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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 technical 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 indicate that during 2002-2014, all farms experienced a TFP progress. Pig and/or poultry farms had the lowest TFP increase, while beef farms had the highest (19.1%). The latter farms had the strongest increase in technical efficiency, while technological progress was the highest for mixed farms. The meta-frontier analysis shows that field crop farms' technology is the most productive of all types of farming.

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

JEL classification: D24, O47, Q10

Changement de productivité et d'efficacité technique, et changement technologique de l'agriculture française sur la période 2002-2014 : Une décomposition de l'indice de Färe-Primont

Résumé

L'objectif de cet article est d'évaluer le changement dans la productivité totale des facteurs de production de l'agriculture française pendant la période 2002-2014. Le changement de productivité est décomposé en changement technologique et en changement dans le niveau d'efficacité technique. A cet effet, nous utilisons l'indice de Färe-Primont qui est un indice multiplicativement complet et transitif. Cette dernière propriété permet d'utiliser cet indice pour des comparaisons multi-temporelles et multilatérales. A des fins de comparaison entre six secteurs de productions, nous élargissons l'indice de Färe-Primont au cadre de la méta-frontière. Les résultats indiquent un gain de productivité pour toutes les exploitations sur la période (2002-2014). Toutefois, les exploitations de granivores ont enregistré la plus faible progression de ladite productivité et les exploitations de bovins allaitants la plus forte (19.1%). De plus, pour ces derniers les gains d'efficacité technique sont les plus élevés. Quant au progrès technologique, il est le plus élevé pour les exploitations mixtes. L'analyse par la méta-frontière montre par ailleurs que les exploitations de grandes cultures ont la technologie la plus productive parmi tous les secteurs de production.

Mots-clés : Productivité totale des facteurs, indice de Färe-Primont, méta-frontière, exploitations agricoles françaises

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1. Introduction

Productivity change is a crucial aspect of structural change. During the past 35 years (from 1980 to 2014), agricultural production in France has increased in volume by nearly 25 percent thanks to crop production (source: Annual national accounts, Insee.fr). Still, this growth has not been sufficient to stop 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 was 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 and to increases in labour productivity. The latter has increased from index 100 in 1980 to 306 in 2013, and the average farm area per worker has consequently risen by nearly threefold, with farms becoming larger and more specialised. 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 had an effect on total factor productivity (TFP). In other words, has productivity improved in French agriculture, and what was the contribution of technical efficiency and technological change to the change in productivity?

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 results for the cereal, oilseeds, and proteinseeds farms point to a TFP progress of 4.6% and a technological progress of 3.9%. A lack of TFP increase is also shown by Boussemart *et al.* (2012). Authors indicate that TFP in French agriculture has grown at an annual rate of 1.44% during 1959-2011, but the annual rate was lower than 1% (namely 0.94%) during 2003-2011, a discrepancy that 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 for 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 per se but using a stochastic frontier including time, Latruffe *et al.* (2017) indicate that French dairy farms experienced technological regress during 1990-2007. The picture is therefore gloomy for French agriculture in recent periods. By contrast, in earlier periods, the picture was more optimistic. Bureau *et al*. (1995) find a productivity increase in the French agriculture during 1973-1989, as do Coelli and Rao (2005) for 1980-2000. In the latter study, the 2% increase in TFP was found to be driven mainly by technological change. Similarly, 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 used the classic Malmquist index to measure 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 indices, which use price information for the computation of quantity and price indices (Färe *et al.*, 2008), are multiplicatively complete (O'Donnell, 2008; O'Donnell, 2010). Yet, these indices 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) and Caves *et al.* (1982b), grounded on the early ideas of Malmquist (1953), the Malmquist index has been largely used in many fields (Färe *et al.*, 1998) for productivity growth assessment and its decomposition into technological change (which is due to a frontier shift over time), and technical efficiency change (Färe *et al.*, 1994a; Färe *et al.*, 1994b). The wide popularity of the Malmquist index is related to its simplicity in

