen med 0,72 °C. Uppvärmningen har visat sig vara störst i de skandinaviska områdena. Diversifiering kan fungera som en försäkring för framtida miljöförändringar. När nya inkomstkällor introduceras på en gård kan det skapa ett mer stabilt inkomstflöde. Mjölkgårdar måste kunna överleva i en föränderlig miljö och att införa diversifiering i verksamheten kan vara en möjlig lösning för att säkra inkomster och tillgång till mat i framtiden.

Denna avhandling bidrar till litteraturen genom att integrera inkomstdiversifiering och temperatur för att utvärdera effekten på mjölkgårdens produktivitet ur ett ekonomiskt perspektiv. Analysmetoden som används är en Stokastisk Frontier Analys (SFA) på en obalanserad paneldata innefattande 684 mjölkgårdar belägna över hela Sverige. Modellen består av 3947 observationer och inkluderar variablerna temperatur, Simpsons diversifieringsindex och en interaktionsterm mellan diversifieringsindex och temperatur. Temperaturdata delas in i årstiderna vinter, vår, sommar och höst.

Resultaten visar att det finns både negativa och positiva effekter av en ökad medeltemperatur beroende på säsong och en indikation på en positiv effekt av inkomstdiversifiering på mjölkproduktionen. Dessutom visar interaktionstermen en positiv påverkan för vår- och sommartemperatur som har en negativ effekt på produktionen för sig själva. Detta innebär att en negativ inverkan av temperaturförändringar på produktiviteten kan minskas genom inkomstdiversifiering av inkomst. Resultaten bör dock tolkas med varsamhet på grund av brister i data.

Nyckelord: mjölkgårdar, stokastisk frontier, inkomstdiversifiering, diversifiering, Simpsons index, temperatur

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Abbreviations

AWU	Average working unit
DEA	Data Envelope Analysis
FADN	Farm Accountancy Data Network
IPCC	Intergovernmental Panel on Climate Change
LFA	Less Favoured Area
SFA	Stochastic Frontier Analysis
SID	Simpsons Index
SMHI	Swedish Metrological and Hydrological Institute
SPF	Stochastic Production Frontier
THI	Temperature Humidity Index

1. Introduction

This chapter will introduce and give background to the main topic of this thesis, further the research questions and research gap will be presented. Following, the delimitations and hypothesis for this thesis is described and motivated.

1.1. Background

The agricultural sector has a vital role in the society, from supplying food and jobs to providing ecosystem services (Howden et al. 2007). The survival of the individual farm is key concept since it provides livelihood to a large share all over the world (Olesen and Bindi 2011). This is the case in foremost developing countries but also in Europe which is one of the largest suppliers of food and fiber.

There is a great deal of challenges and unpredictable elements that the framers face, which influences and disturb the farm system (Barnes et al. 2015). For example, the trend of a growing population and both to reduce and adapt to climate change (Howden et al. 2007; Mukherjee et al. 2012). This implies that the agricultural sector must increase the food production at the same time being challenged to improve its technology and business structure. Environmental changes could affect all levels of the agricultural production, both the biotic (living organisms) and the abiotic (rather physical factors like water, sunlight and air) (Lin 2011). Climate events such as heavy precipitation, heat waves and drought are going to increase considerably due to the temperature changes. All these events and affects will have a large effect on agricultural output (IPCC 2014; Qi et al. 2015).

According to IPCCs fifth assessment report (2014) there are evidence of an increasing global temperature. Between 1951-2012 the global mean surface temperature increased with 0.72°C, this reflects an increasing trend over time. In the Scandinavian areas the warming is shown to have been greatest especially in the winter season (IPCC 2014). The decadal average temperature in these areas is around 1.3°C above the 1850-1899 average. Some of the effects from increased mean temperature in the northern countries are longer growing seasons (Bindi and Olesen 2002). The late springs and early frosts, which effect the agricultural productivity negative, disappears. However, the higher winter temperature could allow for pests to overwinter where it was not possible before due to the low temperature. The temperature changes can be beneficial for livestock production in cooler regions contributing to less fatalities, lower energy costs and a decrease in feed requirements (Bindi and Olesen 2002). On the other hand, there are evidence that livestock systems will be exposed to a higher risk of mortality, decreasing productivity, changes in feed price and availability and diseases due to increase in temperature (Bindi and Olesen 2011; IPCC 2014 7; Key et al. 2014).

Dairy cows are sensitive to increases in temperature and could suffer from both heat and cold stress which could cause effects on dairy production (Key et al. 2014). The literature on the effect of heat stress on dairy production is extensive. The main findings are that extreme weather events and especially heat stress combined with humidity has a negative effect on dairy production (Mukherjee et al. 2012; Key et al. 2014; Qi et al. 2015; Wankar et al. 2012). The loss of milk production is estimated to be between 0.6 % - 1.35% in 2030 and 5%-11% from 2020-2039 (Key et al. 2014; Qi et al. 2015). Though, farms are going to respond differently depending on the prerequisites of for the country, region and farm (Bindi and Olesen 2011; Lin 2011). Variables that could differ are for example management and the climate baseline.

Dairy production is, by value, the largest agricultural sector in Sweden (Rural development program for Sweden 2007-2013; SBC 2016; Jordbruksverket 2019). Dairy farms are getting larger and larger but at the same time also fewer and fewer. Between 1990-2006 the size of the herds in Sweden decreased with only 9%, at the same time number of dairy farms decreased with as much as 69% (Hansson 2008). This pattern has continued, between 2010-2019 dairy producers have decreased with 42% and the number of dairy cows has decreased with only 12% (Jordbrukverket 2019). This means that small farms are either shutting down, choses to produce something else or many small dairy farms merge together to survive (Hansson 2008). Consequently, there is a trend of higher specialization in the Swedish dairy sector to be able to cope with market competition (Purdy et al. 1997; Hansson et al. 2010). Contrary to what these trends might suggest, there is an indication that more specialized farms are less viable than diversified (Barnes et al. 2015). Thus, there may exists a negative relationship between specialization and the economic performance of the farm.

Diversification has been promoted by the rural development program as a strategy to reach goals such as more work opportunities in rural areas, to increase rural economic growth and reducing farm household income risk (Barnes et al. 2015; European Parliament, 2016). The rural development program was initiated to build a stronger and more sustainable farm sector, because agricultural movement is a large part of the rural community (European Parliament, 2016). But also, a way to make rural areas more attractive for tourists and for people to consider moving to these areas (Rural development program for Sweden, 2007-2013). The rural development program is one large reason why farms choose to diversify in Europe.

Support payments specifically aiming to increase farm diversification and farm business development have been a part of the program for all three periods: 2000-2006, 2007-2013 and 2014-2020.

The program is built upon three axes (figure 1) (European commission 2008). Axis one deal with improving competitiveness of agriculture and forestry, the measures under axis two are improving the environment and the countryside and axis number three, which is relevant for this thesis, include measures dealing with quality of life in rural areas and diversification of the rural economy.

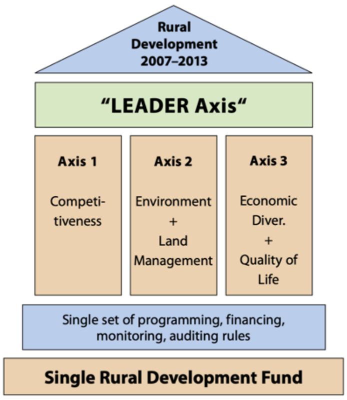


Figure 1: Building blocks for each thematic axis (European Commission 2008)

Axis three focuses on the development of new businesses and an expanded and diversified economy (Swedish Ministry of Agriculture 2008). This is supposed to foster a growth both in the rural economy and a general development of rural areas. The measures of this axis are expected to both contribute to income-generating employment and sustainable use of natural resources and stimulate new enterprises, local entrepreneurship and production methods that are environmentally integrated.

The incorporation of diversification into production system is widely researched and an established method used in analyzing a system's ability to survive in a changing environment (Turner et al. 2003; Burkes 2007; Lin 2011; Barnes et al. 2015; Birthal and Hazrana 2019). However, the focus is mainly on crop production and not on dairy farms. The effect of climate change and specifically heat stress on dairy production is also greatly studied, but not as much from an economic perspective (Mukherjee et al. 2012; Key et al. 2014; Qi et al. 2015).

