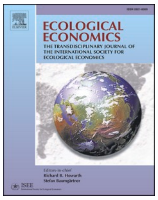
Ecological Economics 209 (2023) 107829

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon



Do ecological protection approaches affect total factor productivity change of cropland production in Sweden?

Subrata Koiry [a], Wei Huang [b,*]

[a] Department of Agricultural Finance and Banking, Sylhet Agricultural University, Sylhet 3100, Bangladesh
[b] Department of Economics, Swedish University of Agricultural Sciences, Uppsala 75007, Sweden

ARTICLE INFO

JEL classification:
D24
Q10
Q57

Keywords:
Organic farming
Integrated farming
Technical efficiency
Crop sector

ABSTRACT

Ecological protection approaches are important in achieving sustainable productivity growth in agriculture. Based on an unbalanced panel dataset for 2010–2016, we used stochastic frontier analysis-based Malmquist total factor productivity index to estimate total factor productivity change of Swedish crop production and its components (efficiency change, technical change, scale change). We then examined the effect of ecological protection approaches on total factor productivity change. The empirical results demonstrated that ecological protection approaches such as organic farming, mixed cropping or integrated farming could hamper total factor productivity growth. The results also indicated that average total factor productivity change in the study period was positive and average technical efficiency of the Swedish crop production was 71%. Among the components of total factor productivity change, average scale change was positive. Average technical efficiency change and average technical change were both negative. If technical efficiency and technological progress can be improved, that would increase the positive change in total factor productivity. This suggests that policies on compensation or insurance against productivity loss are required to encourage mainstreaming of ecological protection approaches among farmers.

1. Introduction

There is growing concern world-wide about protection of the environment and its sustainability, with governments, ecological and environmental sustainability advocates and policymakers now paying greater attention to sustainability issues (Arrow et al., 2012). This has implications for the agriculture sector, as agriculture has significant effects on global economic projections (Stern, 2007) and on the environment. Conventional agriculture is criticised for harming the ecological balance through heavy use of chemical and technological inputs (Shi, 2004). Agriculture also contributes to emissions to air (De Cara et al., 2005) and water (OECD, 2008), soil erosion (Pimentel and Burgess, 2013; Morgan, 2005), biodiversity loss and habitat loss (Kleijn et al., 2006; Tscharntke et al., 2005). On the other hand, agriculture plays a role in producing renewable energy, preserving landscapes and biodiversity (Röös et al., 2018) and ensuring food security and safety. While supporting these positive effects of agriculture, it is necessary to direct agricultural production towards efficient and sustainable practices that can reduce the adverse effects generated by agriculture.

In agriculture, sustainability issues are likely to be compromised when productivity is high (Coomes et al., 2019). There is a triangular problem involving input use, agricultural productivity, and better biodiversity and ecosystem health. Agriculture is sustainable when it is ecologically sound (Shukla and Rajan, 1996) and maintains biodiversity (Kleijn et al., 2019; Anon, 2011; Pretty, 2005). To ensure sustainability, there is a need to adopt farming practices or approaches that protect the ecosystem and biodiversity. Ecological protection agriculture is knowledge-intensive, requires low inputs and fossil fuels (Tittonell, 2013), and secures healthy farming and safe food for both present and future generations by preserving water, soil and climate and promoting biodiversity (Tirado, 2009). Ecological protection approaches in farming can form a good bridge between sustainable resource use and environmental protection. In contrast to the large-scale use of inputs and heavy manipulation of nature in conventional agriculture, ecological protection approaches produce crops based on the functioning of natural systems. Organic farming, mixed cropping, crop rotation, intercropping, planting catch crops or cover crops, reduced or no tillage, integrated pest management systems, integrated farming systems, extensive grass-based systems, reduced-input systems etc. are approaches to farming that consolidate best environmental practices to

---

* Corresponding author.
E-mail addresses: skoiry.afb@sau.ac.bd (S. Koiry), wei.huang@slu.se (W. Huang).

https://doi.org/10.1016/j.ecolecon.2023.107829
Received 12 March 2022; Received in revised form 15 March 2023; Accepted 20 March 2023

preserve biodiversity and natural resources. Hence, the impact of farming on the environment is also reduced (Florian and Rosu, 2020). Many studies have documented the benefits of using compost and manures in farming (Brady, 1990; Pasztor and Kristoforson, 1990; Russell, 1988; Allison, 1973; Kononova et al., 1966). Inter-cropping, crop rotation and use of organic fertilisers benefit the environment through prevention of soil erosion and deforestation, generation of environmentally friendly energy forms such as biogas and solar energy, conservation of energy and reduced dependency on fossil fuels. They also break the virtuous cycle of production using waste (Sanders, 2006), and create coordinated production systems based on ecological benefits (Ye et al., 2002). Ecological protection approaches may provide the opportunity to fill the production gap or improve productivity while lowering input use or using eco-friendly inputs. Such approaches can also enhance productivity for future generations with available local resources such as bio-fertilisers (Dima and Odero, 1997). Therefore ecological protection approaches may be a good solution enabling future agriculture to maintain a balance between productivity and environmental sustainability.

Owing to their importance, productivity and sustainability have both received special attention in European countries through the platform of the European Union (EU). As an EU member state, Sweden has adopted EU environmental and sustainability regulations and has entered into several international agreements to preserve biodiversity and the environment (GO, 2000). The main challenges for Swedish agriculture, especially for the crop production sector, are maintenance of environmental standards, sustainable growth and improving total factor productivity. Constraints originating from climate change, natural factor endowments, rising input costs and biodiversity management create disadvantages for the total factor productivity of agriculture (OECD, 2018). To overcome these disadvantages, ecological protection approaches must ensure both productivity improvements and ecological and environmental sustainability. In Sweden, 19% of the total agricultural area has been converted to organic farming (Swedish Board of Agriculture, 2018), reflecting the focus of Swedish agricultural policies on preserving biodiversity and open landscapes (GO, 2014) and the environment. However, due to the stochastic nature of crop production, it is difficult to establish a win-win situation where productivity is increased and the environment is protected. Thus it is important to identify factors affecting productivity change under ecological and conventional farming.

Adoption of ecological approaches instead of conventional farming also raises other difficulties. For example, organic farming forbids the use of specific inputs that cause emissions, which can reduce productivity (OECD, 2018). This has resulted in calls for less implementation of agro-ecological farming in some cases (Skevas et al., 2013; Brittain et al., 2009; Boatman et al., 2004; Lee et al., 2001). On the other hand, while pesticide use protects current conventional production by reducing pest damage, it may negatively affect the organisms needed for future production (Skevas and Lansink, 2014; Skevas et al., 2013; Brittain et al., 2009; Boatman et al., 2004; Lee et al., 2001). Adopting a particular technology also depends on the investment requirement (Jaeck and Lifran, 2013; Batz et al., 2003). If ecological protection approaches require higher investment, or result in lower productivity, this may discourage farmers from adopting eco-friendly practices. Farmers will only change to ecological farming if adoption of eco-friendly practices increases farm productivity or if they are compensated for productivity losses. There is therefore a need to investigate the complex problem of maintaining or increasing total factor productivity while adopting ecological protection approaches in farming. The aims of the present study were to assess whether total factor productivity of the Swedish crop sector has improved (or not); to identify sources of change in total factor productivity; and to determine the extent of total factor productivity change and whether it follows a positive, negative or inconsistent trend. A novel contribution of the work lies in examining the effect of adopting ecological protection approaches on total factor productivity change of crop production. The results can be expected to be of significant relevance for policy making.

The rest of this paper is organised as follows. Section 2 summarises the literature review. Section 3 introduces the data source, describes the selection of variables and presents statistics on those variables. Section 4 describes the econometric model, while section 5 presents the empirical results. Section 6 discusses the findings and section 7 presents some conclusions.

