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Efficiency analysis of organic farming systems – a review of methods, topics, results and conclusions

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The article summarizes the literature on efficiency and productivity of organic farming. A short overview on theories and models is provided. We can distinguish between studies that concentrate of specific problems of the organic sector and studies that aim to compare conventional and organic farming systems. Sample selection is a major challenge for comparisons between organic and conventional farms, since the organic farms have a different farm-structure and are often represented by a relatively small number of observations. We find that conversion to organic farming is influenced by inefficiency. In three of four studies, organic farms have a lower productivity than conventional farms. Studies on environmental efficiency document that organic farming show a higher degree of efficiency if environmental variables (such as landscape elements and diversity in the crop-rotation) are taken into account. The impact of subsidies on farm efficiency is often found to be negative.

Key words: Organic Farming; Technical Efficiency; Environmental Efficiency; Productivity; Farming Systems; Subsidies;

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1. Introduction

Productivity and efficiency analysis – well established in the economics and management literature – is one important empirical method to analyze and compare different farming systems. In the last fifteen years, organic farming has been investigated and compared to conventional farms using this methodological framework.

The findings of efficiency and productivity analysis in organic farming are first of all important from a **farm perspective**, to better understand farmers' decisions and the functioning of organic farming as a system. In more detail, we like to explain the impact of farm specialization or input-intensity on productivity and efficiency. Efficiency and productivity also influences the decision whether or not to convert to organic farming.

From a **societal perspective** the methods of efficiency and productivity analysis allow for combined evaluation of non-monetary benefits from organic farming such as environmental services together with costs and profits. In addition, productivity and efficiency measures allow to evaluate on one hand organic farms' need for monetary support and on the other hand the higher cost of organic production. Finally, a productivity comparison between organic and conventional farms contributes to the debate on the yield-gap between organic and conventional farming systems (Badgley et al., 2007; De Ponti et al., 2012; Ponisio et al., 2014; Seufert et al., 2012).

Consequently, a review about efficiency and productivity studies of organic farms – sometimes in comparison to conventional farms – can contribute to better understand organic farming as a system with agronomic, economic, environmental and ethical dimensions. Thus, such a review should be dedicated not only to agricultural economists but also to a wider agricultural sciences' and interdisciplinary readership interested in organic production on the farm-level, technological and biological progress in organic farming, in farmers' conversion decisions between farming systems, in well-targeting of subsidies for organic production, in evaluating organic farms' environmental contributions, and, who are interested in understanding the yield gap of organic farming.

Nonetheless, so far a comprehensive overview and summary of the efficiency and productivity literature on organic farming is missing. Therefore, in the following article we provide an overview such studies published in recent years: We summarize the main findings and conclusions on productivity in organic farming systems and on efficiency and productivity comparisons between organic and conventional farming. As a basis of our analysis we will use published journal articles, 19 in indexed journals, five in non-indexed journals. We also present six selected peer-reviewed conference papers and two dissertations in the area, which cover very interesting topics or provide insights, which are not covered by the journal-articles. Overall, the number of studies we present is 35. Most of these studies have a regional focus in Western Europe (12), Southern Europe (10), Scandinavia (7) and the United States (4), but we also include one study from Turkey and from Egypt. The regional focus of the studies represents mainly the countries with established organic production or organic markets like USA, Germany, France, Spain, Austria, Denmark, Sweden, Greece and Switzerland. In this list of countries with an established organic market or production just the United Kingdom is missing (Willer and Lernoud, 2015).

We will structure our paper as follows: In section 2 we give a short introduction into the existing models for productivity and efficiency analysis. Section 3 is dedicated to the results of the studies. We distinguish between literature focused on samples with only organic farms, the comparative studies (conventional vs. organic), and special topics such as the efficiency in the conversion period and the literature on the choice of farm structure, the topic of environmental efficiency and the impact of policy support on efficiency. In section 4 the overall results are summarized, discussed and conclusions are drawn.

2. Methods and Modeling approaches

Productivity and efficiency analysis in general relates inputs and outputs in different model approaches, which all produce estimated 'productivity' or 'efficiency' scores. The first main concept, 'productivity' typically refers to the relation of output relative to the used inputs (Chambers, 1988). In agricultural production sciences this definition is often called 'efficiency', however, in economics we use the term 'productivity'. The second main economic concept is 'efficiency': For the case of e.g. output orientation, we assume the input-level of a farm as given and compare the observed output to any benchmark-output. of a farm or decision making unit (DMU). Efficiency can be measured or estimated at one point in time (cross-section data) or over several periods (panel-data). There are different model-approaches and there is large number of technical and mathematical assumptions when applying efficiency models, which are presented in detail in (Coelli et al., 2005). One of these assumption seem to be crucial in the context of organic framing analysis: The homogenous technology assumption states that only DMU of the same or at least a similar technology can be compared. The typical approach of efficiency analysis is the comparison of a the actual input-output mix of a DMU to a benchmark. This benchmark is modeled with different approaches.

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*'. In this context, we distinguish between output- and input-oriented models (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* (Brümmer, 2001; Simar and Wilson, 2000), which are non-parametric resampling methods. The DEA framework also allows 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 (Battese et al., 2004; Breustedt et al., 2011; O'Donnell et al., 2008). Weaknesses of DEA are that random impacts on the observations (e.g. measurement error) are treated as real and deterministic and that some observations heavily influence the level of the frontier.

In the ***Stochastic Frontier Analysis (SFA)*** the benchmark is estimated through regression analysis. Developed by Aigner et al. (1977) and Meeusen and Broeck (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. An overview on the SFA-modeling can be found in (Kumbhakar and Lovell, 2000).