The objective of this thesis is to scrutinize if Swedish dairy farms that diversify into unconventional income opportunities can cushion a possible negative effect from increases in the mean temperature in Sweden. To be able to analyze the outcome, the effect of changes in the mean temperature and income diversification on output in Swedish dairy farms need to be established. The main research questions to be answered is:

1. *How does mean temperature and income diversification effect output in Swedish dairy farms?*

2. *What effect does income diversification have on possible negative effects on output caused by changes in the mean temperature in Swedish dairy farms?*

This topic is an interesting perspective because of the future threats form the increasing temperature and its negative impact on food security (Mukherjee et al. 2012; Qi et al 2015). The dairy industry is of course dependent on the production of milk and heat stress (due to temperature changes) has been found to generate losses of about 1.7 billion – 2.2 billion dollars in the US (Wankar et al. 2021). Dairy farms need to be able to survive in a changing environment and bringing diversification into the system may be a possible solution to secure framers income and availability to food.

1.2. Delimitation

This thesis will be limited geographically to Sweden and Swedish dairy farms. The observations are from the Farm accountancy data network (FADN) between 2005-2016. The motivation for choosing only dairy farms is the fact that they are the largest livestock production in Sweden and that they could suffer from loss in dairy production from increased temperature (Mukherjee et al. 2012; Key et al 2014; IPCC 2014; Qi et al. 2015; Jordbruksverket 2019)

Income diversification will be reduced to the use of farm resources such as buildings and land, in a way that generates income. Specifically, any type of activity that creates revenues from activities that is not milk production. Additionally, income creation through the process of raw materials, is considered diversification. In other words, new products that are introduced to new markets, for example cheese production from milk produced on the farm.

Productivity will be measured in milk produced on the farm and temperature will be divided into seasons (winter, spring, summer and autumn) and expressed in means for each season.

1.3. Hypothesis

The hypothesis for the first research question is that dairy farms in Sweden are positively affected by income diversification, this follows the literature on farm diversification (Di Falco and Chavas 2008; Birthal and Hazrana 2019; Dedehouanou and McPeak 2020). Diversification could work as an insurance for future changes in the environment (Minot et al. 2006). When a farm introduces new income sources into the business it could create a more stable stream of income

(Barnes et al. 2015). Risks such as increased prices and shortage of feed, lower production of milk or a disease break out is what a farm could be confronted with (Key et al. 2014). To have multiple income sources, the dairy farm could be able to continue the business even when facing such risks and not decrease productivity.

Furthermore, dependent on the season the variable temperature will have different impacts on output. An increase in mean temperature in summer and spring will decrease output, this is because dairy cows could be exposed to heat stress which is coupled with losses in diary production (Qi et al. 2015). While autumn and winter will display the opposite. The reason for that is because the dairy cows will be exposed to a more comfortable temperature. Thus, the cows will not be affected by cold stress.

There is evidence that higher mean global temperature will both increase and decrease yields and similarly affect dairy output positive and negative in colder regions (Olesen and Bindi 2002; Mukherjee et al. 2012; IPCC 2014; Key et al. 2014; Qi et al. 2015). The negative effects of increased mean temperature could affect the incomes and costs and thus revenues of dairy farms. Therefore, it might threaten the survival of Swedish dairy farms.

For the second research question the hypotheses is that income diversification can cushion the negative effect on output due to an increased mean temperature in Sweden. There is evidence that more diversified farms are more viable and can survive in a changing environment (Barnes et al. 2015). Diversification is also something that have been promoted to improve the resilience to future change in northern countries (Ullsten et al. 2004). They encourage cultural, economic and ecological diversity to develop new options and opportunities, which helps to handle setbacks caused by both environmental and social change. Further, Gardner et al. (2019) find that by incorporating diversity into the system by either shifting production paths or by developing value-added processing, the system became more flexible.

2. Literature review

The literature relevant is reviewed in this chapter. First, literature to highlight the effect of temperature changes on dairy production is processed. Second, literature dealing with both income and crop diversification is presented. This is to give a perspective and motivation for the subject, method and result.

2.1. Dairy production and the effect of temperature

The literature on dairy production and the effect of climate change indicators especially temperature changes is something that has been studied less by economists but of increasing interest (Mukherjee et al. 2012). A lot of the literature on the subject introduce and process the problems surrounding increasing temperature in livestock production (Wankar et al. 2012). Key et al. (2014) mentions four ways that the livestock production will be affected by climate change:

1. Feed crops, both the access and price
2. Rangeland and pasture, both the position and productivity
3. Livestock parasite and pathogen spreading
4. The thermal environment for animals

They claim that animal health, efficiency (how livestock turn feed into raw materials such as milk and meat) and reproduction will be affected by the changes in the thermal environment caused by climate change (Key et al. 2014). Likewise, Qi et al. (2015) mention that livestock production is especially at risk of losses in productivity when exposed to hot or cold weather. This is because the energy is diverted to maintain body temperature instead of producing milk. Key et al. (2014) arguses that a lactating dairy cow is especially sensitive to heat stress because of the high metabolic heat production related to lactation (Key et al. 2014). There is also an indication that dairy cows have a higher metabolic turnover compared to beef cattle and that the genetic development in crossbreeds makes the dairy cows more sensitive to heat stress (Wankar et al. 2021).

The thermal-neutral zone for cows lies generally between 5 and 25°C, for Europe it has been found to lie a little bit lower between -1.11 and 15.6 °C (Qi et al. 2015). The thermal-neutral zone for livestock is the temperature where they can keep a normal body temperature without using any additional energy to heat or cool their body. It is of course affected by a lot of other factors such as age, breed, current milk production level, feed intake and more. Consequently, it is hard to say exactly where the thermal-neutral zone lies. But all temperatures that deviates from the thermal-neutral zone can cause stress on livestock and have an adverse effect on productivity. There are other environmental factors that affect both the hot and cold weather, but temperature is an indicator that is available and an understandable measurement, that is why it is often used as a variable (Mukherjee et al. 2012).

Mukherjee et al. (2012) bring together the economic methodology and the climate indexes more used by animal scientists. They introduce the temperature humidity index as an indicator for heat stress to the dairy cows and stress is evident when the index crosses a threshold. The function of the temperature humidity index is that it brings together temperature and humidity to a single number (Mukherjee et al. 2012).

To analyze the effect of the temperature humidity index on output (milk sold per year) in South-eastern United States, Mukherjee et al. (2012) use a panel data type of stochastic production frontier to analyze the impact of the temperature humidity index on output. The dairy production frontier is denoted as $Y = f(X, T, H)$. The vectors X, T and H capture different variables that have an effect on the dairy production. X stand for conventional inputs; T is a vector for technological progress and H is an index for heat stress. The conventional inputs used are average annual number of dairy cows, annual feed use, full time equivalent workers and capital flow (Mukherjee et al. 2012). To capture some technical characteristics of the farm dummy variables are added, such as cooling system, freestall barn and growth hormones. As described above the index for heat stress used is the temperature humidity index.

Mukherjee et al. (2012) panel data simulations show that there is a negative effect of temperature humidity index on output. All technical characteristics have a positive effect on output and by omitting cooling system and freestall barn the effect of the heat stress index increases. This indicates that these technical characteristics help to reduce the negative effect from heat stress on output.

Key et al. (2014) have used a similar approach; the temperature humidity index is used in a stochastic production frontier to see the relationship between technical efficiency in dairy farms and heat stress in United States. They find that the temperature humidity index has a negative effect on technical efficiency. Further, an indication that heat stress decreases the milk production is found. They also analyze the loss in value in the dairy sector and found that a decrease of 1.2 billion dollars for the entire dairy sector.

A study by Qi et al. (2015) uses a method similar to Key et al. (2014) and Mukherjee et al. (2012). They apply a stochastic production frontier to analyze climatic conditions on dairy productivity in Wisconsin using panel data. Different from the two previous papers is that the temperature humidity index is not used to capture the climatic effects. Rather they adopt seasonal average temperature. The argument is that by using the average temperature instead, they can get a clear interpretation of the effect of climate on the dependent variable. Another significant difference is that in the analysis they differentiate between seasons to see if for example warmer winters have a positive effect on output. Other variables that they used are conventional inputs like number of adult cows, labor, depreciation and costs for both animals such as veterinary costs and for crops such as fertilizers. The dependent variable is set to total milk equivalent in metric tons per year.

The simulations presented by Qi et al. (2015) display that dairy herd size and concentrate of feed was the two main conventional inputs influencing production Furthermore, an increase in temperature in summer and autumn has a negative effect on output, whereas an increase in winter and spring temperature has a positive effect.

André et al. (2011) highlight the importance of farm specific factor for heat stress of dairy cows and loss of daily milk production due to heat stress. Heat stress in the Netherlands can occur between April and October.

They analyze the outcome using a time series data from 2003-2006 from six dairy farms in Netherlands. They adapt a dynamic model that apply the mean daily milk yield as the dependent variable and use independent variables such as heat stress and weekday effect. The heat stress variable was created by adding number of days over the critical temperature. The critical temperature where evaluated trough an iterative procedure where they increased the temperature with 0.5°C starting at 15.5 °C until 20°C. This was simultaneously fitted with models of duration in days, starting at four days and increasing with one day at a time, until ten days.

