Productivity, efficiency and technological change in French agriculture during 2002-2014: A Färe-Primont index decomposition

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Abstract

The objective of the article is to assess productivity change in French agriculture during 2002-2014, namely total factor productivity (TFP) change and its components technological change and efficiency change. For this, we use the economically-ideal Färe-Primont index which verifies the multiplicatively completeness property and is also transitive, allowing for multi-temporal/lateral comparisons. To compare the technology gap change between the six types of farming considered, we extend the Färe-Primont to the meta-frontier framework. Results indicated that during 2002-2014, all farms had a TFP progress. Pig/poultry farms had the lowest TFP increase while beef farms had the highest (19.1%). The latter had the strongest increase in efficiency change, while technological progress was the highest for mixed farms. The meta-frontier analysis indicates that field crop farms' technology is the most productive of all types of farming.

Keywords: total factor productivity, Färe-Primont index, meta-frontier, French farms

1. Introduction

Productivity change is a crucial aspect of structural change. During the past 35 years, agricultural production in France has increased in volume by close to 25 percent (from 1980 to 2014) thanks to crop production (source: Annual national accounts, Insee.fr). But this growth has not been sufficient to restrain the downward trend of Total Income From Farming (TIFF). While the value of farm production has decreased (from index 100 in 1980 to index 78 in 2013), expenditures have rather stagnated (the index being 100 in 1980 as well as in 2013). Nevertheless, TIFF per annual work unit (AWU) of entrepreneurial labour (farmers and other unpaid labour) has increased over this period (from index 100 in 1980 to index 160 in 2013). This is due to the improvement of farmers' competitive advantage through a cost leadership strategy. At the same time, labour productivity has increased (from index 100 in 1980 to index 306 in 2013) and the average farm area per worker has risen by nearly threefold, due to farms' specialising and enlarging. In order to produce more with fewer workers, farmers have maintained their fixed assets: the gross fixed capital formation (namely fixed asset acquisitions) corresponds to an annual investment of about 10 billion Euros for the whole country. In this context, a crucial question is whether this strategy has an effect on total factor productivity (TFP). In other word, has productivity improved in French agriculture and what is the contribution of technical and technological change?

In this paper we contribute to this question by investigating TFP change and its components for several farm types in France during the period 2002-2014. Existing studies on recent period report contradictory results. During the period 2001-2007, Latruffe et al. (2012) report almost no TFP change for French dairy farms and a technological change of +2.6%, while the figures for the cereal, oilseeds and proteinseeds farms were a TFP progress of 4.6% and a technological progress of 3.9%. The lack of TFP increase is confirmed by Boussemart et al. (2012). The authors indicate that TFP in French agriculture has grown at an annual rate of 1.44% during 1959-2011 but the annual rate was less than one (namely 0.94%) during 2003-2011, a discrepancy that the authors attribute to a lack of output progress during this last period. Similarly, for the period 1990-2006, Latruffe and Desjeux (2016) report a deterioration of TFP of about 2%, as well as slight technological regress of French farms in the field crop sector, dairy sector, and beef cattle sector. Barath and Ferto (2014) also find that TFP decreased by 2% during 2000-2010 for the whole French agricultural sector. Not focusing on TFP but using a stochastic frontier including time, Latruffe et al. (2016) indicate that French dairy farms experienced technological regress during 1990-2007. The picture is therefore gloomy for French agriculture in recent periods. In earlier periods, the picture was more optimistic. Bureau et al. (1995) find productivity increase in the French agriculture during 1973-1989, as well as Coelli and Rao (2005) between 1980 and 2000. For the latter, the 2% increase in TFP was only driven by technological change. Accounting for nitrogen surplus, Piot-Lepetit and Le Moing (2007) report productivity increase in the French pig sector during the period 1996-2001.

Most of the previous papers have used the classic Malmquist measures of TFP.[1] By contrast, in this paper we use the multiplicatively complete Färe-Primont index (O'Donnell, 2011) to compute TFP and its components, based on non-parametric Data Envelopment Analysis (DEA) (Charnes et al., 1978). Productivity measures of a decision making unit (DMU) that can be expressed as the ratio of an output quantity change index on an input quantity change index, can be referred to as 'multiplicatively complete' (O'Donnell, 2008). Laspeyres, Paasche, Fisher, or Törnqvist indexes which use price information for the computation of quantity and price indexes (Färe et al., 2008), are multiplicatively complete (O'Donnell, 2008, O'Donnell, 2010). Yet, these indexes fail the transitivity property (or circularity test)[2] and can only serve for binary comparisons (O'Donnell, 2011).[3] In the non-parametric framework of DEA, since the pioneering work of Caves et al. (1982a), Caves et al. (1982b) grounded in early ideas of Malmquist (1953), the Malmquist index has been largely use in many fields (Färe et al., 1998) for productivity growth assessment and its decomposition into frontier shift or technological change, and efficiency change (Färe et al., 1994a, Färe et al., 1994b). Its wide popularity is related to its simplicity in computation without requiring price information or functional form assumptions[4]. Many applications to the agricultural sector of the Malmquist index can be found in the literature (Piesse et al., 1996, Fulginiti and Perrin, 1997, Mao and Koo, 1997, Lambert and Parker, 1998, Tauer, 1998, Jaenicke and Lengnick, 1999, Nin et al., 2003,

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[1] Exceptions can be found in Boussemart et al. (2012) and Barath and Ferto (2014) who have respectively used the Bennet indicator and the Lowe TFP index.

[2] The transitivity/circularity test implies that cumulative impacts over time can be assessed using yearly results: the productivity index between t_1 and t_3 can be evaluated through t_2. More explicitly we have: $I(t_1, t_3) = I(t_1, t_2) \times I(t_2, t_3)$ (Fried et al., 2008).

[3] Difference-based productivity measures like the Bennet indicator are additively complete but fail the circularity (transitivity) test (Fox, 2006). Within the price-based indexes, the Lowe index is multiplicatively complete and verifies the transitivity test.

[4] This index uses quantity data and distance functions (input or output) for the efficiency estimation (Shephard, 1953). In this framework, distance functions are handful for the case of several inputs/outputs.

Umetsu et al., 2003, Zhengfei and Lansink, 2006, Latruffe et al., 2008, Yeager and Langemeier, 2011, Baležentis and Baležentis, 2016, Kunimitsu et al., 2016). Despite these numerous applications to agriculture, the Malmquist index does not verify the transitivity property (for more discussion on this property and the Malmquist index one can refer to (Førsund, 2002)). Though many extensions have been developed to comply with this property (for example Berg et al. (1992), Pastor and Lovell (2005), Asmild and Tam (2007)), the Malmquist index is not multiplicatively complete and therefore cannot always be written as a ratio of aggregate output on input indexes (O'Donnell, 2012a, O'Donnell, 2012b, O'Donnell, 2012c). In addition to these issues, O'Donnell (2011) also argues that the Malmquist index ignores changes in the input/output mix.[5] By contrast, the Färe-Primont productivity index based on two quantity indices and proposed by Färe and Primont (1995 pp36-38), is multiplicatively complete and transitive (O'Donnell, 2011, O'Donnell, 2012b). As such the Färe-Primont index can be used for multi-lateral and multi-temporal comparisons.[6] Few applications of this index to the agricultural sector exist in the literature despite its attractive features: Tozer and Villano (2013), Islam et al. (2014), Khan et al. (2015) which all are applications to the Australian agriculture; Rahman and Salim (2013), Baležentis (2015) which respectively use the Färe-Primont index to assess the productivity of agriculture in Bangladesh and Lithuania; and Baráth and Fertő (2016) which focuses to a sample of country-level data of European countries.

The objective of this paper is to apply for the first time to French micro-economic farm data the more rigorous Färe-Primont TFP index. Using data for farms that are representative of French agriculture, we aim at assessing whether the above-mentioned TFP decrease is confirmed during 2002-2014 and at shedding light on the sources of TFP change: technological change and efficiency change, the latter including technical, mix, scale and residual efficiency changes. This period of 13 years allows capturing the 2006

[5] The Malmquist index can also be used when variable returns to scale (VRS) are assumed (Grifell-Tatjé and Lovell, 1995).

[6] The Malmquist index is multiplicatively complete if: (i) the technology is input homothetic and exhibits constant returns to scale (CRS); and (ii) there is no technological change and the technology is CRS (O'Donnell, 2010).

implementation of the decoupled Single Farm Payment (SFP) of the European Union's (EU) Common Agricultural Policy (CAP), following the 2003 CAP Luxemburg reform. Several articles have provided evidence of a positive effect of decoupled payments on farmers' investment decisions (e.g. Sckokai and Moro (2009), Serra et al. (2009)) and it may therefore be expected that technological progress, and hence productivity increases have followed.