As a regression technique SFA accounts for the stochastic nature of most data sets by means of an error term. This 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 for each DMU. 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) and it is also possible to apply the metafrontier approach in the parametric estimation framework (Battese et al., 2004; O'Donnell et al., 2008).

Besides the generation of farm revenue, organic farming also pursue the objective of an environmental friendly farming. If positive or negative externalities are part of the agricultural production, the results of the classical efficiency analysis will not exactly display Pareto-improvements of a farm (Dreesman, 2007), since a substantial part of the production process (in form of the externality) is not included in the model. Productivity and efficiency analysis also provide different options to introduce environmental variables to partly overcome this problem. In the case of negative externalities, environmental variables can be introduced in the model as inputs or (undesired) outputs. In the case of positive externalities, the environmental variables are used as second output-dimension of agricultural production (Allen, 2002; Dreesman, 2007; Reinhard et al., 1999).

3. Empirical efficiency analyses of organic farms

3.1. Studies investigating efficiency on organic farming

There are about nine studies, which work exclusively with organic data-sets and focus on topics that are relevant for the organic farming system. Table 1 on the next page presents a short overview on the studies. SFA is used in nine studies, the DEA is just used four times. With respect to farm type, grassland-farms are analyzed the most (five times), three studies work with different farm types. Six studies are using panel data with a length between 3 and 11 years length, the other five studies are using Cross-section data-sets. Consequently, also the number of observations are varying between 65 farms (min) to 1717 observations (max).

The most important outcome of an efficiency model in organic farming might be the structure of a production function. Figure 1 shows the output-elasticities of different studies:

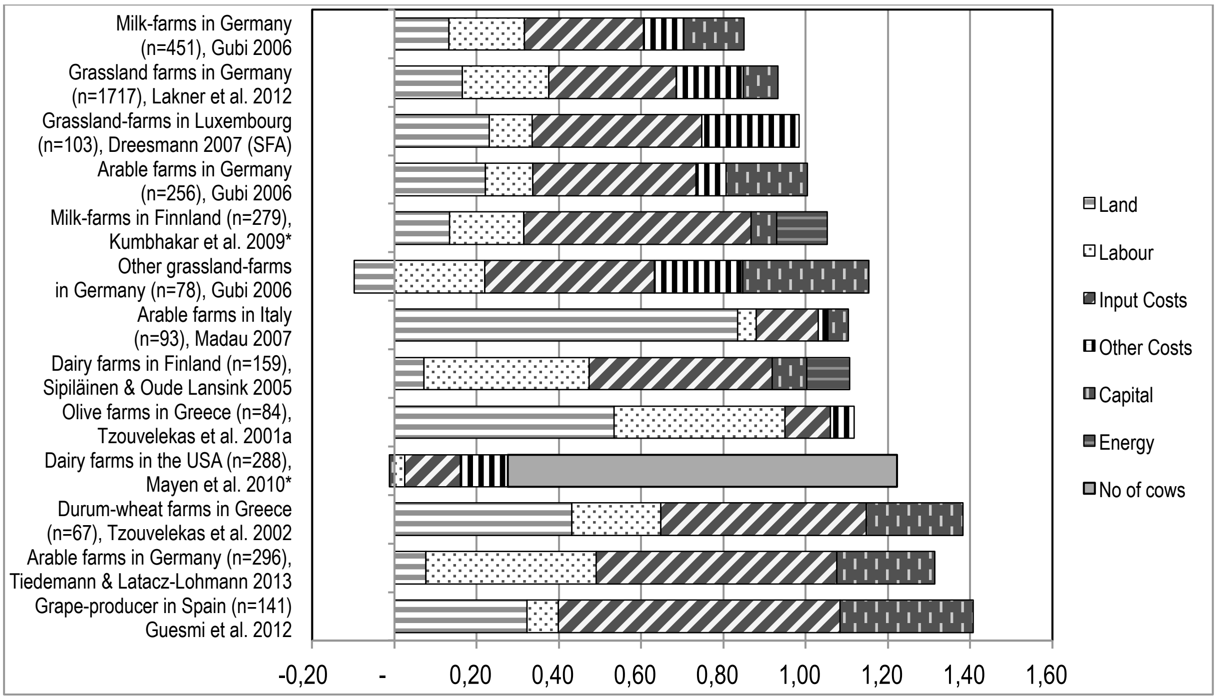

Fig. 1. Estimated output elasticities of different inputs estimated in 10 efficiency studies
Source: Authors
***note:** Mayen et al. 2010 and Kumbhakar et al. 2009 did not calculate constant output elasticities. In these two studies we used *output elasticities at sample mean*.