The results show that average yearly total loss of milk yield per cow because of heat stress where 31.4 kg and that when high temperature occurred a negative relationship on daily milk yield was found (André et al. 2011). A loss of up to 2 kg per day in summer of 2003. They found differences between the farms, that was explained as distinctions in management and specific situations.

2.2. Diversification

To give diversification a simple definition is hard (Ilbery 1991). Farmers often diversify to strengthen their economic position using their existing resources such as labor, buildings and land (Ilbery 1991; Barbieri and Mahoney 2009; Ferguson and Hansson 2014). In a general sense, diversification is when a farm business has multiple income sources within the same business unit (Hansson et al. 2010).

Several papers have, to a large extent, a cohesive picture of diversification (see Barbieri and Mahoney 2009; Hansson et al. 2013; Barnes et al. 2015), which follows the outline of Ilbery (1991). Farm diversification is defined as the use of farm resources, including labor, in a way that generates income. Specifically, any type of activity that creates revenues from activities that is not connected to conventional agriculture. For instance, tourism, farm shops and livestock insemination.

Another dimension, added by Barnes et al. (2015) (see Hansson et al. 2010), is the agricultural diversification. This type of diversification is when a farm has two or more agricultural specializations e.g., grain and milk. Additionally, income creation through the process of raw materials, is considered diversification (Barnes et al. 2015). In other words, new products that are introduced to new markets.

There is a growing interest in trying to understand the effect of diversification in agricultural businesses. Barnes et al (2015) examine the economic viability of a farm and the impact of diversification on farm business performance. This is done by using data from Scotland and Sweden between 2000-2012. They use a multinominal logistic regression including variables such as agricultural and farm diversification, tenure, single payment scheme, less favored area (LFA) and stocking density to analyze the effect. The results indicate that the higher amount of diversification leads to higher viability. This is impact is shown in both long and short run.

Another paper by Barbieri and Mahoney (2009) scrutinize what goals a farmer want to reach when they decide to diversify. The data used for the analysis contained 216 diversified ranches in Texas. They find that diversification is utilized to adjust to existing challenges in the agricultural environment. Furthermore, incorporation of new enterprises is a strategy that enables framers to respond to new market opportunities and adapt their farms to the changing agricultural environment. They also find that farmers diversify to generate extra income, to be able to continue framing, enhance the family's quality of life and use their resources to economic maximization.

There are findings that connect income diversification to a more flexible and resistant production. Gardner et al. (2019) connect resilience to economic diversity through several real examples similar to Barbieri and Mahoney (2009). The farms presented was exposed to variable weather, extreme weather events and price volatility (for both inputs and outputs), which drove them to create a more resilient production. An interesting discovery is that by integrating diversity into the production range and/or system through increasing the rage of crops, shifting production paths or by developing an element of value-added processing, they found that these measures increased the system resilience when the production environment was unreliable.

Olesen and Bindi (2002) investigates the impacts of climate change and how it effects the productivity, land use and policy in the European agriculture. They discuss the long-term adaptions to climate change and conclude that more diverse farms with both livestock and crops (mixed farms), have more options for change and thus are more resilient to environmental change.

There are different indexes that can be applied when measuring diversification, mostly the diversification indexes are used for crop diversification. However, there are several cases where it is used for income diversification. Minot et al. (2006) apply both the Simpsons index and Shannon-Weaver index in a report that process and analyzes the income diversification in Vietnam. The indexes give an indication about patterns and trends when it comes to diversification differences, between rich and poor areas. This is to be able to give government support how to develop policies. Furthermore, a recent paper by Dedehouanou & McPeak (2020) analyzes rural livelihood diversification in Nigeria. They use the Simpson index to define the relationship between income diversification and wealth. They find that there are a positive but diminishing marginal effect between wealth and income diversification. Also, that income diversification helps to increase the food availability, food accessibility and resilience capacity generally.

Even though this thesis process income diversification the literature on crop diversification can give an insight to this thesis on method, results and conclusions. This is because of the solidity, availability and range of papers on the subject. The following section will highlight interesting literature on diversification index, model specification and results dealing with crop diversification.

Birthal & Hazrana (2019) investigates crop diversification in India and the resilience to climatic shocks using Simpson's index for diversification. They use panel data approach to estimate how crop diversification can tone down the negative effects of climatic shocks. The independent variable used is agricultural productivity and indicators for climatic shocks are heat-stress and rainfall-deficit. Other variables added to the model are human labor, fertilizers, tractors, irrigation and Simpson's index of diversity. Birthal & Hazrana (2019) find that climatic shocks have a negative effect on agricultural productivity and that diversification is one central factor in a greater resilience to such shocks.

The Shannon-Weaver index is used by Di Falco & Chavas (2008) when they completed a paper on diversification connected to climate change and agriculture. This paper concentrates on analyzed agroecosystems productivity and how it is affected by rainfall shocks in Italy. The focus is how rainfall patterns affect agroecosystem productivity and how crop biodiversity can decrease the damaging consequences of climate change. The framework is based on a production function which captures output of durum wheat and traditional inputs like labor, fertilizers, capital and land. Rainfall and crop diversity is also included in the production function.

Di Falco & Chavas (2008) continue to build a dynamic model (trans log) with k-th lagged output and input factors. Furthermore, to make a more flexible model an interaction term is added between rainfall and diversification index one of them are lagged with *(t-1).* These terms act as an indicator for resilience. The results show that crop biodiversity effects productivity positively and has a value of 10.4 and for the lagged 4.24. This also indicates that crop biodiversity is important both in the short and intermediate run to increase productivity. Further, when it comes to the interaction term between rainfall and crop biodiversity, both terms (current and lagged) are negative and significant. Di Falco & Chavas (2008) explains the indication of such findings, and that this shows that when an agroecosystem is faced with insufficient rainfall, crop biodiversity can keep the system productive.

3. Methodology and empirical model specification

A brief description of the background and set up of the methodology used for the analysis is presented in this chapter. Initially, a short introduction to production economics is outlined. Afterwards, the Stochastic Frontier Analysis, which is the main method applied, is introduced and described briefly. Further, the equations used to derive elasticities of interest is presented and the index utilized for diversification is familiarized. Lastly, the empirical model specification is presented.

3.1. Method and estimators

3.1.1. Production economics

The general method that will be used in this thesis has its theoretical background in production economic theory. This method is commonly applied in agricultural economic analysis for both investigating efficiency and productivity (Battese 1992). To add exogenous variables such as environmental characteristics to the production function is not as common, though the method is getting more attention (Barrios et al. 2008; Di Falco and Chavas 2008; Mukherjee et al. 2012). The outline of the methodology used in this thesis is mainly based on the book *"An Introduction to Efficiency and Productivity Analysis"* by Coelli et al. (2005), in addition, some relevant papers that have analyzed and used the same method are included.

To be able to examine what effect the production of milk, a production function needs to be estimated. There are different options when it comes to the selection of production function. The functions that will be presented here are the Cobb-Douglas and trans log production functions.

A production function contains of conventional inputs and additional variables that could affect production (Battese 1992). Basically, a function that shows how a farm can produce maximum output from a set of inputs, with the technology that is available to the farm. A simple form of a production function (Di Falco and Chavas 2008) is presented below:

$$y_i = f_i(x_i)$$

(1)

Where y_i stand for output at the i-th farm and x_i is a vector for explanatory variables such as conventional inputs used in production and additional variables at i-th farm. A commonly used production function is the Cobb-Douglas production function (Battese 1992; Debertin 2012). The basic Cobb-Douglas function is expressed in a logarithmic form as:

$$lny = A_0 + \sum_{n=1}^{N} \beta_n \, lnx_n$$

(2)

The problem with the Cobb-Douglas function is less flexible because of its unitary elasticity of substitution between inputs (Di Falco and Chavas 2008). Furthermore, when accounting for technological advances, which is of importance for economic relationships, the Cobb-Douglas function assumes that the technological changes is constant. By adding a time trend (t) to the Cobb-Douglas function it evolves into:

$$lny = A_0 + \theta t + \sum_{n=1}^{N} \beta_n \, lnx_n$$

(3)

The trans log function allows for more flexibility than the Cobb-Douglas function because it is second-order flexible. The trans log function is expressed like this in a logarithmic form:

$$lny = \beta_0 + \sum_{n=1}^{N} \beta_n \, lnx_n + \frac{1}{2} \sum_{n=1}^{N} \sum_{m=1}^{N} \beta_{nm} \, lnx_n lnx_m$$

(4)

The technological change can be calculated in the same way as the Cobb-Douglas function by adding a time trend (t) and taking first derivative to evaluate the technological change.

$$lny = \beta_0 + \theta_1 t + \theta_2 t^2 + \sum_{n=1}^{N} \beta_n \, lnx_n + \frac{1}{2} \sum_{n=1}^{N} \sum_{m=1}^{N} \beta_{nm} \, lnx_n lnx_m$$

(5)

First derivative:

$$\frac{\partial lny}{\partial t} = \theta_1 + 2\theta_2 t$$

(6)

As presented the first derivative show that the time trend (t) is still present and can thus technological change can vary with time. The second derivative determines the rate of technological change which in trans log is constant. This illustrates that the trans log is more flexible and dynamic than the Cobb-Douglas function.