[1] Exceptions can be found in Boussemart *et al.* (2012) and Barath and Ferto (2014), who used the Bennet indicator and, respectively, 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). Among the price-based indices, the Lowe index is multiplicatively complete and verifies the transitivity test.

computation without requiring price information or functional form assumptions. Many applications of the Malmquist index to the agricultural sector 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; 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.[4] 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 between an aggregate output index and an aggregate input index (O'Donnell, 2012a; O'Donnell, 2012b; O'Donnell, 2014). [5] In addition to these issues, O'Donnell (2011) also argues that the Malmquist index ignores changes in the input/output mix.[6] 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, 2014). As such, the Färe-Primont index can be used for multi-lateral and multi-temporal comparisons. 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) applied it to the Australian agriculture; Rahman and Salim (2013), Baležentis (2015) used the Färe-Primont index to assess the productivity of agriculture in Bangladesh and Lithuania; and Baráth and Fertő (2016) considered a sample of European countries and employed macro-level data.

The objective of this paper is to apply the more rigorous Färe-Primont TFP index for the first time to French micro-economic farm data. Using data for farms that are representative of French agriculture, we aim at (i) assessing whether the above-mentioned TFP decrease found by earlier studies is confirmed during 2002-2014, (ii) shedding light on the sources of TFP change, namely technological change and technical efficiency change, with a further decomposition into

[4] For more discussion on this property and the Malmquist index one can refer to Førsund (2002).

5 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).

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

technical, mix, scale, and residual efficiency changes; and (iii) extending the Färe-Primont index to the meta-frontier framework. The period of 13 years covered here allows capturing the 2006 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), suggesting subsequent technological progress and productivity increases.

Several types of farming (i.e. main farm specialisations) are considered here: field crop farms; dairy farms; beef cattle farms; pig and/or poultry farms; mixed crop and livestock farms; and sheep and/or goat farms. TFP is firstly assessed for each type of farming, *i.e.* with respect to their own frontier. Secondly, TFP is assessed with respect to a common frontier, namely a meta-frontier (Battese *et al.*, 2004; O'Donnell *et al.*, 2008). Comparing the two sets of results enables computing technology gap ratios that can reveal 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 $n = 1, \dots, N$ producers and $t = 1, \dots, T$ 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:

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

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

$$\begin{gathered} D_t^I(x, y) = \operatorname*{Sup}_{\theta}\left[\theta > 0 \mid \left(\frac{x}{\theta}, y\right) \in \Psi_t\right] \\ D_t^O(x, y) = \operatorname*{Inf}_{\phi}\left[\phi > 0 \mid \left(x, \frac{y}{\phi}\right) \in \Psi_t\right] \end{gathered} \tag{2}$$

As mentioned above, 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 $X(x^t)$ are 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 and 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 (*i.e.*, technical efficiency is 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) 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.

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

- 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 relaxing 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) as the ratio between observed productivity and maximum productivity (O’Donnell, 2010):

$$
\begin{aligned}
TFPE_t &= \frac{TFP_t}{TFP_t^*} \\
TFPE_t &= OTE_t \times OME_t \times ROSE_t \\
TFPE_t &= OTE_t \times OSE_t \times RME_t \\
TFPE_t &= ITE_t \times IME_t \times RISE_t \\
TFPE_t &= ITE_t \times ISE_t \times RME_t
\end{aligned}
\qquad (6)
$$

To account for both input and output orientations, we propose to measure the components of TFPE as geometric means of input and output orientations (O'Donnell, 2008 pp. 18-19):

$$
\begin{aligned}
TFPE_t &= (OTE_t \times ITE_t)^{\frac{1}{2}} \times (OME_t \times IME_t)^{\frac{1}{2}} \times (ROSE_t \times RISE_t)^{\frac{1}{2}} \\
TFPE_t &= (OTE_t \times ITE_t)^{\frac{1}{2}} \times (OSE_t \times ISE_t)^{\frac{1}{2}} \times RME_t
\end{aligned}
\qquad (7)
$$

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

$$FPP_{t,t+1} = \frac{TFP_{t+1}}{TFP_t} = \frac{TFPE_{t+1}}{TFPE_t} \times \frac{TFP^*_{t+1}}{TFP^*_t} \tag{8}$$

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 to all observations in a particular year. 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:

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

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 a single output is considered, then $\frac{OME_{t+1}}{OME_t} = 1$.

