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Comparing conventional and organic citrus grower efficiency in Spain

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Summary:

This paper compares the organic and conventional citriculture systems in Spain from the perspective of their technical efficiency. The efficiency of the two growing systems is compared in relation to a metafrontier that envelops both technologies in order to identify the limitations each farming system faces. In addition, the paper analyzes how efficient each growing system is at using its own technology, that is, their efficiency in relation to the best practices in their group. Contrary to conventional practice, farms' performance is analyzed in terms of the cost of specific growing tasks: soil and plant cover management, pruning, fertilization and phytosanitary treatments.

The results highlight that both organic and conventional orchards would achieve substantial global cost savings if they reached the maximum level of efficiency that their technological restrictions permit. The gap between the levels of efficiency on the frontier of each of the systems and the metafrontier is much wider in the case of organic than in conventional citriculture. Consequently, there is evidence that the limitations imposed on organic citriculture by regulatory and technological determinants have a significant impact on the relative efficiency of organic orchards in citrus fruit production, with potential consequences as regards their financial viability.

Key words: Organic citrus farming, technical efficiency, Data Envelopment Analysis (DEA), meta-frontier

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1. Introduction

There is currently wide recognition that society receives many benefits, grouped under the label of *ecosystem services*, from both natural and managed ecosystems. Agricultural systems, as managed systems, not only provide food, fiber and fuel, but also a range of non-marketed services. Farmers are the main managers of terrestrial usable lands and are well placed to provide or deny ecosystem services to the rest of society. Positive contributions include the supply of all three major categories of ecosystem services: provisioning, regulating and cultural services (Swinton et al. 2007; Zhang et al. 2007). On the negative side, it is also true that some agricultural practices can reduce the ability of ecosystems to provide goods and services. The external costs and benefits of modern agriculture raise important policy questions both concerning the public support to farmers for the multiple public benefits they produce, as agriculture is deemed inherently multifunctional, and also the most efficient ways for encouraging the right behavioral changes with regards to negative externalities (Pretty et al. 2001).

The concept of sustainable agriculture is prone to emphasize the convenience of adopting techniques that reduce reliance on non-renewable or environmentally harmful inputs and pays special attention to the particular characteristics of the settings where farming takes place. In connection with these basic principles, some practical consequences also arise: technologies and practices must be locally adapted and fitted into place, which implies that there are likely many pathways towards agricultural sustainability (Pretty 2008). Organic farming aims to create a sustainable agricultural production system, which involves maximum reliance on self-regulating ecological or biological processes and renewable resources, while systematic efforts are undertaken to reduce reliance on external inputs.

Organic farming combines delivering societal benefits, through organic land management, and responding to specific consumer demands in the marketplace. But while there is growing social recognition of the positive role played by this type of farming in the conservation of natural resources and the reduction or elimination of the negative externalities of modern agriculture, the economic competitiveness of organic versus conventional farming is a more contentious issue. There is some agreement concerning the fact that yields are frequently lower and output prices higher in organic farms in comparison with conventional farms operating under similar conditions (Offerman and Nieberg 2000). After reviewing the literature, Lotter (2003) pointed to the need to pay attention to output quality and the differential ability of organic systems to face hard climate conditions, when discussing relative yield performance. De Ponti et al. (2012) recently performed a meta-analysis of yield data comparing organic and conventional agriculture, using 362 datasets, being able to show that organic yields of individual crops are on average 80% of conventional yields. Their results correspond to the crop and field level and cannot be up-scaled to higher systems level, but they hypothesize that the special difficulty of organic systems to maintain soil fertility may lead to yield gaps in organic agriculture of more than 20% at higher systems levels.

Productivity comparisons between organic and conventional farming can go beyond searching for yield gaps. Efficiency in input-output transformation and its measurement has originated a large body of literature. Bravo-Ureta et al. (2007) perform a meta-regression analysis of technical efficiency estimates at farm level across countries and geographical regions, exploring the effect on the estimates of using different methodologies. Unfortunately, as far as we know, relatively few studies focus specifically on comparing the efficiency of farms using organic and conventional techniques and operating with the same crop or livestock specialization. Within this subset of the farm-level research work published on efficiency, some authors have used parametric techniques (Tzoulevekas et al. 2001a, 2001b; Mayen et al. 2010), while others have preferred non-parametric methods (Oude Lansink et al. 2002; Arandia and Aldanondo 2007; Bayramoglu and Gundogmus 2008; Serra and Goodwin 2009; Breustedt et al. 2011).

Beyond the distinction between different computation techniques, it is important to realize that farmers' relative efficiency is highly dependent on the technical, institutional and environmental scenario they operate in (i.e. organic versus conventional farming systems), in so far as this context contributes to determining the existence of specific production possibility frontiers. The problem lies in the fact that efficiency scores are not directly comparable across farms if they have been computed taking different technological frontiers as a reference. Therefore, it is convenient to draw a distinction between these frontiers and a metafrontier acting as a global reference free of the environmental or institutional restrictions characterizing specific production frontiers. In the field of agricultural economics, Hayami and Ruttan (1970) were probably the first to define a metaproduction function as the envelopment of all known technologies and in assuming that some of those technologies were only available to particular groups of farmers.

Context-dependent specific production frontiers can be introduced into efficiency analysis by splitting a sample of Decision Making Units (DMUs) into different groups using homogeneity criteria. Charnes et al. (1981) pioneered this field by drawing a distinction between managerial efficiency and programmatic efficiency. On the one hand, managerial efficiency responds to the classical measurement of individual units' performance in Data Envelopment Analysis (DEA), where relative efficiency is computed as the distance with regards to a production possibility frontier. On the other hand, programmatic efficiency is based on the recognition that different groups of DMUs may not face the same production possibility frontiers, comparing the global efficiency of groups using different technologies.