3.1.2. Stochastic frontier analysis

There are two ways to go when estimating the production frontier with econometrics: the data envelope analysis (DEA) and the stochastic frontier analysis (SFA) (Coelli et al. 2005). The DEA is a simpler method and can be implemented even though the functional form of the relationship between inputs and outputs is not known. The SFA on the other hand assumes a given functional form for inputs and outputs and the unknown parameters in the production frontier need to be estimated. The SFA is considered in this thesis and the basics of the SFA methodology will be described. Though the purpose is not to measure the efficiency or put a light on the inefficiency (Battese 1992), which the SFA can be used for. Rather the SFA provides a method to define a production frontier fit to the data used and add variables of interest that can show an effect on production.

There are two choices to model the production frontier: either a deterministic or a stochastic model (Battese 1992). A weakness with the deterministic production frontier is that it does not take account for measurement errors and other statistical noise (Coelli et al. 2005).

All the deviations from the frontier are presumed to be a result of technical efficiency.

The stochastic production frontier on the other hand takes care of that statistical noise by introducing another random variable. The cross-sectional version of the stochastic production frontier is used in this thesis and is presented below (Coelli et al. 2005):

$$lny_i = lnx_i\beta + v_i - u_i$$

(7)

Where y_i stand for the output produced at the i-th farm and x_i is a vector containing inputs and β is the vector of unknown parameters. The random variable u_i captures the technical inefficiencies and v_i is the added random variable to account for statistical noise.

The model will be estimated using the method of maximum likelihood (ML), which is preferable because of its large sample properties (Coelli et al. 2005). The idea behind the ML estimation is that a sample of observations are more likely to originate from some distributions than others. The definition of a ML estimate is a value of a parameter that maximizes the likelihood of randomly drawing a specific sample of observations. The ML estimate are obtained with these assumptions:

$$v_i \sim iidN(0, \sigma_v^2) \tag{8}$$

$$u_i \sim iidG(\lambda, 0) \tag{9}$$

This means that v_i have zero means and variances σ_v^2 and are independently and identically distributed normal random variables (Coelli et al. 2005). There are several choices to distribute u_i , the half-normal, exponential and truncated normal. Which one to select depends on convenience both theoretical and computational. This has mostly to do with technical efficiency and inefficiency measures which is not relevant for this thesis. In thesis, for simplicity, the exponential distribution is used. The assumptions for the exponential distribution are that u_i is independently and identically distributed exponential random variables and the probability density function of each u_i has a λ mean and zero variance (9).

3.1.3. Elasticities

To analyze both the inputs (if Cobb-Douglas is preferred) and the explanatory variables the output elasticities (E_n) will be derived trough the equation (10) (Coelli et al. 2005):

$$E_n = \frac{\partial f(x)}{\partial x_n} \frac{x_n}{f(x)} \tag{10}$$

This is the percentage change in output divided by the percentage change in input. The Cobb-Douglas is restrictive when it comes to its elasticities, the elasticities does not vary with the input levels, this means that both the elasticity of output and scale is constant.

If the trans log is preferred the both the output, input and explanatory variables will be rescaled to have unit means (Coelli et al. 2005).

$$y_i = {Output}\Big/{\overline{Output}} \tag{11}$$

$$x_i = {}^{Input}\!\Big/_{\overline{Input}}$$

(12)

The equations (11) and (12) is used for the rescaling to unit means where the overbars stand for variable means. By doing this the first-order coefficients of the inputs can be read as elasticities of output with respect to inputs (Coelli et al. 2005). The elasticity of scale (ε) can be derived as well, adding all the first-order coefficients from the conventional inputs:

$$\varepsilon = \sum_{n=1}^{N} E_n$$

(13)

Where, E_n is the output elasticity derived in equation (13). The elasticity of scale is evaluated as decreasing return to scale (DRS), increasing return to scale (IRS) or constant return to scale (CRS) (Coelli et al. 2005). Figure 2 show the different graphs depending on the elasticity of scale; A have elasticity of scale equal to one, the elasticity of scale is larger than one for B and lower than one for C. This measure tells us what the outcome on output will be when scaling up or down the inputs by an infinitely small amount.

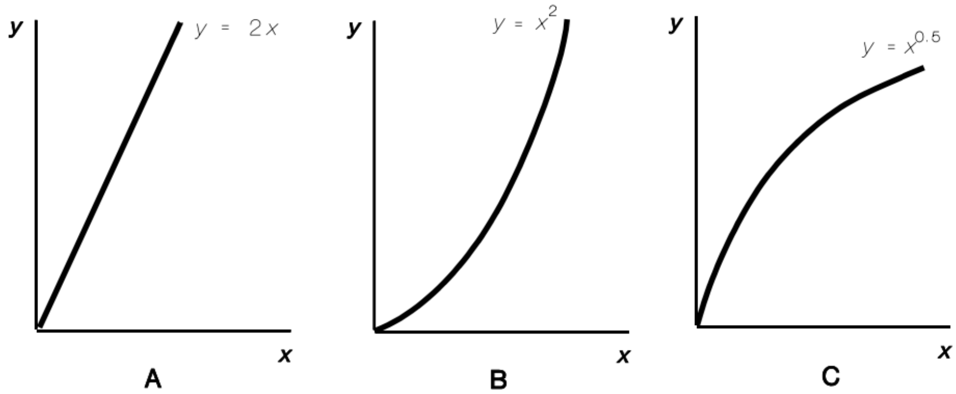


Figure 2: A: CRS, B: IRS and C: DRS (Debertin 2012)

3.1.4. Simpsons index (SID)

To be able to include income diversity as a variable, an index needs to be derived. This index has to capture each farm's level of income diversity. In this thesis the selected index is the Simpson's index (SID). The SID is chosen because it is an index often applied when measuring diversification both for crops and income (Minot et al 2006; Di Falco and Chavas 2008; Birthal and Hazran 2019; Dedehouanou and McPeak 2020). Furthermore, the SID is more sensitive to larger categories added and because of the nature data used to create the index the SID fits better than the Shannon - Weaver index. This will be further elaborated in the discussion. The SID is derived by using the equation (14):

$$SID = 1 - \sum_{i=1}^{n} P_i^2$$

(14)

Where, n is the number of income sources, P_i stand for the proportion of income originating from source i and. The SID takes the value between 0 and 1, if the index is 0 it implies that the farm is specialized and only have one income source (Minot et al. 2006). When the number of income sources increases, the value of P_i decreases which means that SID will approach 1.

3.2. Empirical model specification

The final cross-sectional model to identify the effect of temperature and diversification on output will be specified here. The statistic tool STATA will be used to estimate and simulate the stochastic production frontier (SPF). The model is evaluated trough a likelihood ratio test (LR-test). Between both the Cobb-Douglas model and trans log and if the added explanatory and control variables are jointly different from zero and thus add something to the model. The preferred basic SPF trans log with five conventional inputs is given by equation (15):

$$lny_i = \beta_0 + \sum_{n=1}^{5} \beta_n \, lnx_{ni} + \frac{1}{2}\sum_{n=1}^{5}\sum_{m=1}^{5} \beta_{nm} \, lnx_{ni} lnx_{mi} + \theta_1 \mathrm{lnt} + \theta_2 \mathrm{lnt}^2 + v_i - u_i$$

$i = entity, in\ this\ case\ farms$

(15)

Where lny_i is the logarithmic output measured in kg milk for the i-th farm, lnx_{ni} is the logarithmic n-th input and lnt denotes the time trend. The second expression denote squared terms of the inputs and cross terms between them.