Efficiency change can also be decomposed as follows:

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

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 section 3, we report the decomposition of efficiency change into the three ratios of equation (10). The decomposition expressed by equation (9) is shown in **Appendix 1**.

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 groups' 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 is a fundamental assumption of the meta-frontier construction. Let $s = 1, \dots, S$ represent the different available technologies. The meta-technology in time t can be written as:

$$\mathrm{M}_t = \Psi_t^1 \cup \Psi_t^2 \cup \dots . \cup \Psi_t^S \tag{11}$$

where Ψ_t^s is the benchmark technology of each group s defined as follows:

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

Thereby, we have:

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

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]

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

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, obtained 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:

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

$$TGR_t^s = \frac{TFP_t^{*s}}{MTFP_t^*} \tag{15}$$

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:

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

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

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

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:

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

or as

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

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

In the management literature, the Herfindahl-Hirschman index (HHI) is a commonly used measure of market concentration (Kwoka Jr, 1985). For a specific industry, it compares the level of competition among firms relative to monopoly (HHI=1) and perfect competition (HHI=0). In competition analysis, the HHI is computed as the sum of squares of market shares of all firms in the industry (in terms of total assets). Applied in other contexts, the HHI can be used as a diversity index. Here we use it to analyse the heterogeneity, in terms of TFP, of the different farm types, and, more precisely, how this heterogeneity evolves over time. We use a normalised version of the HHI, in addition to the classic version. The normalised version is computed as follows:

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

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 considered sample.

The HHI ranges from ${}^{1}/_{N}$ to 1 (or ${}^{100}/_{N}$ to $10{,}000$ if one uses percentages). 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^* ranges between 0 and 1, and the lower this index, the greater the heterogeneity in the sample. The difference between expressions in equation (20) (normalized HHI) and in equation (21) (classic HHI) is that the normalised index controls for the sample size and, therefore, is more suitable for distribution comparison.

3. Data

We use farm-level data from the French Farm Accountancy Data Network (FADN) database, managed by the Ministry of Agriculture. This database includes yearly accountancy data (along with some technical and economic information) for around 7,000 representative commercial farms in France. As the FADN annual rotating rate is about 10%, we have an unbalanced panel data sample for the analysed 2002-2014 period. The data are collected using a stratification based on the region where the farms are located, their economic size, and the type of farming. The types of farming are defined in terms of the share of different productions in farms' total standard output.[9] If, for instance, the standard output from dairy of a given farm accounts for more than two-thirds of the farm's total standard output, then this farm is classified as specialised in dairy. Besides, each farm is assigned a specific weight that captures the farm's representativeness.

[9] The total standard output is the monetary value (in euro) of total agricultural outputs at farm-gate prices.

Six types of farming are considered here: field crop farms; dairy farms; beef cattle farms; sheep and/or goat farms; pig and/or 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, namely AWU), intermediate consumption (in constant Euros), and capital (in constant Euros). For comparison purpose, in particular in the case of the meta-frontier, only one output is used: the value of the farm total output (in constant Euros).

We restricted the sample to observations with strictly positive values for all input and output variables and for which the value of capital is above one thousand Euros. Visual descriptions of farms' characteristics have primarily been used to detect some potential outliers and aberrant data. Output super-efficiency estimations were conducted (Andersen and Petersen, 1993) to detect further 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 these cases, we used the correction procedure described in Lee *et al.* (2011).

All analyses were performed with R software (R Core Team, 2017). Part of the computations were carried out with the "productivity" package (Dakpo *et al.*, 2017a).