2. Literature review

Total factor productivity in agriculture and its drivers in both developing and developed economies have been the subject of much research (Han and Zhang, 2020; Rada et al., 2019; Plastina and Lence, 2018; Wang et al., 2017; Rada, 2013; Bokusheva et al., 2012; Rada and Buccola, 2012; Wang et al., 2012; Bragagnolo et al., 2010; Coelli et al., 2003). The increasing importance of research on effects of climate and environment on total factor productivity growth is also reflected in the literature. Several studies have assessed the impact of environmental factors such as temperature, rainfall and weather on agricultural productivity growth (Njuki et al., 2020; Nijuki et al., 2018; Burke and Emerick, 2016; Kaminski et al., 2013; Seo, 2013; Ball et al., 2004; Chaston and Gollop, 2002). The long-term relationship between total factor productivity growth and greenhouse gas emissions from agriculture has also been investigated (Coderoni and Esposit, 2013). Baldoni et al. (2017) examined whether and to what extent total factor productivity and emissions intensity as an environmental indicator affect each other across farm size and specialisation. Several studies have analysed the effect of global warming on total factor productivity growth (Letta and Tol, 2018; Dietz and Stern, 2015; Moore and Diaz, 2015). Productivity has also been evaluated in different policy contexts, such as the effects of subsidising fertilisers and seeds (Abman and Carney, 2020), the effect of conservation agriculture (Das et al., 2020), the effect of green manure and fertiliser (Egodawatta et al., 2012) and the effect of EU common agricultural policy (CAP) subsidies (Mary, 2013).

Ecological protection approaches have also been assessed, e.g. in studies examining factors governing adoption of sustainable agro-ecological farming practices (Dessart et al., 2019; Schoonhoven and Runhaar, 2018; De Snoo et al., 2013; Baumgart-Getz et al., 2012; Prokopy et al., 2008; Knowler and Bradshaw, 2007; Pannell et al., 2006; Kabii and Horwitz, 2006). The feasibility of using ecological inputs in agricultural production has been investigated using partial budget analysis (Ahmed and Shams, 1998). Other studies have examined the role of ecological farming in poverty reduction, environmental regeneration and political stabilisation (Shukla and Rajan, 1996). Ottmann et al. (2013) evaluated whether a diversified and integrated farming system in an ecological perspective has better global sustainability, while Smits et al. (2008) investigated the contribution of effective governance to adoption of eco-friendly farming practices. The dynamic interaction between sustainable and resilient farming systems and total factor productivity growth has also been examined (Coomes et al., 2019), while Owusu-Sekyere et al. (2020) evaluated the heterogeneous demand for ecologically sustainable products among consumers. Based on this literature, it may be argued that ecologically friendly agriculture can play a role in various dimensions and contexts of society, the economy and the environment.

The Swedish economy is highly developed, with the crop sector playing a vital role in the economy. Many studies have examined eco-friendly agriculture in the Swedish crop sector in terms of advantages and disadvantages, ecological modernisation, factors influencing adoption of an eco-friendly approach and natural resources management through eco-friendly farming systems (Chongtham et al., 2016; Uyttenbroeck et al., 2016; Nykvist, 2014; Castellazzi et al., 2008; Archambault, 2004; Rydberg and Milberg, 2000). Some previous studies have analysed total factor productivity of the Swedish crop sector

(Cechura et al., 2014; Zhu and Lansink, 2010). The present study is unique in measuring total factor productivity change of the Swedish crop sector in a different period than in previous studies and in analysing total factor productivity change under ecological protection approaches.

By examining total factor productivity change in the Swedish crop sector and sources of change, the aim in this study was to help diagnose problems related to specific sources that can increase total factor productivity. Specifically, this study examined the causality of ecological protection approaches for total factor productivity change in Swedish crop production. Eco-friendly practices can be acceptable to farmers if they contribute to increased productivity and benefit farm finances. Farmers are unlikely to adopt eco-friendly practices solely for the sake of environmental and ecological conservation. This study extends the literature by examining the effects of choice of a particular ecological protection approach in crop production.

3. Data, variables and descriptive statistics

3.1. Data

The empirical analysis was based on unbalanced panel data taken from the Farm Accounting Data Network (FADN) of the European Commission (EC). The FADN dataset for the period 2010–2016 was obtained from the Swedish Board of Agriculture. In data analysis, three types of farm were considered based on specialisation: 1) farms that produce only one crop or a specific crop, 2) farms with integrated crop and livestock production, and 3) farms with mixed cropping. The integrated and mixed cropping farms can be regarded as eco-friendly farms. As organic production is another approach to ecological production, farms applying organic practices or a combination of organic and conventional practices were categorised as eco-friendly farms. The dataset included data on all types of field crops, fruits and other plant products produced in the Swedish crop sector.

3.2. Variables

One output variable and four input variables were used for analysing total factor productivity change. *Output*, the dependent variable in the production function, was calculated by adding the sales value of all seasons and all types of crops produced by a farm in each year. The four important input variables in the production function are labour, materials, machinery and land. *Labour cost* includes the cost for all labour used in production by a farm, which is calculated by adding together the labour wage and social security contribution for a particular form of labour. *Materials* consists of total cost of purchased seed, the value of self-produced seeds used in production by the farm, cost of plant protection materials, cost of soil-improving chemical fertilisers including manures, and other specific costs directly related to production. *Machinery* represents the total cost of machinery used in production, calculated by adding together the cost of machinery hire, the value of current upkeep of machinery and equipment, cost of fuel and lubricants and vehicle costs. *Land* represents the area under production, measured in '*ares*' (100 m^2). Since 100 *ares* equal 1 ha, in the present analysis land area was converted from *ares* to hectares (ha) by dividing by 100. All inputs except land were measured in Swedish kronor (SEK). The monetary variables were deflated using the Price Index for 2010. Descriptive statistics on these variables are presented in the first block in Table 1.

Table 1
Descriptive statistics.

Variables	Unit	Mean/ %	Standard deviation	Min.	Max.
Production-related variables					
Output	1000 SEK	1847.3	2539.2	1400	23,170
Labour cost	1000 SEK	472.7	573.7	450	4883.5
Material	1000 SEK	424.4	570.7	256	5335.9
Machinery	1000 SEK	412.1	489.3	13.6	5046.5
Land	ha	137	142.6	6	785.5
Inefficiency determinants					
Age	Years	56	10	28	90
Farm support	1000 SEK	262.3	306.9	0	2261.4
Labour support	1000 SEK	6.9	24.6	0	570.4
Less favoured area subsidy	1000 SEK	7.8	41.1	0	242.7
Environment-friendly practices subsidy	1000 SEK	28.1	70.6	0	603
Region:					
Code 710	%	81			
Code 720	%	13			
Code 730	%	6			
Variables related to factors affecting productivity					
Payment of agricultural insurance	1000 SEK	34.4	31	0	197.3
Specialisation					
0	%	76			
1	%	24			
Organic farming					
0	%	88			
1	%	12			
Location in less favoured area					
0	%	72			
1	%	18			
2	%	3			
3	%	6			
4	%	1			

The explanatory variables for the technical inefficiency variance function used in analysing determinants of technical inefficiency are presented in the second block in Table 1. The variable *Age* is year of birth of the operations manager directly involved in on-farm production (farm owner or not). To calculate age, year of birth was deducted from the current year of production. Four types of subsidies were considered in the technical inefficiency variance function as determinants of technical inefficiency. These were: *farm support*, *labour subsidy*, subsidy for farm's location in less favoured area (*less favoured area subsidy*), and subsidy given for adopting practices beneficial for climate and environment (*environment-friendly agricultural practices subsidy*), all measured in SEK. The variable *farm support* represents area-based income subsidy for farms under the CAP. The variable *labour support* is not part of CAP support, but is instead part of Swedish labour policy and available for Swedish farmers. The variable *region* represents the division of area for agriculture and rural development according to FADN. Three areas were considered here, representing the southern and central plains area, the southern and central forest and valley area, and northern Sweden (coded 710, 720 and 730, respectively). Region was considered a dummy variable in the analysis and 710 as the base category, with 720 and 730 as other categories.

The variables used in identifying factors affecting total factor productivity change of the Swedish crop sector are listed in the third block in Table 1. The variable *location in a less favoured area* is a dummy variable, with a value of 0 set for farms not located in less favoured areas of Sweden. A value of 1 was given for farms located in such areas and facing specific and natural constraints, a value of 2 for areas described as less favoured but not mountains according to the EU, a value of 3 for mountain areas and a value of 4 for farms located in phasing-out areas. The variable *payment of agricultural insurance* represents the cost of buying insurance against crop damage. The variable *specialisation* is a dummy variable where a value of 0 was given for farms that only produce specific field crops and a value of 1 for farms with mixed cropping or integrated farming. Similarly, the variable *organic farming* was also regarded as a dummy, where a value of 0 was given for farms not producing crops organically (i.e. using chemical fertilisers and plant protection chemicals in production), and a value of 1 for farms with organic production (i.e. no use of chemical fertilisers and plant protection chemicals in production) or producing crops using both organic and inorganic practices.

