# Efficiency Analysis of Organic Farming Systems – A Review of Concepts, Topics, Results and Conclusions

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## Abstract

*This article summarizes the literature on efficiency and productivity of organic farming. We distinguish between studies that concentrate on specific problems of the organic sector and studies that compare conventional and organic farms. Organic farms can on average improve their efficiency by 21%-points (SFA) and 27%-points (DEA). In comparing efficiency and productivity of organic with conventional farms sample selection is a major challenge, since the organic farms have a different farm-structure and are often represented by a relatively small number of observations. In studies taking into account selectivity problems organic farms are on average 4%-points less efficient than conventional farms. In four of five studies, organic farms are less productive than conventional farms and productivity is for about 20%-points lower than on conventional farms, which fits the results of yield comparisons. Efficiency influences the decision to convert to organic farming, but it is an empirical question, whether this influence is positive or negative. The impact of subsidies on farm level efficiency is found to be negative in most studies. Organic farms show the same or a higher degree of efficiency if environmental variables are taken into account.*

## Key Words

*organic farming; technical efficiency; environmental efficiency; productivity; farming systems; subsidies*

## 1 Introduction

Organic farming has been investigated and compared to conventional farms extensively using productivity and efficiency analysis. Nonetheless, so far a comprehensive overview and a summary of the literature on the efficiency and productivity of organic farming is missing. Thus, important questions that motivate productivity and efficiency studies on organic farming have only been answered on a case by case basis. A comprehensive overview and synthesis can provide some empirical evidence to contribute to the following questions:

First, to what extent is organic farming less productive than conventional farming (BADGLEY et al., 2007; DE PONTI et al., 2012; PONISIO et al., 2014; SEUFERT et al., 2012) and can organic farming provide solutions to international agricultural development problems (IAASTD, 2009; FORESIGHT, 2011; GERMAN COUNCIL FOR SUSTAINABLE DEVELOPMENT, 2011). Efficiency and productivity analysis can contribute to this debate by investigating productivity differences at the farm level and identifying the determinants of these differences.

Second, organic farming is supported by a variety of policies in the European Union (EU) and elsewhere (HÄRING et al., 2004; STOLZE and LAMPKIN, 2009; SCHWARZ et al., 2010). In 12 of 27 member states of the EU, policy makers have gone so far as to establish quantitative goals for the share of organic farming in their countries' agricultural sectors (SANDERS and METZE, 2011). Are such policies well-advised? The general efficiency literature demonstrates that subsidies systematically influence production decisions as well as farm efficiency and productivity (MCCLOUD and KUMBHAKAR, 2007; HENNINGSEN et al., 2011; MINVIEL and LATRUFFE, 2013). To design an efficient policy we need to understand how farm-productivity is affected by different types of support.

Finally, organic farming is based on the principle of environmentally sound production (STOLZE et al. 2000). Positive effects of organic farming on e.g. biodiversity have been documented in the literature (HOLE et al., 2005). But to date there are only few empirical studies on how efficient organic farms are at 'producing' environmental benefits compared to conventional farms.

Consequently, a comprehensive review of the literature on the efficiency and productivity organic farming has the potential to make an important contribution to better informed policy decisions and to a better understanding of organic farming in general as a system with agronomic, economic, and environmental dimensions.

The objective of this article is to summarize the main findings and conclusions on productivity and efficiency in organic farming systems and on efficiency and productivity comparisons between organic and conventional farms. To analyze and compare productivity and efficiency of farming systems, a formal and theory based method is necessary, which uses appropriate data-sets for a comparison. Therefore, an additional objective of this study is to describe and critically reflect the methodological procedures in the specific area and to highlight research potential and shortcomings of the existing studies in the field.

As the basis for our analysis we use published journal articles, 25 in indexed journals and six in non-indexed journals. We also present eight selected peer-reviewed conference papers and two dissertations in the area, which cover important topics and provide insights that are not covered by the journal articles. Overall, our overview is based on 41 publications. We did systematic literature searches in the databases of Ingenta Connect (http://www.ingentaconnect.com), Scholar Google (https://scholar.google.de) and Agecon Search (http://ageconsearch.umn.edu). Most of the studies have a regional focus in Western Europe (14), Southern Europe (12), Scandinavia (seven) and the United States (four), but we also include one study from Turkey, one from Egypt, one from Nepal and one from India. In general, we distinguish between studies that investigate only a group of organic farms from studies that compare organic and conventional farms. 12 of the 41 studies work exclusively with organic data sets; the other 29 studies compare conventional and organic farms in terms of efficiency and productivity.

# 2 Overview of Concepts and Methods

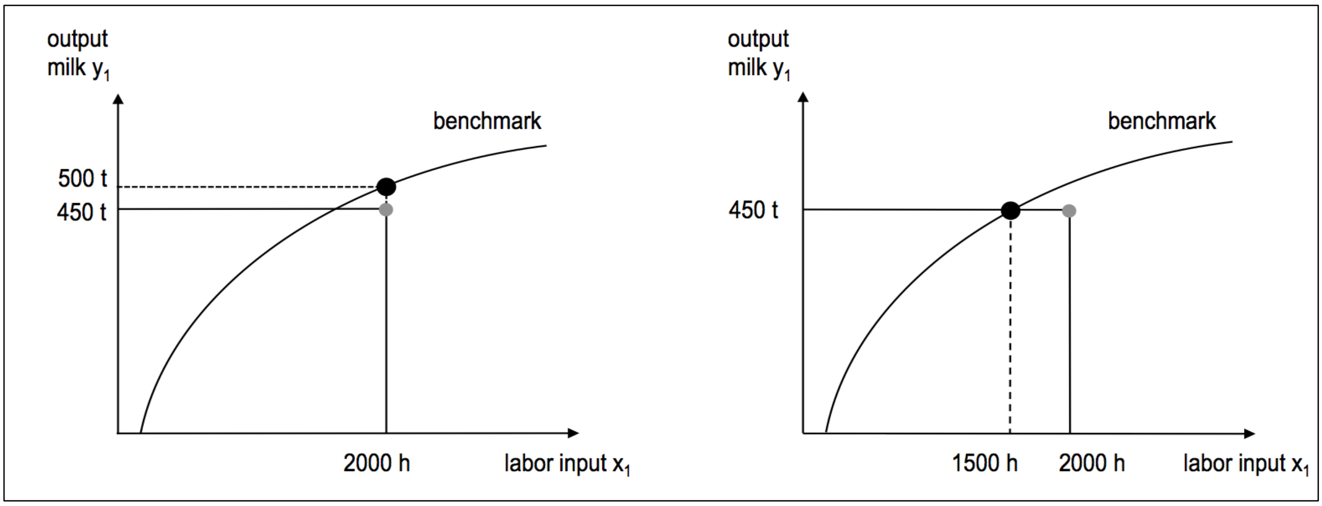
## 2.1 Productivity and Efficiency Concepts

The definitions of productivity and efficiency differ depending on the research area. NOFTSGER and ST-PIERRE (2003) as an example from animal sciences define gross feed efficiency as kilograms milk per kilogram dry matter intake and analogously they define gross nitrogen efficiency as milk nitrogen relative to nitrogen intake. In the same fashion, MARANVILLE et al. (1980) from crop sciences calculate nitrogen efficiency as total dry matter or total grain yield per nitrogen unit uptake. RATHKE et al. (2006) (as another example from crop science) define nitrogen efficiency as '*produced seed dry weight per unit of accumulated N-fertilizer*'. They all define efficiency as output y relative to input x in a production process.

In economics such a relation is defined as *productivity* and not as *efficiency*. Consequently, in the above cases economists would talk about *feed* or *nitrogen productivity*. Economists' interpret, for example, grain yield (in tons per hectare) as (land-) productivity – grain output relative to the input land. Other examples are milk yield per cow and ploughed hectares per day of labour.[1] We now introduce some more terms from economic production theory, which are used in the Sections below. Economists characterize a technology as the *transformation* of *inputs* into *outputs*. This can be conceptualized by a *production function* which relates inputs to outputs and which, thus, can be characterized by e.g. *partial* and *global productivities.* For *partial productivity*, Figure 1 presents the relation of milk output to the input of labour used to produce the milk. For estimating partial productivity from a sample of observations only the labour input varies whereas all other inputs, e.g. number of cows, fodder, and non-milk output such as calves and organic fertilizer are hold constant. A *marginal* (partial) *productivity* is defined as the marginal increase of output due to a marginal increase of a single input. We can also derive a unit-free measure for marginal productivity, by relating the percentage change of output due to a percentage change of inputs: If a farm increases one single input (such as e.g. labour, land or capital) by 1.0%, the output grows by 0.22%. In this case the (partial) *elasticity of output with respect to one input* (CHAMBERS, 1988) amounts to 0.22. We can also describe a production system by its global productivity change: based on the econometric estimates for the production function, one can compute the percentage change of output, if all inputs at the same time are increased by 1%. This figure is called '*scale elasticity*' (SE) or '*returns to scale'* (RTS) (CHAMBERS, 1988). A scale elasticity of e.g. 0.97 shows that by increasing *all* inputs by 1.0% the output would be increased by 0.97%. SE above 1.0 indicate a potential for structural change (e.g. fusion

[1] '*Productivity*' should not be confused with the term '*input intensity*' in economics. Input intensity is the quantity of one input relative to another input, e.g. nitrogen per hectare or labour hours per dairy cow are input intensities.

**Figure 1a and 1b. Output and input oriented technical efficiency**




Source: authors

of two farms or growth of a single farm), since output is increasing by relatively more than the input increases. After having introduced some terms on productivity, we now turn to aspects of efficiency in economic production theory.

In contrast to animal or plant science, economists describe *efficiency* e.g. as an 'outcome' relative to a benchmark. For example, a farm producing 4.5 tons per hectare has an efficiency of 90% if the benchmark yield is 5.0 tons per hectare. In this case, an efficiency score of 90% means that the outcome is 10%-points worse than the benchmark. A labour efficiency of 90% means that, e.g. the milk yield of some observed herd or farm is 10%-points lower than the benchmark yield for the same level of labour input. In Figure 1a, the benchmark is represented by the production function and amounts to 500 tons of milk for a herd at the labour level of $x_1$, i.e. 2 000 hours per year. The observed 'outcome' for some other herd that also uses $x_1$ (2 000 hours per year) is 450 tons milk, i.e. 50 tons below the benchmark. Consequently, this so called '*output-oriented*' efficiency for the outcome observation is 450/500=90% (as in Figure 1a).

Furthermore, this efficiency can also be calculated in the x-coordinate dimension (see Figure 1a and 1b). In Figure 1b, the actual 'outcome' uses 2 000 labour hours to produce $y_1$ while 1 500 hours are sufficient on the benchmark level. In the '*input-orientation*' the efficiency is 1 500/2 000=75%. In addition, several inputs and/or several outputs can be incorporated in the analysis simultaneously.