Further, the explanatory (δ_i) and control variables (γ_i) are added to the trans log model. The decided cross-sectional SPF model is specified below:

$$\begin{aligned} lny_i = \beta_0 + \sum_{n=1}^{5} \beta_n \, lnx_{ni} + \frac{1}{2}\sum_{n=1}^{5}\sum_{m=1}^{5} \beta_{nm} \, lnx_{ni} lnx_{mi} + \delta_1 (MTempAutumn)_i + \delta_2 (MTempSpring)_i \\ + \delta_3 (MTempSummer)_i + \delta_4 (MTempWinter)_i + \delta_5 (MTempAutumnSID)_i \\ + \delta_6 (MTempSpringSID)_i + \delta_7 (MTempSummerSID)_i + \delta_8 (MTempWinterSID)_i + \delta_9 (SID)_i \\ + \gamma_1 (DummyLFA)_i + \gamma_2 (DummyOrganic)_i + \theta_1 \mathrm{lnt} + \theta_2 lnt^2 + v_i - u_i \end{aligned}$$

$i = entity, in\ this\ case\ farms$

(16)

All explanatory and control variables are added as they are for the i-th farm, no manipulation is done besides being generalized with their own mean trough equation (12). The two control variables (γ_i) are added as binary and only takes values 0 or 1. The δ_1-δ_4 are seasonal temperature variables and δ_5-δ_8 are interaction terms between SID and temperature, lastly the δ_9 is the SID by itself. The parameters to be estimated in STATA are β, δ, γ and θ.

4. Data and descriptive statistics

In this chapter, data applied and variables included in the simulations is introduced and described. Firstly, the data for the regression is presented in two sections: temperature and FADN data. A description of the data and how it is constructed are displayed for both data segments. Secondly, variables that is decided for the final model is presented and their expected impact on the dependent variable.

4.1. Temperature data

The temperature data used in the regressions are from Swedish Metrological and Hydrological Institute (SMHI 2021) between 2005-2016. The data are in means and divided into seasons of winter (December, January, February), spring (March, April, May), summer (June, July, August) and autumn (September, October, November). All data is homogenized, changes in instruments used to measure or any inaccuracy in the data have been corrected for all values (SMHI 2021). The collected data are from 35 weather stations spread all over Sweden (figure 3). The temperature data is not matched with production area. There was no available data for specific weather stations.

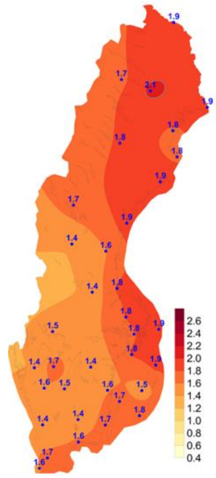


Figure 3: 35 weather stations displaying the deviation from mean temperature in Sweden between 1961-1990 (SMHI 2021)

Figures 4-7 demonstrates the mean temperature from 1860-2020 (black line) and the red and blue staples display the deviation from the mean from previous normal period 1961-1990.

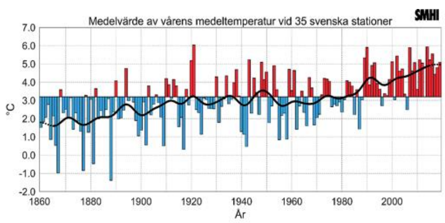


Figure 5: Mean spring temperature between 1860-2020 in Sweden (SMHI 2021)

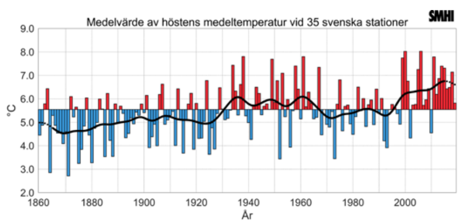
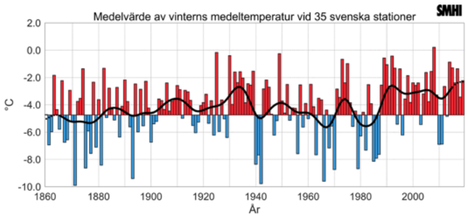


Figure 4: Mean summer temperature between 1860-2020 in Sweden (SMHI 2021)



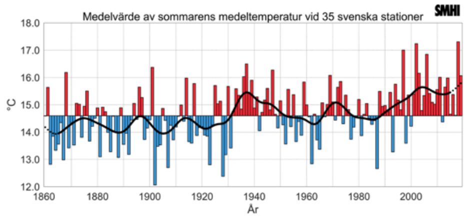


Figure 7: Mean winter temperature between 1860-2020 in Sweden (SMHI 2021)

Figure 6: Mean summer temperature between 1860-2020 in Sweden (SMHI 2021)

Figure 3 and figures 4-7 illustrates the trend of increasing mean temperature in Sweden (SMHI 2021). In figure 3 it is observed that the largest temperature changes are in the east and north of Sweden. The rise in mean spring temperature is observed to be the highest of all seasons (SMHI 2021a). The increase in the mean temperature in Sweden follow changes expected in the rest of the world, where the mean global surface temperature is projected to increase in the short term (2016-2035) between 0.9°C-1.3°C and in the long term (2081-2100) between 0.9°C-2.3°C to 3.2°C-5.4°C (IPCC 2014).

The mean temperatures for winter, spring, summer and autumn collected from SMHI (2021) are displayed in table 1.

Table 1: Mean temperature between 2005-2016 for winter, spring, summer and autumn in C°

Year	*Winter*	*Spring*	*Summer*	*Autumn*
2005	-1.63	3.35	15.34	7.25
2006	-3.76	2.49	16.85	8.03
2007	-1.55	5.89	15.42	5.73
2008	0.22	4.62	15.09	5.96
2009	-3.27	5.07	15.03	6.43
2010	-6.9	3.61	15.56	4.55
2011	-6.88	5.23	16.01	7.79
2012	-2.65	5.04	14.37	6.2
2013	-4.85	3.21	15.65	6.87
2014	-0.87	5.94	15.98	7.4
2015	-1.29	5.22	14.66	7.31
2016	-2.39	5.56	15.38	6.43

4.2. FADN-Data and descriptive statics

The data used for all variables besides temperature, originates from the Farm Accountancy Data Network (FADN), which is provided by the Swedish Board of

Agriculture. The FADN-data is collected to be able to see the development in the agricultural business's costs, incomes and profitability and it is also utilized by EU as a foundation in agricultural policy decisions and to evaluate CAP (Jordbruksverket 2019b).

The panel data set is an unbalanced and consist of 3947 observations between 2005-2016 and 684 dairy farms are included. Every year 1025 farms are selected to be included in the FADN-data set. This is because every year farms always drops out for different reasons. This means that availability of data for the farms vary a lot.

The variables from FADN are both used as they are and merged together to get the variable of interest for the regression, this will be specified in detail later. The descriptive statistics for all variables are shown in table 2:

Table 2: Descriptive statistics

VARIABLES	Number of obs.	Mean	SD	Min	Max
Output milk *(y)*	3,947	5635	8867	1.720	150889
Cows *(x1)*	3,947	65.46	92.50	1	1670
Land *(x2)*	3,947	116.9	117.2	0	1673
Labor *(x3)*	3,947	2.961	1.969	0.183	23.97
Intermediate cost *(x4)*	3,947	237,470	573,306	2,216	1.504e+07
Fixed cost *(x5)*	3,947	795,546	1.223e+06	282	1.525e+07
SID	3,947	0.0356	0.0736	0	0.663
MTempWinter	3,947	-3.008	2.168	-6.900	0.220
MTempSpring	3,947	4.596	1.105	2.490	5.940
MTempSummer	3,947	15.44	0.642	14.37	16.85
MTempAutumn	3,947	6.660	0.943	4.550	8.030

Output milk has a mean of 5635 kg this indicates that there is a large share of Swedish dairy farms that are producing at a smaller scale. This can be observed in figure 8, most of the farms have fewer than 500 cows and produce less than 50000 kg milk. Concluding that there are large outliers in the data, this could affect the outcome.

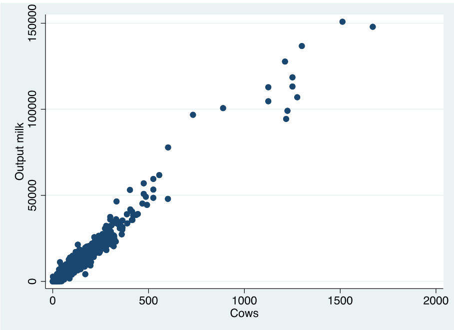


Figure 8: Scatterplot of the variables output milk and cows.

The same applies for the variable land (figure 9), a large land is coupled with a large heard size. Here the outliers are observed as well. This is a pattern for all conventional inputs where the large farms leap out. Compared to the literature addressing dairy farm productivity, the Swedish dairy farms produce less and have smaller herds and the mean is lower for all inputs (Mukherjee et al. 2012; Key et al. 2014; Qi et al. 2015). Though, it is not reasonable to compare production with USA dairy farms, where the dairy production has other prerequisites and is not equivalent with the Swedish.