Tab. 1: Studies investigating only organic farms

Authors	Region	Sample -Size	Farm-type	Years	Method	Question	Main Findings
1 Gubi 2006	Germany	1070	All types	1996-2002	DEA/SFA	Investigates determinants of efficiency in different farm types and the relation of TE to farm-success.	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	USA	774	All types	1997	SFA	Investigates influence of the farmers experience on TE with two farm-groups according experience in OF	Farms with more than 5 years experience are more efficient (more details in section 3.3)
3 Dreesman 2007	Luxembourg	103	Grassland	1999/2000	DEA/SFA	Investigates economic and environmental efficiency of OF	Substantial differences between traditional efficiency and environmental efficiency (section 3.5).
4 Francksen et al. 2007	Germany	461	Arable	1998-2003	DEA	Investigates if OF should specialize or diversify.	5-20% OF should further specialize. Better specialization of farms increases productivity by 14%. (section 3.4)
5 Lohr & Park 2007	USA	774	All types	1997	SFA	Investigates impact on-/off-farm soil improving inputs (e.g. manure, compost or soil fertilizer) on TE	Farms with a high share of on-farm soil improving inputs are less productive but more efficient. Soil improving inputs are integral part of the production function of OF.
6 Sauer & Park 2009	Denmark	56	Milk	2002-2005	SFA	Investigates the effect of subsidies on the market exit of OF.	OF have differences in TE and a negative trend of TE. Investments and Income have a positive impact TE. Off farm income have a negative impact on TE (section 3.6).
7 Lakner 2009	Germany	1348	Milk	1995-2005	SFA + B&C95	Investigates the impact of different types of subsidies on TE.	Payments for organic farming and agri-investment schemes have a negative impact on TE (section 3.6).
8 Karafillis & Papanagiotou 2011	Greece	177	Olive	2004/05	SFA	Investigates whether farms use innovative technologies (measured with an index).	Farms with innovative technology have higher TE, also farms without innovative technologies have potential for improvement (section 3.3).
9 Lakner et al. 2012	Germany	1717	Grassland	1995-2005	SFA + B&C95	Investigates TE during conversion period and determinants of TE including regional heterogeneity.	TE is increasing 6 years after conversion. TE is influenced by regional heterogeneity and the socio-economic environment influence TE. (section 3.3 and 3.6).
10 Nastis et al. 2012	Greece	65	Alfalfa	2008	DEA + bootst	Investigates the role of experience and subsidies on TE.	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	Austria, Switzerland, Germany	244 218 106	Grassland & mixed	2003-2005	SFA DF + Metaf	Investigates the impact of farm diversification and of subsidies.	Diversification contributes to farm productivity, but also reduces TE. Different types of subsidies have a negative impact TE (section 3.6).

Abbreviations:
B&C95 = Inefficiency Effects Model (Battese & Coelli 1995)
bootst = Bootstrapping model (Wilson & Simar 2000)
Metaf = Metafrontier-Models

Source: Authors

Tab. 2: Studies comparing organic and conventional farms

Authors	Region	Sample	Farm-type	Years	Method	Question	Main Findings
1 Tzouvelekas et al. 2001a	Greece	171	Olive	1995/6	SFA + B&C95	Compares TE of OF/CF	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	Greece	58	Cotton	1995/6	SFA + B&C95	Compares TE and allocative efficiency of OF/CF	CF more technical and allocative efficient. Therefore economic efficiency also higher on CF than in OF
3 Tzouvelekas et al. 2002	Greece	57	Durum wheat	1998/99	SFA	Compares TE of OF/CF.	OF with more efficient to their own frontier. More heterogeneity of OF with respect to labor.
4 Oude Lansink et al. 2002	Finland	868/ 3,159	Arable/ Livestock	1994-1997	DEA	Compares of productivity and TE of OF/CF.	OF are more efficient to their own frontier, but 23% less productive.
5 Sipiläinen & Oude-Lansink 2005	Finland	1921	Milk	1995-2002	SFA DF + B&C95 + Select.	Compares TE of OF/CF corrected by a selectivity model.	Learning process on OF of 6-7 years. Conversion-decision to OF dependent from the age of farmer and region. Energy on OF has a higher output-elasticity.
6 Larsen & Foster 2005	Sweden	2738	All types	2000-2002	DEA DF + Select	Compares TE and determinants of TE of OF/CF by considering selectivity.	OF with lower TE. OF achieve better performance within the OF-system than within the CF-system.
7 Madau 2007	Italy	231	Cereal	2001-2002	SFA + B&C95	Compares TE of OF/CF.	If fully efficient, OF (CF) could increase their income by 79 €/h (50 €/ha).
8 Bayramoglu & Gundogmus 2008	Turkey	82	Raisin	2003/4	DEA	Compares TE of OF/CF.	If fully cost-efficient, OF (CF) could improve family income by 652 € (445 €).
9 Kantelhardt et al. 2009	Germany	102	Mixed	–	DEA	Compares economic and environmental efficiency of farms in agri-environmental schemes.	OF more successful combining economic and ecological efficiency in comparison to other farms in agri-environmental schemes (section 3.5).
10 Kumbhakar et al. 2009	Finland	1921	Milk	1995-2002	SFA + Select.	Compares TE of OF/CF accounting for selection bias due to conversion to OF.	The conversion to OF is dependent of subsidies, experience and past conversion decision, but not inefficiency. CF is more productive.
11 Serra & Goodwin 2009	Spain	129	Arable	2002	SFA + LML	Compares TE of OF/CF depending of the farm size.	OF with lower TE against their own frontier.
12 Mayen et al. 2010	USA	425	Milk	2005	SFA + Match.	Compares TE of OF/CF capturing structural differences with matching.	OF has a lower productivity. No TE between OF/CF. The hypothesis of homogenous technology is rejected.
13 Sauer 2010	Denmark	3431	Milk	1986-2005	LDF	Investigates the reaction of OF/CF on the introduction of a quota trading system.	No efficiency differences between the OF and CF. (section 3.6)
14 Breustedt et al. 2011	Germany	1341	Milk	2002-04	DEA + Metaf.	Investigates if OF have chosen the most efficient farming system.	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).
15 Tiedemann & Latacz-Lohmann 2011	Germany	1040/ 592/ 784	Grassland/ arable/ mixed farms	1999-2006	DEA + Match. SFA + Match.	Compares the development of total factor productivity (TFP) on OF/CF.	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).