3.3. *Descriptive statistics*

Among the input variables considered in this study, the greatest average cost was labour cost (472 thousand SEK) followed by materials (424 thousand SEK), and machinery capital (412 thousand SEK). Land inputs were not measured in SEK. Among the subsidies, the greatest was the area-based income support (i.e. farm support) paid to crop-producing farms (262 thousand SEK). The majority of farms were located in the southern and central plains region and in less favoured areas of Sweden. In terms of eco-friendly practices, 88% of farms were not operating such systems. The majority of farms involved in non-organic production specialised in production of a specific crop. The average age of farm operation managers (not necessarily owners) was estimated to be 56 years. However, the maximum age recorded was 90 years, reflecting the average life expectancy in Sweden of 83 years (World Bank, 2019).

4. Methodology

4.1. *Productivity analysis*

A range of measures of productivity, such as the Fisher, Tornqvist, Hicks-Moorsteen and Malmquist indices, are available, but there is no consensus in the literature on which index is best for measuring farm productivity. O'Donnell (2012) concluded that the Hicks-Moorsteen index is best, whereas Balk (2001) favoured the Malmquist index. The Malmquist total factor productivity index is extensively used in the agricultural economics literature (Song et al., 2016; Coelli and Rao, 2005; Karagiannis and Tzouvelekas, 2005). The benefit of using this index is that it permits decomposition of productivity changes into several components. It also does not require information on the prices of inputs and output. In this study the Malmquist index was used to estimate total factor productivity, which was then decomposed into three components: technical efficiency change, technical change (or progress) and scale change. This index measures the productivity change between two data points by calculating the ratio of the distances for each point relative to a common technology. The output and all inputs are characterised by vectors y_t and x_t at time *t*. The production frontier representing the reference technology provides the maximum possible output with given inputs at a certain point in time. It is possible to calculate both an output- and input-oriented index. In the output-oriented index, output is maximised with given production technology assuming fixed input vector. The output-oriented Malmquist total factor productivity index is estimated as the geometric mean of two Malmquist index values, for periods *k* and *t* (Färe et al., 1994):

$$m^0(x_k, x_t, y_k, y_t) = \left[m_k^0(x_k, x_t, y_k, y_t) \times m_t^0(x_k, x_t, y_k, y_t)\right]^{0.5} \tag{1}$$

Efficiency is usually lost in the process of production, so eq. (1) can be written as:

$$m^0(x_k, x_t, y_k, y_t) = \frac{d_t^0(x_t, y_t)}{d_k^0(x_k, y_k)} \times \left[\frac{d_k^0(x_t, y_t)}{d_k^0(x_k, y_k)} \times \frac{d_k^0(x_k, y_k)}{d_t^0(x_k, y_k)}\right]^{0.5} \tag{2}$$

where $d_k^0(x_t, y_t)$ represents the distance function for the distance between farm observation at time *t* and technology frontier at time *k*. The term before the square bracket measures technical efficiency change between period *k* and *t*, while the geometric mean of the term within square brackets indicates technical change.

According to Coelli et al. (2006), efficiency change and technical change are the only sources of productivity growth in the presence of constant returns to scale generated by production technology. They also point out that by increasing scale efficiency, productivity can be improved even the technology remains the same in both periods compared and farms are efficient. Since crop production is dynamic, subject to structural change, and variables return to scale, the effects of scale change can be included in decomposition of Malmquist total factor productivity index, as also proposed by Orea (2002). Changes in scaling of the production frontier due to technical change and combination of inputs both generate scale change.

Since part of total factor productivity change results from efficiency change and output-oriented efficiency requires estimation of production frontier, both parametric and non-parametric approaches can be used. The advantages of parametric approaches in this context are that they provide estimates of elasticities and accommodate measurement errors and other noise in the data (Skevas and Lansink, 2014). The stochastic production frontier approach is mainly employed in parametric studies (e.g. Emvalomatis, 2011; Zhengfei and Lansink, 2006; Brümmer et al., 2002; Kumbakhar and Heshmati, 1995), for both efficiency and productivity estimates. Given its advantages, the stochastic production frontier approach was employed in this study to estimate total factor productivity change in terms of the Malmquist productivity index. The stochastic frontier production function for panel data suggested by Aigner et al. (1977) and Meeusen and van den Broeck (1977) was used. It takes the form:

$$Y_{it} = X_{it}\beta + v_{it} - u_{it} \tag{3}$$

where $\boldsymbol{Y_{it}}$ represents the output of region *i* ($i = 1,2,3$……… n) at time *t* ($t = 1,2,3,$ ………n); β is the vector of parameters to be estimated; v_{it} is a random error component that follows a normal distribution assumed by Aigner et al. (1977) with mean 0 and standard deviation σ_v^2 i.e. $v_{it} \sim N(0, \sigma_v^2)$; and u_{it} is a non-negative random variable related to technical inefficiency in production.

There are several options for selecting the distribution of the inefficiency term u_{it}, but the exponential distribution can be chosen for convenience. The exponential distribution assumes that u_{it} is an independently and identically distributed random variable. The probability density function of each u_{it} has mean λ and zero standard deviation, i.e. $u_{it} \sim N(\lambda, 0)$. The technical efficiency of production of region *i* at time *t* is defined as:

$$TE_{it} = exp[E(-u_{it})|(v_{it} - u_{it})] \tag{4}$$

Following Battese and Coelli (1995), the model incorporates both the exponential specifications of the time-varying inefficiencies and technical change in the stochastic frontier. As the aim in this study was to investigate sources of productivity change along with total factor productivity change, it was necessary to use a model which assumes that farm efficiency is time-variant. The Battese and Coelli (1995) model was also suitable for the panel dataset. In productivity research, the model is well-accepted and used widely, e.g. by Jin et al. (2010), Rae et al. (2006), Coelli et al. (2003) and Brümmer et al. (2002). For these reasons, the Battese and Coelli (1995) model was used here for stochastic frontier analysis.

4.2. *Empirical model*

4.2.1. *Stochastic frontier translog production function*

Determination of Malmquist total factor productivity index using the stochastic frontier analysis approach requires a production function to use in the estimation procedure. Due to superior performance in terms of theoretical consistency, the translog production function is extensively used (Mennig and Sauer, 2019; Coelli et al., 2003). This production function also does not contravene curvature properties, such as concavity (Färe et al., 2005). Therefore the translog production function was used in this study and the translog functional form of the stochastic frontier model was defined as:

$$lnY_{it} = \beta_0 + \sum_{n=1}^{N} \beta_n lnX_{nit} + \frac{1}{2} \sum_{n=1}^{N} \times \sum_{k=1}^{N} \beta_{nk} lnX_{nit} lnX_{kit} + \sum_{n=1}^{N} \beta_{tn} \mathrm{tln}X + \beta_t t + \frac{1}{2} \beta_{tt} t^2 + v_{it} - u_{it} \tag{5}$$

where Y_{it} is the aggregated output of farm i at time t; X_{nit} is the n^{th} input variable in the farm at time t; v_{it} is normally distributed random error, i.e. $v_{it} \sim N(0, \sigma_{\mathrm{v}}^2)$; and u_{it} is the effect that arises from technical inefficiency in production. The interaction of time trends with the input variables allows non-neutral technical change.

Since productivity change results from scale change (Orea, 2002), technical change and efficiency change (Coelli et al., 2006), the first component of productivity change, (technical) efficiency change, was calculated as:

$$TEC = \frac{TE_{it}}{TE_{ik}} \tag{6}$$

From the estimated parameters of the stochastic production frontier, the index of technical change ($\mathrm{TC}_{\mathrm{it}}$) between period k and t was calculated for farm i. The partial derivatives of the production function concerning the time at x_{it} and x_{ik} were then converted into indices, and their geometric mean was calculated. Technical change index was estimated as:

$$TC = \left[\left(1 + \frac{df(x_{ik}, k, \beta)}{dk} \right) \times \left(1 + \frac{df(x_{it}, t, \beta)}{dt} \right) \right]^{0.5} \tag{7}$$

To capture the effect of scale on productivity change, as proposed by Orea (2002), the scale change was calculated as:

$$SC = exp\left\{ \frac{1}{2} \sum_{n=1}^{N} [\varepsilon_{nik} SF_{ik} + \varepsilon_{nit} SF_{it}] ln\frac{x_{nit}}{x_{nik}} \right\} \tag{8}$$

where $SF_{ik} = \frac{(\varepsilon_{ik} - 1)}{\varepsilon_{ik}}$, $\varepsilon_{ik} = \sum_{n=1}^{N} \varepsilon_{nik}$, and $\varepsilon_{nik} = \frac{dlny_{ik}}{dlnx_{nik}}$.