Several types of farming (i.e. main farm specialisations) are considered here: field crop farms; dairy farms; beef cattle farms; pig farms and poultry farms; mixed crop and livestock farms; and sheep farms and goat farms. TFP will firstly be assessed for each type of farming, that is to say with respect to their own frontier. Secondly, TFP will be assessed with respect to a common frontier, namely a meta-frontier (Battese et al., 2004, O'Donnell et al., 2008). Comparing the results obtained with respect to the separate frontiers and those with respect to the meta-frontier, will enable computing technology gap ratios that can show the most productive types of farming. To the best of our knowledge, this is the first extension of the transitive Färe-Primont index to the meta-frontier framework in light of O'Donnell and Fallah-Fini (2011).

The rest of the paper is organised as follows. Section 2 presents the methodology, namely the Färe-Primont TFP index and the extension of the meta-frontier concept to this index. Section 3 describes the data. Section 4 presents the results and Section 5 concludes.

2. Methodology

2.1. Färe-Primont TFP index

Let's consider a set of $n = 1, \ldots, N$ producers and $t = 1, \ldots, T$ periods of time. Each producer uses $x \in \mathbb{R}_+^K$ inputs to produce $y \in \mathbb{R}_+^Q$ outputs. The benchmark technology for period t, whose properties have been discussed in Färe (1988), is defined as follows:

$$\Psi_t = \left[(x^t, y^t) \in \mathbb{R}_+^{\mathrm{K+Q}} \mid x^t \text{ can produce } y^t\right] \quad (1)$$

The Shephard input (D_t^I) and output (D_t^O) distance functions can be estimated using:

$$D_t^I(x,y) = \underset{\theta}{\text{Sup}}\left[\theta > 0 \mid \left(\frac{x}{\theta}, y\right) \in \Psi_t\right]$$
$$D_t^O(x,y) = \underset{\phi}{\text{Inf}}\left[\phi > 0 \mid \left(x, \frac{y}{\phi}\right) \in \Psi_t\right] \tag{2}$$

As mentioned, TFP is the ratio of an output quantity index on an input quantity index:

$$TFP_t = \frac{Y(y^t)}{X(x^t)} \tag{3}$$

where $Y(y^t)$ is the aggregate level of outputs and $X(x^t)$ is the aggregated inputs. The aggregator functions[7] $Y()$ and $X()$ used for the Färe-Primont index are based on the distance functions in **(2)**. For fixed reference vectors of inputs and outputs $\bar{x}, \bar{y}$ and a fixed period $\bar{t}$, TFP can be evaluated as:

$$TFP_t = \frac{D_{\bar{t}}^O(\bar{x}, y^t)}{D_{\bar{t}}^I(x^t, \bar{y})} \tag{4}$$

From **(4)**, the Färe-Primont TFP index can be computed as follows:

$$FPP_{t,t+1} = \frac{TFP_{t+1}}{TFP_t} = \frac{D_{\bar{t}}^O(\bar{x}, y^{t+1})}{D_{\bar{t}}^I(x^{t+1}, \bar{y})} \times \frac{D_{\bar{t}}^I(x^t, \bar{y})}{D_{\bar{t}}^O(\bar{x}, y^t)} \tag{5}$$

Practically, the reference (benchmark) input/output vectors and the fixed period are chosen to be representative of the sample under analysis.

Following O'Donnell (2008), O'Donnell (2010), the Färe-Primont index in **(5)** can be decomposed using several efficiency measures. From an output (input) orientation perspective, the following measures can be computed.

- OTE (respectively, ITE) is the output (respectively, input) technical efficiency: this is a classic measure of pure technical efficiency (that is to say technical efficiency calculated under the assumption of VRS), which assesses the radial expansion (respectively, contraction) of all outputs (respectively, inputs) in order to reach the production frontier (Farrell, 1957). In other words, OTE (respectively, ITE)

[7] The aggregator functions must verify non-negative, non-decreasing and homogeneity of degree 1 properties.

measures the maximum achievable TFP using the same amount of aggregated inputs (respectively, outputs) while holding input and output mixes fixed.

- OSE (respectively, ISE) is the output (respectively, input) scale efficiency: this measure is computed as the ratio of the OTE scores under CRS and the OTE scores under VRS. OSE therefore captures the difference between TFP at a technically efficient point and maximum TFP that is possible at the point of mix-invariant optimal scale associated to the CRS mix-invariant production frontier.
- OME (respectively, IME) is the output (respectively, input) mix efficiency: while OTE (respectively, ITE) is measured at a point located on the mix-invariant frontier, OME (respectively, IME) is evaluated at a point located on the unrestricted frontier. More precisely, OME (respectively, IME) evaluates the difference between TFP at a technically efficient point (on the mix-invariant frontier) and maximum possible TFP using the same amount of aggregated inputs (respectively, outputs) while holding input (respectively, output) mix fixed and relax restrictions on output (respectively, input) mix.
- ROSE (respectively, RISE) is the residual output (respectively, input) efficiency: this efficiency score represents the potential gains in TFP from a technically and mix efficient point (on the unrestricted frontier) - where aggregate input (respectively, output) level and mix are fixed and output (respectively, input) mix is relaxed - to the point of maximum productivity. This movement is only possible through changes in the scale of operations (i.e. economies of scale). The point of maximum productivity (TFP^*) represents the maximum feasible productivity considering the technology of a specific period of time t and is located on the CRS unrestricted production frontier.
- RME is the residual mix efficiency: it captures the difference between TFP at a point located on the CRS mix-invariant production frontier and maximum attainable productivity (TFP^*).

Using these efficiency measures, one can define TFP efficiency (TFPE), which is the ratio between observed productivity and maximum productivity (O'Donnell, 2010):

$$TFPE_t = \frac{TFP_t}{TFP_t^*}$$

$$TFPE_t = OTE_t \times OME_t \times ROSE_t$$

$$TFPE_t = OTE_t \times OSE_t \times RME_t \qquad (6)$$

$$TFPE_t = ITE_t \times IME_t \times RISE_t$$

$$TFPE_t = ITE_t \times ISE_t \times RME_t$$

To account for both input and output orientations, we propose to measure TFPE as a geometric means:

$$TFPE_t = (OTE_t \times ITE_t)^{\frac{1}{2}} \times (OME_t \times IME_t)^{\frac{1}{2}} \times (ROSE_t \times RISE_t)^{\frac{1}{2}} \qquad (7)$$

$$TFPE_t = (OTE_t \times ITE_t)^{\frac{1}{2}} \times (OSE_t \times ISE_t)^{\frac{1}{2}} \times RME_t$$

Using equations in **(6)** and **(7)**, the Färe-Primont index of productivity change between period *t* and period *t*+1, can then be assessed as follows:

$$FPP_{t,t+1} = \frac{TFP_{t+1}}{TFP_t} = \frac{TFPE_{t+1}}{TFPE_t} \times \frac{TFP_{t+1}^*}{TFP_t^*} \qquad (8)$$

In **(8)**, $TFPE_{t+1}/TFPE_t$ is a measure of efficiency change (EC) and TFP_{t+1}^*/TFP_t^* captures technological change (frontier shift) (TC). Technological change is evaluated at points of maximum productivity which are common each year to all observations of each period. The rationale behind this is explained by Asmild and Tam (2007 pp137-138): 'the frontier shift or technological change can be considered to be a global phenomenon, caused by such factors as changed economic conditions or improved technology becoming available. These factors can in many cases reasonably be assumed to be identical, or at least very similar, for all observations in an analysis (that are already assumed to be comparable) and therefore a single value can be used to represent the frontier shift for all DMUs'.

The efficiency change component (*EC*) can be further decomposed into various components:

$$EC_{t,t+1} = \frac{(OTE_{t+1} \times ITE_{t+1})^{\frac{1}{2}}}{(OTE_t \times ITE_t)^{\frac{1}{2}}} \times \frac{(OME_{t+1} \times IME_{t+1})^{\frac{1}{2}}}{(OME_t \times IME_t)^{\frac{1}{2}}} \times \frac{(ROSE_{t+1} \times RISE_{t+1})^{\frac{1}{2}}}{(ROSE_t \times RISE_t)^{\frac{1}{2}}} \quad (9)$$

where the first ratio is technical efficiency change, the second ratio is mix efficiency change, and the last ratio is residual scale efficiency change. If there is a single output for the analysis, then $\frac{OME_{t+1}}{OME_t} = 1$.