16 Guesmi et al. 2012	Spain	141	Grape	2008	SFA + B&C95 + LML	Compares of efficiency of OF/CF, depending from different size-classes.	OF are by 12% less productive. Efficiency on OF is positively affected by experience in OF, but negatively related to unpaid family labor, the farm location and farmers strong environmental preservation.
17 Kargiannis et al. 2012	Austria	170	Milk	1997-2002	SFA + GTFEM	Compares scale efficiency of OF/CF taking into account fixed effects by GTFEM.	OF have a lower scale efficiency than CF.
18 Nehring et al. 2012	USA	3751	Milk	2005/2010	SFA DF	Compares scale efficiency of OF/CF in different sizes.	Small scale farms in both OF&CF are less efficient than large scale farms.
19 Tiedemann & Latacz-Lohmann 2013	Germany	74	Arable	1999-2006	SFA + Match.	Compares efficiency (TFP) and risk behaviour of OF/CF.	Land and labor are increasing risk on both farm systems, whereas capital, seed costs and soil quality reduce risk.
20 Sipiläinen & Huhtala 2013	Finland	798	Arable	1994-2002	DEA DF + Metaf	Compares environmental & economic efficiency on OF/CF.	If environmental variables are included and the sample is bias-corrected, then both technologies achieve the same technical efficiency (section 3.5).
21 Aldanondo-Ochoa et al. 2014	Spain	83	Vineyards	2004	DEA + Metaf	Compares environmental & economic implications of the conversion to OF.	OF with higher environmental efficiency to their own frontier and to the metafrontier (section 3.5).
22 Beltran-Esteve & Reig-Martinez 2014	Spain	212	Citrus	2009	DEA DF + Metaf.	Compares efficiency of OF/CF and the cost-saving potential of specific tasks.	If fully efficient OF (CF) can achieve cost-savings of 60% (45%). Specific tasks have different cost-saving potential.
23 Latruffe & Nauges 2014	France	5830	All farm types	2003-2007	DEA, SFA, FDH	Investigates the influence of past TE on the decision to convert to OF.	The decision depends on TE prior the conversion, but the direction of the effect depends of farms size and type of production (section 3.3).
24 Guesmi et al. 2014	Egypt	60	Cereal + horticulture	2010	SFA + LML	Compares of efficiency of OF/CF, depending from different size-classes.	OF slightly more efficient than CF. Input Elasticities different depending of farm-size.

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

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 0.38. 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[1]. Labor has a lower output-elasticity with a mean value of 0.2. In the comparable studies, four studies find higher output elasticities of labor than in the conventional reference group, and in four studies the output elasticity of labor is lower on organic farms. However, if conventional farms are modeled alone, we find rather low output-elasticities of labor (Abdulai and Tietje, 2007; Brümmer and Loy, 2000). Capital (0.16) and other costs (0.12) achieve on average smaller output-elasticities.

Analyzing the **returns to scale** (i.e. the sum of output-elasticities of all inputs), we can see that most studies rather find constant or increasing returns to scale: six of fourteen samples show constant RTS (Dreesman, 2007; Gubi, 2006; Kumbhakar et al., 2009; Madau, 2007), seven samples find increasing RTS (Guesmi et al., 2012; Mayen et al., 2010; Nehring et al., 2012; Sipiläinen and Oude Lansink, 2005; Tiedemann and Latacz-Lohmann, 2013; Tzouvelekas, 2001; Tzouvelekas et al., 2001; Tzouvelekas et al., 2002), and one study finds decreasing RTS (Lakner et al., 2012). If farms increase their input-use, we can always expect the same or an even proportionately higher output increase. In a more general sense this might still indicate an incentive for structural change in the organic sector.

Many of the studies focussing exclusively on organic farming are investigating the main factors influencing technical efficiency (determinants). In most cases, the model proposed by Battese and Coelli (1995) is used, which simultaneously models production frontier and the determinants of inefficiency. The following tab. 2 is sumarizing the main determinants of technical efficiency (based on 15 studies):

Tab. 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	5	2	7
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

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

Tab. 2: Determinants of technical efficiency in organic farming (*continued*)

	Impact of variable on TE		no. of Studies
	positive	negative	
2. Farm structures and resources			
Degree of specialization of the farm	8	3	11
Family farms	3	5	8
Capital	5	0	5
Size	4	1	5
Diversification/direct marketing	1	2	3
Full time farm	1	1	2
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
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 favored area	1	2	3
Altitude	1	2	3
Land fragmentation	0	1	1
Other Variables			
Subsidies	3	5	8
Region-Variables	included in 9 studies		

Source: Authors
Note: The result is based on 20 different samples within 15 studies. Only significant results in the studies are counted.

An important topic of efficiency studies foussing only on organic farms is the question how **Management skills and education (1)** influence technical efficiency. This group of factors can be influenced directly by a farmer, since especially education and konwledge can constantly be improved. Education and the age of the farmer (as a proxy for gathered experience in farming) exhibit a positive influence on farms 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.

Also **farm structure and resources (2)** play an important role. This group of variables can be influenced by a farmer, but not as directly as in with management skills and education. Here we can find, that especially a high degree of specialization contributes to a higher efficiency, however, this is not always the case. The opposite case, farm diversification outside agriculture (i.e. in direct marketing), reduces TE in agriculture (see also in section 3.4). Family farms are in five of eight studies found to be less efficient. Capital-endowment and the size of a farm often contrubute to an increased efficiency. Another group of determinants are variables describing the **location of a farm (3)**, 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 5 of 8 cases. Finally, **Regional differences (4)** also play an important role for the formation of farms efficiency and are included in nine studies.