By adding the indices obtained through calculations using eqs. (6)–(8), total factor productivity (TFP) was calculated:

$$TFPC = TEC + TC + SC \tag{9}$$

To estimate the factors affecting total factor productivity change, the functional form of the pooled ordinary least regression model can be written as:

$$TFPC = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \varepsilon \tag{10}$$

where *TFPC* is the dependent variable and represents total factor productivity change; X_1 is a dummy representing farm adoption of integrated farming and mixed cropping; X_2 is a dummy representing farm adoption of organic farming; X_3 is a dummy representing location of the farm in a less favoured area; and X_4 indicates the payment for purchasing agricultural insurance. The term ε captures the unobserved effect on total factor productivity change.

5. Empirical results

5.1. Estimates of stochastic production frontier and the technical inefficiency model

The estimates obtained using the maximum likelihood random effect model are presented in Table 2. The maximum likelihood values were estimated using *the sfcross* command in STATA, due to the strongly unbalanced nature of the dataset. The benefit of using the *sfcross* command is that it controls for time and considers the panel dataset as cross-sectional. Capturing the effect of time on efficiency and productivity changes the time trend included in the model as an explanatory variable. The estimated first-order coefficients can be interpreted as the sample mean production elasticities, as both the output and input variables are divided by their respective mean value. The results showed that the estimated first-order coefficients of labour cost, material cost and machinery cost had expected positive signs and were statistically significant at 1% level. The elasticity of labour cost, material cost and machinery capital was estimated to be 0.073, 0.714 and 0.141, respectively. The most crucial input was materials regarding the magnitude of elasticity, followed by machinery and labour cost. The coefficient of land was not significant and its sign was positive. Although land as an input could be expected to be positively significant, an insignificant coefficient of the "land" variable was not a new outcome in our research. A possible explanation is that technology use Swedish integrated crop farming and organic crop farming may not be influenced by farm location and farm size?????. Another explanation is that other input variables play such a major role in production that they mask the contribution of land. Total factor productivity change was estimated based on the coefficients shown in Table 2.

The estimated coefficients of variables in the technical inefficiency model are shown in Table 3. In this model, the dependent variable is technical inefficiency, which means that a positive estimate indicates a positive correlation between technical inefficiency and the variable, while a negative estimate indicates a negative correlation. Regarding determinants of technical inefficiency, the coefficient of farm support was estimated to be −0.269 (significant at 1% level), implying that the greater the area-based income subsidy paid to a farm, the lower the technical inefficiency. The estimated sign of the coefficient for both the environment-friendly agricultural practices subsidy and labour support was positive and statistically significant at 1% level, indicating that the greater the amount of those subsidies paid to a farm, the lower the technical efficiency of that farm. The coefficient for northern Sweden was estimated to be 0.869 (significant at 1% level), implying that farms located in northern Sweden are significantly technically more inefficient than farms located in the southern and central plain areas of Sweden. Although the estimated coefficient of farm location in the south-central forest and valley area was not significant, the estimated sign was

Table 2
Maximum likelihood estimation of the stochastic production frontier.

Variables	Coefficient	Standard error	z	P >|z|
Ln labour	0.073***	0.014	5.03	0.000
Ln material	0.714***	0.040	17.56	0.000
Ln machinery	0.141***	0.064	2.19	0.029
Ln land	0.022	0.048	0.46	0.646
Time	0.041	0.029	1.38	0.167
Ln labour^2	0.006***	0.001	4.36	0.000
Ln material^2	0.059***	0.004	13.87	0.000
Ln machinery^2	−0.171***	0.056	−3.01	0.003
Ln land^2	0.064***	0.019	3.35	0.001
Time^2	−0.026***	0.007	−3.62	0.000
Ln labour x ln material	0.005***	0.001	2.61	0.009
Ln labour x ln machinery	−0.002	0.002	−0.60	0.549
Ln labour x ln land	−0.009***	0.001	−5.10	0.000
Ln material x ln machinery	0.038	0.023	1.62	0.105
Ln material x ln land	−0.101***	0.020	−4.85	0.000
Ln machinery x ln land	0.081***	0.036	2.21	0.027
Time x ln labour	−0.0001	0.0007	−0.17	0.861
Time x ln material	−0.006	0.008	−0.69	0.490
Time x ln machinery	0.018	0.011	1.58	0.114
Time x ln land	−0.017*	0.009	−1.78	0.075
Constant	0.423***	0.063	6.63	0.000
Number of observations	1719			

Table 3
Inefficiency determinant estimates.

Variables	Coefficient	Z	P >| Z|
Dependent variable: technical inefficiency (Usigma)			
Age	0.001 (0.007)	0.18	0.855
Farm support	−0.269*** (0.015)	−17.46	0.000
Less favoured area subsidy	0.005 (0.011)	0.39	0.700
Labour support	0.032*** (0.013)	2.43	0.015
Subsidy for environment-friendly practices	0.024*** (0.008)	2.94	0.003
Region dummy (720)	0.304 (0.212)	1.43	0.152
(730)	0.869*** (0.315)	2.76	0.006
Constant	−1.417*** (0.517)	−2.74	0.006
Vsigma	−1.971*** (0.058)	−33.66	0.000
Sigma v	0.373*** (0.010)	34.15	0.000
Mean technical efficiency	0.71		
E(Sigma u)	0.573		
Log-likelihood value	−1398.2229		
Wald chi^2(20)	7604.96		
Prob > chi^2	0.0000		
Number of observations	1719		

positive, indicating that farms located in this part of Sweden have lower technical efficiency. The greater magnitude of the coefficient for northern Sweden indicates that farms are least efficient in this region. The average technical efficiency was estimated to be 0.71 or 71%, which implies that the inefficiency in crop production can be reduced by 29%.

5.2. Total factor productivity change decomposition

The change in total factor productivity from 2010 to 2016 was calculated using the estimated coefficients from the stochastic frontier model and then decomposed to reveal the sources. The results indicated that the overall change in total factor productivity originated from all three sources, i.e. technical efficiency change, technical (or technological) change and scale change (Table 4). Technical efficiency change was positive in 2011, 2012, 2015 and 2016 with respect to the previous year, indicating that efficiency improved in those years. However, in 2013 and 2014, technical efficiency change was negative. The technical change estimates for each year from 2010 to 2016 with respect to the previous year were negative and fluctuating, indicating that there was no technological improvement in production systems in the Swedish crop sector in the period. The magnitude of technical change was also more or less similar after 2012 (Table 4). Scale change was negative only in 2014 and 2016; otherwise, the change was positive in all years. Total factor productivity change was positive until 2012, and became negative thereafter. The average technical efficiency change was negative, but the magnitude was small (−0.4%). There was also negative average technical change (−2.6%), whereas mean scale change was larger and positive (3.8%). The positive scale change implies that the total factor productivity change of farms was driven by changes in the scale of production, which increased return to scale. The average total factor productivity change was estimated to be positive (0.7%), implying that from 2010 to 2016, total factor productivity improved in the Swedish crop sector.

Table 4
Components of total factor productivity change 2010–2016.

Year	Technical efficiency change	Technical change	Scale change	Total factor productivity change
2010	–	–	–	–
2011	0.005	−0.018	0.265	0.251
2012	0.027	−0.034	0.039	0.032
2013	−0.012	−0.026	0.0003	−0.038
2014	−0.074	−0.029	−0.045	−0.148
2015	0.006	−0.028	0.010	−0.011
2016	0.023	−0.026	−0.039	−0.042
Mean	−0.004	−0.026	0.038	0.007

5.3. Factors affecting total factor productivity change

Factors driving the total factor productivity change for crop-producing farms in Sweden are shown in Table 5. The indices of change in total factor productivity were regressed on the four variables that can affect farm-level total factor productivity change, i.e. specialisation, organic farming, payment of agricultural (crop) insurance, and farm location in a less favoured area. Among these variables, specialisation and organic farming are the two approaches of ecological farming. All variables except payment of agricultural insurance were dummy, so for convenience payment of agricultural insurance was normalised. The coefficient of specialisation and organic farming indicated the effect of ecological protection approaches on total factor productivity change (Table 5). The sign of both coefficients was negative, which implies that adopting ecological protection approaches in farming is not satisfactory for total factor productivity change in the Swedish crop sector. The coefficient of organic farming was only statistically significant for specialisation (−0.077, significant at 1% level).