For empirical efficiency analysis actual 'outcomes' can be on one hand output and input quantities and on the other hand profits or costs. The determination of the benchmark is the core objective in efficiency analysis. The benchmark or the 'frontier' – representing a function of potential benchmarks – can be found by econometric estimation or mathematical programming based on all or a selection of sample farms.

Efficiency is computed as a relative measure, the 'outcome' of some entity, e.g. a farm, relative to some benchmark. Most studies estimate the so-called *technical efficiency*, which relates farms' physical outcomes of a production process or productivities, such as milk output per labour or grain yield per hectare. Efficiency can also be calculated for farms' revenues, costs, profits or some environmental 'outcomes'. Then, e.g. *profit efficiency* per hectare of land or per full-time worker per year describes some actual profit relative to some benchmark profit. Often monetary variables allow for easy aggregation of several inputs or outputs such that technical efficiency might be calculated for an output variable that is measured as revenue. The classical efficiency analysis estimates or calculates the potential Pareto improvement of a firm. With the existence of externalities, a classical efficiency measure might be misleading (DREESMAN, 2007). The concept of *environmental efficiency* incorporates such externalities using one or more environmental indicators in addition to the 'usual' inputs and outputs. We will explain some details on the concept of environmental efficiency in Section 2.4.

Besides technical efficiency, so-called *allocative efficiency* can be computed too. Allocative efficiency can be roughly said to show a farm's adjustment to market prices. For example, under certain conditions it is profit-reducing to produce output for marginal costs (per unit) that are higher than the value of the output (per unit), which can be measured by its market price. The closer the actual production quantity to the optimal quantity the higher is the allocative efficiency. Another example is the combination of inputs that are – at least partially – substitutes in the production process. The optimal bundle of inputs, thus, must take into account input prices – intuitively, a cheap input should be used relatively more than an expensive (substitutable) input. The closer the chosen input bundle of a farm to the optimal bundle the higher is the allocative efficiency.

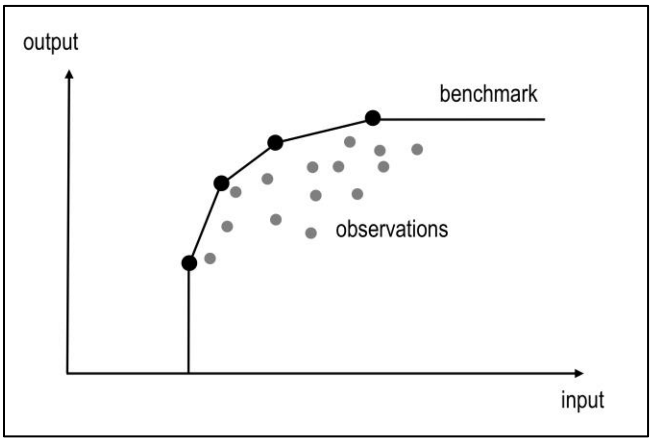
In the following two Sections we present the main model-approaches to analyze productivity and efficiency. They mainly differ in the construction of the frontier function.

## 2.2 Non-parametric Methods: Data Envelopment Analysis (DEA)

The *Data Envelopment Analysis (DEA)*, first developed by CHARNES et al. (1978), is a non-parametric method used to measure the productivity and efficiency of a decision making unit (DMU) based on linear optimization. In the DEA the benchmark function – often referred to as '*frontier*' – is estimated from the observations via an optimization condition. So the best observed DMUs define the so-called '*best practice frontier*' (COELLI et al., 2005).

The following Figure 2 illustrates a DEA benchmark for producing one output with one input. The benchmark is constructed from benchmark observations that have the highest yield for their input level. The linear Sections of the benchmark (function) are convex combinations of the benchmark observations resulting in a higher yield than the non-benchmark observations for the same input level. In other words,

**Figure 2. Benchmark function of the Data Envelopment Analysis (DEA)**




Source: authors

the benchmark observations get positive weights which sum to one and these weighted combinations draw the lines between benchmark observations. For an algebraic formulation of the linear program we refer the interested reader to the seminal text books of (THANASOULIS, 2001; COELLI et al., 2005).

The advantage of the DEA is the straightforward interpretation and the ability to get results with few observations. For DEA models it is not necessary to define a functional form for the production or any other function. Statistical inference can be applied via *bootstrapping techniques* (SIMAR and WILSON, 2000; BRÜMMER, 2001), which are non-parametric resampleing methods.

Weaknesses of DEA are that random impacts on the observations (e.g. measurement error) are treated as real and deterministic and that few observations may heavily influence the level of the frontier. For example, in Figure 2 only the most right observation on the frontier determines the benchmark level for the four most right observations in the sample. If this single observation is an outlier in the data the efficiency measures are highly biased.

Besides the core production variables, there is a number of factors that influence the technical efficiency of farms, often referred to as 'determinants of technical efficiency'. The DEA-framework does not allow to directly include such environmental variables or determinants into the frontier estimation. Many studies include a second stage-estimation of determinants of technical efficiency by a tobit-model. In the last years, there has been a debate, which models are appropriate for the second-stage estimation (HOFF, 2007; SIMAR and WILSON, 2007; MCDONALD, 2009). SIMAR and WILSON (2007) as well as MCDONALD (2009) criticise the extensive use of tobit-models and argue that the data-generating process (DGP) of the TE-scores should be analysed, in order to find a consistent estimation method.

## 2.3 Parametric Methods: Stochastic Frontier Analysis (SFA)

In the *Stochastic Frontier Analysis (SFA)* the benchmark is estimated through regression analysis. Developed by AIGNER et al. (1977) and MEEUSEN and BROEK (1977), SFA allows for estimating firm-specific technical efficiency conditional to the specification of a production function and distributional assumptions for the composed error term.

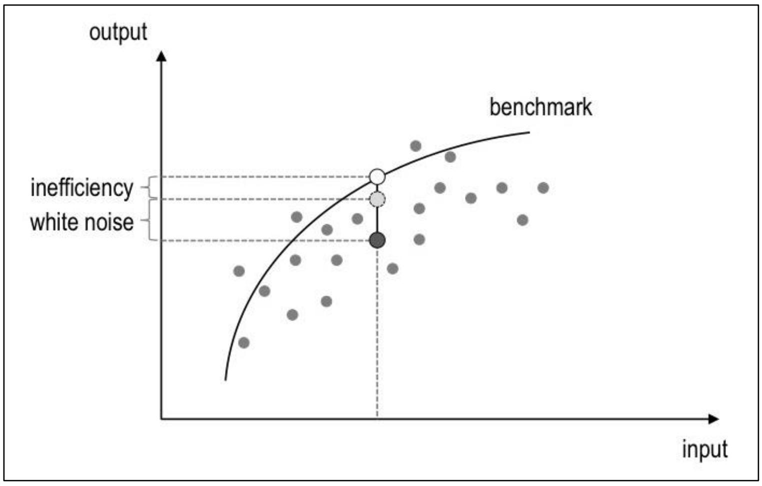
As a regression technique SFA accounts for the stochastic nature of most data sets by means of an error term. The error term does not only represent measurement error and the impact of missing explanatory variables (as in common basic regression analysis). The SFA error term also accounts for the inefficiency. Consequently, the error term is composed by two terms $v$ and $u$. The first $v$ represents the 'common' white noise in regression models caused by effects that are not under the control of the farmer, such as luck, unforseen events or weather disasters, while the second term $u$ represents an observation's inefficiency. A SFA model might be compactly written as:

$$y = f(x;\beta) * e^{w} = f(x;\beta) * e^{v-u}$$

where $y$ is a farm's output and $x$ is a vector of production inputs. The functional form specification $f(\cdot)$ for the production function should be sufficiently flexible in order to avoid miss-specification. $\beta$ denotes the vector of coefficients for the production function to be estimated. The first (white noise) error term $v$ is assumed to be identically and independently normally distributed: $v \sim iid\ N(0, \sigma_v^2)$. The second (inefficiency) error term $u$ captures the non-negative farm-specific inefficiency; one can assume different distributions for the inefficiency term such as half-normal-, truncated-normal- or gamma-distribution (KUMBHAKAR and LOVELL, 2000).

The following Figure 3 illustrates the SFA model. The filled dots in Figure 3 represent the observed data. The benchmark is estimated from the data, its curvature follows from the assumed functional relationship $f(\cdot)$ between input and output and the estimated coefficients $\beta$. The regression accounts for the assumptions of the two error terms and finds the $\beta$ with the best statistical fit – given the functional form of the production function. We have chosen one observation to explain the error composition: the observation is defined by its input- and output-coordinates given by the vertical line and the lowest horizontal line. Since we measure output-oriented inefficiency here, the vertical distance – some kind of an output gap – from the benchmark is relevant. However, in contrast to DEA, this gap is not only influenced by inefficiency but also by white noise. Unfortunately, neither the first nor the latter can be observed, but they can be estimated within the SFA. For our exemplary observation we may get a negative error term $v$ for the white noise, i.e. the predicted output (represented by the light gray dot, including the white noise but not the inefficiency) is higher than the observed output. The vertical distance between this predicted output and the benchmark (the white dot) is the observation's inefficiency $u$.

**Figure 3. Benchmark function of the Stochastic Frontier Analysis (SFA)**




Source: authors

Since SFA belongs to the family of regression models, the above basic model can be extended by several 'regression add-ons'. The potential determinants for inefficiency can be estimated in a '*technical inefficiency-model*' (BATTESE and COELLI, 1995), another model component can capture potential effects of size with a so called '*heteroscedasticity-model*' (CAUDILL et al., 1995). The '*fixed-effects models'* from the classical panel-econometrics can be combined with SFA (GREENE, 2005).

## 2.4 Environmental Efficiency

Productivity and efficiency analysis provides a methodological framework to also evaluate the environmental dimension of farming. Environmental variables can be included into the efficiency and productivity models without the problem of aggregating and weighting the different units of the environmental variables (FÄRE et al., 1996; FRANCKSEN and LATACZ-LOHMANN, 2008b). Inefficiencies identified in 'common' efficiency analysis represent potential for improvement beneficial to some and not harmful to anybody (Pareto-improvement) – as long as all relevant dimensions of production are taken into account. If the chosen efficiency model ignores positive or negative externalities of production, like harmful emissions or increasing or decreasing biodiversity, the inefficiency does not always correspond to a Pareto improvement. To overcome this shortcoming environmental efficiency studies incorporate the environmental dimension in three different manners.