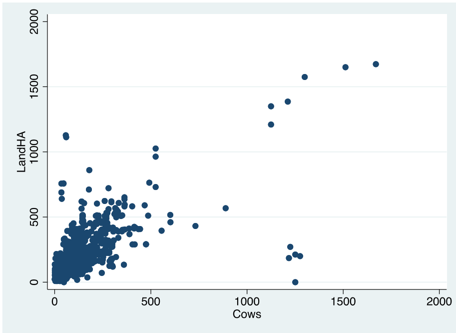


Figure 9: Scatterplot of the variables land and cows.

The SID have a mean 0.0356 which implies that most of the farms are specialized and do not diversify that much. However, the largest value is 0.663 which indicates that this specific farm has several income sources from unconventional activities. The temperature variables have similarities with the variables applied by Qi et al. (2015). However, mean summer temperature is lower and mean spring and autumn temperature is higher in Sweden. Autumn has about the same mean as Qi et al. (2015). The problem with comparing the data is that the included months in each season are different.

4.3. Variables

The dependent, independent, explanatory and control variables used in the production function are selected based on literature reviewed earlier and some additional literature of relevance. That applies for the expected impacts on the dependent variable also. A short description of each variable and its effect on output will be described below.

4.3.1. Dependent variable

Milk production (y)

The dependent variable used is milk produced in 100 kg. Milk production where selected because milk is the main output in dairy farms, which makes it the main income source for these farms. Using production (yield) as a dependent variable is common both when it comes to analysis of diversity and resilience (see Di Falco and Chavas 2008) and the effect of temperature on milk production (see Mukherjee et al. 2012; Qi et al. 2015).

4.3.2. Conventional inputs

Cows (x1)

The cows are expected to have the largest positive effect on milk production of the conventional inputs, because is the main input in dairy framing (Qi et al. 2015). The variable consists of the annual opening balance for each year. Specifically, the number of dairy cows per farm that produces milk counted in the beginning of each year.

Land (x2)

The variable land is created by adding three variables; owned and cultivated agricultural land, leased and cultivated agricultural land and share cropped area. This includes land used for grazing as well. Land is expected to have a positive effect on milk production (Lansink et al. 2002), though land is not as important for milk production as for meat production based on grazing and specialized crop production. This means that the impact on output would be smaller compared to other inputs.

Labor (x3)

The input labor is converted to average working unit (AWU). For every farm the equation $\frac{total\ hours\ worked}{1800}$ is derived. The labor variables are commonly used as an input in the literature reviewed (Mukherjee et al. 2012; Qi et al. 2015; Birthal and Hazrana 2019). The total hours worked is derived by adding several variables that account for worked hours; husband/wife, relatives that are regularly employed, irregular unpaid worker and temporarily employed. Further, there are five variables that is not specified for whom they account for, they report worked hours in the agricultural sector, these are added as well. Labor is expected to have a positive effect on milk production in the beginning, but it could demonstrate an inverted u-shape as well. This indicates that at a certain point more labor will not increase productivity.

Intermediate costs (x4)
Intermediate costs are costs that can be changed in the short run, though what is considered such a cost may vary between farms. The variables merged together are purchase of roughage for grazing livestock, purchase of seeds and plants, electricity, fuel and heating, water, veterinary costs for animal husbandries and other costs for domestic animals. All costs vary between farms dependent on the scope of the farm, such as herd and land size. Costs are included differently in all literature (Mukherjee et al. 2012; Qi et al. 2015), and for this analysis a more general variable for intermediate cost is included in the SPF.

Fixed costs (x5)
The fixed costs are derived by adding several variables that are assumed to be unchangeable in the short run. The included costs are salary and social fees, rents and lease, interest fees, depreciation, tax and maintenance for land development and buildings. Similarly, to the variable intermediate cost, the fixed cost varies with farm size. Long term investments into the farm can affect the productivity and thus the output. The fixed cost will therefore have an expected positive and relatively large impact on output.

4.3.3. Other explanatory variables

Simpson's index (SID)
The SID is derived using equation (16) described earlier. The index includes income sources both connected to dairy farming and other activities that generate income. The variables incorporated are tourism (*tourism)*, other products and incomes (*othprinc)*, production of renewable energy (*renewenergy*), sales of dairy (*dairysale*) and processing of dairy(*processdairy*). The SID is derived accordingly:

$$SID = 1 - \sum_{i=1}^{5}\left(\left(\frac{tourism}{total\ income}\right)^2 + \left(\frac{otprinc}{total\ income}\right)^2 \left(\frac{renewenergy}{total\ income}\right)^2 + \left(\frac{dairysale}{total\ income}\right)^2 + \left(\frac{processdairy}{total\ income}\right)^2\right) \tag{17}$$

The SID is expected to have a positive effect on output (Di Falco and Chavas 2008; Barnes et al. 2015; Birthal and Hazaran 2019). Because income diversification is a way to cope with a changing environment and other risks such as changing input and output prices. Income diversification could make the farm more stable and thus reduce risk (Berkes 2007).

Temperature
The different seasons are predicted to have different effect on output. An increase of the temperature in the seasons summer and spring is assumed to have negative

impact on output. This is because of the heat stress that the cows are exposed to (Qi et al. 2015). The cows have to put energy on keeping their body cold, which causes losses in dairy production. In autumn and winter, the opposite is expected, an increase in output. When the temperature increases in these seasons the cows do not have to put as much energy on keeping their heat, which makes them less stressed and produce more milk than usual in these seasons (Qi et al. 2015).

Organic production

Organic production is expected to have a negative impact on output. Organic farms are believed to be less productive than conventional farms (Lansink et al. 2002). The variable is added to the model as a binary variable, if organic farming is present the variable equals to one and zero otherwise. The organic dummy is added to the model to control for land specific properties and is not of special interest for this thesis.

Less favored areas (LFA)

The LFA variable is included to the model as a binary variable. If the dummy equals one it means that the farm is not in an area with constraints or LFA area. This means that the sign of the coefficient is predicted to be positive (Barnes et al. 2015). The LFA dummy is added to the model to control for particular properties connected to land and not of specific interest for the analysis

LFA areas are regions above the 62 latitudes, that means the north of Sweden (Jordbruksverket 2005). These areas have tougher prerequisites and production possibilities and thus permitted support to preserve the rural areas, to continue to produce in a sustainable manner and for the agricultural land to remain cultivated.

5. Results and discussion

The results from hypothesis tests and the decided final regression model are presented and discussed in this section. Further, the results from the elasticity calculations are displayed subsequently. Weaknesses and other analytical options will be brought to attention throughout this chapter.

5.1. Hypothesis test

As described in the methodology LR-tests will be conducted between models. The LR-test evaluates if the added variables are worth including in the model (Gujarati and Porter 2009). To see if a model with more variables is adding differences that is statistically significant. The following LR-test test static is used:

$$\lambda = 2(Unrestricted\ model - Restricted\ model) \tag{18}$$

If the sample size is large, then the test statistic λ follows the chi-square distribution with degrees of freedom equal to the restrictions imposed by the null hypothesis (Gujarati and Porter 2009). The LR-test will be applied both in the choice between production functions and to test if variables of special interest for this thesis are adding differences. First, the choice between a Cobb-Douglas or a trans log production function will be assessed, results from the test is presented in table 3.

Table 3: Hypothesis tests (LR-tests)

Models in the LR-test	Degrees of freedom	λ	P-value
Cobb-Douglas (2) or trans log (15)	15	1039	0.000
Trans log (15) or MODEL I (16)	11	216	0.000

The P-value is below 0.01 which states that the test is significant at one percent with 15 degrees of freedom, thus the unrestricted model (trans log) is preferred.
The trans log model is also tested against MODEL I. The results in table 3 display that the included variables temperature, SID, interaction terms and the binary

variables for organic production and LFA should not be excluded. Thus, rejection of the hypothesis that the variables added are jointly zero. The LR-test show a P-value below 0.01with 11 degrees of freedom, it makes the test significant at a 1% level.

5.2. Estimates for production function

The model estimated in SATA is a cross-sectional SPF model. The FADN data was very unbalance which made the command aimed for cross sectional work better with the data. The result from the estimated SPF model (16) is displayed in table 4.

The estimated coefficients of the conventional inputs in MODEL I show the expected positive signs and vary between zero and one which is consistent with economic theory. Furthermore, all the inputs are significant besides land in the first order. The main input that seems to influence the production is *Cows*. If *Cows* are increasing with 1% then production of milk will increase with 0.842 %, this is in line with the literature (see Mukherjee et al. 2012; Key et al. 2014; Qi et al. 2015). The second largest coefficient are *Fixedcost* with 0.0917% followed by *Intermediatecost* 0.0788%. *Labor* has a minor effect of 0.0226%. *Land* has the least influence on output, only 0.00656%, and as mentioned is not significant. *Labor* and *Land* also display an inverted u-shape, though the second order coefficient is not significant for *Labor*.