The descriptive statistics of final sample for 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 specialised in pig and/or poultry production, which have the lowest area of all farm types. Pig and/or 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 and/or poultry farms have the highest output produced on average, namely about 341 thousand Euros, far above the other types of farming: the second highest being mixed farms with about 200 thousand Euros, and the lowest being beef farms with about 80 thousand Euros. The latter farms, nevertheless, use the least labour on average (1.54 AWU). These statistics suggest that different types of farming are the most performing ones, depending on the partial productivity indicators. The meta-frontier analysis, by considering all inputs at the same time, helps assess the most productive type of farming in terms of a global productivity indicator (TFP). We expect to find a large variation in TFP across farm types, due to the substantial heterogeneity that seems to prevail regarding the use of inputs and the production of output across the types of farming (the coefficients of variation are greater than 25%).

Table 1: Descriptive statistics of the French FADN sample used, per type of farming for 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 and/or 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 and/or 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: Computations by the authors based on 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 improvement. Given the unbalanced structure of the used panel, the Färe-Primont change index and its components have been computed using for each variable the geometric mean of all observations in a specific year. For instance, the output technical efficiency in year *t* is the geometric mean of technical efficiencies of all farms in the sample in 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 changes in TFP components, for each year between 2002 and 2014. The indices shown in 2014 reveal the changes during the whole period 2002-2014. These 2014 indices indicate that, for all types of farming, there has been a TFP growth during the whole period, as all average indices are above 1. The smallest growth is recorded for the pig and/or 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 and/or 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 considerable value of 27.7% for mixed farms,[10] and lower values for dairy farms (12.1%) and sheep and/or goat farms (7.2%). By contrast, beef farms, which performed the best in terms of TFP change, experienced a technological regress

[10] This high value cannot be attributed to a change in the combination of inputs and outputs, since the latter is captured by mix efficiency.

(-2.2%), but a strong efficiency progress (+21.8%). For pig and/or 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 moderate compared to field crop farms and dairy farms. For dairy farms, we observe an improvement in both technology and efficiency. This performance is worth noting since technological change frequently goes in the opposite direction to the change in efficiency, 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 here for field crop farms and sheep and/or 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 type of farming have improved their farming practices, enabling the increase of output produced and/or the decrease of input use. All three efficiency components improved also for field crop farms, in similar terms: +3.8%, +6.8%, and +5.4%, for technical efficiency, scale efficiency, and residual mix efficiency change, respectively. Dairy farms progressed in terms of technical efficiency and scale efficiency, sheep and/or goat farms in terms of scale efficiency, and pig and/or poultry farms in terms of scale efficiency, but above 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 and/or goat farms. However, in contrast to **Table 2**, **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 and/or poultry farms, and the strongest decrease in the residual scale component for mixed farms.

Table 2: Average change in TFP and components for 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 and/or 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 and/or 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: Estimated by the authors, based on French FADN data and using R software.

Turning to the annual evolution of TFP and of 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 until 2010. For the latter two types of farms, this increasing trend is very symmetric to technological change. As regard the other types of farms, i.e. beef farms, sheep and/or goat farms and pig and/or poultry farms, the TFP change trends appear to be stable over the whole period. For all farm types, it is clear that efficiency change and technological change were in opposite directions. Another interesting feature is that technical efficiency change presents lower 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 (such as technological change peaks, policy reforms) faced during the period. The smoothest trend of technical efficiency change is for pig and/or poultry farms, which keeps close to 1 during the period, similarly to scale efficiency change.

As for heterogeneity, the HHI and its normalised version for TFP are reported in **Table 3**. The results reveal that, in terms of productivity, the most homogenous farm type is pig and/or poultry (with the highest average HHI) while the most heterogeneous is field crop. In terms of evolutions, as shown on **Figure 1**, the most notable change is observed for pig and/or poultry farms, with a gradual shift from a homogenous situation to larger heterogeneity in TFP over time.