Later on, Battese et al. (2004) developed a stochastic metafrontier production function aimed at assessing technological gaps between particular technologies and O'Donnell et al. (2008) advanced this line of research in a DEA context by defining group frontiers as boundaries of restricted technology sets, and an enveloping common metafrontier as the boundary of an unrestricted technology set. Groups of firms operating in areas with poor natural endowments, or constrained by highly-regulated production environments, may only have access to a restricted technology set. In this case, distance functions can be used to measure technical efficiency with regards to the unrestricted metatechnology set and to the restricted technology sets of different groups of producers, and the closeness of group frontiers to the metafrontier can be measured.

Another line of research has also worked towards gaining further insight into efficiency analysis by measuring technical efficiency in specific directions. In that sense, the concept of sub-vector efficiency has been proposed to obtain technical efficiency measures for a subset of inputs rather than for the entire input vector and can be understood as gauging the efficiency of some specific inputs that are exposed to scaling in the production process, while the others remain fixed (Färe et al. 1994). Oude Lansink et al. (2002) pioneered the use of sub-vector efficiency in drawing comparisons between conventional and organic farms, employing an unbalanced panel of specialized Finnish crop and livestock farms. Directional distance functions (Chung et al. 1997; Chambers et al. 1998; Färe and Grosskopf 2003) have opened a fruitful path to perform this type of analysis. This analytical tool departs from the conventional distance function in that the directional distance function gauges efficiency in a particular direction, therefore efficiency becomes conditional on the choice of the directional vector.

The aforementioned distinction between particular group frontiers and the metafrontier is taken up by Sáez-Fernández et al. (2012), in combination with the use of directional distance functions, to obtain efficiency indicators. These indicators allow the analyst to assess DMUs' efficiency with regards to their own technology and also the relative efficiency of each group's technology with regards to the metafrontier, using an array of different directions corresponding to a variety of scenarios of interest (i.e. paying special attention to DMU performance with regards to some inputs while keeping others fixed).

This paper applies the above methodology (Sáez-Fernández et al. 2012) to compute efficiency measures for two Spanish citrus growing systems, organic and conventional, drawing comparisons of their relative performance. We follow these authors and also Picazo-Tadeo et al. (2012) in extending the approach by O'Donnell and colleagues to achieve our goal of computing efficiency scores and calculating metatechnology ratios in directions other than proportional reductions in all types of costs. One particular feature of our research is that instead of relying on the use of conventional inputs, we prefer to analyze farms' performance in terms of the cost of specific growing tasks. An important advantage of this method is that it allows estimating the scope for adopting efficiency-enhancing practices by organic and conventional farmers, while at the same time recognizing that the same type of cultivation task can be performed in different ways by both groups of citrus farmers (i.e. using widely different inputs in fertilization, or alternative techniques to fight weeds).

By using directional distance functions we are able to discover the amount of cost-saving, for all growing tasks taken together or for particular sub-sets, which could be obtained without decreasing sales revenue. We are also able to infer the efficiency of each system with regards to an enveloping metafrontier.

Following this Introduction, Section 2 expounds in more detail the methodology and Section 3 describes the technical aspects of citrus farming in the Region of Valencia (Spain) and the sample data. Section 4 presents the results and highlights some policy implications, while a final Section summarizes and concludes.

2. Methodology

2.1. Metatechnology and group technologies

This section describes the two building blocks of our methodological approach. In the first place, we draw a basic distinction between farm and system technical efficiency using the concept of metafrontier. Then, operating within a DEA framework, we favor the use of directional distance functions to compute task-specific efficiency scores. Therefore, we are able to establish which particular cultivation tasks each farming system performs better with regard to the available technology.

Now, let us start by considering that we are able to observe the economic performance of a set of farms $k = 1,\ldots, K$, represented by sales revenue v and that their production processes require performing a series of N growing tasks observed at farm level and denoted by the vector of task costs $t = (t_1,\ldots, t_N)$. The metatechnology set (T), representing all feasible combinations of sales value and task costs, is defined as:

$$\mathrm{T} = \{(\mathrm{v},\mathrm{t}) \epsilon \mathrm{R}^{1+\mathrm{N}} \big| v\ can\ be\ generated\ with\ task\ costs\ t\} \quad (1)$$

The task requirement set, representing all the vectors of task costs that permit the generation of at least sales value v, can be defined as:

$$\mathrm{TRS}(\mathrm{v}) = \{\mathrm{t}|(\mathrm{v},\mathrm{t}) \in \mathrm{T}\} \quad (2)$$

The directional metadistance function (Chambers et al. 1998) is a complete representation of metatechnology and can be defined as:

$$\mathrm{MD}[\mathrm{v},\mathrm{t}; \mathrm{g} = (\mathrm{g_v}, -\mathrm{g_t})] = \mathrm{Sup}\{\beta|(\mathrm{t} - \beta \mathrm{g_t}) \in \mathrm{TRS}(\mathrm{v} + \beta \mathrm{g_v})\} \quad (3)$$

the direction vector being

$$g = (g_v, -g_t) \tag{4}$$

We assume that production technology satisfies the usual properties, which can be summarized as follows (Picazo-Tadeo et al. 2012): (a) generating sales value necessarily involves assuming some task costs; (b) lower sales value can always be obtained with the same level of task costs; (c) task costs can always be increased while maintaining the same sales revenue; (d) any convex combination of two or more feasible pairs of sales value and task costs is also feasible.

The directional metadistance function in expression (3) is also a highly flexible efficiency measurement tool. It allows the researcher to explore the maximum potential for simultaneously increasing the value of farm sales and decreasing the task costs of particular farm operations along a path that has been previously established through the selection of a particular direction vector. This function is always equal to or greater than zero, with a score of zero meaning that no further reduction in task costs or expansion of the value of farm sales is feasible within the available technology, thus allowing the farm concerned to qualify as efficient. Increasing values of the function imply a higher potential to save in task costs and to expand sales value from the observed levels, which means that farm inefficiency also increases.