3.2 Studies comparing efficiency of organic and conventional farms

A second group of twenty-four studies compare efficiency and productivity between organic and conventional farms. Tab. 2 (on p.7/8) gives an overview on the evaluated studies. SFA-model (in 15 studies) are used more frequently than DEA-models (10). 13 studies are working with cross-sectional data, which are in most cases from data-collections. 11 studies work with panel data-sets (from 3 up to 20 years length) stemming in most cases from the European Farm Accounting Data Network (F.A.D.N.) (European Commission, 2010). With respect to **farm types**, all farm types are included in the different studies. However, the number of studies dedicated to special crops is to some extent surprising. On the other hand, horticulture and specifically vegetables (important in organic farming) are just investigated in two studies.

Before dealing with the main outcomes of efficiency and productivity analysis, we need to present one important challenge for comparing efficiency and productivity of organic and conventional farms. Any comparison of a group of organic farm with a group of conventional farms raises the question on how the sample was constructed. A framework for comparing organic and conventional farms was originally proposed by Offermann and Nieberg (2001), showing the different levels of comparisons. The sampling-strategy can in a bad case systematically influence the estimated results and thereby restrict the interpretation.

First, one difference between both groups might just be due to different farm structures within the farming systems. In many European countries, organic farms have a different farm structure[2] 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

[2] According to our best knowledge, there is no actual overview of an organic farming system throughout Europe. 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 an organic farming system.

higher (Häring et al., 2004). A **second** problem might by a 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. There are different approaches to accommodate this problem. The **third** problem might be a difference in reliability between the organic and conventional subsample. 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 in this category work with data sets which contain, in general, a large-group of conventional farms and a small subgroup of organic farms (fig. 2):

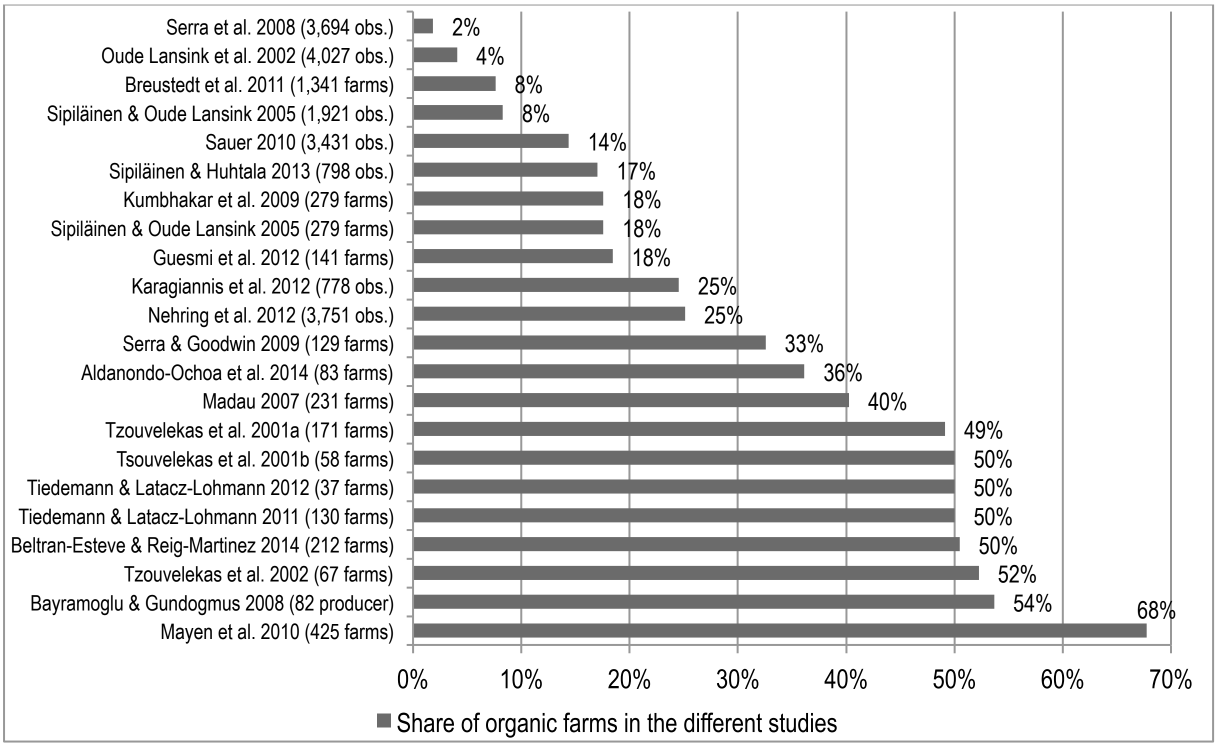

Fig. 2. Share of organic farms on the total farms in different comparative studies on technical efficiency

Source: Authors calculations

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.

In the case of an uneven size of farm-groups, the reliability of both groups can be different and besides this, we might at the same time find the other two sampling problems. However, this is not an automatic criticism, since uneven sampling might also be justified depending on research question and interpretation.

Besides distributional issues, the questions of potential selection bias and of how the sample was constructed are not always discussed in detail. There are different strategies and approaches to accommodate these problems:

1.) **Metafrontier:** A first minimum approach would be a separate group-estimation and the use of a metafrontier, that envelopes both group-frontiers. In such a case, efficiency measures against the joint metafrontier would produce efficiency results which 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 about 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. Three other studies reduced the conventional group by matching models: Mayen et al. (2010) use a propensity score matching model (PSM) and Tiedemann and Latacz-Lohmann (2011, 2013) use Euclidean-Distance Matching. Tiedemann and Latacz-Lohmann (2011) point out that selectivity issues due to unobserved characteristics cannot be totally avoided with matching models. But we might add, that matching still 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 the potential selectivity bias, Kumbhakar et al. (2009) combine in an one-step estimation a SFA-model with a Heckman correction-model. Their results show to be independent from different distribution assumptions in the error terms.