The input coefficients can also be interpreted as the partial output elasticity when they have been normalized by their geometric mean (Mukherjee et al. 2012; Qi et al. 2015). This means that the first order parameters of the conventional inputs can be inferred as impacts on output. The elasticity of scale is calculated to 1.0417≈ 1, that reveals that the production function exhibit CRS.

Many models where simulated, including and excluding variables but also excluding outliers. This did not give a significant effect in the model; the outliers were thus kept in the model. An alternative model (MODEL II) can be viewed in appendix 2, where all farms that have more than 700 cows and land larger than 500 hectares were excluded. The coefficients got smaller but kept the same sign.

The explanatory and control variables are not logarithmic and have to be transformed. This is because of the log-liner relationship between the independent and the dependent variables (Stock and Watson 2015). The following equation $100 * \beta_n$ (where β_n stands for the estimated coefficients) have to be derived for the temperature coefficients *SID*, *DummyLFA* and *DummyOrganic*. The interpretation will then be that one-unit change in the independent variable is a $100 * \beta_n$ change in the dependent variable.

The results from the SFA indicate that an increase in temperature in *MTempAutumn* will increase the output with 6.88 %. On the other hand, the *MTempWinter*, *MTempSummer* and *MTempSpring* have negative impacts on output. If the mean temperature increases with 1 % the output will decrease with 1.18%, 13.9 % and 5.33 % respectively. Note, however the summer temperature is not significant. Consequently, the results indicates that there are both negative and positive relationships between the temperature variables and milk production which was expected. The negative coefficient of *MTempSummer* confirms the evidence for heat stress effecting the cow's milk production with a coefficient of -2.26% shown by Qi et al. (2015). André et al. (2011) found the same direction of the relationship between the months April-October in the Netherlands an annual loss is detected of 31.4 ± 12.2 kg for one cow in one year. This indicates that even though the coefficient in this thesis was not significant, there is evidence supporting a negative relationship.

Both *MTempWinter* and *MTempSpring* display a negative relation with output. *MTempSpring* follow the same theory as for the *MTempSummer* and was expected. The *MTempWinter*, however, was not anticipated. This might be explained by the fact that the that an increase in the mean temperature with 1% in the winter might still result in a temperature outside the comfort zone and will thus not affect the cold stress of the cow. The opposite relationship that is displayed by Qi et al. (2015) might be explained by geographical differences; their data is for Wisconsin which have warmer winters and an increase in the temperature could then show different results.

MTempAutumn is related with milk production positively. Qi et al. (2015) finds that higher temperature in autumn have a negative effect on milk output. As described earlier for the variable *MTempWinter* their data are from Wisconsin which lies at a lower latitude and has warmer autumns. The results follow the outcome of Qi et al. (2015) to the extent that when the colder Swedish autumns gets warmer and warmer, an increase in the mean temperature will lie closer to the comfort zone for the cow and thus less cold stress. Also, there are specific projections for the northern countries, where the cultivating season often is shorter, compared to countries in central Europe. That the length of the cultivating season is going to be longer due to changes in the climate supports the result from the SPF (Bindi and Olesen 2002).

There is an uncertainty with temperature and other environmental variables. This is because they are unpredictable and could vary a lot between days and years and that other variables could have an effect on temperature such as wind, rain and humidity, which are not accounted for. Also, different facilities that surrounds the cows could have effect on their heat or cold stress such as cooling systems or freestall barns (Mukherjee et al. 2012), which is not included in this thesis. Another limitation is that the temperature variables could not be coupled to specific areas. The weather in Sweden varies a lot from the south to the north. This means that farms situated in the north could face one mean temperature while in the south they face another. This is not accounted for in the analysis and could cause bias to the results.

There are options on how to include temperature variables, a choice that might affect the end result. For example, there are other measurements that account for both temperature and the humidity and is often applied by animal scientists (Mukherjee et al. 2012). Both Mukherjee et al. (2012) and Key et al. (2014) uses this index in their analysis. Unfortunately, this assumes more availability and more time for treating the data. Another alternative is to derive an index for heat wave. This is used by Birthal & Hazrana (2019) when they analyze the impact of heat stress on crop biodiversity. They define heat stress when the temperature exceeds the long term mean with three degrees Cº for three or more days. This as well demands more time for processing the data and daily temperature is required. Both these options could give a more reasonable and solid result.

The *SID* coefficient has a positive effect on output with 0.93 %, though it is not significant. The positive sign indicates that it is positively correlated with production of milk, at least this gives a clue about the effect. There could be many reasons why the *SID* is not significant. First, the data need to be discussed. There are some weaknesses in the data which causes the results to be less reliable. The data has a lot of gaps and that is probably why the FADN panel data in STATA worked better with commands devoted for cross-sectional models. Some farms are included only one year while others for ten years. There is also a weakness in the description of each variable and what is accounted for. There is a possibility that there are values missing for some and values that are not supposed to be included that are included in others.

To be able to separate farm specialization the FADN data include a code. The problem is that it is not specified which code that belongs to what specialization. There were four codes that was connected to production of milk. The codes were then narrowed down to two codes that seem to produce the most milk. These data weaknesses combined might bias not only the SID result, but the results in its entirety.

Second, the data only covers one period (2007-2013) in the Rural development program. This means that support payments directed to diversification of farm businesses is only included for about seven years. If at least two periods were included in the data, farmers that received support to diversify their businesses in the first period could be displayed in the second period.

Third, the SID was chosen because it is widely used as a measurement for diversity the problem is that it is more sensitive to larger categories in the index (Minot et al. 2006; Di Falco and Chavas 2008). The Shannon-Weaver index could have been applied, as this index is used because of its sensitivity to both richness and evenness when it comes to crop diversity (Di Falco and Chavas 2008). Clarifying, it accounts for both number and the proportional abundance of species included. Though, income sources are not as complex as crop species or biodiversity.

Further, data on each specific income source for a farmer are not available in this case. This means that the variables are a created by adding a lot of income sources into one variable. This too speaks for using the SID because it is more sensitive to larger income sources. Even though the SID is not significant the sign is consistent with the literature, which means that there is an indication that income diversification has a positive impact on output (Birthal and Hazrana 2019; Dedehouanou and McPeak 2020).

The interaction terms between *SID* and temperature are inserted into the model to analyze the interaction effects of income diversification and temperature on output (Di Falco and Chavas 2008; Birthal and Hazrana 2019). There is only one significant interaction term, and it is the *MTempAutumnSID* at a 1% level and it is negative. The *MTempWinterSID* likewise show a negative sign while *MTempSummerSID* and *MTempSpringSID* display positive signs. The signs confirm the hypothesis for all variables besides *MTempAutumnSID* and *MTempWinterSID* which have negative signs.

This could be a result of measures that cannot be seen in the data yet (Birthal and Hazrana 2019). By adding a lagged term for income diversification and interaction term this might be revealed, this also makes the model more dynamic (Di Falco and Chavas 2008). Negative outcomes from temperature changes in previous years could have motivated dairy framers to invest in other income alternatives the year after (Birthal and Hazrana 2019). It could also be that the income activities added in the SID are coupled with summer and spring more than winter and autumn such as tourism and renewable energy (referring to solar).

Di Falco & Chavas (2008) explain their negative interaction term as a reason for higher diversification to cope with environmental impact on output. They illustrate it through a simulation where they decrease the climate variable (rainfall) with 20% and observe the elasticity of diversification. Di Falco & Chavas (2008) find that when the system was exposed to scarce rainfall the elasticity of diversity increased and had a larger and positive impact on productivity. A similar simulation exercise could have been performed for this analysis to be able to see the impact of income diversification on output. Though, that is past the scope of this thesis. The outcome could also be a product of mentioned weaknesses in the data.

The positive signs of *MTempSummerSID* and *MTempSpringSID* suggest that income diversification can reverse or cushion the negative effect of change in mean temperature (Di Falco and Cahvas 2008; Birthal and Hazrana 2019). This is especially interesting for the summer and spring seasons which affects the milk output negatively by an increase in the mean temperature. By introducing new income sources into the business, income diversification could work as an insurance for future changes in the environment (Minot et al. 2006). Evidence shows that farms that are diversified are more viable. Having multiple income sources could create more steady flow of revenue, both to handle changes caused by seasonal variation and changes in the business cycle (Barnes et al. 2015). By additional income sources the dairy farm could be able to continue the business even when access and prices of feed increase, milk production is lowered, facing a breakout of diseases or higher costs for cooling or heating (Key et al. 2014). All these factors could cause both higher costs and loss of income and thus a shortfall in revenues for a longer time. The positive interaction term gives an indication that diversification can help to lessen the effects from an increase in the mean temperature on productivity.