As noted previously, specific constraints imposed by the characteristics of admissible production techniques or natural conditions configure different farming systems, that is, production functions are not homogeneous. Producers belonging to a given farming system are prevented from accessing the full range of combinations between sales value and production costs that are potentially available in the metatechnology. Following O'Donnell et al. (2008), we start by splitting farms in our sample into several groups or farming systems, named h. Therefore, we are able to define a technology subset for group h, representing all combinations of sales value and task costs available to farms in that group, which we name T^h, and also a task costs requirement set for that group, TRS^h. Furthermore, we assume that the technology of each group h satisfies the same properties as the metatechnology, including convexity.

Group h technology can be formally defined by the technology set (5)

$$T^h = \{(v,t) \epsilon R^{1+N} \big| v \text{ can be generated by farms in group } h \text{ with task costs } t\} \tag{5}$$

The task requirement set

$$TRS^h(v) = \{t \big| (v,t) \epsilon T^h\} \tag{6}$$

and the group directional distance function

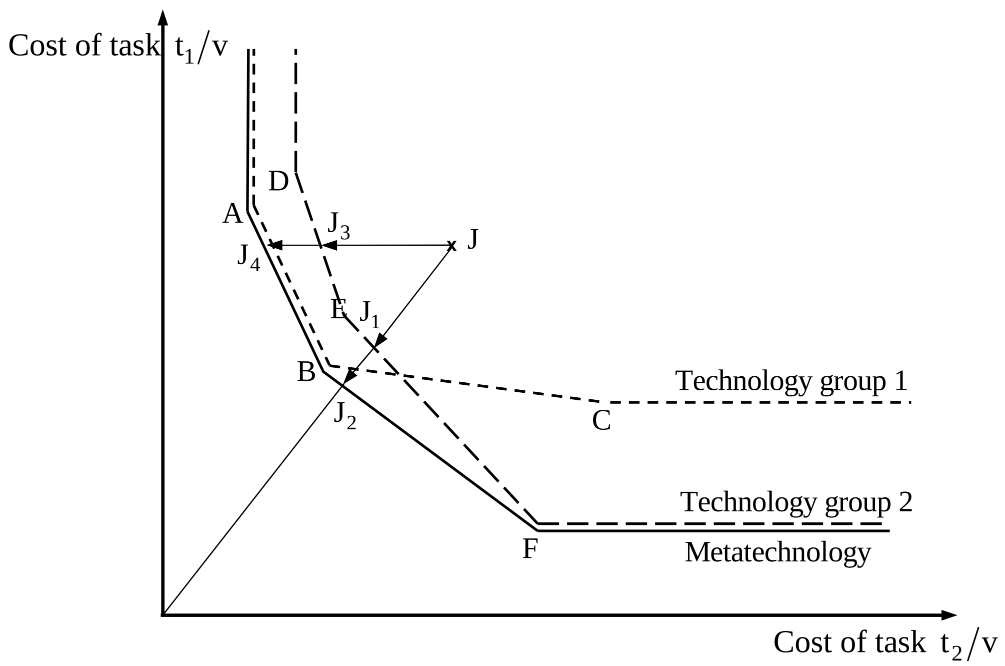
$$D^h[v,t;g=(g_v,-g_t)] = \text{Sup}\{\beta^h | (t-\beta^h g_t) \in TRS^h(v+\beta^h g_v)\} \tag{7}$$

being $g=(g_v,-g_t)$, as before, the directional vector.

Group directional distance functions can also be employed to estimate the efficiency of farms in group h against the technology of their own group. Once again, we are able to define distance functions that can be used to evaluate the potential to cut all task costs proportionally or to reduce the cost of a specific task or group of tasks i, always within the limits imposed by the technology of group h, and in both cases scaling sales value in the direction expressed by the g vector.

Let us now provide graphic illustration (Figure 1). We start by assuming a farm technology that generates sales value v by performing two cultivation tasks, namely t_1 and t_2. A number of efficient farms, from A to F, are observed, in addition to farm J. Observations A, B and C belong to group 1, while farms D, E, F and J belong to group 2. The technological frontier for group 1 is defined by efficient farms A, B and C and their convex combinations, while the segment connecting the efficient farms D, E and F shapes technological frontier of group 2. The metatechnology is built up as a convex combination of the technologies of both groups and is shaped by observations A, B and F.

Figure 1. Metatechnology, group technologies and directional distance functions



Farm J is inefficient because it generates one unit of sales revenue with higher task costs than strictly necessary, with regards to both its own group technology and the metatechnology. When farm J is projected onto the technological frontier of group 2, with a direction vector that proportionally reduces task costs t_1 and t_2, it yields point J_1, while projection onto the metatechnology yields point J_2. The distance between both projections measures the technological gap between the best practice achievable within the limits imposed by group 2 technology and the frontier of the unrestricted metatechnology[1]. The technological gap can also be computed in a direction that only reduces task cost t_2 while maintaining t_1 and sales value, using expression (13). According to this new scenario, which has to do with the management of specific growing task t_2, DMU J is being projected onto points J_3 and J_4, onto the technology of group 2 and the metatechnology respectively.

2.2 Efficiency measurement with directional distance functions and Data Envelopment Analysis

Let us briefly introduce the main tenets of DEA. DEA computes a measure of the relative position of each Decision Making Unit (DMU) with regards to a frontier defined by observed best practices and their linear convex combinations. For each of the DMUs laying below the frontier, a measure of relative inefficiency can be calculated by comparing their performance, through their observed input and output vectors, with the performance of a reference unit located on the frontier or with a convex combination of different efficient units located on the frontier. It means that the potential improvement of the inefficient DMU's performance (i.e. increasing output, decreasing input use, or both), is not necessarily obtained with regards to a *single* efficient unit, but can be calculated by taking as benchmark a *virtual* unit, made up of a weighted mix of the output and input profiles of several efficient units acting as a reference. The efficiency measure is obtained as a part of the solution of a mathematical optimization program solved for each DMU (see Cooper et al. 2007, for further details).

This paper employs Directional Distance Functions (DDF) to compute efficiency scores. DDF can be parameterized for estimation, as in Färe et al. (2005) and Serra et al. (2011), or computed non-parametrically (see Färe and Grosskopf 2003, for some examples of empirical applications). This paper takes the second route to compare the efficiency of our two farming systems.