Efficiency change can also be decomposed as follows:

$$EC_{t,t+1} = \frac{(OTE_{t+1} \times ITE_{t+1})^{\frac{1}{2}}}{(OTE_t \times ITE_t)^{\frac{1}{2}}} \times \frac{(OSE_{t+1} \times ISE_{t+1})^{\frac{1}{2}}}{(OSE_t \times ISE_t)^{\frac{1}{2}}} \times \frac{RME_{t+1}}{RME_t} \quad (10)$$

where the first ratio is technical efficiency change, the second ratio is scale efficiency change and the last ratio is residual mix efficiency change. In the results, we will report the decomposition of efficiency change into the three ratios of equation (10), while the decomposition shown by equation (9) will be shown in Appendix.

2.2. Meta-frontier Färe-Primont index

When DMUs belong to a reasonable number of groups with distinct technologies, an appropriate approach for their comparison is through the estimation of a meta-technology which envelopes all the group technologies (Battese and Rao, 2002, Battese et al., 2004, O'Donnell et al., 2008). The difference between one group frontier and the meta-frontier is assessed through a technology gap ratio (TGR) also called the meta-technology ratio (MTR). This ratio captures the potential improvements in the group performance if all DMUs in this group have access to all available technologies (i.e. technologies of other groups). This latter is a fundamental assumption of the meta-frontier construction. Let $s = 1, \dots, S$ represents the different available technologies. The meta-technology in time t can be represented as:

$$\mathrm{M}_t = \Psi_t^1 \cup \Psi_t^2 \cup \dots \cup \Psi_t^S \quad (11)$$

where Ψ_t^s is the benchmark technology of each group s defined as in **(12)**.

$$\Psi_t^s = \left[(x_s^t, y_s^t) \in \mathbb{R}_+^{K+Q} \mid x_s^t \text{ can produce } y_s^t\right] \quad (12)$$

thereby

$$\mathrm{M}_t = \left[(x^t, y^t) \in \mathbb{R}_+^{K+Q} \mid x^t \text{ can produce } y^t\right] \quad (13)$$

M_t in **(13)** is defined independently of the group of each DMU. Similarly to the case of separate (group) frontiers, the meta-frontier Färe-Primont index is computed for the global technology (the one that envelopes all the individual technologies), as follows[8]:

$$MFPP_{t,t+1} = \frac{MTFP_{t+1}}{MTFP_t} = \frac{MTFPE_{t+1}}{MTFPE_t} \times \frac{MTFP_{t+1}^*}{MTFP_t^*} \quad (14)$$

As discussed in O'Donnell and Fallah-Fini (2011), the TGR can be assessed by comparing the points of maximum productivity on the group frontier and on the meta-frontier. Since these points are common to all observations in each specific period, the TGR is a single common measure for all observations, assessed without imposing any restrictions on input and output levels and mixes. This single structure of the TGR makes sense since the heterogeneous technologies are defined on a qualitative basis, i.e. in each group all observations use the same technology (e.g. beef vs. crop production technology) or face the same environmental conditions (e.g. plain vs. mountain area conditions). Algebraically we have:

$$TGR_t^s = \frac{TFP_t^{*s}}{MTFP_t^*} \quad (15)$$

where TGR_t^s is the meta-technology ratio for group s in period t, TFP_t^{*s} is the point of maximum productivity relative to the group s' frontier, and $MTFP_t^*$ is the meta-frontier point of maximum productivity.

The meta-frontier TFP efficiency can be written as:

[8] The prefix 'M' stands for meta-frontier related measures.

$$MTFPE_t = \frac{TFP_t}{MTFP_t^*} = \frac{TFP_t}{TFP_t^{*s}} \times \frac{TFP_t^{*s}}{MTFP_t^*} = TFPE_t^s \times TGR_t^s \qquad (16)$$

Therefore, the meta-frontier Färe-Primont productivity change can be obtained with:

$$MFPP_{t,t+1} = \frac{TFPE_{t+1}^s}{TFPE_t^s} \times \frac{TGR_{t+1}^s}{TGR_t^s} \qquad (17)$$

where the last ratio can be referred to as the technology gap ratio change (TGRC).

The meta-frontier Färe-Primont index can be further decomposed as:

$$MFPP_{t,t+1} = \frac{\left(OTE_{t+1}^s \times ITE_{t+1}^s\right)^{\frac{1}{2}}}{\left(OTE_t^s \times ITE_t^s\right)^{\frac{1}{2}}} \times \frac{\left(OME_{t+1}^s \times IME_{t+1}^s\right)^{\frac{1}{2}}}{\left(OME_t^s \times IME_t^s\right)^{\frac{1}{2}}} \times \frac{\left(ROSE_{t+1}^s \times RISE_{t+1}^s\right)^{\frac{1}{2}}}{\left(ROSE_t^s \times RISE_t^s\right)^{\frac{1}{2}}} \times \frac{TGR_{t+1}^s}{TGR_t^s} \qquad (18)$$

or as

$$MFPP_{t,t+1} = \frac{\left(OTE_{t+1}^s \times ITE_{t+1}^s\right)^{\frac{1}{2}}}{\left(OTE_t^s \times ITE_t^s\right)^{\frac{1}{2}}} \times \frac{\left(OSE_{t+1}^s \times ISE_{t+1}^s\right)^{\frac{1}{2}}}{\left(OSE_t^s \times ISE_t^s\right)^{\frac{1}{2}}} \times \frac{RME_{t+1}^s}{RME_t^s} \times \frac{TGR_{t+1}^s}{TGR_t^s} \qquad (19)$$

2.3. Assessing the heterogeneity of the samples in terms of productivity and its components

In the management literature, the Herfindahl-Hirschman is a commonly used index to measure market concentration (Kwoka Jr, 1985). At an industry level, it assesses monopolistic situations versus competition situations for firms. In competition analysis, the Herfindahl-Hirschman index (HHI) is computed as the sum of the square of each firm's market share (in terms of total assets). Applied in other contexts, the HHI can be used as a diversity index. Here it is used to analyse the heterogeneity, in terms TFP, of the different farm types, and more precisely, how this heterogeneity evolves over time. We use here a normalized version of the HHI, in addition to the classic version. The normalized version can be computed as follows in the case of TFP:

$$HHI^* = \frac{HHI - {}^{1}/_{N}}{1 - {}^{1}/_{N}} \tag{20}$$

where

$$HHI = \sum_{i=1}^{N} \left(\frac{TFP_i}{\sum TFP_i} \right)^2 \tag{21}$$

is the classic version of HHI and *N* is the number of observations in the sample considered. The HHI ranges from ${}^{1}/_{N}$ to 1 (or ${}^{100}/_{N}$ to $10{,}000$ if one uses proportion). The highest value of the HHI can be referred to as a unique characteristic of firms or, as underlined in Baležentis and Baležentis (2016), as a 'single direction' in the evolution of TFP; while lower values imply greater heterogeneity. The normalized HHI^* varies between 0 and 1, and the lower this index, the greater heterogeneity in the sample. The difference between expressions **(20)** (normalized HHI) and **(21)** (classic HHI) is that the normalized index controls for the sample size and therefore is more suitable for distributions comparison.

3. Data

We use farm-level data from the French Farm Accountancy Data Network (FADN) database. This database includes yearly accountancy data (along with some technical and economic information) for around 7,000 professional French farms with an annual rotating rate of about 10% making the sample used an unbalanced panel data sample during the period considered here, 2002-2014. The FADN database is representative of professional farms which have a total standard output above a given threshold (25,000 Euros for France) to be considered as commercial farms.

The data are collected using a stratification based on the region where the farms are located, their economic size and their type of farming. Types of farming are defined in terms of the relative importance of the different productions on the farm in terms of total standard output. If, for instance, the dairy enterprise's standard output of a given farm accounts for more than two-third of farm's total standard output, then this given far is classified as specialist dairy. Besides, each farm is assigned a specific weight that captures the farm's representativeness.

Six types of farming are subject to our analysis: field crop farms; dairy farms; beef cattle farms; sheep/goat farms; pig/poultry farms; mixed farms (with crop and livestock productions). For the analysis, four inputs are used: the farm utilised agricultural area (UAA) (in hectares), the labour force (expressed in full time equivalent units, the annual working units – AWU), intermediate consumption (in constant Euros) and capital (in constant Euros). For comparison purpose (and also for an easy implementation of meta-frontier approach) only one output is used: the value of the farm total output (in constant Euros).