Similarly, the average difference between organic farm and non-organic farms was −3.2%, but this difference was not significant. This is supported by the findings in Table 6 that average total factor productivity change was negative for the farms that adopted ecological protection approaches and positive for the farms that did not. Moreover, the cost of purchasing agricultural insurance negatively affected total factor productivity change, although the effect was not statistically significant. The coefficient for farms located in less favoured areas (not mountain) was −0.144 (statistically significant at 1% level). This means that the average difference between farms in such areas and farms in other locations was 14.4% on average. As expected, the estimated sign of farm location in areas facing specific and natural constraints was negative. On farms not located in less favoured areas, total factor productivity change can be increased. For mountain area and phasing-out area the values were positive, which was unexpected, but they were not statistically significant.

Table 6 compares total factor productivity change for farms that had adopted ecological protection approaches and those that had not. The total factor productivity change for mixed or integrated farming and for

Table 5
Factors affecting total factor productivity change.

	Coefficient	**Z**	**P>|Z|**
Specialisation	−0.077*** (0.035)	−2.18	0.029
Organic farming	−0.032 (0.032)	−0.99	0.320
Ln Payment of agricultural insurance	−0.007 (0.006)	−0.97	0.334
Location in less favoured area			
(1) Constraints area	−0.074 (0.054)	−1.38	0.169
(2) Less favoured but not mountain	−0.144*** (0.063)	−2.26	0.024
(3) Mountain area	0.009 (0.079)	0.12	0.907
(4) Phasing-out area	0.053 (0.109)	0.48	0.630
Constant	0.048 (0.042)	1.11	0.266

Table 6

Comparison of total factor productivity change.

	Specialisation		Organic farming	
	Specific	Mixed or integrated	Yes	No
Mean total factor productivity change	0.037	−0.054	−0.036	0.023

organic farming was −0.054 and − 0.036, respectively, which indicates that the average productivity change was negative for the farms that adopted ecological protection approaches.

6. Discussion

6.1. *Technical efficiency and its determinants*

Average technical efficiency was estimated to be 71%, indicating that there is scope to increase technical efficiency by 29% in Swedish crop production through efficient use of inputs in production. Inefficient farms need to be more careful about choosing efficient inputs and using optimum amounts of inputs in their production process. For the same sector, Heshmati and Kumbhakar (1997) found technical efficiency of 62% for the period 1976–1988, indicating that technical efficiency has improved over time. Average technical efficiency of around 74% in different periods has been reported elsewhere (Cechura et al., 2014; Zhu and Lansink, 2010). In terms of determinants of technical efficiency, subsidies such as labour support, less favoured area subsidy and environment-friendly practices subsidy had negative effects on technical efficiency. This is possibly because subsidies are considered as extra income by farmers, which in turn affects production decisions and reduces technical efficiency. Due to the income and insurance effect of subsidies, motivation for improving efficiency might be lower among farms receiving subsidies. Farm support is a decoupled subsidy payment under the EU CAP that is paid to farms based on their area and entitlement. The positive impact of farm support on technical efficiency might be explained by the area- and entitlement-based conditions for securing this subsidy, e.g. farms might be motivated to earn more through efficient production and purchase more land. However, the effects of subsidies appeared to be inconsistent, confirming previous findings that subsidies have mixed effects (Latruffe et al., 2016; Minviel and Latruffe, 2016). Regions of Sweden differ in terms of weather, geographical and climate conditions, which affect production. The significant negative effect of the northern Sweden region on technical efficiency revealed that regional variations play an important role in determining technical efficiency, as reported previously (Barnes, 2008; McCloud and Kumbhakar, 2008; Hadley, 2006).

6.2. *Sources of total factor productivity change*

Mean total factor productivity change 2010–2016 was positive for the Swedish crop sector but the changes in its components were mixed, with mean technical efficiency change and mean technical change found to be negative, while mean scale change was positive. However, although mean technical efficiency change was negative overall, it was positive for some years between 2010 and 2016. Positive technical efficiency change on Swedish crop-producing farms has been reported previously (Rasmussen, 2010; Zhu and Lansink, 2010), although for different study periods. Farms may not be the same in different periods, so it is not easy to compare the results. Overall, however, the results indicate that positive efficiency change can be achieved on Swedish crop farms if action is taken to improve the efficiency of the most inefficient farms, although some previous studies have observed negative technical efficiency change (Darku et al., 2016; Cechura et al., 2014). Eco-friendly farms also experience the problem of declining technical efficiency, with Sauer and Park (2009) reporting negative change in the case of organic farms. While mean technical efficiency change in the present study was also negative, the value was very small (−0.4%), which means that it deducted little from total factor productivity change. This small but negative technical efficiency change could result from farms using fewer inputs than the optimal to get subsidies for environment-friendly practices, or from farms being located in areas where the environment or weather hampers crop production.

Technical change (progress) was negative for all years and consequently mean technical change was negative (−0.026 or − 2.6%). This result is not consistent with findings in the literature of positive mean technical change in different periods, but with negative change in some years within these periods (Mennig and Sauer, 2019; Rasmussen, 2010). Findings by Sauer and Park (2009) for organic farms support the negative technical change observed in this study. Our negative technical change values indicate that, for every year from 2010 to 2017, output of farms did not increase with respect to the previous year, and there was no declining shift in production technology in each year. The reason could be that the farms did not change their technology in the production process within the study period 2010–2016. They may have faced extreme weather conditions due to their location, rested more of their land or used fewer inputs to receive more financial support from the government.

Mean scale change in efficiency was positive (3.8%), which is consistent with findings by Rasmussen (2010), Darku et al. (2016), Sauer and Park (2009), Mennig and Sauer (2019) and Lansink et al. (2002). The magnitude of the scale component change outweighed the negative technical change, making total factor productivity change positive. Since crop production is subject to returns to scale, the positive change in scale efficiency indicates that, on average, the farms were operating at a technologically optimal scale of production by changing their scale with respect to the previous year.

Although total factor productivity change was positive overall, it was negative after 2012. This result is consistent with findings by Cechura et al. (2014) that mean total factor productivity change for the Swedish crop sector was negative within the period 2004–2011. Our main finding of overall positive mean total factor productivity change also confirms previous findings (Mennig and Sauer, 2019; Darku et al., 2016; Rasmussen, 2010). Values reported by Sauer and Park (2009) for Danish organic farms were similar to those in Table 6, i.e. mean total factor productivity change was negative for organic crop production. Total factor productivity change was positive overall in the present study because the positive scale change outweighed (by almost twofold) the negative technical change. This means that the average total factor productivity change in the Swedish crop sector between 2010 and 2016 was mainly driven by scale change and technical change.

6.3. *Effects of ecological protection approaches*

One of the novel contributions of this study was to evaluate how ecological protection approaches affect total factor productivity change. The results obtained do not support adoption of ecological protection approaches, owing to negative effects on total factor productivity change, as found in other studies (e.g. Sauer and Park, 2009; Lansink et al., 2002). A probable reason for the negative effect of using ecological approaches in production is the characteristics or components of particular ecological practices. For instance, organic farming does not permit chemical fertilisers, pesticides, insecticides or other plant protection chemicals, which means that crop production may face constraints in improving soil fertility or dealing with insect and pest attacks. Although less use of fertilisers and plant protection materials may improve soil health in the long term, it will not increase crop productivity in the particular year or in the short term. In mixed cropping, applying fertilisers or manures to a specific crop may be challenging and harvesting may be difficult for mixed crops, creating wastage. Waste accumulation and disease or pest attack in one crop can harm another. Crop-livestock integrated farming may also have higher labour requirements and demand more specialist knowledge, so labour shortages can harm the productivity of integrated farms. The existence of labour support in Sweden signals that labour is costly, as farms need labour costs to be subsidised.

7. Conclusions

Against a background of ecological degradation problems in conventional agriculture, this study examined total factor productivity change in the Swedish crop sector and sources driving this change. In a novel contribution filling an existing knowledge gap, it also evaluated the effect of ecological protection approaches on total factor productivity change. Stochastic frontier-based Malmquist factor productivity index was used to measure total factor productivity change, using farm-level panel data for the period 2010–2016 taken from the FADN dataset collected by the Swedish Board of Agriculture. A change pooled regression model was used to analyse the effect of ecological protection approaches on total factor productivity. The empirical results showed that the average technical efficiency of the Swedish crop sector was 71%, indicating that the sector could increase output by 29% with given inputs and technology. An important determinant of technical efficiency was farm support, which could be designed to increase technical efficiency. Being located in northern Sweden resulted in significant inefficiency for farms.