DDF have the important property of being very flexible as an efficiency analysis tool. DDF permit efficiency measurement by making use of the ability of researchers to adopt a variety of directions by changing the directional vector. Here, this analysis focuses on detecting inefficiencies concerning the costs corresponding to particular cultivation tasks and assessing differences with regards to this concern arising from two technologically different

[1] Later, Section 2.3 introduces the concept of the metatechnology ratio to obtain an empirical measurement of this gap.

citrus farming systems, namely conventional and organic. We model the directional vector in order to achieve these objectives.

Formally, we target the maximal proportional task costs reduction achievable while keeping the observed values of farm sales constant by using the following directional vector

$$\mathrm{g_{all}} = (\mathrm{g_v}, -\mathrm{g_t}) = (0, -\mathrm{t}) \quad (8)$$

and, within a DEA framework, the mathematical optimization program that computes the distance to the metafrontier, $\beta_{\mathrm{all}}^{k'}$, for farm k' in expression (3) is

$$\text{maximize}_{\beta_{\mathrm{all}}^{k'}, z^{\mathrm{k}}} \ \beta_{\mathrm{all}}^{k'} \qquad k' \in \mathrm{k} = 1, \dots, \mathrm{K} \quad (9)$$

subject to:

$$v^{k'} \leq \sum_{\mathrm{k}=1}^{\mathrm{K}} z^{\mathrm{k}} v^{\mathrm{k}} \qquad \text{(i)}$$

$$(1 - \beta_{\mathrm{all}}^{k'}) \mathrm{t}^{k'} \geq \sum_{\mathrm{k}=1}^{\mathrm{K}} z^{\mathrm{k}} \, \mathrm{t}^{\mathrm{k}} \qquad \mathrm{i} = 1, \dots, \mathrm{n} \qquad \text{(ii)}$$

$$z^{\mathrm{k}} \geq 0 \qquad \mathrm{k} = 1, \dots, \mathrm{K} \qquad \text{(iii)}$$

$\beta_{\mathrm{all}}^{k'}$ represents the maximum proportional reduction in the cost of all tasks taken together that can be achieved by farm *k'*. By way of example, a value of $\beta_{\mathrm{all}}^{k'}$ equal to 0.4 means that the cost of the whole set of farming tasks performed by this farm could be cut by 40% without the farm being forced to reduce its sales revenue. However, when we aim to assess efficiency for a particular task, denoted by *i*, without increasing the cost of the remaining tasks, denoted by *–i*, and keeping farm sales revenue constant, the directional vector is

$$\mathrm{g_i} = (\mathrm{g_v}, -\mathrm{g_t}) = [0, (-\mathrm{t_i}, -0)] \quad (10)$$

and the DEA program that computes efficiency in task *i* with regards to the metafrontier, $\beta_{\mathrm{i}}^{k'}$, is

$$\text{maximize}_{\beta_{\mathrm{i}}^{k'}, \mathrm{z}^{\mathrm{k}}} \ \beta_{\mathrm{i}}^{k'} \qquad k' \in \mathrm{k} = 1, \dots, \mathrm{K} \quad (11)$$

subject to:

$$v^{k'} \leq \sum_{\mathrm{k}=1}^{\mathrm{K}} z^{\mathrm{k}} v^{\mathrm{k}} \qquad \text{(i)}$$

$$(1 - \beta_{\mathrm{i}}^{k'}) \mathrm{t}_{\mathrm{i}}^{k'} \geq \sum_{\mathrm{k}=1}^{\mathrm{K}} z^{\mathrm{k}} \, \mathrm{t}_{\mathrm{i}}^{\mathrm{k}} \qquad \mathrm{i} \in \mathrm{n}; \mathrm{i} \notin -\mathrm{i} \qquad \text{(ii)}$$

$$\mathrm{t}_{-\mathrm{i}}^{k'} \geq \sum_{\mathrm{k}=1}^{\mathrm{K}} z^{\mathrm{k}} \, \mathrm{t}_{-\mathrm{i}}^{\mathrm{k}} \qquad -\mathrm{i} \in \mathrm{n} \qquad \text{(iii)}$$

$$z^{\mathrm{k}} \geq 0 \qquad \mathrm{k} = 1, \dots, \mathrm{K} \qquad \text{(iv)}$$

where $\beta_{\mathrm{i}}^{k'}$ represents the maximal proportional reduction in the cost of task *i* that farm *k'* could achieve while keeping sales revenue constant and avoiding any increase in other task costs. By way of example, if $\beta_{\mathrm{i}}^{k'}$ takes a value equal to 0.45, it means that the cost of cultivation task i in farm k' (i.e. fertilization) could be cut by 45% while maintaining the observed sales revenue and without an increase in the costs of performing other cultivation tasks. When both total and task-specific efficiency is computed, the value of $\beta_{\mathrm{all}}^{k'}$ shows the minimum threshold for $\beta_{\mathrm{i}}^{k'}$.

Distances to own group h frontier, according to expression (7), can be obtained in similar fashion by taking best within-group practices as a benchmark. We call them distances $\beta_{\mathrm{all}}^{hk'}$ and $\beta_{\mathrm{i}}^{hk'}$ respectively. The first one expresses the ability to obtain a maximal proportional reduction of all task costs, while the second one only measures the maximal feasible contraction of a particular task cost i. The scores obtained with DDF computed with respect to the technology of group h must necessarily be, by construction, equal to or lower than those being computed with directional metadistance functions.

2.3. Efficiency and metatechnology ratios

The relative distance that separates efficient performance under a group-specific technological frontier and efficient performance under the metatechnology can be measured using a ratio formula where the value of the directional metadistance function enters the numerator and the value of group h directional distance function the denominator. It represents the difference between the best performance that can be achieved within the restrictions imposed by the technical characteristics of group h's farming system and the best performance when no such group restrictions are imposed.