We have restricted the samples to observations with strictly positive values for all the variables and with a value of capital above one thousand Euros. Visual descriptions of the farms' characteristics have primarily been used to detect some potential outliers and aberrant data. Then output super-efficiency estimations were conducted (Andersen and Petersen, 1993) to detect more global extreme observations. With this procedure we discarded about 1% of the observations in each type of farming. It is worth noting that since all our estimations have been conducted assuming VRS, infeasibility issues appeared in the super-efficiency estimation. In those cases, we used the correction procedure discussed in Lee et al. (2011).

The descriptive statistics of the final samples during the whole period are displayed in **Table 1**. During 2002-2014 mixed farms were on average the biggest farms in terms of input use, but not in terms of total output produced. They operated about 155 hectares of UAA, compared to slightly less than 140 hectares for field crop farms and about 55 hectares for farms specialized in pig and poultry production which have the lowest area of all samples. Pig/poultry farms have nevertheless the second highest labour use on average (2.10 AWU compared to 2.22 AWU for mixed farms), revealing their highly labour intensive technology. Pig/poultry farms have the highest output produced on average, about 341 thousand Euros, far above the other types of farming: the second sample being mixed farms with about 200 thousand Euros, and the last sample being the beef sample with about

80 thousand Euros. The latter nevertheless uses the least labour on average (1.54 AWU). These statistics suggest that each sample has some pros compared to the other samples when looking at specific partial productivity indicators. The meta-frontier analysis, by considering all inputs at the same time, will help assess the most productive sample in terms of a global productivity indicator (TFP). Within the samples, we can expect a wide range of TFP due to the substantial heterogeneity that seems to prevail regarding the use of inputs and the production of output (the coefficients of variation are greater than 25%).

Table 1: Descriptive statistics of the French FADN samples used over the period 2002-2014

	Min	Max	Mean (μ)	Standard deviation (σ)	Coefficient of variation (σ/μ)
Field crop farms					
UAA (hectares)	6.40	705.63	**139.27**	83.88	0.60
Labour (AWU)	0.20	26.45	**1.81**	1.31	0.73
Intermediate consumption (thousand Euros)	5.54	682.15	**78.71**	54.61	0.69
Capital (thousand Euros)	1.10	1,304.16	**137.45**	125.44	0.91
Total output (thousand Euros)	2.66	1,674.97	**163.72**	122.88	0.75
Number of observations			**22,208**		
Dairy farms					
UAA (hectares)	10.25	431.13	**88.61**	48.88	0.55
Labour (AWU)	0.95	8.19	**1.88**	0.90	0.48
Intermediate consumption (thousand Euros)	5.78	456.11	**71.26**	47.35	0.66
Capital (thousand Euros)	8.31	1,217.82	**192.54**	132.38	0.69
Total output (thousand Euros)	10.59	615.60	**137.87**	83.22	0.60
Number of observations			**13,316**		
Beef farms					
UAA (hectares)	16.00	484.26	**118.19**	66.37	0.56
Labour (AWU)	0.78	6.00	**1.54**	0.72	0.47
Intermediate consumption (thousand Euros)	3.38	274.34	**46.11**	31.19	0.68
Capital (thousand Euros)	10.16	973.09	**198.23**	121.88	0.61
Total output (thousand Euros)	4.54	421.85	**79.69**	52.10	0.65
Number of observations			**7,341**		
Sheep/goat farms					
UAA (hectares)	0.50	555.70	**99.91**	76.53	0.77
Labour (AWU)	0.50	8.39	**1.82**	0.98	0.54

Intermediate consumption (thousand Euros)	3.63	355.12	**50.60**	40.16	0.79
Capital (thousand Euros)	4.38	840.25	**143.68**	108.06	0.75
Total output (thousand Euros)	3.41	607.38	**86.87**	74.02	0.85
Number of observations			**3,948**		
Pig/poultry farms					
UAA (hectares)	0.10	299.40	**54.84**	43.36	0.79
Labour (AWU)	0.50	12.00	**2.10**	1.32	0.63
Intermediate consumption (thousand Euros)	5.18	2,356.71	**230.35**	228.25	0.99
Capital (thousand Euros)	1.12	2,667.01	**191.35**	205.09	1.07
Total output (thousand Euros)	14.18	2,217.74	**340.86**	301.16	0.88
Number of observations			**2,639**		
Mixed farms					
UAA (hectares)	22.00	737.76	**154.52**	92.40	0.60
Labour (AWU)	0.60	10.52	**2.22**	1.15	0.52
Intermediate consumption (thousand Euros)	8.35	650.57	**107.46**	70.98	0.66
Capital (thousand Euros)	2.15	1,374.09	**247.74**	166.76	0.67
Total output (thousand Euros)	7.49	1,196.53	**199.76**	131.72	0.66
Number of observations			**7,623**		
All types of farming together					
UAA (hectares)	0.1	737.80	**120.2**	79.07	0.66
Labour (AWU)	0.2	26.45	**1.86**	1.14	0.61
Intermediate consumption (thousand Euros)	3.38	2,356.71	**81.68**	79.81	0.98
Capital (thousand Euros)	1.10	2,667.01	**175.77**	141.64	0.81
Total output (thousand Euros)	2.66	2,217.74	**154.57**	133.20	0.86
Number of observations			**57,075**		

Source: the authors, based on the French FADN data.

4. Results

Results obtained with separate frontiers per type of farming are first reported, followed by results obtained with a meta-frontier enveloping all types of farming. The results reported are change indices, where an index below 1 indicates deterioration, an index equal to 1 indicates stagnation, and an index above 1 indicates progress. Given the unbalanced structure of the panel used here, the Färe-Primont change index and its components have been computed using the geometric mean of each year as observations for the different necessary variables. For instance, the output technical efficiency in year *t* is the geometric mean of all observations for year *t*.

4.1. Results with separate (group) frontiers per type of farming

Table 2 reports the average Färe-Primont TFP change indices as well as the average change components for each year between 2002 and 2014. The indices in 2014 indicate the change during the whole period 2002-2014. They indicate that for all samples, there has been a TFP growth, as all average indices are above 1. The smallest growth is recorded for the pig/poultry farms (4.5%) and the largest for the beef farms (19.1%). The latter are followed by field crop farms and dairy farms with a similar growth (16.3% and 16.1%, respectively), while mixed farms and sheep/goat farms had a growth of 10.6% and 7.4%, respectively. Still in 2014, technological change is positive for only three types of farming, with a massive value of 27.7% for mixed farms, and more common values for dairy farms (12.1%) and sheep/goat farms (7.2%). By contrast, the beef farms, which performed the best in terms of TFP change, experienced technological regress (-2.2%) but a strong efficiency progress (+21.8%). For pig/poultry farms, technological regress is about -3.3%. Field crop farms recorded almost no technological change over the period of analysis (2002-2014). Mixed farms had a substantial decrease in technical efficiency of -13.4% which explains why their global TFP growth is medium compared to the field crop farms and dairy farms. In dairy farms, not only technology progressed but efficiency as well, which is unusual. It has been documented that technological change often goes in opposite to efficiency development, as not all producers are able to adjust instantly to the new technology (Brümmer et al., 2002, Latruffe et al., 2012). This is the case for field crop farms and sheep goat farms, where either technological change or efficiency change has improved.

The further decomposition of efficiency change shows that for beef farms, the main source of efficiency growth between 2002 and 2014 is technical efficiency improvement (15.4%), although the other components of efficiency also progressed (+2.1% for scale efficiency and +3.3% for residual mix efficiency). This suggests that farmers in this sample have improved their farming practices, enabling the increase of output produced and/or the decrease of input use. The field crop farm sample is the other sample where all three efficiency components improved, in similar terms: +3.8%, +6.8% and +5.4%, for technical efficiency, scale efficiency and residual mix efficiency change, respectively. Dairy farms rather progressed in terms of technical efficiency and scale efficiency, sheep/goat farms in terms of scale efficiency, and pig/poultry farms in terms of scale efficiency but before all in terms of residual mix efficiency (+10.9%). By contrast, mixed farms experienced no progress in efficiency: they maintained their technical efficiency (the index is close to 1), but had a decrease in scale efficiency and in residual mix efficiency. Results from the alternative decomposition of efficiency change, developed in equation (9), are reported in Appendix 1. They confirm the results of **Table 2** for dairy farms and for sheep/goat farms. However, Appendix 1 reveals no change in mix efficiency and a large increase in residual scale efficiency for field crop farms, a decrease in mix efficiency for beef farms, the strongest increase in the residual scale component for pig/poultry farms and the strongest decrease in the residual scale component for mix farms.