Total factor productivity change (0.7%) was positive over the whole study period, but there were variations in its three sources, i.e. technical efficiency change, technical change and scale change. Mean technical efficiency change and technical change for the period 2010–2016 were both negative, but scale change was positive, indicating that the farms were operating at increasing returns to scale on average. The positive value of total factor productivity change from 2010 to 2016 indicates that the total factor productivity of Swedish crop-producing farms increased in the period. If positive technical efficiency change and technical change can be achieved through improved efficiency and technological progress, higher positive total factor productivity change in the crop sector is possible in future.

The results also showed that farm specialisation, adoption of organic farming, and farm location in a less favoured area are important factors affecting the total factor productivity change, in a negative direction in almost all cases. In particular, farm specialisation in mixed cropping or integrated production and location in a less favoured (not mountain) area of Sweden had significant negative effects on total factor productivity change. As organic farming, mixed cropping and integrated crop-livestock farming are ecological protection approaches, these results indicate that adoption of ecological approaches has a negative effect on total factor productivity change. Ecological protection approaches can also help to achieve sustainability in crop production, however, making it necessary to incorporate eco-friendly approaches in production. Considering the findings on sources of total factor productivity change and the negative effect of ecological practices on productivity change, policies are urgently required to improve total factor productivity while also promoting widespread adoption of ecological approaches. Compensation or insurance against productivity loss due to adopting ecological approaches could make these approaches more acceptable to farmers.

Declaration of Competing Interest

The authors declare that they have no known competing financial interest or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

Acknowledgement

The authors would like thank the Swedish Board of Agriculture for granting access to the FADN dataset and to personnel who arranged seminars on use of the FADN dataset, on which this work was based. This work is supported by grant application *economic policy instruments to reduce greenhouse gas emissions from the Swedish food sector*, funded by a Swedish research council for sustainable development (FORMAS) (Funding registration number: 2020-00187).

References

Abman, R., Carney, C., 2020. Agricultural productivity and deforestation: evidence from input subsidies and ethnic favouritism in Malawi. J. Environ. Econ. Manag. 103, 102342.

Ahmed, M., Shams, N., 1998. Ecological input-costs in agricultural production in northwest Kampuchea. J. Sustain. Agric. 12 (4), 5–23.

Aigner, D., Lovell, C., Schmidt, P., 1977. Formulation and estimation of stochastic frontier production function models. J. Econ. 6 (1), 21–37.

Allison, R.E., 1973. Soil Organic Matter and its Role in Crop Production. Elsevier Scientific Publishing Co, pp. 277–376.

Anon, 2011. Our Life Insurance, our Natural Capital: An EU Biodiversity Strategy 2020. Available on. https://ec.europa.eu/environment/nature/biodiversity/comm2006/pdf/EP_resolution_april2012.pdf.

Archambault, S., 2004. Ecological modernization of the agriculture industry in southern Sweden: reducing emissions. J. Clean. Prod. 12, 491–503.

Arrow, K.J., Dasgupta, P., Goulder, L.H., Mumford, K.J., Oleson, K., 2012. Sustainability and the measurement of wealth. Environ. Dev. Econ. 17 (03), 317–353.

Baldoni, E., Coderoni, S., Esposti, R., 2017. The productivity and environment nexus with farm-level data. The case of carbon footprint in Lombardy FADN farms. Bio-based Appl. Econ. 6 (2), 119–137.

Balk, B.M., 2001. Scale efficiency and productivity change. J. Prod. Anal. 15 (3), 159–183.

Ball, V.E., Lovell, C.A.K., Luu, H., Nehring, R., 2004. Incorporating environmental impacts in the measurement of agricultural productivity growth. J. Agric. Resour. Econ. 29 (3), 436–460.

Barnes, A., 2008. Technical efficiency estimates of Scottish agriculture: a note. J. Agric. Econ. 59, 370–376.

Battese, G.E., Coelli, T.J., 1995. A model for technical inefficiency effects in a stochastic frontier production function for panel data. Empir. Econ. 20 (2), 325–332.

Batz, F.-J., Janssen, W., Peters, K.J., 2003. Predicting technology adoption to improve research priority-setting. Agric. Econ. 28, 151–164.

Baumgart-Getz, A., Prokopy, L.S., Floress, K., 2012. Why farmers adopt best management practice in the United States: a meta-analysis of the adoption literature. J. Environ. Manag. 96 (1), 17–25.

Boatman, N.D., Brickle, N.W., Hart, J.D., Morris, A.J., Murray, A.W.A., Murray, K.A., Robertson, P.A., 2004. Evidence for the indirect effects of pesticides on farmland birds. Ibis Intern. J. Avian Sci. 146, 131–143.

Bokusheva, R., Hockmann, H., Kumbhakar, S.C., 2012. Dynamics of productivity and technical efficiency in Russian agriculture. Eur. Rev. Agric. Econ. 39 (4), 611–637.

Brady, N.C., 1990. The Nature and Properties of Soils, 10th edition. Macmillan Publishing Co, New York.

Bragagnolo, C., Spolador, H., de Camargo Barros, G., 2010. Regional Brazilian agriculture TFP analysis: a stochastic frontier analysis approach. Economia 11 (4), 217–242.

Brittain, C.A., Vighi, M., Bommarco, R., Settele, J., Potts, S.G., 2009. Impacts of a pesticide on pollinator species richness at different spatial scales. Basic Appl. Ecol. 11, 106–115.

Brümmer, B., Glauben, T., Thijssen, G., 2002. Decomposition of productivity growth using distance functions: the case of dairy farms in three European countries. Am. J. Agric. Econ. 84 (3), 628–644.

Burke, M., Emerick, K., 2016. Adaptation to climate change: evidence from U.S. agriculture. Am. Econ. J. Econ. Pol. 8 (3), 106–140.

Castellazzi, M.S., Wood, G.A., Burgess, P.J., Morris, J., Conrad, K.F., Perry, J.N., 2008. A systematic representation of crop rotations. Agric. Syst. 97, 26–33.

Cechura, L., Grau, A., Hockmann, H., Kroupova, Z., Levkovych, I., 2014. Total Factor Productivity in European Agricultural Production. Compete Working Paper N9, pp. 1–60. Available on: http://www.compete-project.eu/fileadmin/compete/files/working_paper/COMPETE_Working_Paper_9_TPF_in_Agriculture.pdf.

Chaston, K.A., Gollop, F.M., 2002. The effect of surface water and groundwater regulation on productivity growth in the farm sector. In: Ball, V.E., Norton, G.W. (Eds.), Agricultural Productivity: Measurement and Sources of Growth. Kluwer Academic Publishers, Boston, pp. 277–292.

Chongtham, I.R., Bergkvist, G., Watson, C.A., Sandström, E., Bengtsson, J., Öborn, I., 2016. Factors influencing crop rotation strategies on organic farms with different time periods since conversion to organic production. Biol. Agric. Hortic. 33 (1), 14–27.

Coderoni, S., Esposit, R., 2013. Is there a long-term relationship between agricultural GHG emissions and productivity growth? A dynamic panel data approach. Environ. Resour. Econ. 58 (2), 273–302.

Coelli, T., Rahman, S., Thirtle, C., 2003. A stochastic frontier approach to total factor productivity measurement in Bangladesh crop agriculture, 1961-92. J. Int. Dev. 15, 321–333.

Coelli, T.J., Rao, D.S.P., 2005. Total factor productivity growth in agriculture: a Malmquist index analysis of 93 countries, 1980–2000. Agric. Econ. 32 (1), 115–134.

Coelli, T.J., Rao, D.S.P., O'Donnell, C.J., 2006. An Introduction to Efficiency and Productivity Analysis. Springer-Verlag Inc, Dordrecht/New York.

Coomes, O.T., Barham, B.L., MacDonald, G.K., Ramankutty, N., Chavas, J.P., 2019. Leveraging total factor productivity growth for sustainable and resilient farming. Nature Sustainabil. 2, 22–28.

Darku, A.B., Malla, S., Tran, K.C., 2016. Sources and measurement of agricultural productivity and efficiency in Canadian provinces: crops and livestock. Can. J. Agric. Econ. 64, 49–70.

Das, T.K., Nath, C.P., Das, S., Biswas, S., Bhattacharyya, R., Sudhishri, S., Raj, R., Singh, B., Kakralia, S.K., Rathi, N., Sharma, A.R., Dwivedi, B.S., Biswas, A.K., Chaudhari, S.K., 2020. Conservation agriculture in rice-mustard cropping system for five years: impacts on crop productivity, profitability, water-use efficiency, and soil properties. Field Crop Res. 250, 1–12.