In order to compute our metatechnology ratios it is convenient to express the directional metadistance and distance functions in a more conventional way[2]. Let us thus define the following all-task cost reducing efficiency measures for group h's farm k with unrestricted access to available technological combinations, that is with regards to the metatechnology, as

$$\mathrm{Metaefficiency}_{\mathrm{all}}^{k'} = 1 - \mathrm{MD}[\mathrm{v}, \mathrm{t}; \mathrm{g} = (0, -\mathrm{t})] = (1 - \beta_{\mathrm{all}}^{k'}) \quad (12)$$

While with regards to its own group h, that is, with restricted access to technology, the efficiency is

$$\mathrm{Efficiency}_{\mathrm{all}}^{\mathrm{h}k'} = 1 - \mathrm{D}^{\mathrm{h}}[\mathrm{v}, \mathrm{t}; \mathrm{g} = (0, -\mathrm{t})] = (1 - \beta_{\mathrm{all}}^{\mathrm{h}k'}) \quad (13)$$

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[2] The reason is that, as defined by O'Donnell et al. (2008), metatechnology ratios involving efficient farms could not be defined as directional distances since these observations are equal to zero (Picazo-Tadeo et al. 2012).

It may be observed that expressions (12) and (13) have been defined considering a directional vector that keeps sales revenue constant and reduces all tasks costs proportionally. Similar calculations may be undertaken to obtain metatechnology ratios using a direction vector that contracts only one particular type of cultivation task or a group of them, while maintaining the remaining tasks and farm sales value unchanged.

The relationship between metadistance/distance functions and the measures of efficiency defined in (12) and (13) can be easily illustrated. For example, a metadistance function of, say, 0.4 means that farm k' could reduce all its costs by 40% and yet maintain sales value; however, it also means that the same value could be generated with only 60% of the costs actually involved in growing the product, which is just the meaning of expression (12), that is, the metaefficiency score is 0.6. This measure of efficiency is upper-bounded to one, which corresponds to full efficiency, and a decrease in the score represents a worsening of the efficiency level. Furthermore, efficiency assessed with regards to the metatechnology —i.e., metaefficiency— will always be equal to or lower than the efficiency calculated relative to group-specific technology, because of the enveloping property of the metafrontier.

We now proceed to formalize the metatechnology ratio for a farm k belonging to group h, in the same direction, g = (0, –t), as:

$$\text{Metatechnology Ratio}_{\text{all}}^{\mathrm{h}k'}[\mathrm{v},\mathrm{t};\mathrm{g}=(0,-\mathrm{t})]=\frac{\text{Metaefficiency}_{\text{all}}^{k'}}{\text{Efficiency}_{\text{all}}^{\mathrm{h}k'}}=\frac{(1-\beta_{\text{all}}^{k'})}{(1-\beta_{\text{all}}^{\mathrm{h}k'})} \quad (14)$$

which allows for the following relationship

$$\text{Metaefficiency}_{\text{all}}^{k'}=\text{Metatechnology Ratio}_{\text{all}}^{\mathrm{h}k'} * \text{Efficiency}_{\text{all}}^{\mathrm{h}k'} \quad (15)$$

Metatechnology ratios, as defined in (14), depict the closeness of the technology of group h to the metatechnology, assessed in a $\mathrm{g}_{\text{all}}=(0,-\mathrm{t})$ direction. Therefore, they measure the gap between the technology of group h and the metatechnology. Let us assume, for illustration purposes, that the metaefficiency score of farm k' is 0.6 and that the efficiency score with regards to its own technology h is 0.7. The metatechnology ratio would be 0.85, which means that only 85% of the efficient task costs corresponding to the technological frontier of group h will be needed if farms are not operated under the technological restrictions on group $h's$ farming system (i.e. if the metafrontier was employed as a benchmark).

3. Citrus farming techniques and data set

The spread of organic citriculture is sometimes hindered by a lack of economic viability, in comparison with conventional citriculture. Organic citriculture has distinctive technical aspects with regards to conventional citriculture which clearly establish differential environmental impacts, mainly concerned with fertilization practices, and also gives rise to cost differences by hectare. Organic citrus orchards use compost manure, which is then supplemented with complex organic materials such as animal and plant remains, algae extracts, food industry products, guano etc. Green manure crops of rapid growth, which are cut and buried in the place where they have grown, are able to afford annually large quantities of humus and nutrients. Pruning waste incorporated into the soil also helps to improve soil quality, reduces the requirements for additional crop fertilization and contributes to reducing CO_2 emissions.

An organic citrus orchard maintains biodiversity through ground cover, of which the most interesting plants are alfalfas, for their positive relationship with fertilization, and wild grasses, because of their relationship with wildlife. Hedgerows are also important in this respect, preventing wind damage and hosting populations of beneficial insects and birds. They may be formed by fruit trees, Mediterranean shrubs, ornamental plants or others. A high level of plant biodiversity fosters a corresponding diversity of microbial and insect species, which contribute to fighting pests. Notwithstanding, when natural predators are not enough to exert biological pest control, it is permissible in organic farming to carry out treatment with mineral oil or paraffin. Organic producers are also recommended to use traditional techniques such as 'scratching', which consists of making a shallow circular cut in the main branches. The aim is to block the sap in the branches above, thus favoring the fruit set and fattening, replacing most extended hormone treatments in conventional citrus growing.

Pruning is carried out in a similar way to that of conventional citrus growing, but with some differences concerning the way of dealing with waste. In organic citrus farming, pruning remains are crushed and left as waste compost on the soil surface, thereby restoring a lot of nutrients. By contrast, the common practice of burning pruning wastes in conventional citrus farming causes large losses of organic matter and increases CO_2 emissions. With regards to irrigation, it has been remarked that organic citrus can make better use of limited water resources in the Region of Valencia —a Spanish Mediterranean region— because organic plots of land have a greater proportion of soil humus and organic matter in the soil, which retains moisture better and extends the interval between watering[3].