First, an environmental good (typically positive externalities like maintaining biodiversity) can be treated as an (additional) output in the common efficiency analysis. For a given combination of output levels – say 20 000 € value of production and 22 bird pairs – less input (e.g. 10 hectares) is more efficient than more input (e.g. eleven hectares). In the second approach, resource use or emissions are treated as an additional input. For example, land and nitrogen surplus are treated as inputs and value of production is output. For example, an input-oriented inefficiency of 90% than means that both inputs can be reduced by 10%-points without reducing the output. In the third approach, emissions are treated as negative outputs. All approaches can be problematic since important basic assumptions of efficiency models are not necessarily met.

### 2.5 Metafrontier Analysis

For comparing organic and conventional farms metafrontier analyses are powerful. Both model approaches, parametric (SFA) and non-parametric models (DEA) allow the application of so-called '*metafrontier models*' that formulate a frontier for a subgroup (e.g. organic vs. conventional farms) and a common frontier for both groups. The metafrontier is a frontier enveloping all observations from both farm groups. To compare different farming systems which can be hardly combined in a single farm, it is most appropriate to construct the metafrontier step-by-step from Sections of each group frontier. It should be ensured that the metafrontier is not based on combinations from organic and conventional farm observations because such benchmarks are hardly realistic. A metafrontier analysis can be very useful to determine a potential yield-gap in organic farming (see details in Section 3.2). It is also possible to apply the metafrontier approach in combination with the parametric estimation framework (BATTESE et al., 2004; O'DONNELL et al., 2008).

## 3 Empirical Efficiency Analyses of Organic Farms

### 3.1 Studies Investigating Efficiency on Organic Farms

There are twelve studies, which work exclusively with organic data sets. Table 1 presents an overview of the studies. SFA is used in nine studies; the DEA is used four times. With respect to farm type, grassland-farms are analyzed the most often (five times) and three studies work with different farm types. Six studies use panel data with a length between three and eleven years, the other five studies use cross-Sectional data sets. Finally, the number of observations varies between 65 farms to 1,717 observations.

The most important outcome of an efficiency model in organic farming is the structure of the production function. Figure 4 shows the output-elasticities of different studies:

The modeled results show some heterogeneity among the estimated output-elasticities of inputs: The direct input-costs have the highest output elasticities with a mean value of 0.4. The results for the output elasticity of land are heterogeneous, with a mean value of 0.25 and estimates from 0.07 to 0.83[2]. Labor has a lower output-elasticity with a mean value of 0.19. Capital (0.16) and other costs (0.12) achieve on average smaller output-elasticities.

By analyzing the returns to scale, we see that most studies find rather constant or increasing returns to scale: six of fourteen samples show constant RTS (GUBI, 2006; DREESMAN, 2007; MADAU, 2007; KUMBHAKAR et al., 2009), seven samples find increasing RTS (TZOUVELEKAS et al., 2001b; TZOUVELEKAS et al., 2001a; TZOUVELEKAS et al., 2002b; SIPILÄINEN and OUDE LANSINK, 2005; MAYEN et al., 2010; GUESMI et al., 2012; NEHRING et al., 2012; TIEDEMANN and LATACZ-LOHMANN; 2013), and one study finds decreasing RTS (LAKNER et al., 2012). If farms increase their input-use under increasing RTS, we can expect a proportionately higher output increase. In a more general sense this might indicate an incentive for structural change in the organic sector.

Besides productivity and production structure, a second main outcome of the models are the technical efficiency (TE)-scores, which describe to what extent the farms in a sample are working efficiently (in comparison to a frontier). The following Figure 5 presents the average technical efficiency-scores in the two main methods DEA and SFA:

Figure 5 documents some heterogeneity with respect to the estimated technical efficiency: Organic farms achieve on average values of 0.73 (in DEA-models) and 0.79 (in SFA-models), however with some variation. The interpretation is, that organic

[2] GUBI (2006) even found a negative elasticity, but since the result was not significant we did not include it into the calculus.

**Table 1. Studies investigating only organic farms**

| Authors | Type of publication | Region | obser-vations | Farm-type | Years | Method | Main Findings |
|---|---|---|---|---|---|---|---|
| 1 GUBI, 2006 | Dissertation | Germany | 1,070 | All types | 1996-2002 | DEA/SFA | Farm-efficiency and farm-success are related. Arable farms achieve the highest TE, mixed, grassland and milk farms achieve a lower TE. |
| 2 LOHR and PARK, 2006 | Journal non-indexed | USA | 774 | All types | 1997 | SFA | Farms with more than 5 years experience are more efficient (more details in Section 3.3) |
| 3 DREESMAN, 2007 | Dissertation | Luxembourg | 58 | Grassland | 1999/2000 | DEA/SFA | Substantial differences between traditional efficiency and environmen-tal efficiency (Section 3.5). |
| 4 FRANCKSEN et al., 2007 | Journal indexed | Germany | 461 | Arable | 1995-2004 | DEA | 5-20% OF should further specialize. Better specialization of farms increases productivity by 14%. (Section 3.4) |
| 5 LOHR and PARK, 2007 | Journal indexed | USA | 774 | All types | 1997 | SFA | Farms with a high share of on-farm soil improving inputs are less pro-ductive but more efficient. Soil improving inputs are integral part of the production function of OF. |
| 6 SAUER and PARK, 2009 | Journal indexed | Denmark | 168 | Milk | 2002-2005 | SFA | OF have differences in TE and a negative trend of TE. Investments and Income have a positive impact TE. Off-farm income has a negative impact on TE (Section 3.6). |
| 7 LAKNER, 2009 | Journal non-indexed | Germany | 1,348 | Milk | 1995-2005 | SFA + B&C95 | Payments for organic farming and agri-investment schemes have a negative impact on TE (Section 3.6). |
| 8 KARAFILLIS and PAPANAGIOTOU, 2011 | Journal non-indexed | Greece | 177 | Olive | 2006 | SFA | Farms with innovative technology have higher TE, also farms without innovative technologies have potential for improvement (Section 3.3). |
| 9 LAKNER et al., 2012 | Journal indexed | Germany | 1,717 | Grassland | 1995-2005 | SFA + B&C95 | TE is increasing 6 years after conversion. TE is influenced by regional heterogeneity and the socio-economic environment influences TE. (Section 3.3 and 3.6). |
| 10 NASTIS et al., 2012 | Journal indexed | Greece | 38 | Alfalfa | 2008 | DEA + bootst | Experienced adopters (>2 years experience in OF) have higher TE. Subsidies have a negative impact on TE (Section 3.3). |
| 11 LAKNER et al., 2014 | Conference paper | Austria, Switzerland, Germany | 244 218 106 | Grassland and mixed | 2003-2005 | SFA DF + Metaf | Diversification contributes to farm productivity, but also reduces TE. Different types of subsidies have a negative impact on TE (Section 3.6). |
| 12 PAUL et al., 2016 | Journal non-indexed | India | 270 | Pineapple production | 2014/15 | DEA | OF with average TE 0.48. TE with inverted U-shaped form depending on age of the orchard. |

Abbreviations:
B&C95 = Inefficiency Effects Model (BATTESE and COELLI, 1995)
bootst = Bootstrapping model (SIMAR and WILSON, 2000)
Metaf = Metafrontier-Models
OF/CF = Organic Farming/Conventional Farming
Source: authors, sample size expresses observations

**Table 2. Studies comparing organic and conventional farms**

| Authors | publication type | Region | Obser-vations | Farm-type | Years | Method | Main Findings |
|---|---|---|---|---|---|---|---|
| 1 TZOUVELEKAS et al., 2001a | Journal indexed | Greece | 171 | Olive | 1995/1996 | SFA + B&C95 | OF are more efficient in relation to their own frontier. There are significant regional differences. Cost reduction potential for OF is 26.9%. |
| 2 TZOUVELEKAS et al., 2001b | Journal - non-indexed | Greece | 58 | Cotton | 1995/1996 | SFA + B&C95 | CF are more technical and allocative efficient than OF. Average economic efficiency is also higher on CF than on OF. |
| 3 TZOUVELEKAS et al., 2002a | Journal non-indexed | Greece | 26 | Raisin production | 1995/6 | SFA & B&C95 | Analysis of different production systems in Greece: cotton, olive, raisin and grape production |
| 4 TZOUVELEKAS et al. 2002b | Journal indexed | Greece | 57 | Durum wheat | 1998/1999 | SFA | OF with more efficient to their own frontier. More heterogeneity of OF with respect to labour. |
| 5 OUDE LANSINK et al., 2002 | Journal indexed | Finland | 868/ 3,159 | Arable/ Live-stock | 1994-1997 | DEA | OF are more efficient to their own frontier, but 23% less productive. |
| 6 SIPILÄINEN and OUDE-LANSINK, 2005 | Conference paper | Finland | 1,921 | Milk | 1995-2002 | SFA DF + B&C95 + Select. | Learning process on OF of 6-7 years. Conversion decision to OF depends on farmer`s age and farm`s region. Energy on OF has a higher output elasticity than on CF. |
| 7 LARSEN and FOSTER, 2005 | Conference paper | Sweden | 2,738 | All types | 2000-2002 | DEA DF + Select | OF with lower TE. OF achieve better performance within the OF system than within the CF system. |
| 8 DIMARA et al., 2005 | Journal indexed | Greece | 198 | Black currant | 2004 | DEA | TE varies for CF with and without Protected Designation of Origin (PDO), whereas PDO does not affect TE of OF. |
| 9 MADAU, 2007 | Journal non-indexed | Italy | 231 | Cereal | 2001-2002 | SFA + B&C95 | If fully efficient, OF (CF) could increase their income by 79 €/ha (50 €/ha). |
| 10 BAYRAMOGLU and GUNDOGMUS, 2008 | Journal indexed | Turkey | 126 | Raisin | 2003/2004 | DEA | If fully cost-efficient, OF (CF) could improve family income by 652 € (445 €) on average per year. |
| 11 KANTELHARDT et al., 2009 | Conference paper | Germany | 102 | Mixed | – | DEA | OF more successful combining economic and ecological efficiency in comparison to other farms in agri-environmental schemes (Section 3.5). |
| 12 KUMBHAKAR et al., 2009 | Journal indexed | Finland | 1,921 | Milk | 1995-2002 | SFA + Select. | The conversion to OF is depends on subsidies, experience and past conversion decision, but not on inefficiency. CF is more productive. |
| 13 SERRA and GOODWIN, 2009 | Journal indexed | Spain | 129 | Arable | 2002 | SFA + LML | OF with lower TE against their own frontier. |
| 14 MAYEN et al., 2010 | Journal indexed | USA | 425 | Milk | 2005 | SFA + Match. | OF has a lower productivity. No TE between OF/CF. The hypothesis of homogenous technology is rejected. |
| 15 SAUER, 2010 | Journal indexed | Denmark | 3,431 | Milk | 1986-2005 | LDF | No efficiency differences between OF and CF. (Section 3.6) |
| 16 BREUSTEDT et al., 2011 | Journal indexed | Germany | 1,341 | Milk | 2004/2005 | DEA + Metaf. | 68.6% of the organic farms have chosen the most profitable farm system. Around 31.4% (22.1%) of the OF (CF) should reconvert to CF (OF). (Section 3.4). |