Turning to the annual evolution of TFP and its components (figures in **Table 2**, graphically presented in **Appendix 2**), for field crop farms, dairy farms and mixed farms there is a clear increasing trend of TFP change until 2010. For the latter two types of farms, this increasing trend is very symmetric to the evolution of technological change. As regard the other types, i.e. beef farms, sheep/goat farms and pig/poultry farms, the TFP change trends appear to be stable over the whole period. For all the farm types, it is clear that efficiency change and technological change evolved in opposite directions. Another interesting feature is that technical efficiency change is less subject to variations than technological change, scale efficiency change and residual mix efficiency change. It suggests that farmers manage to adapt their practices smoothly, despite the shocks (technological change peaks, policy reforms) faced during the period. The smoother trend of technical efficiency change is for pig/poultry farms, which evolves around 1 during the period, similarly to scale efficiency change.

Table 2: Average TFP change and components for the French FADN farms in each year over the period 2002-2014, using separate frontiers per type of farming

Years	TFP change	Technological change (TC)	Efficiency change (EC)	Technical efficiency change	Scale efficiency change	Residual mix efficiency change
Field crop farms						
2002	1.000	1.000	1.000	1.000	1.000	1.000
2003	0.978	0.881	1.112	0.999	0.997	1.116
2004	1.021	0.921	1.110	1.052	0.998	1.057

2005	1.050	0.853	1.232	1.032	1.031	1.157
2006	1.093	1.068	1.023	1.037	0.977	1.010
2007	1.251	1.042	1.200	1.061	1.004	1.127
2008	1.188	0.949	1.251	1.050	1.034	1.152
2009	1.134	1.080	1.050	1.026	1.004	1.020
2010	1.382	1.289	1.073	1.020	0.953	1.103
2011	1.368	1.033	1.325	1.087	1.055	1.154
2012	1.421	1.080	1.315	1.078	1.103	1.106
2013	1.158	1.063	1.090	0.976	1.054	1.059
2014	**1.163**	**0.996**	**1.168**	**1.038**	**1.068**	**1.054**
Dairy farms						
2002	1.000	1.000	1.000	1.000	1.000	1.0000
2003	0.942	0.963	0.978	1.022	1.003	0.955
2004	1.006	1.014	0.992	1.026	1.019	0.949
2005	1.063	1.077	0.988	1.000	1.001	0.987
2006	0.989	0.983	1.006	0.988	1.005	1.012
2007	0.980	0.990	0.989	0.995	0.985	1.009
2008	1.023	1.056	0.968	1.011	1.006	0.952
2009	1.059	1.230	0.861	0.971	0.958	0.927
2010	1.127	1.181	0.954	1.009	1.011	0.936
2011	1.111	1.014	1.095	1.020	1.014	1.059
2012	1.041	1.100	0.946	1.001	0.993	0.952
2013	1.057	1.025	1.031	1.010	1.012	1.009
2014	**1.161**	**1.121**	**1.035**	**1.025**	**1.022**	**0.988**
Beef farms						
2002	1.000	1.000	1.000	1.000	1.000	1.000
2003	0.978	0.928	1.055	1.082	0.951	1.025
2004	1.075	1.081	0.995	1.031	0.989	0.975
2005	1.209	1.283	0.942	0.994	0.975	0.972
2006	1.209	1.204	1.004	1.024	0.981	1.000
2007	1.052	0.923	1.140	1.076	1.031	1.027
2008	1.028	1.031	0.997	1.068	0.969	0.964
2009	1.182	1.416	0.834	0.972	0.952	0.901
2010	1.120	1.354	0.827	1.052	0.949	0.829
2011	1.052	1.306	0.805	0.981	0.997	0.824
2012	1.121	1.263	0.888	1.045	0.953	0.891
2013	1.119	1.154	0.970	1.100	0.917	0.961
2014	**1.191**	**0.978**	**1.218**	**1.154**	**1.021**	**1.033**
Sheep/goat farms						
2002	1.000	1.000	1.000	1.000	1.000	1.000
2003	0.861	1.003	0.859	0.945	0.939	0.967
2004	0.971	1.086	0.894	0.996	1.015	0.885
2005	1.028	1.153	0.892	0.998	0.982	0.910
2006	1.040	1.082	0.961	0.985	0.983	0.993
2007	0.960	0.939	1.023	1.010	1.006	1.007

2008	0.928	1.074	0.864	0.968	0.912	0.978
2009	1.095	1.161	0.943	1.001	0.959	0.982
2010	1.035	1.277	0.810	0.923	1.041	0.843
2011	0.973	1.231	0.790	0.921	0.997	0.860
2012	0.962	1.047	0.919	0.940	1.020	0.958
2013	0.933	1.052	0.887	0.908	0.947	1.004
2014	**1.074**	**1.072**	**1.002**	**0.962**	**1.042**	**0.999**
Pig/poultry farms						
2002	1.000	1.000	1.000	1.000	1.000	1.000
2003	0.991	0.672	1.474	1.074	1.036	1.325
2004	1.033	0.721	1.432	1.062	1.032	1.307
2005	1.213	0.900	1.348	1.066	1.021	1.238
2006	1.177	0.876	1.345	1.061	1.029	1.232
2007	1.051	0.773	1.360	1.035	1.023	1.284
2008	1.067	0.836	1.276	1.008	1.011	1.252
2009	1.242	0.954	1.302	1.014	1.016	1.263
2010	1.107	1.021	1.084	0.954	0.960	1.184
2011	1.059	0.945	1.121	0.951	0.970	1.215
2012	1.088	0.902	1.205	0.955	1.021	1.235
2013	1.030	0.859	1.199	0.942	1.009	1.261
2014	**1.045**	**0.967**	**1.081**	**0.944**	**1.032**	**1.109**
Mixed farms						
2002	1.000	1.000	1.000	1.000	1.000	1.000
2003	0.959	1.147	0.836	0.950	0.969	0.907
2004	1.047	1.039	1.008	1.000	1.027	0.981
2005	1.113	1.255	0.886	0.978	0.999	0.907
2006	1.097	1.141	0.962	1.018	0.994	0.950
2007	1.100	1.259	0.874	0.973	1.001	0.898
2008	1.096	1.175	0.933	0.983	1.001	0.849
2009	1.116	1.284	0.869	0.936	0.944	0.984
2010	1.277	1.439	0.887	0.997	0.976	0.912
2011	1.242	1.475	0.842	1.016	1.000	0.829
2012	1.237	1.332	0.929	1.026	0.981	0.923
2013	1.077	1.426	0.755	0.883	0.942	0.907
2014	**1.106**	**1.277**	**0.866**	**0.994**	**0.940**	**0.927**

Notes: TFP change is decomposed into technological change (TC) and efficiency change (EC) (see equation 8). Efficiency change is then decomposed into technical efficiency change, scale efficiency change and residual mix efficiency change (see equation 10).

Source: the authors, based on the French FADN data and using R software.

In terms of heterogeneity, the HHI and its normalized version for TFP are reported in **Table 3**. The results reveal that in terms of productivity, the most homogenous sample is the pig/poultry farms (with the highest average HHI) while the most heterogeneous is the sample of field crop farms. In terms of evolution, as shown on **Figure 1**, the most notable change can be observed for the pig/poultry farm sample, which has gradually shifted from a homogenous situation to larger heterogeneity in TFP over time.