One main model outcome is **productivity**. Organic farms show a lower productivity in three of four studies (Kumbhakar et al., 2009; Mayen et al., 2009; Oude Lansink et al., 2002; Tiedemann and Latacz-Lohmann, 2011). Oude Lansink et al. (2002) find organic arable and livestock farms in Finland to be 23 % less productive than conventional arable farms. However, the study is modeling both groups separately and there is no strategy to accommodate the problem of selectivity.

In contrast, Tiedemann and Latacz-Lohmann (2011) identify comparable farm-pairs with a matching-model for their efficiency and productivity comparison. The result shows that there are no significant differences in total factor productivity for the full period between 1999 and 2006. The organic grassland farms and organic mixed farms could both increase their productivity in the observed period. Surprisingly, organic arable farms had a slightly higher productivity at the beginning of the observed period, but they could not keep the level of productivity (Tiedemann and Latacz-Lohmann, 2011).

Mayen et al. (2010) also applied a matching model to create 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 reconvert.

In conclusion, three of four studies find organic farms to be less productive, but these results are not surprising overall, because the organic farming system imposes restrictions on the use of inputs. If these restrictions did not imply that farmers have to switch to a less productive technology, they would lose their binding character, and farmers would likely adopt organic farming practices even without specific support. A first meta-study of Badgley et al. (2007) found a yield ratio in grain production of 69% (Badgley et al., 2007). Their approach, using a broader definition of organic farming practices, was criticized by (Avery, 2007). Another meta-review on yield studies by de Ponti et al. (2014) shows, that organic yields e.g. in cereal production are on average 79%, of the conventional yield-level, but ranging from 40-145%(De Ponti et al., 2012). Seuffert et al. (2012) found an average yield ratio of 75% (with a 95%-confidence-interval between 71-79%) in their meta-study (Seufert et al., 2012). In contrast, Ponisio et al. (2015) found a yield ratio of 80.8% with a more strict method of meta-analysis by excluding '*subsistence yields of unimproved agriculture*' (Ponisio et al., 2014). This selection on different meta-analysis on the yield-ratio documents, that taking into account inputs and outputs by efficiency and productivity models, we get comparable productivity values for organic farming, however not on a production, but on the farm level.

The second main model outcome is **technical efficiency**. In the following figure 3 we present the efficiency difference between the organic and conventional farm-group in studies with any joint benchmark or with models that accommodate with potential selectivity bias:

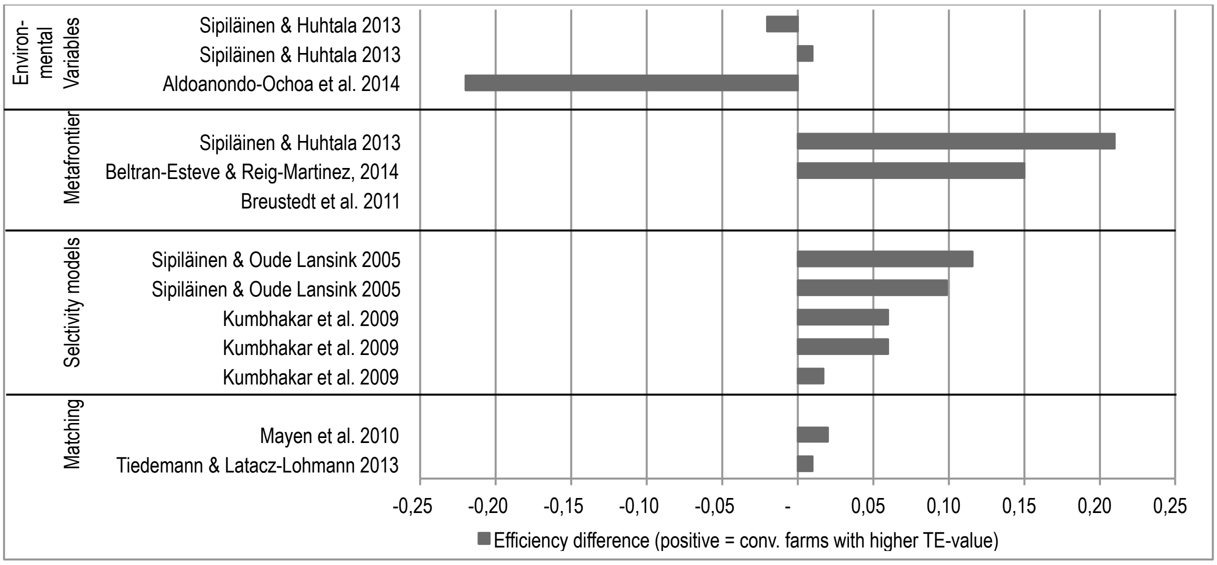

Fig. 3: Comparison of technical efficiency between organic and conventional farming.
Source: Authors

In most cases, organic farms are less efficient or achieve the same level of TE (as in Tiedemann & Latacz-Lohmann 2011, Breustedt et al. 2011). Interestingly, in two studies including environmental variables (Aldanondo-Ochoa et al., 2014; Sipiläinen and Huhtala, 2013), organic farms achieve 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 some kind of joint estimation techniques. However the problem of sample selection has been ignored by many studies, until recently where a few studies systematically take structural differences or sample selectivity issues into account (Kumbhakar et al., 2009; Mayen et al., 2010; Tiedemann and Latacz-Lohmann, 2011, 2013). Overall the comparative studies are very heterogeneous: technical efficiency strongly 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 seen critically.