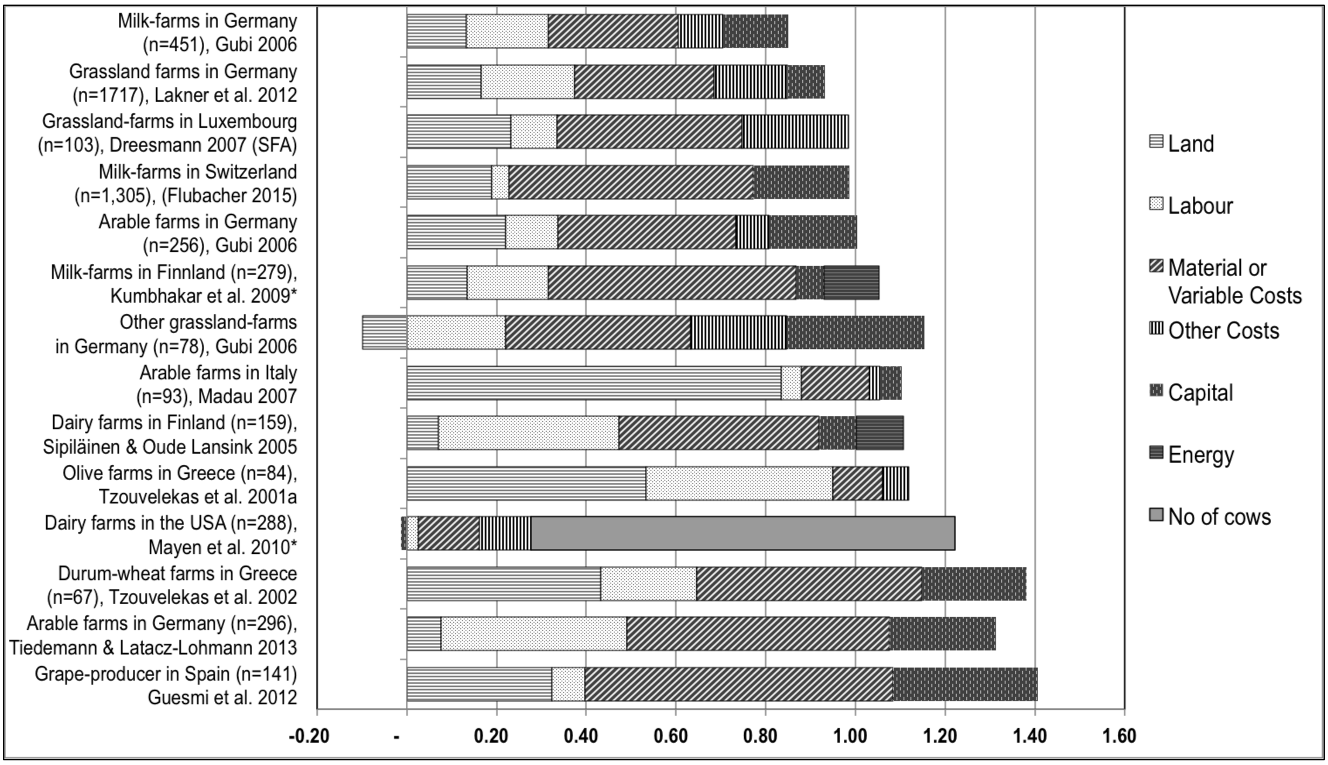
| Authors | publication type | Region | Obser-vations | Farm-type | Years | Method | Main Findings |
|---|---|---|---|---|---|---|---|
| 17 TIEDEMANN and LATACZ-LOHMANN, 2011 | Journal indexed | Germany | 1,040/ 592/ 784 | Grassland/ arable/ mixed farms | 1999-2006 | DEA + Match. SFA + Match. | The development of TFP of OF is different among farm types. The lack of technical and scale efficiency is a main problem of OF (Section 3.4). |
| 18 SUTHERLAND et al., 2012 | Journal indexed | England | 16/16 | mixed | 2006 | DEA + Match. | CF with higher TE are located in areas with high shares of conventional farms ('coldspots'), OF are more efficient in areas with high shares of organic farms ('hotspots'). |
| 19 GUESMI et al., 2012 | Journal indexed | Spain | 141 | Grape | 2008 | SFA + B&C95 + LML | OF are by 12% less productive. Efficiency on OF is positively affected by experience in OF, but negatively related to unpaid family labour, the farm location and farmers strong environmental preservation. |
| 20 KARAGIANNIS et al., 2012 | Conference paper | Austria | 170 | Milk | 1997-2002 | SFA + GTFEM | OF have a lower scale efficiency than CF. |
| 21 NEHRING et al., 2012 | Conference paper | USA | 3751 | Milk | 2005 / 2010 | SFA DF | Small scale farms in both OF and CF are less efficient than large scale farms. |
| 22 TIEDEMANN and LATACZ-LOHMANN, 2013 | Journal indexed | Germany | 269 | Arable | 1999-2006 | SFA + Match. | Land and labour increase risk on both farm systems, whereas capital, seed costs and soil quality reduce risk. |
| 23 SIPILÄINEN and HUHTALA, 2013 | Journal indexed | Finland | 798 | Arable | 1994-2002 | DEA DF + Metaf | If environmental variables are included and the sample is bias-corrected, then both technologies achieve the same technical efficiency (Section 3.5). |
| 24 ALDANONDO-OCHOA et al., 2014 | Journal indexed | Spain | 83 | vine | 2004 | DEA + Metaf | OF have a higher environmental efficiency to their own frontier and to the metafrontier thn CF (Section 3.5). |
| 25 BELTRAN-ESTEVE and REIG-MARTINEZ, 2014 | Journal indexed | Spain | 212 | Citrus | 2009 | DEA DF + Metaf. | If fully efficient OF (CF) can achieve cost-savings of 60% (45%). Specific tasks have different cost-saving potentials. |
| 26 LATRUFFE and NAUGES, 2014 | Journal indexed | France | 5,830 | All farm types | 2003-2007 | DEA, SFA, FDH | The decision depends on TE prior to the conversion, but the direction of the effect depends of farm size and type of production (Section 3.3). |
| 27 GUESMI et al., 2014 | Conference Paper | Egypt | 60 | Cereal + horti-culture | 2010 | SFA + LML | OF are slightly more efficient than CF. Input elasticities depend on farm-size. |
| 28 POUDEL et al., 2015 | Journal non-indexed | Nepal | 240 | Coffee production | 2011 | DEA | OF with lower output, higher costs and a lower gross margin compared to CF. TE of OF is about 0.89. |
| 29 FLUBACHER, 2015 | Journal non-indexed | Swiss | 1,305 | Milk farms | 2009-2011 | SFA + Match | OF have TE=073, CF TE=0.74. Productivity higher in OF, which is due to prices. The production output is lower in OF in comparison to CF. |

Abbreviations

GTFEM = Greene True Fixed Effects Model (GREENE, 2005)
B&C95 = Inefficiency Effects Model (BATTESE and COELLI, 1995)
Metaf = Metafrontier-Models
Select. = Selectivity Model, as eg. in HECKMAN (1979)
DF = Distance Frontier Model
OF/CF = Organic Farming/Conventional Farming
Match. = Matching model applied to adjust for structural differences
LDF = Leontiev Distance Function, see SAUER (2010)
LML = Local Maximum Likelihood (SERRA and GOODWIN, 2009)
TFP = Total Factor Productivity

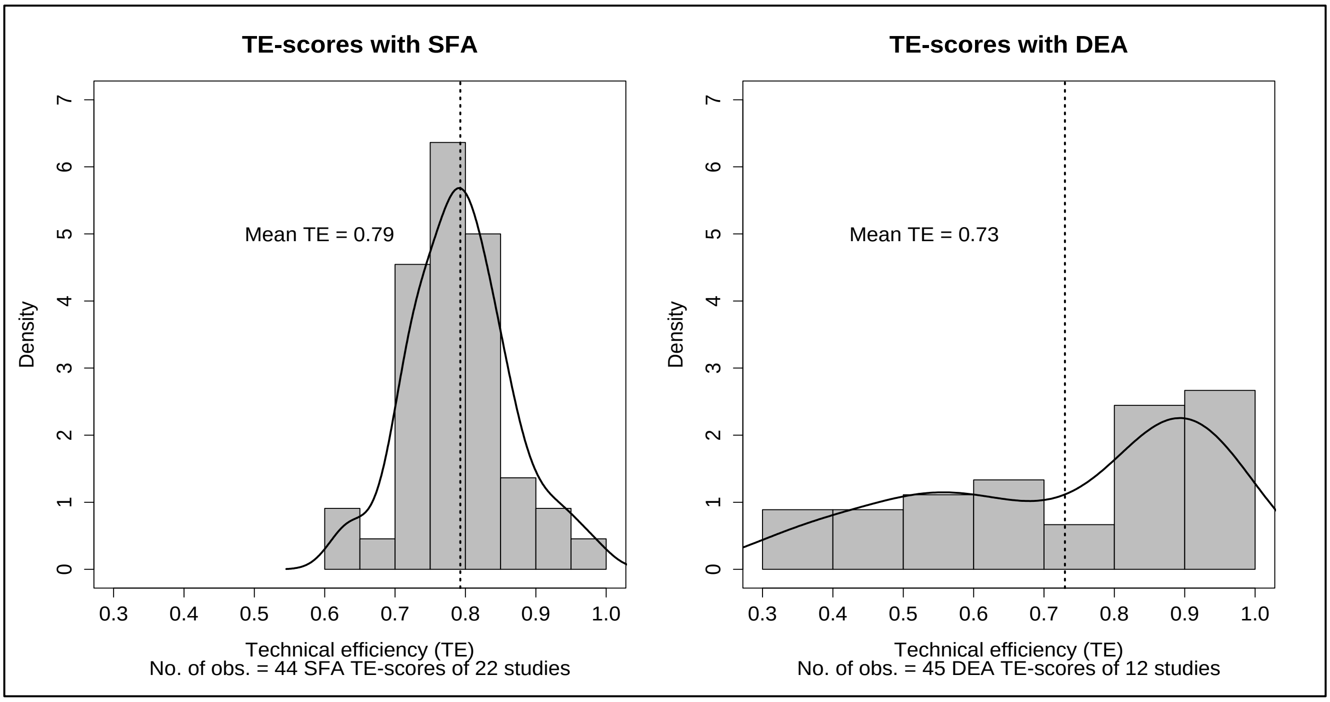
Source: authors

**Figure 4. Estimated output elasticities of different inputs estimated in 11 efficiency studies**




*Note: MAYEN et al. (2010) and KUMBHAKAR et al. (2009) did not calculate constant output elasticities. In these two studies we used *output elasticities at sample mean*.
Source: authors