De Cara, S., Houzé, M., Jayet, P.-A., 2005. Methane and nitrous oxide emissions from agriculture in the EU: a spatial assessment of sources and abatement costs. Environ. Resour. Econ. 32 (4), 551–583.

De Snoo, G.R., Herzon, I., Staats, H., Burton, R.J., Schindler, S., van Dijk, J., Musters, C.J. M., 2013. Toward effective nature conservation on farmland: making farmers matter. Conserv. Lett. 6 (1), 66–72.

Dessart, F., Barreiro-Hurle, J., van Bavel, R., 2019. Behavioural factors affecting the adoption of sustainable farming practices: a policy oriented review. Eur. Rev. Agric. Econ. 46 (3), 417–471.

Dietz, S., Stern, N., 2015. Endogenous growth, convexity of damage and climate risk: how Nordhaus' framework supports deep cuts in carbon emissions. Econ. J. 125 (583), 574–620.

Dima, S.J., Odero, A.N., 1997. Organic farming for sustainable agricultural production. Environ. Resour. Econ. 10, 177–188.

Egodawatta, W.C.P., Sangakkara, U.R., Stamp, P., 2012. Impact of green manure and mineral fertilizer inputs on soil organic matter and crop productivity in a sloping landscape of Sri Lanka. Field Crop Res. 129, 21–27.

Emvalomatis, G., 2011. Productivity growth in German dairy farming using a flexible modelling approach. J. Agric. Econ. 63, 83–101.

Färe, R., Grosskopf, S., Norris, M., Zhang, Z., 1994. Productivity growth, technical progress and efficiency changes in industrialised countries. Am. Econ. Rev. 84, 66–83.

Färe, R., Grosskopf, S., Noh, D.W., Weber, W., 2005. Characteristics of a polluting technology: theory and practice. J. Econ. 126 (2), 469–492.

Florian, V., Rosu, E., 2020. Ecological farming- rural realities, socio-ecological arguments and comments: CLUJ county case study. Agric. Econ. Rural Develop. XVII 1, 101–112.

Government Offices (GO), 2000. The Environmental and Rural Development Plan for Sweden 2000–2006. Swedish Ministry of Agriculture, Food and Fisheries. Available on. https://www.government.se/con-tentassets/eec500b6a0f449e493d3fa682fcde9de/the-environmental-and-rural-development-plan-for-sweden-2000-2006.

Government Offices (GO), 2014. The Farm Support 2015–2020, – Proposal for Swedish Implementation, Ds 2014, p. 6. Available on: https://www.riksdagen.se/sv/dokument-lagar/dokument/departementsserien/gardsstodet-2015-2020_H2B46/html.

Hadley, D., 2006. Patterns in technical efficiency and technical change at the farm-level in England and Wales, 1982–2002. J. Agric. Econ. 57, 81–100.

Han, H., Zhang, X., 2020. Exploring environmental efficiency and total factor productivity of cultivated land use in China. Sci. Total Environ. 726, 1–15.

Heshmati, A., Kumbhakar, S.C., 1997. Estimation of technical efficiency in Swedish crop farms: a pseudo panel data approach. J. Agric. Econ. 48 (1), 22–37.

Jaeck, M., Lifran, R., 2013. Farmers' preferences for production practices: a choice experiment study in the Rhone river delta. J. Agric. Econ. 65 (1), 112–130.

Jin, S., Ma, H., Huang, J., Hu, R., Rozelle, S., 2010. Productivity, efficiency and technical change: measuring the performance of China's transforming agriculture. J. Prod. Anal. 33 (3), 191–207.

Kabii, T., Horwitz, P., 2006. A review of landholder motivations and determinants for participation in conservation covenanting programmes. Environ. Conserv. 33 (1), 11–20.

Kaminski, J., Kan, I., Fleischer, A., 2013. A structural land-use analysis of agricultural adaptation to climate change: a proactive approach. Am. J. Agric. Econ. 95 (1), 70–93.

Karagiannis, G., Tzouvelekas, V., 2005. Explaining output growth with a heteroscedastic non-neutral production frontier: the case of sheep farms in Greece. Eur. Rev. Agric. Econ. 32 (1), 51–74.

Kleijn, D., Baquero, R.A., Clough, Y., Diaz, M., Esteban, J., de Fernandez, F., Gabriel, D., Herzog, F., Holzschuh, A., Johl, R., Knop, E., Kruess, A., Marshall, E.J.P., Steffan-Dewenter, I., Tscharntke, T., Verhulst, J., West, T.M., Yela, J.L., 2006. Mixed biodiversity benefits of Agri-environment schemes in five European countries. Ecol. Lett. 9 (3), 243–257.

Kleijn, D., Bommarco, R., Fijen, T.P.M., Garibaldi, L.A., Potts, S.G., van der Putten, W.H., 2019. Ecological intensification: bridging the gap between science and practice. Trends Ecol. Evol. 34 (2), 154–166.

Knowler, D., Bradshaw, B., 2007. Farmers' adoption of conservation agriculture: a review and synthesis of recent research. Food Policy 32 (1), 25–48.

Kononova, M.M., Nowakawski, T.Z., Newman, A.C.D., 1966. Soil Organic Matter: Its Nature, its Roles in Soil Formation and in Soil Fertility. Pergamon Press, London and New York, pp. 183–228.

Kumbakhar, S.C., Heshmati, A., 1995. Efficiency measurement in Swedish dairy farms: an application of rotating panel data, 1976–88. Am. J. Agric. Econ. 77, 660–674.

Lansink, A.O., Pietola, K., Backman, S., 2002. Efficiency and productivity of conventional and organic farms in Finland 1994-1997. Eur. Rev. Agric. Econ. 29 (1), 51–65.

Latruffe, L., Bravo-Ureta, B.E., Carpentier, A., Desjeux, Y., Moreira, V.H., 2016. Subsidies and technical efficiency in agriculture: evidence from European dairy farms. Am. J. Agric. Econ. 99 (3), 783–799.

Lee, J.C., Menalled, F.D., Landis, D.A., 2001. Refuge habitats modify impact of insecticide disturbance on carabid beetle communities. J. Appl. Ecol. 38, 472–483.

Letta, M., Tol, R.S.J., 2018. Weather, climate and total factor productivity. Environ. Resour. Econ. 73, 283–305.

Mary, S., 2013. Assessing the impacts of pillar 1 and 2 subsidies on TFP in French crop farms. J. Agric. Econ. 64 (1), 133–144.

McCloud, N., Kumbhakar, S.C., 2008. Do subsidies drive productivity? A cross-country analysis of Nordic dairy farms. In: Chib, S., Griffiths, W., Koop, G., Terrell, D. (Eds.), Bayesian Econometrics: Advances in Econometrics. Emerald group publishing limited.

Meeusen, W., van den Broeck, J., 1977. Efficiency estimation from cobb-Douglas production functions with composed error. Int. Econ. Rev. 8 (2), 435.

Mennig, P., Sauer, J., 2019. The impact of Agri-environment schemes on farm productivity: a DID-matching approach. Eur. Rev. Agric. Econ. 47 (3), 1045–1093.

Minviel, J.J., Latruffe, L., 2016. Effect of public subsidies on farm technical efficiency: a meta-analysis of empirical results. Appl. Econ. 49 (2), 213–226.

Moore, F.C., Diaz, D.B., 2015. Temperature impacts on economic growth warrant stringent mitigation policy. Nat. Clim. Chang. 5 (2), 127–131.

Morgan, R.P.C., 2005. Soil Erosion and Conservation. Blackwell Publishing, Malden, MA.

Nijuki, E., Bravo-Ureta, B.E., O'Donnell, C.J., 2018. Decomposing agricultural productivity growth using a random-parameters stochastic production frontier. Empir. Econ. 57 (3), 839–860.

Njuki, E., Bravo-Ureta, B.E., Cabrera, V.E., 2020. Climate effects and total factor productivity: econometric evidence for Wisconsin dairy farms. Eur. Rev. Agric. Econ. 47 (2), 1276–1301.

Nykvist, B., 2014. Does social learning lead to better natural resource management? A case study of the modern farming community of practice in Sweden. Soc. Nat. Res. Int. J. 27 (4), 436–450.

O'Donnell, C.J., 2012. An aggregate quantity framework for measuring and decomposing productivity change. J. Prod. Anal. 38 (3), 255–272.

OECD, 2008. Environmental Performance of Agriculture in OECD Countries since 1990. OECD, Paris.

Orea, L., 2002. Parametric decomposition of a generalized Malmquist productivity index. J. Prod. Anal. 18 (1), 5–22.