Organic citrus currently represents a small proportion of total farmland devoted to citrus production in the Region of Valencia. Some reasons have been advanced to explain the slow

[3] For a more detailed description of the technical aspects of local organic citriculture, see Porcuna et al. (2010) and Domínguez-Gento (2008).

diffusion of organic citrus farming: the difficulties in isolating small-sized organic citrus farms from neighboring intensive conventional plantations, the region's long history of intensive production, a lack of appropriate distribution channels for organic produce in the domestic market and the scarcity of available subsidies to compensate for the higher costs incurred in organic production (Peris and Juliá 2006). The costliest items in citrus farming are variable inputs, and variable costs per hectare are always higher in organic farms. Organic manure is more expensive and difficult to obtain than chemical fertilizers and must be used in higher quantities to meet the requirements of adult plantations. Organic orchards are also substantially more labor-demanding than conventional ones: weeds must be removed mechanically, instead of using chemical products, organic manure application uses more labor than conventional fertilization and mulching formation from crushing ground wood after pruning also consumes labor input. Besides those tasks, the organic farmer must spend time on maintaining hedgerows in good conditions and cultivate a plant cover. Savings in expenditures related to herbicides, fungicides and insecticides do not normally compensate for these higher labor costs. Finally, yields are lower than in conventional production, thus increasing cost per kilogram and raising the differential break-even point of organic farming (Peris et al. 2005; Peris and Juliá 2006).

Despite factors hindering the shift from conventional to organic citrus production, some farmers have been driven to adopt organic techniques. Concerning the motivations of citrus farmers in the Region of Valencia to become organic producers, recent research has shown that the main explanatory factors are: environmental concerns, concern for the wellbeing of future generations, an aspiration to produce high quality output and a willingness to reduce dependence on agrochemicals, with pecuniary aspects playing a less important role (Beltrán-Esteve et al. 2012).

The data used in this paper come from a survey designed for a larger research project aimed at analyzing both the economic and environmental performance of conventional and organic citrus farming in the Spanish region of Valencia.[4] In 2009, all organic citrus farmers registered as certified ecological producers in Valencia were contacted and 153 of them agreed to answer a questionnaire. Furthermore, 129 conventional citrus farmers, from a control group of two hundred, completed the survey. After removing some outliers and observations with missing data, the sample comprised 107 organic citrus farms and 105 conventional citrus farms.

The survey provides information on average performance and the average sale price of the product for each farm. In addition, in relation to costs, it details the amounts of the

[4] Beltrán-Esteve et al. (2012) provide more detail on this issue.

various intermediate inputs, labor and machinery used to perform the different tasks. Survey information has been completed with data from other sources. More specifically, the price of phytosanitary products, herbicides, labor and various types of machinery comes from the agricultural cooperatives in the area, the same prices being applied to all farms.[5]

In reference to farms' financial yields, **sales revenue** is used. This information is obtained by multiplying average returns per hectare, in kilograms, by the average sale price of the product declared by the producer. Consequently, differences in price per unit of product are considered to represent differences in quality.

As far as inputs are concerned, as mentioned previously, this paper takes a somewhat different methodological approach to those normally used in efficiency analysis. In this sense, instead of using the traditional variables of labor, machinery and intermediate inputs, we consider the cost of performing certain farming tasks that, despite sharing a specific common purpose such as fertilizing crops, can have different characteristics across farms and/or growing systems. Such differences can be due to either the farmers themselves deciding to use different techniques or combinations of production factors or because they are required to do so by the Government as a condition for being awarded certification as an organic producer. More specifically, this research considers four different farming tasks, namely soil and plant cover management, pruning, fertilization and finally the group of tasks related to pest control and fruit setting and fattening:[6]

- ***Soil and plant cover management*** includes both tillage and also mowing and treating weed cover with herbicides. These farming practices constitute alternative ways of handling the needs of the crop and entail different requirements in regard to the use of labor, machinery and herbicides. This research takes into account the labor and also the machinery used for each of these tasks by each farm, together with their expenditure on herbicides.[7]
- ***Pruning*** includes the tasks related to pruning fruit trees and the subsequent treatment of pruning debris, either by burning remains or by shredding them for use as plant cover on the farm itself. Pruning also encompasses other related tasks, such as maintaining hedgerows, primarily in the case of organic orchards. Costs include both the labor and also the machinery used.

[5] We use the same prices for all farms because we consider they are market prices for each product and production factor. However, labour and machinery prices differ depending on the degree of labor specialization and the type of machinery.

[6] Irrigation could not be considered due to a lack of data.

[7] We consider total hours worked both in the case of labor and also machinery, regardless of whether the hours correspond to internal or contracted work. The cost attributed to the farm's own labor, using opportunity cost criteria, is the same as that attributed to contracted labor. The same applies to machinery.

— ***Fertilization*** includes all the costs derived from purchasing chemical and organic fertilizers and the labor and machinery (belonging to the farm and contracted) necessary for application.
— ***Phytosanitary treatment and fruit setting and fattening*** includes the tasks intended to control pests that can negatively affect the quality and appearance of the fruit and the treatments aimed at setting and fattening the fruit, either by chemical means (hormone treatment) or physical means (fruit tree thinning and scratching). For each farm, we have considered both the cost of labor and also machinery, together with the cost of purchasing phytosanitary and hormone products.

The data used in all cases are per hectare, which permits a more direct comparison of farms and growing systems.

Table 1 presents the main statistics of the variables used in the efficiency analysis for both citriculture systems, as well as the t-test of equality of means. On the one hand, it is worth highlighting that conventional farms obtain higher sales revenue than organic orchards due to the price differences in favor of the latter being insufficient to offset their disadvantage in terms of returns per unit of area. Furthermore, the cost of treating soil and plant cover as well as fertilization costs are significantly lower in the case of conventional orchards. In contrast, conventional farms face higher pruning costs, at statistical significance levels of 10%. Finally, no significant differences are observed in average phytosanitary costs or in terms of the size of the farm.