**Figure 5. Average Technical Efficiency (TE)-scores of organic farms modelled**




Note: in the case of the DEA-studies, we simultaneously used input- and output-oriented TE-scores, so in most cases two scores per study. In cases of model-variations, one study can contribute with up to six TE-scores (as in the case of DREESMAN (2007) and SIPILÄINEN and HUHTALA (2013)).
Source: authors calculations

farms can on average improve their efficiency by 21%-points and 27%-points respective to the modeling-approach. The lower average TE-score and the wider distribution of estimation results in the non-parametric models (Data Envelopment Analysis (DEA)) is consistent with the results of other meta-studies (OGUNDARI, 2014; MARETH et al., 2016; MINVIEL and LATRUFFE, 2016), however, two meta-studies do not find a significant difference between the two model- types (THIAM et al., 2001; BRAVO-URETA et al., 2007). There are some systematic reasons for this difference, why we would expect this result: First, non-parametric models like DEA have not any *a priori* assumption on how TE-scores are distributed, whereas in the parametric models of the Stochastic Frontier Analysis (SFA) researchers make explicit distribution assumptions for the inefficiency term (KUMBHAKAR and LOVELL, 2000; COELLI et al., 2005), which might lead to the more concentrated distribution of TE-scores in the SFA-models. Second, in non-parametric models (DEA), any misspecification can have a larger impact on the estimated efficiency outcome, since stochastic errors are not captured by an error-term, in contrast to the SFA-models, as ANDOR and HESSE (2014) point out. Consequently, an extreme outlier with a very good input-output relation would strongly shift the frontier and lead to many low TE-scores in a DEA-model, whereas some of this effect might be capured by the stochastic error-term in a SFA-model. This methodological difference might explain the lower TE-score in the DEA-models.

In total fifteen studies[1] investigate the main factors influencing technical efficiency (deter minants), see Table 3. In most cases, the '*technical inefficiency-model*' (BATTESE and COELLI, 1995) is used.

**Table 3. Determinants of technical efficiency in organic farming**

| | Impact of variable on TE | | no. of studies |
|---|---|---|---|
| | **positive** | **negative** | |
| **1. Management skills and education** | | | |
| Age of farmer | 5 | 3 | 8 |
| Education of the farmer | 6 | 2 | 8 |
| Experience of farmer | 1 | 1 | 2 |
| Ecological motivation of the farmer | 0 | 2 | 2 |
| Gender (1=male) | 2 | 0 | 2 |
| Advisory service | 0 | 1 | 1 |
| Training | 1 | 0 | 1 |
| **2. Farm structure and resources** | | | |
| Degree of specialization of the farm | 9 | 3 | 12 |
| Family farms | 4 | 5 | 9 |
| Capital | 5 | 1 | 6 |
| Size | 4 | 1 | 5 |
| Diversification/direct marketing | 1 | 2 | 3 |
| Full time farm | 2 | 1 | 3 |
| Milk quota | 2 | 0 | 2 |
| Special legal status farm | 2 | 0 | 2 |
| In conversion to organic farming | 0 | 2 | 2 |
| Sales Taxation | 1 | 0 | 1 |
| Market access | 1 | 0 | 1 |
| **Farm location variables** | | | |
| Soil quality (quality measure or paid rent) | 8 | 0 | 8 |
| Share rented land | 3 | 1 | 4 |
| Area with restrictions | 3 | 1 | 4 |
| Intensity land use | 2 | 1 | 3 |
| Less favoured area | 1 | 2 | 3 |
| Altitude | 1 | 2 | 3 |
| Land fragmentation | 0 | 1 | 1 |
| Age of the orchard | 0 | 1 | 1 |
| **Other Variables** | | | |
| Subsidies | 3 | 5 | 8 |
| Region-Variables† | included in 9 studies | | |

Note: The result is based on 21 different samples within 16 studies. Only significant results in the studies are counted.
† The variable can be a regional dummy-variable or other variables describing characteristics of the region the farm is located like e.g. population density. 'Fixed effects models' are not included.
Source: authors

An important topic for efficiency studies focused only on organic farms is the question of how **management skills and education** influence technical efficiency (see also in Section 3.3). The farmer can directly influence such factors. Education and the age of the farmer (as a proxy for gathered experience in farming) exhibit a positive influence on farm efficiency, which is expected. Interestingly, in two cases the ecological motivation of a farmer is included in the study, and in both cases farmers with special ecological motivation achive lower TE-scores.

[1] We included nine comparative studies and six studies focussing on organic farming.

**Farm structure and resources** also play an important role. This group of variables can be influenced by a farmer, but not as directly as with management skills and education. Here we often find that especially a high degree of specialization contributes to higher efficiency. In the opposite case, farm diversification reduces TE in agriculture. Family farms are, in five of eight studies, found to be less efficient. Capital endowment and the size of a farm contribute to increased efficiency. Another group of determinants are variables describing the **location of a farm**, which is out of control of the farmer. Here we can find clear evidence that organic farms on good soils achieve higher efficiency scores. Farms with a high share of rented land work more efficient. The finding that farms working with special production restrictions on land are more efficient, is surprising. However, we know that some of those areas with production restrictions also generate income by increased payments for e.g. nature protection. Subsidies exhibit a negative impact on technical efficiency in five of eight cases (see Section 3.6). Finally, **regional differences** also play an important role for the formation of farm`s efficiency and are included in nine studies.

Organic farms usually operate in less favorable areas, i.e. in locations with lower production potential, as it was empirically shown for the case of Germany (SCHMIDTNER et al., 2012). However, organic farms on more favorable locations perform with higher efficiency (TIEDEMANN and LATACZ-LOHMANN, 2011; LAKNER et al., 2012; TIEDEMANN and LATACZ-LOHMANN, 2013). Therefore, the large share of organic farming in marginal production areas could be misleading: the efficiency studies reveal, that farms working on higher soil qualities achieve higher efficiency scores. Organic farms on more favorable locations have more scope for increasing their farms efficiency and productivity; and therefore also their farm income (FRANCKSEN and LATACZ-LOHMANN, 2008a). A study from LAKNER et al. (2012) identifies ‘efficiency-clusters’ for organic grassland farms within Germany. The results indicate that technical efficiency is especially high in Northern and Western Germany, whereas the Eastern German farms are rather inefficient. They find evidence that primary and secondary agglomeration effects and the regional socio-economic environment influence technical efficiency of organic grassland farms.

## 3.2 Studies Comparing Efficiency of Organic and Conventional Farms

A second group of twenty-nine studies compare efficiency and productivity[2] of organic and conventional farms. Table 2 gives an overview of the evaluated studies. SFA-models (in 16 studies) are used more frequently than DEA-models (13).[3] Eighteen studies are working with cross-sectional data, which are in most cases from primary data collections. Twelve studies work with panel data sets (from three up to twenty years length) stemming in most cases from the European Farm Accounting Data Network (F.A.D.N.) (EU COMMISSION 2010).

Any comparison of a group of organic farms with a group of conventional farms raises the general question on how the sample was constructed to ensure sufficient comparability. The sampling strategy can systematically influence the estimated results and thereby restrict the interpretation (OFFERMANN and NIEBERG, 2001).

First, one difference between both groups might be due to different farm structures within the farming systems. In many European countries, organic farms have a different farm structure[4] and in many countries, grassland and mixed farms dominate the sample of organic farms, whereas in conventional samples, the share of arable and meat-producing farms is higher (HÄRING et al., 2004). A second problem could be systematic selection bias: conventional farms in the past might be converted to organic farming because of lower farm efficiency. In this case, a system-comparison might suffer from selection bias. The third prob-

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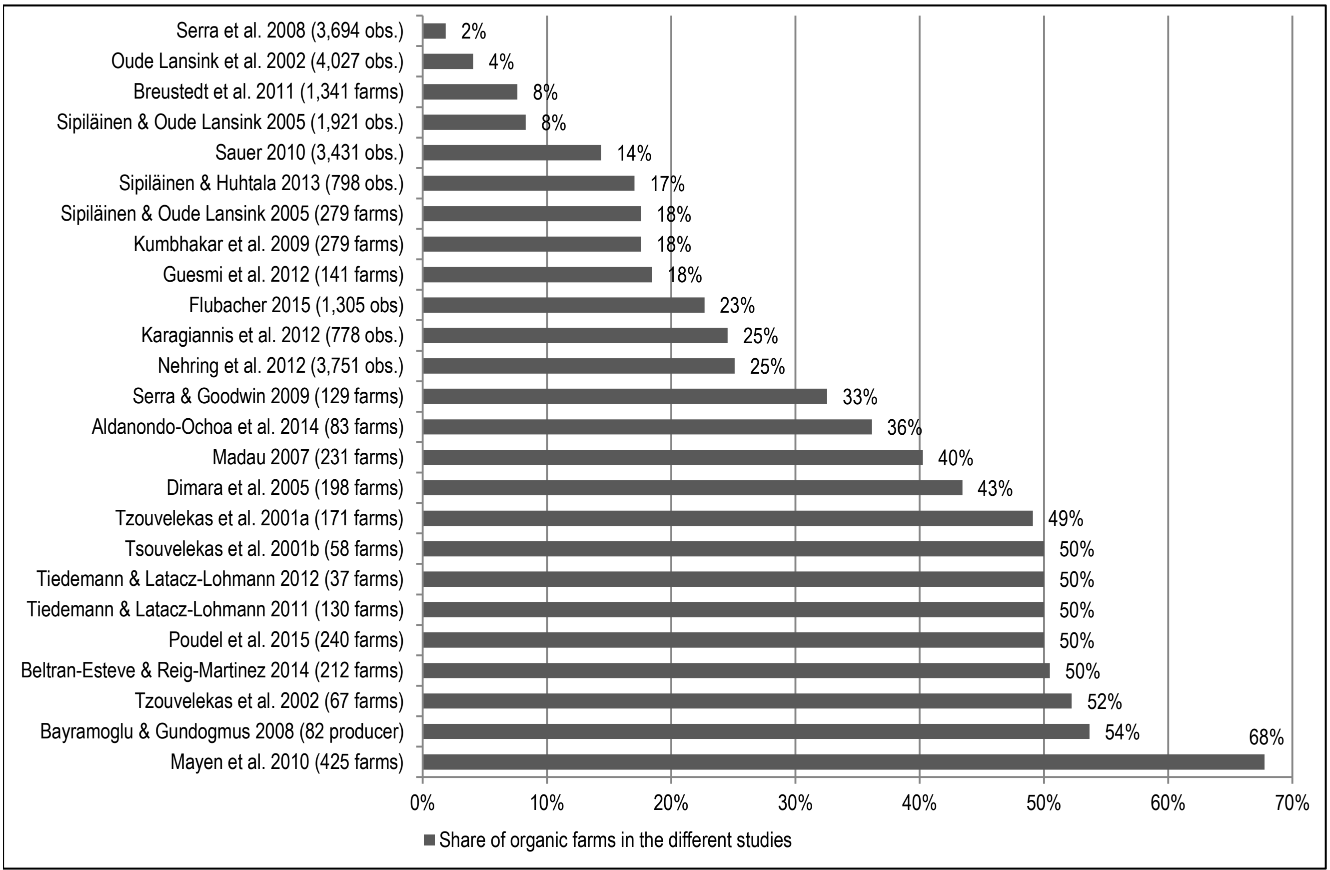
2 *Productivity* (global) in efficiency analysis is defined as the sum of inputs in relation to the sum of outputs.