3.3 Technical efficiency in the conversion period

There are three main research-topics with respect to efficiency and the conversion to organic farming. First, different studies investigate, whether farmers' experience and knowledge about organic farming exhibits a systematic impact on the single farm efficiency: Two studies (Lohr and Park (2006); Sipiläinen and Oude Lansink (2005) 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) could also show that organic farms using innovative techniques achieve better total factor productivity values. The study also highlights the scope for improvements even for those farms which haven't used new technologies yet (Karafillis and Papanagiotou, 2011).

Second, the measure technical efficiency is often interpreted as learning costs for managing an organic farm. Following the results of Sipiläinen and Oude Lansink (2005) this learning process following the decision to convert to organic 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 curve during the conversion-period has a U-shape with an substantial efficiency-increase after six years. Therefore, from an efficiencies 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 respec to conversion to organic farming is the general question, whether the decision to change the farming system and convert to farm to the organic farming system might be driven by efficiency or 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 play an important role (Hollenberg, 2001; Mußhoff and Hirschauer, 2008; Rahmann et al., 2004; 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, by using a Heckman sample-selection technique, Kumbhakar et al. (2009) find that inefficiency is reduction the probability of adopting the organic farming technology. The authors state, "*we do not find any evidence to support that inefficiency is a driving force behind adoption of organic farming technology*" (Kumbhakar et al., 2009). So finally, efficiency seems to influence the adoption decision, however, it seems to be an empirical question, whether this influence is positive or negative.

Latruffe and Nauges (2013) also introduce a cross-term, which aims to model the impact of an interaction term of farm-size and technical efficiency on the probability to convert: with a given equal TE-score, very small farms show to have a lower conversion probability, whereas large farms have an increased probability to convert to organic farms. These results are also in line with the results from Pietola and Oude Lansink (2001) for Finland. On the other hand, in a non-efficiency analysis with Irish farm data, Läpple (2010) finds that the smaller farms are more likely to convert organic farming.

Overall, most of the studies show that experience and knowledge is a crucial factor to improve technical efficiency within the organic farming system. The finding is logic 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 different studies do not give a clear indication in which direction technical efficiency influences the decision to convert to organic farming.

3.4. Choice of farm structure

Some studies focus on the topic of choice of farming system: For single farm development, the farm manager has to decide whether to remain in the existing production program, or to switch to another farming system. However, a recent study shows (Sahm et al., 2013), that also the opposite case is a relevant issue for some organic farms, who have to change back to the conventional system. In a more general sense, these strategic decisions for a farm are about the allocation of scarce resources. Technical efficiency can also be increased by the choice of the appropriate farm system (organic/non-organic) or by an appropriate degree of specialization or diversification.

Francksen et al. (2007) investigate the degree of optimal farm specialization on 358 organic mixed and specialized crop farms. The farms are split into three specialization classes[3]. The efficiency of a farm is 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 rather 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.

Other studies show, that diversification can have different impacts within the organic farming system: A study on organic farms in Southern Germany, Switzerland and Austria shows that diversification beyond agriculture ('para-agriculture') contribute on the one hand to farm income, but on the other hand also reduces the technical efficiency of the farm as a whole

[3] In specialization-class 1 farms are creating 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 %.

(Lakner et al. 2014). A diversified crop rotation also reduces the yield-risk of organic farms in Germany (Tiedemann and Latacz-Lohmann (2013).

Another allocation topic is the question, whether a farm has chosen the most profitable farming system: A study on Bavarian dairy farms shows, that about 68.6 % of the organic dairy farms have chosen the most profitable farm system. But still, around 31.4 % of the organic farms should reconvert to conventional farming in order to achieve higher short-run 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 €) (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'.

3.5. 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. Most of the efficiency models comparing organic and conventional farming do not include environmental variables (Oude Lansink et al., 2002), which represents a part of the objective function of an organic farm.

Dreesman (2007) analyzes data from fifty-eight organic milk farms in Luxembourg in 1999 and 2000 with respect to their environmental efficiency, modeled with data on nitrogen, phosphorous and energy use of the farms. These three variables were treated as undesired environmental inputs. In different model setups, both phosphorus (in the SFA-mode) and as well energy (in the DEA-model) have a substantial impact on productivity, whereas nitrogen doesn't contribute to farm productivity. The results also show, that increased specialization also contributes to an 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) in southern Bavaria. The variables 'low-intensively used area', 'area covered with landscape elements' are used as positive environmental outputs, the indicator 'nitrogen use' is introduced into the model as undesired environmental output. Within the different offered programs, organic farms simultaneously high economic and environmental efficiency. Also other program types were more efficient than the no-participation option. According to the authors, the organic farms seems to be quite successful in combining environmental and economic efficiency (Kantelhardt et al., 2009). The methodology is one way to address the problem of neglected externalities, however, the number of farms is too small to draw reliable general conclusions.

Sipiläinen and Huhtala (2013) investigate the impact of crop diversity on farm efficiency for both organic and conventional crop farms in Finland. Crop diversity (by a Shannon diversity index) is introduced as a secondary environmental output besides 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 83 organic and conventional vineyards in the region Navarra, Spain. The used environmental variables are nitrogen surplus, potential toxicity of pesticides, however, the authors also stress, that the conventional vineyards are not strikingly different from organic farming[4]. The method is a DEA combined with a metafrontier, 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. The authors therefore conclude, that organic vineyards are more efficient in using natural resources.