The *DummyLFA* has the anticipated positive sign, this indicates that not being in a LFA area increases the output with 2.28%. The coefficient is significant at a 5% level. *DummyOrganic* has a negative impact on output. Having an organic production reduces the output with 10 % and the coefficient is significant at 1%. This is an expected effect of organic production on output (Lansink et al. 2002). As mentioned in the in section 4.3.3., these variables were added to control for specific land characteristics and where not of special interest for this thesis. They will not be discussed further.

To capture the technical efficiency was not the aim for this thesis, though it can give support to the model. The mean and histogram are displayed in appendix 1.

Table 4: Regression results from the SFA

	MODEL I	
VARIABLES	Coff.	SE
lnx1	0.842***	(0.0153)
lnx2	0.00656	(0.0123)
lnx3	0.0226*	(0.0129)
lnx4	0.0788***	(0.0102)
lnx5	0.0917***	(0.0110)
lnx1Sq	0.244***	(0.0259)
lnx2Sq	-0.0215***	(0.00631)
lnx3Sq	-0.00166	(0.0258)
lnx4Sq	0.0472***	(0.0153)
lnx5Sq	0.0135	(0.0149)
lnx1x2	-0.175***	(0.0254)
lnx1x3	0.0295	(0.0348)
lnx1x4	-0.101***	(0.0194)
lnx1x5	0.0133	(0.0191)
lnx2x3	0.0203	(0.0257)
lnx2x4	0.0587***	(0.0158)
lnx2x5	0.0529***	(0.0144)
lnx3x4	-0.0123	(0.0187)
lnx3x5	-0.0425**	(0.0169)
lnx4x5	-0.0254**	(0.0108)
MTempAutumn	0.0688*	(0.0352)
MTempWinter	-0.0118*	(0.00716)
MTempSpring	-0.0533**	(0.0216)
MTempSummer	-0.139	(0.140)
MTempAutumnSID	-0.0396***	(0.0151)
MTempWinterSID	-0.00372	(0.00328)
MTempSpringSID	0.00182	(0.00886)
MTtempSummerSID	0.0141	(0.0564)
SID	0.00930	(0.0555)
DummyLFA	0.0228**	(0.00917)
DummyOrganic	-0.0987***	(0.00949)
lnt	0.135***	(0.0244)
lntSQ	-0.0492***	(0.00914)
Usigma	-2.451***	(0.0440)
Vsigma	4.175***	(0.0567)
Constant	0.322**	(0.130)
Observations	3,947	

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

5.3. Impact analysis

The elasticities are derived to be able to highlight the impact of the explanatory variables on output (Di Falco and Chavas 2008). The output elasticities derived in STATA are displayed in table 5.

The temperature elasticities demonstrate that *MTempSummer* has the largest impact on output with -0.14 followed by *MTempAutumn* with 0.069, this confirms the regression results. The estimated elasticity of the mean temperature in summer is not significant though it follows the literature (Qi et al. 2015). The possibility of heat stress occurring in summer is highest and will impact output the greatest. *MTempWinter* has the least impact on output with -0.012 and complies with the SPF.

Table 5: Elasticities of output

VARIABLES	Elasticities Coff.	SE
MTempAutumn	0.0688*	(0.0352)
MTempWinter	-0.0118*	(0.00716)
MTempSpring	-0.0533**	(0.0216)
MTempSummer	-0.139	(0.140)
MTempAutumnSID	-0.0396***	(0.0151)
MTempWinterSID	-0.00372	(0.00328)
MTempSpringSID	0.00182	(0.00886)
MTempSummerSID	0.0141	(0.0564)
SID	0.00930	(0.0555)
Observations	3,947	

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The interaction terms display that *MTempAutumnSID* has the largest impact on output with -0.04 and is significant, followed by *MTempSummerSID* with an impact of 0.014. This indicates that there are benefits on productivity from income diversity when there is a negative impact from increase in mean temperature (Di Falco and Chavas 2008). The SID show a very small but positive impact on output with 0.009 though it is not significant. Nevertheless, this supports the SPF results of and positive impact on output.

6. Conclusion

The effects of climate change are an endless list which has an impact on all levels in the society and nature (IPCC 2014). From the fish in the sea to the small nematodes in the soil, environmental changes in air quality and glaciers melting making sea level rise. One of the concerns is the effect of an increase in the global mean temperature on the agricultural sector. This is because agricultural food production is an important piece to secure food availability in the future. This thesis set out to investigate if income diversification is a possible solution for Swedish dairy farms to be able to cope with negative impact of increased mean temperature. The method used to analyze is an SFA, simulating a model including temperature variables, index for income diversification and an interaction term between diversification index and temperature.

To connect to the research questions, the results show that there are both negative and positive effects from increased mean temperature dependent on the season and an indication of a positive effect from income diversification on output. Further the interaction term displays a positive sign for spring and summer temperature which have a negative effect on output by themselves. Though the interaction terms are not significant they follow the literature and can give a clue to what the real effect is. This connects to research question two. Concluding, there are both negative and positive effects on dairy farm productivity from increased mean temperature in Sweden. Where the negative effects to some extent could be cushioned by income diversification. Though the result should be interpreted with caution because of the mentioned weaknesses in the discussion.

These finding could give implication to continue directing policies that supports farmers to diversify. This is a subject that is important and to incorporated environmental variables into economic analyses should be investigated more because of the environmental challenges in the future.

For further research, alternative indexes both for temperature and income diversification could give more knowledge of the impact on output. To include a risk factor might also give additional perspective both to why framers choose to diversify and if there are some other elements that effects their choice which have impact on output. Furthermore, a projection of future impacts of temperature and diversification could give a more solid analysis.

For policy makers, a variable that account for differences between farms, such as facilities and management distinctions. Could give an increased understanding and implications for further development of policies regarding both income diversification and temperature effects on dairy production.

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Appendix 1

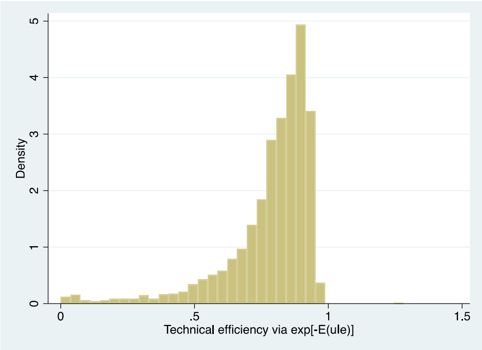

Figure 10: Histogram for the technical efficiency MODEL I

Table 6: Mean for the technical efficiency MODEL I

Variable	Obs	Mean	Std. Dev.
Te	3,947	.785247	.16468

Appendix 2

Table 7: MODEL II including only farms that have less than 700 cows and land smaller than 500 hectares.

VARIABLES	MODEL II Coff.	SE
Frontier		
lnx1	0.837***	(0.0155)
lnx2	0.00301	(0.0124)
lnx3	0.0235*	(0.0130)
lnx4	0.0836***	(0.0104)
lnx5	0.0897***	(0.0110)
lnx1Sq	0.239***	(0.0261)
lnx2Sq	-0.0242***	(0.00629)
lnx3Sq	-3.33e-05	(0.0260)
lnx4Sq	0.0419***	(0.0154)
lnx5Sq	0.0127	(0.0149)
lnx1x2	-0.180***	(0.0255)
lnx1x3	0.0240	(0.0349)
lnx1x4	-0.0946***	(0.0195)
lnx1x5	0.00984	(0.0193)
lnx2x3	0.0160	(0.0257)
lnx2x4	0.0624***	(0.0158)
lnx2x5	0.0518***	(0.0144)
lnx3x4	-0.00846	(0.0187)
lnx3x5	-0.0424**	(0.0169)
lnx4x5	-0.0234**	(0.0109)
MTempAutumn	0.0664*	(0.0353)
MTempWinter	-0.0124*	(0.00719)
MTempSpring	-0.0513**	(0.0217)
MTempSummer	-0.126	(0.141)
MTempAutumnSID	-0.0392***	(0.0152)
MTempWinterSID	-0.00386	(0.00329)
MTempSpringSID	0.00139	(0.00888)
MTempSummerSID	0.0147	(0.0565)
SID	0.00881	(0.0556)
DummyLFA	0.0232**	(0.00918)
DummyOrganic	-0.0989***	(0.00951)
lnt	0.130***	(0.0246)
lntSQ	-0.0467***	(0.00922)
Usigma	-2.454***	(0.0442)
Vsigma	-4.167***	(0.0567)
Constant	0.312**	(0.131)
Observations	3,940	

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1