Table 1. Main sample descriptive statistics of conventional and organic citrus farming

	Conventional farms (105)		***Organic farms (107)***		***Equality of means***	
	Mean	Std. Dev.	Mean	Std. Dev.	t-test	p-value
Income (€ ha^{-1})	6451	3505	5114	3128	2.929	0.004
Tillage (€ ha^{-1})	593	466	1070	747	-5.589	0.000
Pruning (€ ha^{-1})	870	549	752	475	1.678	0.095
Fertilization (€ ha^{-1})	610	339	777	504	-2.841	0.005
Phytosanitary (€ ha^{-1})	563	367	611	469	-0.843	0.400
Surface (ha)	3.61	7.17	3.21	4.40	0.493	0.623

4. Results

Tables 2 to 5 present some synthetic indicators of the results obtained in the efficiency estimations of each of the growing systems analyzed, together with some efficiency measures of organic and conventional technologies in relation to the metafrontier, following the methodology described in Section 2.

Table 2. Estimates of distance, metadistance and metatechnology ratio: Radial direction

	Mean	Std. Dev.	Min	Max
Directional metadistance function: β_{all}				
Conventional citrus farming	0.477	0.299	0.000	0.952
Organic citrus farming	0.656	0.232	0.000	0.963
Directional distance function: β_{all}^{h}				
Conventional citrus farming	0.459	0.299	0.000	0.947
Organic citrus farming	0.607	0.258	0.000	0.956
Metatechnology ratio: $(1-\beta_{\mathrm{all}})/(1-\beta_{\mathrm{all}}^{h})$				
Conventional citrus farming	0.959	0.048	0.768	1
Organic citrus farming	0.880	0.095	0.518	1

Table 2 includes the results when considering the maximal simultaneous proportional reduction in the cost of all the tasks while maintaining the observed level of sales revenue of the farm – direction vector (8). In the first place, it is possible to observe that each citriculture farm, on average, can make large overall savings in regard to the best practices applied with the respective technology of each growing system, in the vicinity of 45% for conventional orchards and 60% for organic orchards. Organic orchards may have recorded a higher level of inefficiency as a result of farmers having to implement techniques that are not commonplace in their environment and which require a specific learning process. Likewise, the results obtained for the metatechnology ratio highlight that operating within the typical technological references of each system imposes greater limitations on organic systems. In fact, the efficient level of costs on the metatechnology frontier, on average, is only 88% of what should correspond to the efficient use of the organic system technology. The technological frontier of the conventional system is closer to the metafrontier. Its metatechnology ratio of close to 96% indicates that the restrictions imposed by the traditional growing system are hardly significant.

The results presented in Table 2 above do not show the full potential for improvement that exists for a given farming task, nor do they show which task or tasks represent the greatest disadvantage that each system must face. Table 3 includes the results when considering the efficiency indicators that take into account the maximal potential reduction in cost of each task, while keeping the cost of the rest of tasks and the farm's sales revenue constant – direction vector (10). As regards the efficiency of farms in relation to their own growing system technology, the results of the directional distance function reveal substantial differences in efficiency levels depending on the farming task considered. These differences are greater in the case of conventional orchards. Conventional farms record their highest levels of inefficiency in pruning operations, where it would be possible to reduce costs by 71% on average, while maintaining the cost of the rest of tasks and sales revenue unchanged. The possible savings in cost for tillage, fertilization and phytosanitary treatment are smaller, albeit always greater than 60%. As far as organic orchards are concerned, the scores obtained indicate that the most inefficient task is tillage (78%), while the least inefficient, albeit still very high, corresponds to fertilization (almost 75%).

Table 3. Estimates of distance, metadistance and metatechnology ratio: Task-specific directions

	Tillage		***Pruning***		***Fertilization***		***Phytosanitary***	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Directional metadistance function: β_i								
Conventional citrus farming	0.617	0.338	0.718	0.339	0.659	0.320	0.657	0.323
Organic citrus farming	0.851	0.203	0.838	0.225	0.800	0.226	0.788	0.227
Directional distance function: β_i^h								
Conventional citrus farming	0.608	0.341	0.713	0.342	0.651	0.323	0.627	0.332
Organic citrus farming	0.781	0.252	0.774	0.271	0.747	0.264	0.767	0.261
Metatechnology ratio: $(1-\beta_i)/(1-\beta_i^h)$								
Conventional citrus farming	0.979	0.067	0.989	0.054	0.982	0.053	0.916	0.107
Organic citrus farming	0.654	0.187	0.724	0.142	0.769	0.079	0.954	0.094

The metatechnology ratio, as indicated previously, shows the relative proximity between the frontier of each system and the metafrontier, which acts as enveloping. In relation to the conventional citriculture system, it is worth highlighting how close its technological frontier is to the metafrontier both in tillage and also pruning and fertilization. As regards these tasks, the most efficient cost levels of the best practices in the conventional system barely differ by an average of 1% or 2% from those of the metatechnology frontier. However, this gap is considerably larger in the case of phytosanitary treatment, at 8%. In the case of organic citriculture, proximity to the metatechnology frontier varies remarkably depending on the direction or type of task considered in the estimation. In this sense, although the organic farming system is not subjected to particularly significant restrictions where phytosanitary treatment is concerned, with cost differences of barely 5%, limitations are considerable in the case of fertilization and pruning, while the greatest disadvantage corresponds to tillage. In reference to this last task, the efficient levels of cost in an unrestricted technological scenario would only represent 65% of the figure that the most efficient practices possible would record within the organic system.

Table 4 includes the results for Mann and Whitney's test of statistical significance of the differences in the metatechnology ratios obtained for each of the systems, both when considering the simultaneous reduction of costs in all tasks and also when analyzing the individual reduction in each task. The results indicate that these differences are statistically significant except in the case of phytosanitary treatment, where we cannot reject the hypothesis that there are no differences between the ratios of the two systems. Consequently, it can be stated that the technological differences work clearly in favor of conventional farming systems where tillage, pruning and fertilization are concerned, and also when considering all farming tasks as a whole, while this is not the case of phytosanitary treatment.