Organization for Economic Co-operation and Development (OECD), 2018. Innovation, Agricultural Productivity and Sustainability in Sweden. OECD publishing. Available on, OECD Food and Agricultural Reviews, Paris. https://doi.org/10.1787/9789264085268-en.

Ottmann, G.S., Renzi, D.G., Miretti, A., Spiaggi, E., 2013. Sustainability of production practices from an agro-ecological perspective in two farms, Santa fe province, Argentina. Agroecol. Sustain. Food Syst. 37 (4), 430–443.

Owusu-Sekyere, E., Abdulai, A., Jordaan, H., Hansson, H., 2020. Heterogeneous demand for ecologically sustainable products on ensuring environmental sustainability in South Africa. Environ. Econ. Policy Stud. 22, 39–64.

Pannell, D.J., Marshall, G.R., Barr, N., Curtis, A., Vanclay, F., Wilkinson, R., 2006. Understanding and promoting adoption of conservation practices by rural landholders. Aust. J. Exp. Agric. 46 (11), 1407–1424.

Pasztor, J., Kristoforson, L.A., 1990. Bioenergy and the Environment. Westview Studies in Natural Resource and Energy Management, Westview Press, Colorado.

Pimentel, D., Burgess, M., 2013. Soil erosion threatens food production. Agriculture 3 (3), 443–463.

Plastina, A., Lence, S.H., 2018. A parametric estimation of total factor productivity and its components in U.S. agriculture. Am. J. Agric. Econ. 100 (4), 1091–1119.

Pretty, J., 2005. Sustainability in agriculture: Recent progress and emergent challenges. In: Hester, R.E., Harrison, R.M. (Eds.), Sustainability in Agriculture. RSC, Cambridge, pp. 1–15.

Prokopy, L.S., Floress, K., Klotthor-Weinkauf, D., Baumgart-Getz, A., 2008. Determinants of agricultural best management practice adoption: evidence from the literature. J. Soil Water Conserv. 63 (5), 300–311.

Rada, N., 2013. Assessing Brazil's cerrado agricultural miracle. Food Policy 38, 146–155.

Rada, N., Buccola, S., 2012. Agricultural policy and productivity: evidence from Brazilian censuses. Agric. Econ. 43, 353–365.

Rada, N., Helfand, S., Magalhaes, M., 2019. Agricultural productivity growth in Brazil: large and small farms excel. Food Policy 84, 176–185.

Rae, A.N., Ma, H., Huang, J., Rozelle, S., 2006. Livestock in China: commodity specific total factor productivity decomposition using new panel data. Am. J. Agric. Econ. 88 (3), 680–695.

Rasmussen, S., 2010. Scale efficiency in Danish agriculture: an input distance-function approach. Eur. Rev. Agric. Econ. 37 (3), 335–367.

Röös, E., Mie, A., Wivstad, M., Salomon, E., Johansson, B., Gunnarssonm, S., Wallenbeck, A., Hoffmann, R., Nilsson, U., Sundberg, C., Watson, C.A., 2018. Risks and opportunities of increasing yields in organic farming. A review. Agron. Sustain. Dev. 38 (2), 14–34.

Russell, E.J., 1988. Russell's Soil Conditions and Plant Growth, 11th edition. Longman and John Wiley & Sons, New York.

Rydberg, N.T., Milberg, P., 2000. A survey of weeds in organic farming in Sweden. Biol. Agric. Hortic.: Intern. J. Sustain. Product. Syst. 18 (2), 175–185.

Sanders, R., 2006. A market road to sustainable agriculture? Ecological agriculture, green food and organic agriculture in China. Dev. Chang. 37 (1), 201–226.

Sauer, J., Park, T., 2009. Organic farming in Scandinavia-productivity and market exit. Ecol. Econ. 68, 2243–2254.

Schoonhoven, Y., Runhaar, H., 2018. Conditions for the adoption of agro-ecological farming practices: a holistic framework illustrated with the case of almond farming in Andalusia. Int. J. Agric. Sustain. 16 (6), 442–454.

Seo, S.N., 2013. An essay on the impact of climate change on US agriculture: weather fluctuations, climatic shifts, and adaptation strategies. Clim. Chang. 121 (2), 115–124.

Shi, T., 2004. Operationalizing sustainability: an emerging eco-philosophy in Chinese ecological agriculture. J. Sustain. Agric. 24 (4), 113–131.

Shukla, A.N., Rajan, V., 1996. Towards ecological farming in India for poverty alleviation, environmental regeneration, and political stabilization. J. Sustain. Agric. 6 (4), 61–96.

Skevas, T., Lansink, A.O., 2014. Reducing pesticide use and pesticide impact by productivity growth: the case of Dutch arable farming. J. Agric. Econ. 65 (1), 191–211.

Skevas, T., Stefanou, S.E., Lansink, A.O., 2013. Do farmers internalise environmental spillovers of pesticides in production? J. Agric. Econ. 64, 624–640.

Smits, M.J., Driessen, P., Glasbergen, P., 2008. Governing Agri-environmental schemes: lessons to be learned from the new institutional economics approach. Environ. Plann. C: Govern. Policy 26 (3), 627–643.

Song, W., Han, Z., Deng, X., 2016. Changes in productivity, efficiency and technology of China's crop production under rural restructuring. J. Rural. Stud. 47, 563–576.

Stern, N., 2007. The Economics of Climate Change: The Stern Review. Cambridge University Press, Cambridge, UK.

Swedish Board of Agriculture, 2018. Attractive Countryside National Action Plan for the Rural Program 2014–2020 for the Year 2019. Record number: 6.2.17–17854/2018. Available on: https://www2.jordbruksverket.se/download/18.7f12ae1f16b63406191e55a9/1560948616970/ovr500.pdf.

Tirado, R., 2009. Defining Ecological Farming. Greenpeace Research Laboratories Technical Note 04/2009. Available on: https://www.greenpeace.to/publications/Defining-Ecological-Farming-2009.pdf.

Tittonell, P., 2013. Farming Systems Ecology. Towards Ecological Intensification of World Agriculture. Inaugural Lecture upon Taking up the Position of Chair in Farming Systems Ecology at Wageningen University on 16 May 2013. Available on: http://www.wageningenur.nl/en/show/Feeding-the-world-population-sustainably-andefficiently-with-ecologically-intensive-agriculture.htm.

Tscharntke, T., Klein, A.M., Kruess, A., Steffan-Dewenter, I., Thies, C., 2005. Landscape perspectives on agricultural intensification and biodiversity-ecosystem service management. Ecol. Lett. 8 (8), 857–874.

Uyttenbroeck, R., Hatt, S., Paul, A., Boeraeve, F., Piqueray, J., Francis, F., Danthine, S., Frederich, M., Dufrêne, M., Bodson, B., Monty, A., 2016. Pros and cons of flowers strips for farmers. A review. Biotechnol. Agron. Soc. Environ. 20, 225–235.

Wang, S.L., Ball, V.E., Fulginiti, L.E., Plastina, A., 2012. Accounting for the impact of local and spill-in public research, extension and roads in U.S. regional agricultural productivity, 1980–2004. In: Fuglie, K.O., Wang, S.L., Ball, V.E. (Eds.), Productivity Growth in Agriculture: An International Perspective. CAB International, Wallingford, UK, pp. 13–32.

Wang, S.L., Plastina, A., Fulginiti, L.E., Ball, V.E., 2017. Benefits of public R & D in U.S. agriculture: spill-ins, extension, and roads. Theoret. Econ. Lett. 7, 1873–1898. https://doi.org/10.4236/tel.2017.76128.

World Bank, 2019. Life Expectancy at Birth, Total (Years)-Sweden. Available on. https://data.worldbank.org/indicator/SP.DYN.LE00.IN?locations=SE.

Ye, X.J., Wang, Z.Q., Li, Q.S., 2002. The ecological agriculture movement in modern China. Agric. Ecosyst. Environ. 92, 261–281. https://doi.org/10.1016/S0167-8809(01)00294-8.

Zhengfei, G., Lansink, A.O., 2006. The source of productivity growth in Dutch agriculture: a perspective from finance. Am. J. Agric. Econ. 88, 644–656. https://doi.org/10.1111/j.1467-8276.2006.00885.x.

Zhu, X., Lansink, A.O., 2010. Impact of CAP subsidies on technical efficiency of crop farms in Germany, the Netherlands and Sweden. J. Agric. Econ. 61 (3), 545–564. https://doi.org/10.1111/j.1477- 9552.2010.00254.x.