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 (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 (Henningsen et al., 2011; Latruffe et al., 2011; McCloud and Kumbhakar, 2007). In that sense, farmers may not use the best available input- or output-choice for their farm, since that might affect the sum of subsidies. This was confirmed by a meta-study by Minviel and Latruffe showing a negative impact of subsidies on the efficiency of (conventional) farms (Minviel and Latruffe, 2013). A 1 % increase in subsidies can lead to a 1.65 % decrease in farms' efficiency, which according to the authors suggests a distortive impact of subsidies on farmers' decisions.

[4] The study uses a Environmental Impact Quotient of Farm (EIQF) for capturing the potential impact of pesticides. The authors point out, that the EIQF-value is higher on organic vineyards.

This finding can also be derived from the efficiency literature: In the case of German grassland- and milk-farms, agri-environmental payments ((Lakner et al., 2012) and also agri-investment-schemes show a negative impact on efficiency (Lakner, 2009), which might be by 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, which (according to the authors) raises '*serious doubts about the efficiency of such policies*' (Nastis et al., 2012). In contrast, Tiedemann and Latacz-Lohmann find a significant positive impact of subsidies on technical efficiency (Tiedemann and Latacz-Lohmann, 2011) 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, 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 of technical change – although it was tested – can only be interpreted with caution.

4. Discussion and Conclusions

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

1.) Organic farms show a lower productivity in three of four studies (Kumbhakar et al., 2009; Mayen et al., 2010; Oude Lansink et al., 2002; Tiedemann and Latacz-Lohmann, 2011), however, the efficiency and productivity differences almost in the same range than organic-conventional yield-ratios (Badgley et al., 2007; De Ponti et al., 2012; Ponisio et al., 2014; Seufert et al., 2012). If we just consider studies with strategies to avoid sampling problems, then organic farming also achieve lower efficiency. This is not the case for models, where also environmental variables are included, where organic farms achieve the same efficiency performance than 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, the efficiency and productivity has scope to model and describe the agricultural production with respect to organic farming system.

2.) Many studies do not discuss the selection of data critically. This is especially true for the relation of technical efficiency and the question whether to convert to organic farming. If we are to compare efficiency of conventional and organic farms, but the conversion to organic farming is determined by high or low technical efficiency of a farm, any analysis will suffer from a systematic selectivity bias. The cited literature has different results on the question in which direction efficiency influences the decision whether or not to convert to organic farming (Kumbhakar et al., 2009; Latruffe and Nauges, 2013). Farms 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, it is clear that selectivity issues have to and can be taken into account as many recent studies do by matching data before modeling (Mayen et al., 2009, 2010; Tiedemann and Latacz-Lohmann, 2011, 2013) or by introducing a type of Heckman selection model (Kumbhakar et al., 2009; Serra et al., 2008) into the core efficiency model.

3.) The available studies also show that allocation decisions on organic farms might not always be optimal (Breustedt et ald., 2011; Francksen et al., 2007) and that there is still scope to specialize and choose the best available production program for a farm. On the other hand, some studies do not critically discuss the allocation limitations on organic farms within the regulation framework. Technical efficiency, in general is a topic that has to be discussed within the logic of the organic farming systems. In general, 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, which are necessary in order to produce ecological services wanted by society. So specialization might in some cases lead to an 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 when interpreting the results of some the analysis. Besides this, some of the studies also find positive efficiency effects of a diversified crop rotation (Sipiläinen and Huhtala, 2013; Tiedemann and Latacz-Lohmann, 2013), which would give an argument for risk-averse farmers to convert. Therefore, the efficiency literature to some extent shows that organic farming decisions have to be balanced between *sufficient profits and attainable ethical* *values*. Increasing efficiency on organic farms has to therefore take into account the both drivers of the farming system.

4.) The topic of environmental efficiency has been analyzed in a few studies (Aldanondo-Ochoa et al., 2014; Dreesman, 2007; Kantelhardt et al., 2009; Sipiläinen and Huhtala, 2013). Furthermore, two of the three studies have the characteristics of case studies (Dreesman, 2007; Kantelhardt et al., 2009) and their results have to be interpreted with caution due to a low number of observations. Only two recent studies (Aldanondo-Ochoa et al., 2014; Sipiläinen and Huhtala, 2013) show through a broader data set which includes environmental variables, that environmental performance – if explicitly taken into account in the model – can lead to an increased farm efficiency for organic farms. Still, this coincides with findings of the two other studies using other methodologies (Dreesman, 2007; Kantelhardt et al., 2009).

From society's point of view, environmental efficiency is crucial in order to identify adequate policy measures since this efficiency measure takes 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 while 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. Finally, more research in the field of environmental efficiency seems necessary to answer the questions of society towards efficient and sustainable farming.

5.) The efficiency studies show that subsidies have an impact on technical efficiency. Since the efficiency models (in the reported studies) do not include the 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 decision (Henningsen et al., 2011; McCloud and Kumbhakar, 2007; Minviel and Latruffe, 2013). One explanation for those results might be rent-seeking behavior of farmers: organic farmers (similar to their conventional colleagues) might pursue optimization strategies either for their farms' competitiveness or for their farms' subsidy revenue. This explanation is only valid for countries and regions with some flexibility in the support regime, which gives some scope for combining and optimizing the sum subsidy. However, this is not the case in all EU-member-states (Sanders et al., 2011)

Overall, the conclusions of many studies are that subsidies even when supporting the environmental objectives of organic farming distort markets and might be inefficient. Therefore, it is necessary to further study the impact of policy measures on organic farming in order to increase the efficiency and effectiveness of agricultural policies in this area.

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