Table 4. Differences in the metatechnology ratio: Conventional versus organic citrus farming

	Mean difference	***Mann and Whitney test***	
		z	***p-value***
Radial direction	0.080	7.398	0.000
Task-specific direction			
Tillage	0.325	11.907	0.000
Pruning	0.265	12.521	0.000
Fertilization	0.213	11.796	0.000
Phytosanitary	-0.038	0.481	0.630

Finally, we have delved deeper into the characteristics of efficient orchards in relation to the inefficient farms that belong to each growing system (Table 5). The efficient farms record more revenue through citrus fruit sales and also lower execution costs for the four groups of tasks considered. However, not all the differences in favor of the orchards that apply the best practices are statistically significant. In order to improve, conventional farms that are not efficient must pay special attention to the differences in revenue and tillage costs in regard to the efficient counterparts. Meanwhile, the organic orchards that are not efficient must focus their attention on revenue and pruning and fertilization costs to improve their performance.

Table 5. Characteristics of efficient and inefficient farms in the group technology

	Efficient (15)		***Inefficient (90)***		***Equality of means***	
Conventional farms	Mean	Std. Dev.	Mean	Std. Dev.	t-test	p-value
Income (€ ha^{-1})	9868	2902	5881	3276	4.833	0.000
Tillage (€ ha^{-1})	399	266	626	485	-2.646	0.013
Pruning (€ ha^{-1})	660	553	905	544	-1.595	0.127
Fertilization (€ ha^{-1})	557	525	619	301	-0.448	0.661
Phytosanitary (€ ha^{-1})	528	435	568	357	-0.345	0.734
Surface (ha)	5.1	5.9	3.4	7.4	1.007	0.325

	Efficient (7)		***Inefficient (100)***		***Equality of means***	
Organic farms	Mean	Std. Dev.	Mean	Std. Dev.	t-test	p-value
Income (€ ha^{-1})	9669	3136	4795	2883	3.995	0.006
Tillage (€ ha^{-1})	779	617	1091	754	-1.273	0.242
Pruning (€ ha^{-1})	365	240	779	476	-4.037	0.003
Fertilization (€ ha^{-1})	458	314	800	508	-2.645	0.028
Phytosanitary (€ ha^{-1})	544	594	616	463	-0.316	0.762
Surface (ha)	4.6	5.7	3.1	4.3	0.661	0.532

5. Conclusions

At present, farmers consider adopting organic farming systems bearing in mind their long-term contribution to enhancing the environmental sustainability of agriculture. However, the financial viability of these systems entails certain limitations (less returns per hectare) when compared to conventional farms. This paper compares the organic and conventional citriculture systems in Spain from the perspective of their technical efficiency. The primary objective of the research is to compare the relative efficiency of the two growing systems in relation to a metafrontier that envelops both technologies in order to identify the limitations each farming system faces. In addition, the article analyzes how efficient each growing system is at using its own technology, that is, their efficiency in relation to the best practices in their group.

In order to achieve both goals, the research has taken into account the values observed at individual farm level of product sales and the cost of four large groups of agricultural tasks: tillage, pruning, fertilization and phytosanitary treatment. Scores have been calculated using DDF within the framework of DEA and by distinguishing between radial efficiency measures and indicators based on selecting a subvector of farming tasks. In the first case, the inefficiency observed measures the existing potential to proportionally reduce the growing costs of all the agricultural tasks, without reducing the revenue generated by product sales. In the second case, that potential or margin for cost savings is calculated for specific tasks.

The results obtained highlight in the first place that both organic and conventional orchards would be able to achieve substantial global cost savings if they reached the maximum level of efficiency that their technological restrictions permit. The results also reveal, through the metatechnology ratio, that the gap between the levels of efficiency on the frontier of each the systems and the metafrontier is much wider in the case of organic citriculture than in conventional growing systems. Consequently, there is evidence that the limitations imposed on organic citriculture by regulatory and technological determinants have a significant impact on the relative efficiency of organic orchards in citrus fruit production. The difference found is important, as it quantifies the initial handicap faced by organic farms in relation to conventional farming systems as regards their financial viability.

In the second place, the analysis also provides confirmation of the specific farming tasks that display the greatest margins of inefficiency. When analyzing each orchard in regard to the technological frontier of its group, these differences provide information regarding the tasks that farmers can address in order to enhance their performance to a greater or lesser extent. Furthermore, when considering the distance between the group technologies and the metatechnology, we can appreciate which tasks impose the greatest cost overruns on a given growing system. More specifically, conventional systems should particularly improve their management of pruning operations, a task they are less efficient at performing, while organic farms display similar levels of inefficiency in all tasks, although tillage records a slightly higher level. The knowledge of the tasks that are on average performed least efficiently by each growing system could constitute an interesting benchmark for agricultural policymakers, helping them to focus on disseminating relevant technical information and to enhance the effectiveness of agricultural extension and professional training programs. Solving the problem of excessive costs in performing certain farming tasks, such sowing and mowing plant cover and soil tillage, could improve the profitability of organic citriculture and facilitate producer decisions to convert their conventional orchards into organic farms. As regards how the two growing systems compare, conventional citriculture has a clear advantage in efficiency where tillage, pruning and fertilization are concerned, while organic farms have no clear advantage over the former in the case of phytosanitary treatment. This situation means conventional farms are generally more financially viable than organic orchards.

Finally it is necessary to clarify that our analysis has been conducted in terms of a task and cost-oriented technical efficiency model. However, neither the positive environmental externalities (that is, reduction in CO_2 emissions, protection of biodiversity, etc.) generated by organic farm practices nor the negative environmental spillovers of conventional farming practices have been taken into account. Hence, the results should therefore be interpreted bearing these considerations in mind. A fair consideration of all environmental impacts of conventional and organic citrus farming systems could therefore justify public support of organic farms in order to overcome their economic disadvantages and facilitate farmer conversion from conventional to organic citrus farming.

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