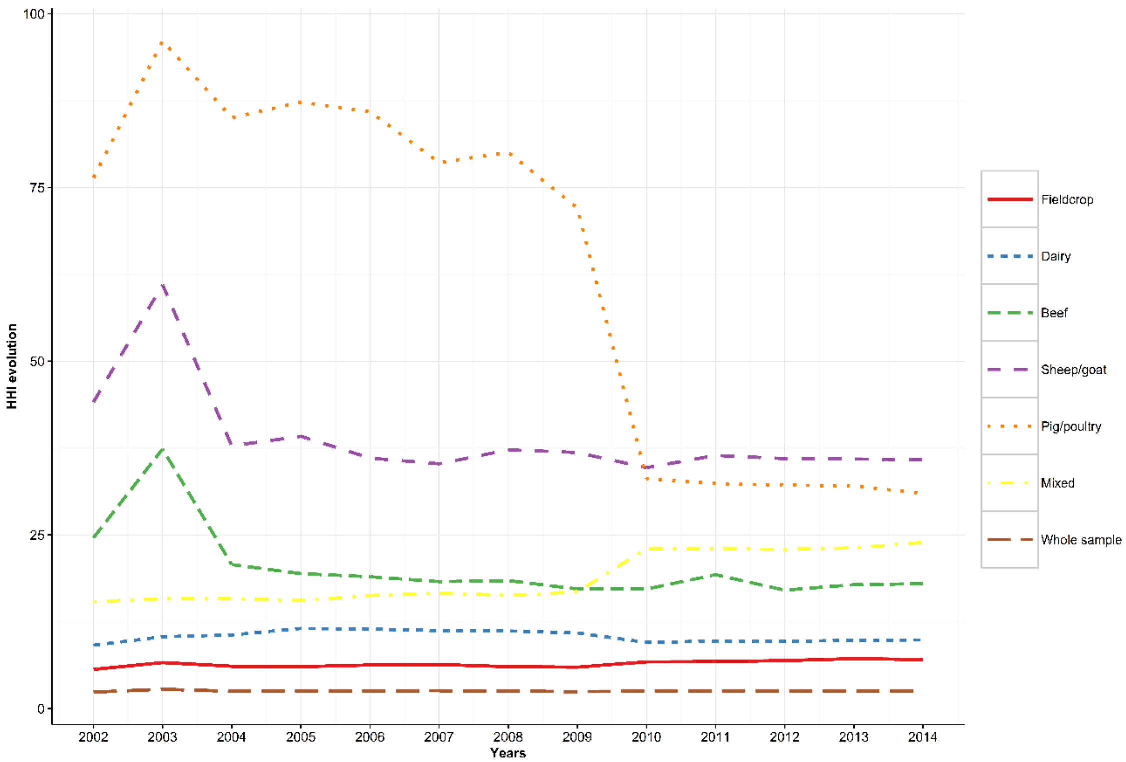
Table 3: HHI and normalized for the French FADN farms' TFP in each year over the period 2002-2014

Years	Field crop farms	Dairy farms	Beef farms	Sheep/goat farms	Pig/poultry farms	Mixed farms	All types of farming together
HHI							
2002	5.633	9.107	24.581	44.098	76.390	15.388	2.367
2003	6.620	10.331	37.354	61.009	96.114	15.810	2.781
2004	6.085	10.595	20.721	37.807	85.055	15.814	2.490
2005	6.035	11.531	19.415	39.181	87.282	15.551	2.507
2006	6.264	11.429	18.969	36.043	85.931	16.275	2.542
2007	6.325	11.209	18.266	35.230	78.590	16.659	2.578
2008	6.031	11.152	18.419	37.216	80.066	16.277	2.519
2009	5.959	10.885	17.212	36.858	72.056	16.810	2.438
2010	6.716	9.510	17.202	34.668	33.063	23.048	2.504
2011	6.755	9.714	19.268	36.442	32.385	22.983	2.567
2012	6.900	9.660	17.037	35.971	32.151	22.927	2.553
2013	7.177	9.836	17.829	35.907	32.052	23.123	2.569
2014	7.046	9.872	17.962	35.788	30.953	23.929	2.542
Average	**6.427**	**10.372**	**20.326**	**38.940**	**63.238**	**18.815**	**2.535**
Normalized HHI (in %)							
2002	0.052	0.084	0.232	0.416	0.726	0.141	0.022
2003	0.062	0.096	0.360	0.585	0.924	0.145	0.026
2004	0.056	0.098	0.194	0.353	0.813	0.145	0.023
2005	0.056	0.108	0.181	0.367	0.835	0.142	0.023
2006	0.058	0.107	0.176	0.335	0.822	0.150	0.024
2007	0.059	0.105	0.169	0.327	0.748	0.153	0.024
2008	0.056	0.104	0.171	0.347	0.763	0.150	0.023
2009	0.055	0.101	0.159	0.343	0.683	0.155	0.023
2010	0.063	0.088	0.158	0.321	0.293	0.217	0.023
2011	0.063	0.090	0.179	0.339	0.286	0.217	0.024
2012	0.065	0.089	0.157	0.334	0.284	0.216	0.024
2013	0.067	0.091	0.165	0.334	0.283	0.218	0.024

2014	0.066	0.091	0.166	0.333	0.272	0.226	0.024
Average	**0.060**	**0.096**	**0.190**	**0.364**	**0.595**	**0.175**	**0.024**

Source: the authors, based on the French FADN data and using R software.

Figure 1: Evolution of the HHI for the French FADN farms' TFP in each year over the period 2002-2014



Source: the authors, based on the French FADN data and using R software.

4.2. Results with the meta-frontier

Table 4 presents the meta-technology Färe-Primont productivity change index and its components in each year during 2002-2014 (as well as Appendix 3 for the alternative decomposition). When all French farms are taken together (except permanent crop farms and vegetable farms which are not considered here), the agricultural sector experienced a TFP growth of 13% between 2002 and 2014, mostly due to efficiency change (+13.4%) while technology has stagnated (technological change index close to 1). TFP evolution and its different components for all types of farming can be seen in the last panel of **Appendix 2**. For many farm types, the evolution of TFP shows an increasing trend until 2010 and starts falling down after this date. Here also the opposition between technological change's and efficiency change's evolution is visible.

Table 5 presents the overall technology gap ratios (TGR) and **Table 6** displays the TGR changes during the period. The results in **Table 5** reveal that the meta-technology is mostly made of the field crop farms as they have the highest TGR, suggesting that they have access to a more productive technology than the other farming types. Actually the overall technology gap for field crop farms is almost equals to one, indicating that almost only field crop farms are on the meta-frontier. The least productive technology is the one associated to sheep/goat farms with a TGR of 0.645%, indicating that those farms reach only 64.5% of the maximum productivity that is feasible under the meta-technology.

In terms of evolution of the TGR (**Table 6**), mixed farms recorded the highest change over the period of study with a gain higher than 28%. They are followed by dairy farms and sheep/goat farms which show respectively an increase of 12.6% and 7.6%. As shown by **Figure 1**, pig/poultry farms had a decrease in TGR change in most years.

Table 4: Average TFP change and components for the French FADN farms in each year over the period 2002-2014, using a meta-frontier

Years	TFP change	Technological change (TC)	Efficiency change (EC)	Technical efficiency change	Scale efficiency change	Residual mix efficiency change
All types of farming together						
2002	1.000	1.000	1.000	1.000	1.000	1.000
2003	0.971	0.881	1.103	1.013	0.987	1.102
2004	1.010	0.921	1.097	1.064	0.994	1.037
2005	1.064	0.861	1.235	1.057	1.020	1.146
2006	1.059	1.068	0.992	1.016	0.980	0.996
2007	1.083	1.042	1.039	1.008	0.967	1.066
2008	1.070	0.949	1.127	1.019	1.000	1.105
2009	1.096	1.080	1.015	0.977	0.982	1.058
2010	1.199	1.289	0.930	0.925	0.914	1.101
2011	1.176	1.033	1.139	1.010	0.998	1.130
2012	1.174	1.080	1.086	0.960	1.050	1.077

2013	1.075	1.063	1.012	0.942	1.038	1.034
2014	**1.130**	**0.996**	**1.134**	**1.020**	**1.066**	**1.043**

Notes: TFP change is decomposed into technological change (TC) and efficiency change (EC) (see equation 14). Efficiency change is then decomposed into technical efficiency change, scale efficiency change and residual mix efficiency change (see equation 19).

Source: the authors, based on the French FADN data and using R software.