3 One study uses a very specific estimation model approach with the ‘Leontief Distance Function’ estimated by Bayesian Estimation techniques (SAUER, 2010). Another rather specific approach is the ‘Local Likelihood Approach’ to accommodate efficiency levels at different points of a size distribution (SERRA and GOODWIN, 2009; GUESMI et al., 2012; GUESMI et al., 2014). LATRUFFE and NAUGES (2014) additionally use a Free Disposal Hull (FDH)-model, details of the FDH-method can be read in the article (LATRUFFE and NAUGES, 2014).

4 According to HÄRING et al. (2004), who investigate structural differences of organic farms in the EU before 2003, organic farms typically had a lower share of cereals and root crops and a higher share of pulses and fodder crops and leys on arable land. Also the grassland share is higher. On the other hand, intensive land use systems, such as vegetables, fruits, olives, wine, have a lower share in organic farming systems.

**Figure 6. Share of organic farms on the total farms in different comparative studies on technical efficiency**




Note: If number of farms is reported for a study, data are only from one year. If observations (obs.) are given, farm data are observed in more than one year. However, the number of observed years may differ among farms in the same data set.
Source: authors calculations

lem might be different sizes of the subsamples. If a small group of organic farms is modeled against a large group of conventional farms, the representativeness and reliability between both groups might be different and, therefore, results might not be of the same quality. Most of the studies work with a large group of conventional farms and a small subgroup of organic farms (Figure 6):

In the case of an uneven size of farm groups, the reliability of both groups can be different. Besides this, we may encounter the other two sampling problems at the same time. In general, there are different strategies and approaches to accommodate the problems of potential selection bias and sample construction:

1. **Metafrontier:** a first approach would be to conduct a separate group estimation and the use of a metafrontier that envelops both group frontiers. In such a case, efficiency measures against the joint metafrontier would produce efficiency results that can be directly compared between organic and conventional farms. On the other hand, modeling a metafrontier does not automatically solve the problem of diverging farm structures or potential selectivity bias.
2. Seven studies report on specific **sampling strategies** for the data collection process, where only conventional farms with a similar structure or neighboring farms are taken into account as conventional counterparts of the organic farms. Four other studies reduced the conventional group by matching models: MAYEN et al. (2010) and FLUBACHER (2015) use a propensity score matching model (PSM) and TIEDEMANN and LATACZ-LOHMANN (2011), TIEDEMANN and LATACZ-LOHMANN (2013) use Euclidean-Distance Matching. Although selectivity issues cannot be totally avoided with matching models (TIEDEMANN and LATACZ-LOHMANN, 2011), matching improves data quality for a comparison.
3. **Selectivity models** can be introduced in order to capture a potential selection bias stemming from the conversion to organic. The studies of LARSEN and FOSTER (2005) and SIPILÄINEN and OUDE

LANSINK (2005) use a two-step procedure to accommodate for the potential selectivity bias, KUMBHAKAR et al. (2009) combine in a one-step estimation a SFA-model with a Heckman correction model, other modeling options are presented in GREENE (2010) and BRAVO-URETA et al. (2012).

We now turn to the comparison between organic and conventional farms. The first main model outcome is productivity: organic farms show a lower productivity in four of five studies (OUDE LANSINK et al., 2002; KUMBHAKAR et al., 2009; MAYEN et al., 2010; GUESMI et al., 2012; ALDANONDO-OCHOA et al., 2014).

MAYEN et al. (2010) applied a matching model to establish a comparable conventional group. Their results show that the technology of organic dairy farms in the USA is 13% less productive than the conventional technology. KUMBHAKAR et al. (2009) used a selectivity model to capture potential sources of a selectivity bias. According to their results, organic dairy farms in Finland are between 21% and 37% less productive than conventional farms (depending on the estimation model). The results also show, that organic farms could produce 5.3% more output by producing in the conventional farm system, i.e. if they would convert back. GUESMI et al. (2012) finds organic grape farms to be 12% less productive than conventional farms. In contrast, ALDANONDO-OCHOA et al. (2014) estimate a so-called environmental productivity by including environmental variables (nitrogen and pesticide use, see details in Section 4.5). They find environmental productivity of organic farms to be 8.4% higher than for conventional farms (ALDANONDO-OCHOA et al., 2014). The productivity differential of organic milk-farms in Switzerland is also found to be higher. FLUBACHER (2015) explains this finding with significantly higher organic prices, which overcompensate a lower production output on organic farms. However, the production differential of FLUBACHER (2015) is not directly comparable to the other productivity differences, since it includes price effects, which is not the case in the other studies.

To sum up, the productivity is found to be between 12% and 37% lower for organic farms, with an average value of 19%. The lower productivity on organic farms is not surprising overall, because the organic farming system imposes more restrictions on the use of inputs than in conventional farming. If we link the productivity results with the literature on the yield gap, we find similarities: a first meta-study of BADGLEY et al. (2007) found a yield ratio between organic and conventional grain production of 69% (BADGLEY et al., 2007). Their approach, using a broad definition of organic farming practices, was criticized by AVERY (2007). Another meta-review on yield studies by DE PONTI et al. (2014) showed, that organic yields in cereal production are on average 79%, of the conventional yield level, but range from 40-145% (DE PONTI et al., 2012). SEUFERT et al. (2012) found an average yield ratio of 75% (with a 95%-confidence interval between 71-79%) in their meta-study. PONISIO et al. (2014) found a yield ratio of 80.8% with a stricter method of meta analysis by excluding '*subsistence yields of unimproved agriculture*' (PONISIO et al., 2014).

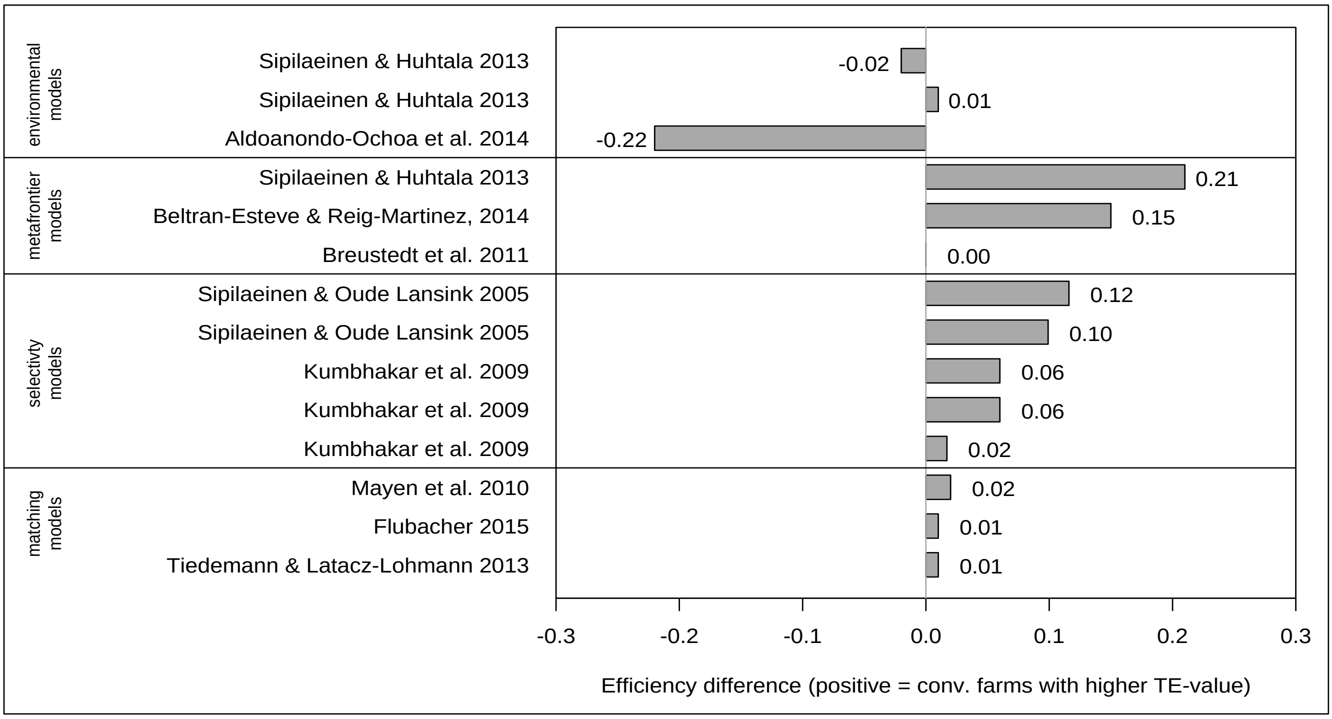
These 'pure' yield comparisons are confirmed by our above cited productivity comparisons between organic and conventional farms. As a rule of thumb, a 20% productivity gap between organic and conventional farming is not only true with respect to land but also to the whole bundle of economic production inputs.

The second main model outcome is technical efficiency. In Figure 7 we present the efficiency difference between organic and conventional farm groups in studies with any joint benchmark or with models that accommodate for potential selectivity bias:

In most cases, organic farms are less efficient, however, with a wide variety of results ranging from minus 0.21% to plus 0.22%. On average, organic farms are about 4% less efficient. However, in some single cases, organic farms can achieve the same level of efficiency (as in BREUSTEDT et al., 2011) and interestingly, in two studies including environmental variables (SIPILÄINEN and HUHTALA, 2013; ALDANONDO-OCHOA et al., 2014), organic farms achieve even a higher level of efficiency.

To summarize, comparing organic and conventional farming requires an appropriate selection of '*comparable conventional farms*' (OFFERMANN and NIEBERG, 2001) and joint estimation techniques. However, the problem of sample selection has been ignored by many studies for a long time. This was corrected by a few studies, which systematically took structural differences or sample selectivity issues into account (KUMBHAKAR et al., 2009; MAYEN et al., 2010; TIEDEMANN and LATACZ-LOHMANN, 2011; TIEDEMANN and LATACZ-LOHMANN, 2013). The appearance of these methods also documents a substantial methodological progress, which has also taken place in other areas of agricultural economics (PUFAHL and WEISS, 2009; GREENE, 2010; BRAVO-

**Figure 7. Comparison of technical efficiency between organic and conventional farming**




Source: authors

URETA et al., 2012). In the studies correcting potential sample selectivity, organic farms are found to be around 20% less productive, however, with some variation (see above). Technical efficiency is on average 4% lower on organic farms, however, with some variation ranging from a lower efficiency of 21% (SIPILÄINEN AND HUHTALA, 2013) to a higher efficiency of 22% (ALDANONDO-OCHOA et al., 2014). Technical efficiency also depends on the farm focus of the study (arable, milk or grassland farms) and the specific background of a study. A clear concept of data selection by either matching or a Heckman selection procedure creates comparable data sets; otherwise comparisons of mean efficiency scores have to be taken sceptically.

### 3.3 Technical Efficiency in the Conversion Period

There are four main research topics with respect to efficiency and the conversion to organic farming. First, different studies investigate if farmers' experience and knowledge about organic farming exhibits a systematic impact on the single farm efficiency. Two studies of SIPILÄINEN and OUDE LANSINK (2005), LOHR and PARK (2006) find organic farms with more than five years experience in organic farming to be more technically efficient. A study by NASTIS et al. (2012) on organic alfalfa producers in Greece finds experienced adopters (with more than two years experience) to be more technically efficient. KARAFILLIS and PAPANAGIOTOU (2011) also show that organic farms using innovative techniques achieve better total factor productivity values. The study also highlights the scope for improvements for those farms that have not used new technologies yet (KARAFILLIS and PAPANAGIOTOU, 2011).

Second, the measure of technical efficiency after conversion is often interpreted as learning costs for managing an organic farm. Following the results of SIPILÄINEN and OUDE LANSINK (2005) this learning process after leaving conventional farming takes about six to seven years. A similar result was found by (LAKNER et al., 2012), who observed efficiency for each year after the conversion. They found that the efficiency level of converting farms to be lower than efficiency of established organic farms, but substantially increased after six years. Therefore, from an efficiency point of view, the learning process in managing a fully converted organic farm takes more than the legally defined conversion period of two years (LAKNER et al., 2012).

A third topic with respect to conversion to organic farming is the general question, whether or not the decision to convert to the organic farming system is driven by efficiency and productivity issues. From the general economic literature we know that organic farmers are not only motivated by economic, but also by other factors. However, economic consideration still plays an important role (HOLLENBERG, 2001; RAHMANN et al., 2004; MUßHOFF and HIRSCHAUER, 2008; SERRA et al., 2008). LATRUFFE and NAUGES (2013) use some of the aforementioned factors to model the determinants of conversion to organic farming: a technical efficiency score in the previous period influence the probability of conversion; however the direction of influence depends on the farm type. In contrast KUMBHAKAR et al. (2009) find that inefficiency is reducing the probability of adopting the organic farming technology. So finally, efficiency seems to influence the adoption decision; however it seems to be an empirical question, whether this influence is positive or negative.

Overall, most of the studies show that experience in the organic farming system is an important factor to improve technical efficiency within the organic farming system. This finding is logical on the background that organic farmers rely more on natural regulation mechanisms of the eco-system. An increase in technical efficiency during and after the conversion process reflects the learning process of a farmer after converting to the new farming system. The empirical studies reveal that this learning process takes longer than the official two-year conversion period.

The fourth research topic is ‘reconversion’. A recent meta-study on the topic of ‘reconversion’ shows (SAHM et al., 2013) that among multiple other factors like certification issues and problems with organic techniques, economic motives are one important reason for farms to reconvert: on a very fundamental level, it is crucial for a farmer to know whether the most profitable farming system for him/herself is organic or conventional farming. A study on Bavarian dairy farms shows that about 68.6% of the organic dairy farms have chosen the most profitable farm system. Still around 31.4% of the organic farms should reconvert to conventional farming in order to achieve higher profits. For farms that were not working under the best farming system, a switch to the other farming technology organic (conventional) farms can increase their short-run profit by 199 €/ha (121 €/ha) (BREUSTEDT et al., 2011). This matches empirical findings by SANDERS et al. (2010), who asked organic farmers in 2009 to give a subjective estimate on their economic situation under the conventional farming system: 8% of the organic farmers estimated their profit to be higher and another 16% of the organic farmers stated in the interview that the profit would be the same under a conventional farming regime. BREUSTEDT et al. (2011) also discuss other economic barriers for adoption of the ‘optimal farming regime’.

## 3.4 Specialization versus Diversification

Technical efficiency can also be increased through the choice of the optimal degree of specialization or diversification within the organic farming system. FRANCKSEN et al. (2007) investigate the degree of optimal farm specialization. The farms were split into three specialization classes.[5] The efficiency of a farm was measured in relation to the frontier of the respective specialization class and alternatively in relation to the frontier of the other specialization classes. The authors find that around 44-54% of the farms have chosen the optimal degree of specialization. From an efficiency point of view, about 8-13% of the farms should diversify, whereas between 33-47% should specialize (FRANCKSEN et al., 2007). Although the authors mention the integrating factors of organic farms (crop-rotation, balanced labor-input and a lower risk), they do not critically discuss, whether such a ‘mathematical specialization strategy’ in organic farming is applicable in reality, without taking into account the available natural resources and the restrictions of organic farming.

A study of LAKNER et al. (2014) based on organic farms in Southern Germany, Switzerland and Austria shows that diversification can have different impacts within the organic farming system: diversification beyond agriculture (‘para-agriculture’) contributes on the one hand to productivity, but on the other hand also reduces the technical efficiency of the farm as a whole (LAKNER et al., 2014). A diversified crop rotation also reduces the yield-risk of organic farms in Germany (TIEDEMANN and LATACZ-LOHMANN, 2013).

## 3.5 Environmental Efficiency of Organic Farms

Organic farming provides many environmental services and reduces negative externalities (STOLZE et al., 2000). Since the protection of the environment is one of the objectives of organic farming, an appropriate representation of farm efficiency is environmental efficiency (OUDE LANSINK et al., 2002). However, still most of the efficiency models comparing organic

[5] In specialization class 1 farms create 90% of the total farm revenue from crop farming, in class 2 revenues of crop farming only make 70-90% of the farm income and in class 3 it is less than 70%.

and conventional farming do not include environmental variables.

DREESMAN (2007) analyzes data from fifty-eight organic milk farms with respect to their environmental efficiency, modeled with data on nitrogen, phosphorous and energy use of the farms. Depending on the model framework, the three environmental variables were treated as undesired environmental inputs or outputs. In different model setups both phosphorus (in the SFA-mode) as well as energy (in the DEA-model) have a substantial impact on productivity; whereas nitrogen does not contribute to farm productivity. The results also show that increased specialization contributes to increased environmental efficiency (DREESMAN, 2007).

KANTELHARDT et al. (2009) investigate the technical and environmental efficiency of 102 farms participating in different agri-environmental programs (AEP). The variables ‘low-intensively used area’ and ‘area covered with landscape elements’ are used as positive environmental outputs. The indicator ‘nitrogen use’ is introduced into the model as an undesired environmental output. Among the farms participating in different agri-environmental programs, the organic farms simultaneously achieve high economic and environmental efficiency scores. Also other program types were more efficient than the no-participation option. According to the authors, the organic farms seem to be quite successful in combining environmental and economic efficiency (KANTELHARDT et al., 2009).

SUTHERLAND et al. (2012) investigated the performance of 16 organic and 16 conventional farms in England taking into account regions with high and low shares of organic farms. In their modelling they also include two biodiversity indices beside the agricultural output. In regions with low shares of organic farming (‚coldspots’), conventional farms achieve a higher efficiency, organic farms outperform conventional farms in regions with high shares of organic farms (‘hotspots’). The research design is multidisciplinary, therefore, the data are very detailed. However, the number of evaluated farms is very low for a reliable DEA, as the authors admit themselves (SUTHERLAND et al., 2012).

SIPILÄINEN and HUHTALA (2013) investigate the impact of crop diversity on farm efficiency for both organic and conventional crop farms. Crop diversity (by means of the Shannon diversity index) is introduced as a secondary environmental output in addition to the output from agricultural production. After introducing the environmental variable, the efficiency results substantially change: organic farms achieve the same efficiency level as conventional farms.

ALDANONDO-OCHOA et al. (2014) investigate the environmental efficiency of eighty-three organic and conventional vineyards. The incorporated environmental variables are nitrogen surplus and potential toxicity of pesticides. The method is a DEA combined with a metafrontier and the environmental variables are treated as inputs. The results show a significantly higher environmental efficiency of organic vineyards with respect to their own frontier and also to the joint metafrontier (0.784 vs. 0.559). The productivity is also higher on organic vineyards. Therefore, the authors conclude that organic vineyards are more efficient in using natural resources.

To summarize, environmental efficiency is an interesting but also data-demanding method. Therefore, we find only a few studies using this methodology. In some of the studies, the number of observations is too low to draw general conclusions for e.g. the organic sector as a whole. The evidence is often restricted to a specific farm-type, to a specific region or to a specific research question (participants of agri-environmental schemes). There is a slight trend, that organic farms perform much better, if environmental variables are included in the model. However, there is more research necessary to verify or falsify this trend.

## 3.6 Impact of Policy Support on Efficiency

Organic farming in many European countries is subject to distinct policy schemes (SANDERS et al., 2011); in most EU member states there are specific area payments dedicated to the organic farming scheme. The main argument for those payments are public goods produced by organic farms (STOLZE and LAMPKIN, 2009). Several conceptual and empirical studies (using data of conventional farms) reveal an impact of subsidies on efficiency and productivity of farms. The main finding of this general literature is that farmers include the potential subsidies in their production decision so that subsidies can be treated as an input of a production function (MCCLOUD and KUMBHAKAR, 2007; HENNINGSEN et al., 2011; LATRUFFE et al., 2011). Farmers may not choose the best input- or output-bundle for their farm according to market prices, as another choice may lead to higher subsidies. This finding was confirmed by a meta-study by MINVIEL and LATRUFFE (2013) indicating a negative impact of subsidies on the efficiency of (conventional) farms.