Table 5: Overall technology gap ratios for the French FADN farms

Farming types	TGR
Field crop farms	0.999
Dairy farms	0.738
Beef farms	0.681
Sheep/goat farms	0.645
Pig/poultry farms	0.828
Mixed farms	0.834

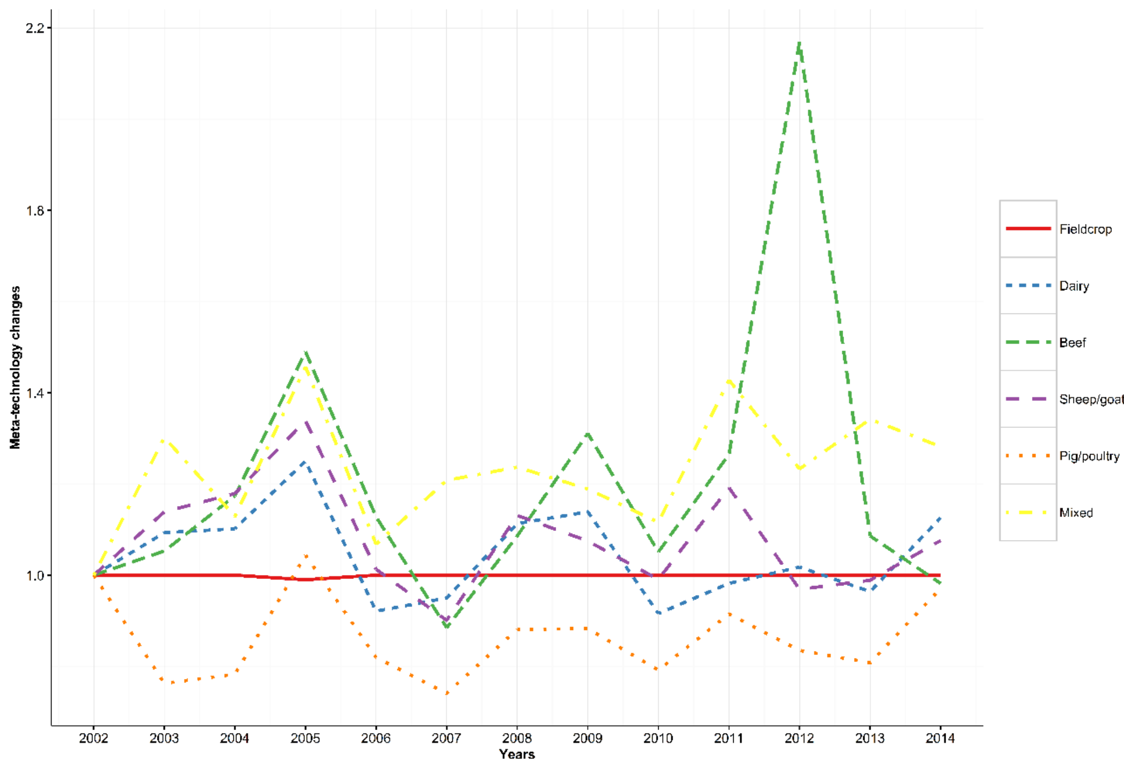
Source: the authors, based on the French FADN data and using R software.

Table 6: Technology gap ratios changes for the French FADN farms in each year over the period 2002-2014

Years	Field crop farms	Dairy farms	Beef farms	Sheep/goat farms	Pig/poultry farms	Mixed farms
2002	1.000	1.000	1.000	1.000	1.000	1.000
2003	1.000	1.093	1.053	1.139	0.763	1.302
2004	1.000	1.102	1.174	1.179	0.783	1.129
2005	0.990	1.250	1.490	1.339	1.044	1.457
2006	1.000	0.921	1.128	1.013	0.820	1.068
2007	1.000	0.950	0.885	0.901	0.741	1.208
2008	1.000	1.113	1.086	1.131	0.881	1.237
2009	1.000	1.139	1.311	1.075	0.883	1.189
2010	1.000	0.916	1.051	0.991	0.792	1.116
2011	1.000	0.982	1.265	1.192	0.915	1.428
2012	1.000	1.018	2.169	0.969	0.835	1.233
2013	1.000	0.964	1.086	0.989	0.808	1.342
2014	**1.000**	**1.126**	**0.982**	**1.076**	**0.971**	**1.282**

Source: the authors, based on the French FADN data and using R software.

Figure 1: Evolution of the changes in technology gap ratios for the French FADN farms over the period 2002-2014



5. Conclusion

The objective of this article was to assess productivity change in French agriculture during 2002-2014, namely total factor productivity (TFP) change and its components technological change and efficiency change. For this, we used the economically-ideal Färe-Primont index which verifies the multiplicatively completeness property and is also transitive, allowing for multi-temporal/lateral comparisons. To compare the technology gap change between the six types of farming considered, we extended the Färe-Primont to the meta-frontier framework.

Results indicated that during 2002-2014, all farms had a TFP progress. Pig/poultry farms had the lowest TFP increase (4.5%) while beef farms had the highest (19.1%). The latter had the strongest increase in efficiency change (21.8%), suggesting that for these farms technological progress was rather existent in the 90es due to the introduction of advanced technologies such as feed distribution equipment. In the 2000es beef farmers managed to adjust their practices to the new technology and became highly efficient. Pig/poultry farms had the least changes in technical efficiency during the period. As shown by the review by Minviel and Latruffe (2016), the technical efficiency of farms in the EU is influenced by the CAP subsidies, the influence depending on the type of subsidies. Latruffe et al. (2016) also showed that the effect of CAP subsidies on EU dairy farms was diminished after the introduction of the decoupled Single Farm Payments. The fact that technical efficiency for pig/poultry farms is relatively stable throughout the period studied here, which encompasses two CAP reforms, may be due to the fact that such farms are not highly dependent on CAP subsidies. During the period studied, technological progress was the highest for mixed farms (27.7%), with an upward trend between 2002 and 2011. Technological change was the highest for the whole French agricultural sector (under the meta-frontier) in 2010, and when taking types of farming separately, it is also clear that the peak of technological change is within 2009-2011, while is has rather decreased during 2006-2008. The decrease occurred after the main CAP reform, which saw the introduction of decoupled payments (SFP), although it could have been expected that such payments may increase technological change and thus productivity change. By contrast, the economic crisis in the following years seems to have forced farmers to adjust their technology.

When technologies are compared to each other using a meta-frontier, results indicate that field crop farms had the most productive technology. This result may be even more confirmed if data on labour were more precise. Labour data are recorded in terms of AWU that is to say of full time equivalents. But one AWU may not have the same meaning in crop farming than in livestock farming, where farmers are known to work long hours to take care of the animals. Hence, if real working hours were accounted for, livestock farms may be even less productive than field crop farms. However, in future research non-agricultural goods should be accounted for when computing and comparing productivity changes across types of farming. Livestock farming and crop farming contribute to various environmental and social goods which are more and more demanded by policy makers and society (Cooper et al., 2009). Findings such as the classification of types of farms may not be the same when these goods are accounted for. (Dakpo et al., 2016) for example showed for French sheep meat farms a discrepancy in efficiency evolution depending on whether the focus was on meat or on greenhouse gases.

From a methodological point of view, the Färe-Primont index which, as aforementioned, is multiplicatively complete and satisfies the transitivity property, requires the definition of a representative observation. For our case study, we chose the average observation of the pooled sample containing all the farm types. It is worth mentioning that the decomposition of the Färe-Primont productivity index might be sensitive to this representative observation. Therefore, in further research, for robustness check a sensitivity analysis of this decomposition should be performed using different representative observations. Subsampling techniques as discussed in Simar and Wilson (2011) can certainly be helpful in dealing with this issue and at the same time deriving statistical properties (confidence intervals).

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Appendixes

Appendix 1: Average TFP change and components for the French FADN farms in each year over the period 2002-2014, using separate frontiers per type of farming

Years	TFP change	Technological change (TC)	Efficiency change (EC)	Technical efficiency change	Mix-efficiency change	Residual scale efficiency change
Field crop farms						
2002	1.000	1.000	1.000	1.000	1.000	1.000
2003	0.978	0.881	1.112	0.999	0.961	1.159
2004	1.021	0.921	1.110	1.052	0.973	1.084
2005	1.050	0.853	1.232	1.032	0.980	1.218
2006	1.093	1.068	1.023	1.037	1.013	0.975
2007	1.251	1.042	1.200	1.061	0.991	1.142
2008	1.188	0.949	1.251	1.050	1.015	1.174
2009	1.134	1.080	1.050	1.026	0.991	1.033
2010	1.382	1.289	1.073	1.020	1.015	1.036
2011	1.368	1.033	1.325	1.087	1.037	1.175
2012	1.421	1.080	1.315	1.078	1.021	1.195
2013	1.158	1.063	1.090	0.976	1.019	1.096
2014	**1.163**	**0.996**	**1.168**	**1.038**	**1.009**	**1.115**
Dairy farms						
2002	1.000	1.000	1.000	1.000	1.000	1.000
2003	0.942	0.963	0.978	1.022	1.003	0.954
2004	1.006	1.014	0.992	1.026	0.996	0.971
2005	1.063	1.077	0.988	1.000	0.995	0.993
2006	0.989	0.983	1.006	0.988	0.987	1.031
2007	0.980	0.990	0.989	0.995	1.001	0.993
2008	1.023	1.056	0.968	1.011	0.988	0.970
2009	1.059	1.230	0.861	0.971	0.976	0.909
2010	1.127	1.181	0.954	1.009	0.989	0.956
2011	1.111	1.014	1.095	1.020	0.999	1.074
2012	1.041	1.100	0.946	1.001	0.977	0.968
2013	1.057	1.025	1.031	1.010	1.002	1.019
2014	**1.161**	**1.121**	**1.035**	**1.025**	**0.984**	**1.026**
Beef farms						
2002	1.000	1.000	1.000	1.000	1.000	1.000
2003	0.978	0.928	1.055	1.082	0.973	1.001
2004	1.075	1.081	0.995	1.031	0.980	0.985
2005	1.209	1.283	0.942	0.994	0.970	0.977
2006	1.209	1.204	1.004	1.024	0.966	1.016
2007	1.052	0.923	1.140	1.076	0.995	1.064