This finding can also be derived from the efficiency literature on organic farms. In the case of German grassland and dairy farms, agri-environmental payments (LAKNER et al., 2012) and also agri-investment-schemes show a negative impact on efficiency (LAKNER, 2009), which may be due to the heterogeneity of the special organic subsidies within the federal states of Germany and the different options to combine programs. The same result can be found for direct and environmental payments in Switzerland and Austria (LAKNER et al., 2014) and for organic alfalfa farms in Greece (NASTIS et al., 2012). In contrast, TIEDEMANN and LATACZ-LOHMANN (2011) find a significant positive impact of subsidies on technical efficiency for all organic farm types (arable, grassland and mixed farms). In addition to the efficiency impact, subsidies are also one driving factor for the conversion to organic farming. Consequently, they have to be accounted for in the non-random selection of organic farm samples (KUMBHAKAR et al., 2009).

In contrast to the former results, SAUER and PARK (2009) find the amount of subsidies to increase technical efficiency and technological progress of organic farms in Denmark. Subsidies on the other hand reduce the probability of farm exit. Since the farms were only observed for three years, the result for technical progress – although it was statistically tested – should be interpreted with caution. DIMARA et al. (2005) show that organic currant production in Greece is hardly affected by the additional standard of the EU's protected designation of origin (PDO), whereas conventional producers show lower efficiency with this additional standard.

Overall, the efficiency literature on organic farming shows that efficiency is affected by the different policy instruments: direct payments have a negative impact on efficiency, for agri-environmental payment the evidence is mixed. And the EU's protected designation of origin (PDO) can be better combined with organic than with conventional farms. However, those findings are based on a few studies, therefore there is still potential for further in-depth research.

## 4 Discussion and Conclusions

A number of key conclusions can be derived from the empirical literature on the efficiency of organic farms:

1. With regards to research question one in the introduction, the literature reveals that organic farms have a lower productivity in four out of five studies (OUDE LANSINK et al., 2002; KUMBHAKAR et al., 2009; MAYEN et al., 2010; GUESMI et al., 2012; ALDANONDO-OCHOA et al., 2014) and the productivity differences of about 20% are in the same range as organic-conventional yield-ratios (BADGLEY et al., 2007; DE PONTI et al., 2012; SEUFERT et al., 2012; PONISIO et al., 2014). There are substantial methodological differences between the yield-differences from the agronomic sciences and the modeled productivity differences from the presented studies: in the case of yield differences we deal with precisely measured *partial productivity* differences whereas in productivity analysis we model (in most cases) *global productivity*. A convergence from both scientific area is not *a priori* given and the fact that results from both disciplines almost converge, documents that productivity and efficiency analysis produces similar results for the productivity differences between organic and conventional farming. However, the productivity results are modeled at an aggregated farm level whereas yield comparisons are mostly evaluated at the plot or field level, therefore, the results do not reflect the same level of comparison.
   In the studies, lower productivity can be explained by production restrictions associated with the objective of environmental friendly production. A productivity comparison between organic and conventional farms contributes to the current literature as it estimates the productivity differential (similar to the yield gap literature) but not on the field level but rather by aggregating all inputs and outputs at the farm level.
   Organic farming also achieves lower efficiency of about 4% in studies accounting for sampling problems, ranging from -21 to +22% efficiency differences. A lower efficiency of organic farms is not the case for models, where environmental variables are included. In the latter kind of studies organic farms achieve the same efficiency as their conventional counterparts. Efficiency is closely linked to farms' success, since farms with an improved efficiency also achieve a higher level of profits (GUBI, 2006), documenting the relevance of efficiency and productivity modeling. However, efficiency and productivity analyzes are powerful instruments to model and describe the agricultural production with respect to organic farming system.
2. Many studies do not sufficiently discuss the data selection. This is true for the impact of technical

efficiency on the decision of whether or not to convert to organic farming. If we want to analyze efficiency of conventional and organic farms, but the conversion to organic farming is determined by, e.g. low farm efficiency any analysis will suffer from a selectivity bias. In the literature, there is a debate which role efficiency plays within the process of converting to organic farming. KUMBHAKAR et al. (2009) and LATRUFFE and NAUGES (2013) find a negative impact of efficiency on the decision to convert. Farmers decide to convert to organic production according to different factors, which are not all taken into account in most of the applied models. If we model the probability to convert (KUMBHAKAR et al., 2009), we can introduce factors such as the motivation or the attitude of a farmer towards organic farming. But unfortunately, this type of data often does not exist. However, selectivity issues have to and can be taken into account as many recent studies show by matching data before modeling (MAYEN et al., 2009; MAYEN et al., 2010; TIEDEMANN and LATACZ-LOHMANN, 2011; TIEDEMANN and LATACZ-LOHMANN, 2013) or by introducing a type of Heckman selection model (SERRA et al., 2008; KUMBHAKAR et al., 2009) into the core efficiency model.

3. Efficiency and productivity literature on organic farms also describe the impact of farm specialization or input-intensity on productivity and efficiency. The available studies show that organic farms still have scope to specialize and choose the optimal production program (BREUSTEDT et al., 2011; FRANCKSEN et al., 2007). Besides these findings a lot of efficiency analyzes do not discuss the allocation limitations on organic farms. Technical efficiency in general is a topic that should be discussed within the logic of the organic farming systems. Organic farming is strongly influenced *on the one hand* by the classical economic drivers such as scarcities and the process of competition - so specialization and economies of scale can also lead to an increased efficiency on organic farms. *On the other hand* organic farms pursue environmental objectives and are, therefore, restricted by production regulations necessary in order to produce ecological services. So specialization might in some cases lead to increased efficiency, but reduce diversity in the crop rotation (as one example of specialization). This might be legally allowed, but technically difficult since a diverse crop rotation is also an instrument to avoid diseases and to collect nitrogen by leguminous plants in the organic farming system. Therefore, organic farming as a system is not completely flexible in specializing and reducing diversity in crop rotation, which should be taken into account in recommendations for organic farms. In general, the efficiency studies point to the problem that decisions on organic farms have to be balanced between *sufficient profits and attainable organic objectives*. Both drivers can strongly influence decisions on organic farms. Nevertheless, some of the studies find positive efficiency effects of a diversified crop rotation (SIPILÄINEN and HUHTALA, 2013; TIEDEMANN and LATACZ-LOHMANN, 2013), which would support a wide crop-rotation even from an economic standpoint. To sum up, efficiency on organic farms has to take into account both drivers of the organic farming system.

Beyond these core efficiency results, we foresee further research needed for the following three topics:

4. Coming back to question two from the introduction, the efficiency studies show that subsidies have an impact on technical efficiency, which is of strong interest from a societal point of view. As the efficiency models (in the reported studies) do not include environmental services, we might expect subsidies to be efficiency-neutral. The fact that subsidies have an impact on efficiency shows the distortive nature of subsidies in general, which (even when paid for environmental services) have an impact on farmers' decisions (MCCLOUD and KUMBHAKAR, 2007; HENNINGSEN et al., 2011; MINVIEL and LATRUFFE, 2013). A rather simple explanation of this finding is that organic subsidies can sometimes be combined with other environmental payments, which additionally restrict the production system and thereby indirectly reduce the yield and thereby the productivity of a production system. An alternative explanation for those results might be rent-seeking behavior of farmers: organic farmers might pursue optimization strategies for their farm's revenue, which also includes subsides as one type of revenue. This points out to the problem of optimal program design to support organic farms and to 'produce' environmental services by farming. Rent-seeking as a theoretical explanation for this phenomenon is only valid for countries and regions with some flexibility in the support regime, which gives farmers some scope for combining programs for

organic farming with other agri-environmental programs and thereby optimizing the total subsidies received. However, this is not the case in all EU-member-states (SANDERS et al., 2011), therefore, 'rent-seeking' does not always explain the previously mentioned result.

5. The empirical studies presented in Section 3.3 show that efficiency of converting farms are significantly lower in comparison to established farms. In addition, this learning process takes longer than the official two-year conversion period in the EU. Some studies also present experience in the organic farming system as one key determinant of technical efficiency. This finding raises the question, whether the specific support during the conversion period should be extended to a longer period or not. Taking the support of the EU for organic arable farming in 2009 as an example, two types of conversion support is typically granted. A first type of support scheme sets a substantially higher conversion support for the first two years, going to the level of payment granted for the maintenance of organic farming in year three after the conversion. The second type of conversion support grants a moderately higher conversion support for up to five years (NIEBERG et al., 2011). Only twenty of sixty-one EU regions offer type two support on arable land for the first five years after conversion (SCHWARZ et al., 2010). A sustained conversion premium (even beyond the five year limit) can be justified with reduced technical efficiency in the conversion period stemming from the learning process in that period. On the other hand an increased support only for the first two years is usually justified by reduced marketing options; organic farms during the first two years cannot market their products with the label 'organic' (NIEBERG et al., 2011). Therefore, any conversion support has to take into account both learning costs and reduced marketing options. In addition, increasing this support does not automatically increase conversion rates in a socially optimal manner.

6. A clear statement on research question three from the introduction has shown to be more difficult: The topic of environmental efficiency has been analyzed in only a few studies (DREESMAN, 2007; KANTELHARDT et al., 2009; SUTHERLAND et al., 2012; SIPILÄINEN and HUHTALA, 2013; ALDANONDO-OCHOA et al., 2014). From society's point of view, environmental efficiency is crucial in order to identify adequate policy measures that take the environmental dimension of farming into account. However, there is a substantial lack of appropriate data – as the few studies above show. Common farm data sets used in efficiency analysis lack appropriate ecological indicators; however a few sustainability studies from California (POUDEL et al., 2002) or Norway (ELTUN et al., 2002) about farms provide much more detailed data sets. Unfortunately, a higher degree of detailed data comes at the cost of the lower number of observations or higher data collection costs. Therefore, the challenge to appropriately model the environmental dimension of farming is often not solved due to a lack of data. The efficiency literature shows that there is still the need for more reliable and detailed data sets.
   The results and conclusions with respect to environmental efficiency are restricted due to the low number of studies in the field. However, we can show that productivity and efficiency analysis provides a methodological framework to evaluate the environmental dimension of farming and it avoids problems of aggregation and weighting of environmental variables (FÄRE et al., 1996; FRANCKSEN and LATACZ-LOHMANN, 2008b). The methodological advantages of the methods are given, however the number of studies are still low. To fully answer the question, whether e.g. organic, low-input, integrated or conventional farming is the most efficient way to provide environmental services for a society, we also need to include results from other scientific disciplines like farm-economics (e.g. ELTUN et al., 2002), from agronomic sciences (e.g. POUDEL et al., 2002) or from e.g. ecosystem-modeling. A full description of the literature in these fields is beyond the scope of this study (see e.g. REGANOLD and WACHTER, 2016). Finally, more conceptual and empirical research in the field of environmental efficiency and productivity is necessary to answer the questions of society, whether and to what extent a farming system is able to efficiently use scarce resources and to combine them for the production of marketable goods and non-marketable public goods.

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