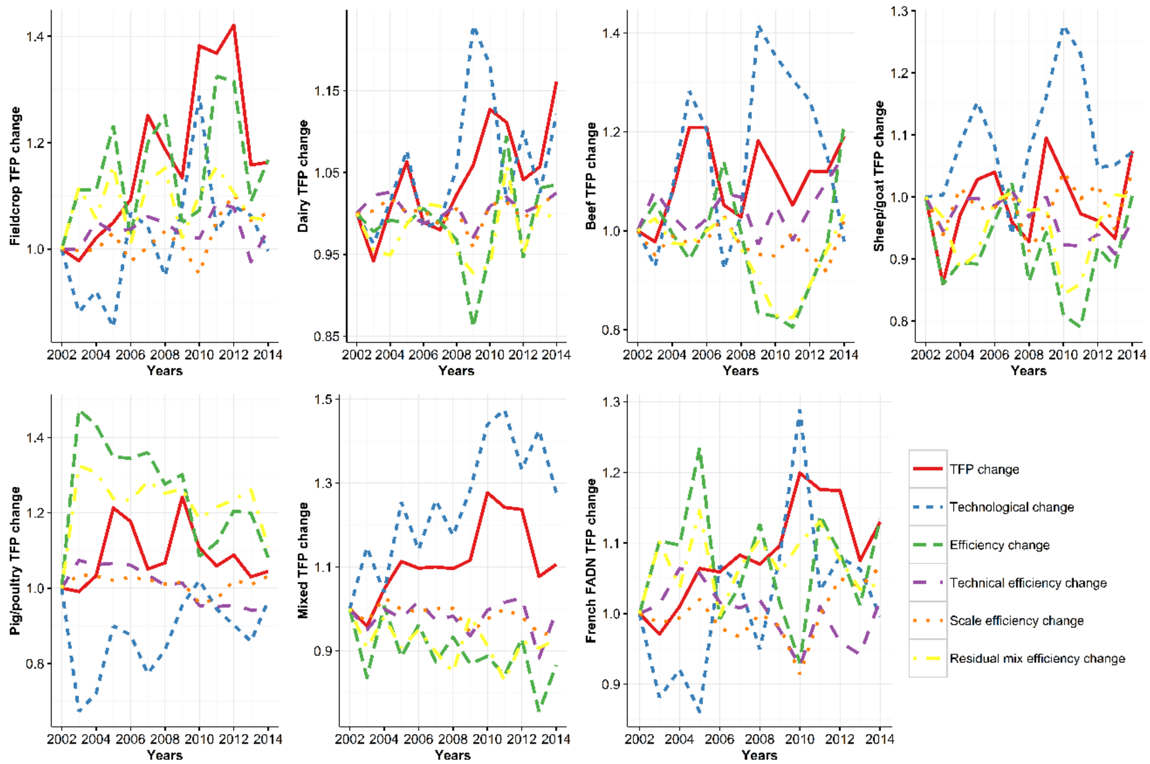
2008	1.028	1.031	0.997	1.068	1.010	0.925
2009	1.182	1.416	0.834	0.972	0.984	0.873
2010	1.120	1.354	0.827	1.052	0.956	0.822
2011	1.052	1.306	0.805	0.981	0.972	0.845
2012	1.121	1.263	0.888	1.045	0.997	0.852
2013	1.119	1.154	0.970	1.100	0.984	0.896
2014	**1.191**	**0.978**	**1.218**	**1.154**	**0.972**	**1.085**
Sheep/goat farms						
2002	1.000	1.000	1.000	1.000	1.000	1.000
2003	0.861	1.003	0.859	0.945	1.001	0.908
2004	0.971	1.086	0.894	0.996	0.985	0.912
2005	1.028	1.153	0.892	0.998	0.986	0.907
2006	1.040	1.082	0.961	0.985	0.997	0.979
2007	0.960	0.939	1.023	1.010	0.995	1.018
2008	0.928	1.074	0.864	0.968	0.992	0.900
2009	1.095	1.161	0.943	1.001	0.988	0.953
2010	1.035	1.277	0.810	0.923	0.993	0.883
2011	0.973	1.231	0.790	0.921	1.010	0.850
2012	0.962	1.047	0.919	0.940	1.007	0.971
2013	0.933	1.052	0.887	0.908	0.987	0.991
2014	**1.074**	**1.072**	**1.002**	**0.962**	**0.989**	**1.052**
Pig/poultry farms						
2002	1.000	1.000	1.000	1.000	1.000	1.000
2003	0.991	0.672	1.474	1.074	1.072	1.280
2004	1.033	0.721	1.432	1.062	1.074	1.255
2005	1.213	0.900	1.348	1.066	1.055	1.198
2006	1.177	0.876	1.345	1.061	1.052	1.205
2007	1.051	0.773	1.360	1.035	1.052	1.249
2008	1.067	0.836	1.276	1.008	1.046	1.211
2009	1.242	0.954	1.302	1.014	1.055	1.216
2010	1.107	1.021	1.084	0.954	1.008	1.128
2011	1.059	0.945	1.121	0.951	1.023	1.153
2012	1.088	0.902	1.205	0.955	1.049	1.202
2013	1.030	0.859	1.199	0.942	1.049	1.213
2014	**1.045**	**0.967**	**1.081**	**0.944**	**1.025**	**1.116**
Mixed farms						
2002	1.000	1.000	1.000	1.000	1.000	1.000
2003	0.959	1.147	0.836	0.950	0.971	0.905
2004	1.047	1.039	1.008	1.000	1.003	1.005
2005	1.113	1.255	0.886	0.978	0.995	0.911
2006	1.097	1.141	0.962	1.018	1.003	0.942
2007	1.100	1.259	0.874	0.973	0.989	0.908
2008	1.096	1.175	0.933	0.983	0.992	0.957
2009	1.116	1.284	0.869	0.936	0.990	0.939
2010	1.277	1.439	0.887	0.997	0.989	0.900

2011	1.242	1.475	0.842	1.016	0.973	0.852
2012	1.237	1.332	0.929	1.026	0.991	0.914
2013	1.077	1.426	0.755	0.883	1.000	0.854
2014	**1.106**	**1.277**	**0.866**	**0.994**	**0.984**	**0.885**

Notes: The decomposition of efficiency change into technical efficiency change, mix efficiency change and residual scale efficiency change is shown in equation (9).

Source: the authors, based on the French FADN data and using R software.

Appendix 2: TFP changes and components evolution over the period 2002-2014 for the French FADN farms



Notes: The six first panels show the evolutions of changes calculated with respect to the separate (group) frontiers, while the last panel shows the evolutions of changes calculated for all farms with respect to the meta-frontier.

Source: the authors, based on the French FADN data and using R software.

Appendix 3: Average TFP change and components for the French FADN farms in each year over the period 2002-2014, using a meta-frontier

Years	TFP change	Technological change (TC)	Efficiency change (EC)	Technical efficiency change	Mix-efficiency change	Residual scale efficiency change
		All types of farming together				
2002	1.000	1.000	1.000	1.000	1.000	1.000
2003	0.971	0.881	1.103	1.013	0.990	1.099
2004	1.010	0.921	1.097	1.064	1.015	1.016
2005	1.064	0.861	1.235	1.057	1.006	1.162
2006	1.059	1.068	0.992	1.016	1.005	0.971
2007	1.083	1.042	1.039	1.008	1.015	1.015
2008	1.070	0.949	1.127	1.019	1.029	1.075
2009	1.096	1.080	1.015	0.977	1.015	1.023
2010	1.199	1.289	0.930	0.925	1.012	0.994
2011	1.176	1.033	1.139	1.010	1.042	1.082
2012	1.173	1.080	1.086	0.960	1.050	1.078
2013	1.075	1.063	1.012	0.942	1.033	1.039
2014	**1.130**	**0.996**	**1.134**	**1.020**	**1.039**	**1.070**

Notes: The decomposition of efficiency change into technical efficiency change, mix efficiency change and residual scale efficiency change is shown in equation (18).

Source: the authors, based on the French FADN data and using R software.