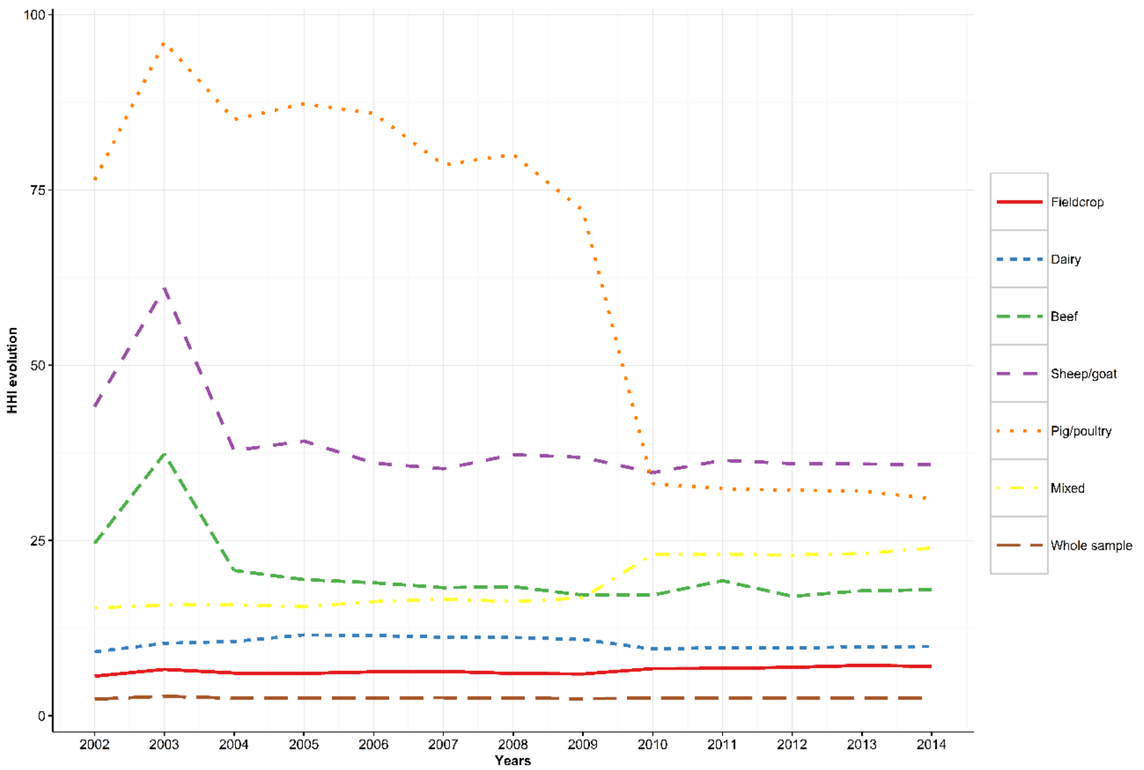
Table 3: HHI and normalised HHI for French FADN farms' TFP in each year over the period 2002-2014

Years	Field crop farms	Dairy farms	Beef farms	Sheep and/or goat farms	Pig and/or 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**

Normalised 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: Estimated by the authors, based on French FADN data and using R software.

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



Source: the authors, based on 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 excluded from our analysis), the agricultural sector experienced a TFP growth of 13% between 2002 and 2014, mostly due to efficiency improvement (+13.4%), while technology has stagnated (technological change index remained close to 1). The evolution of TFP and its different components for all types of farming is illustrated in the last panel of **Appendix 2**. For many farm types, the evolution of TFP shows an increasing trend until 2010 and a fall after this date. The picture also reflects the contrast between the evolution of technological change and of efficiency change.

Table 5 presents the overall TGR and **Table 6** displays the TGRC during the period. The results in **Table 5** reveal that the meta-technology is mostly made of field crop farms, as these farms have the highest TGR on average, suggesting that they have access to a more productive technology than other types of farms. In fact, the overall TGR for field crop farms is almost equal to one, indicating that farms on the meta-frontier are almost exclusively field crop farms. The least productive technology is the one associated to sheep and/or goat farms with a TGR of 0.645%, indicating that these 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 above 28%. They are followed by dairy farms and sheep and/or goat farms, for which the TGR increase is respectively 12.6% and 7.6%. As shown in **Figure 2**, pig and/or poultry farms had a decrease in TGR change in most years.

Table 4: Average change in TFP and components 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: Estimated by the authors, based on French FADN data and using R software.

Table 5: Overall technology gap ratios (TGR) for French FADN farms

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

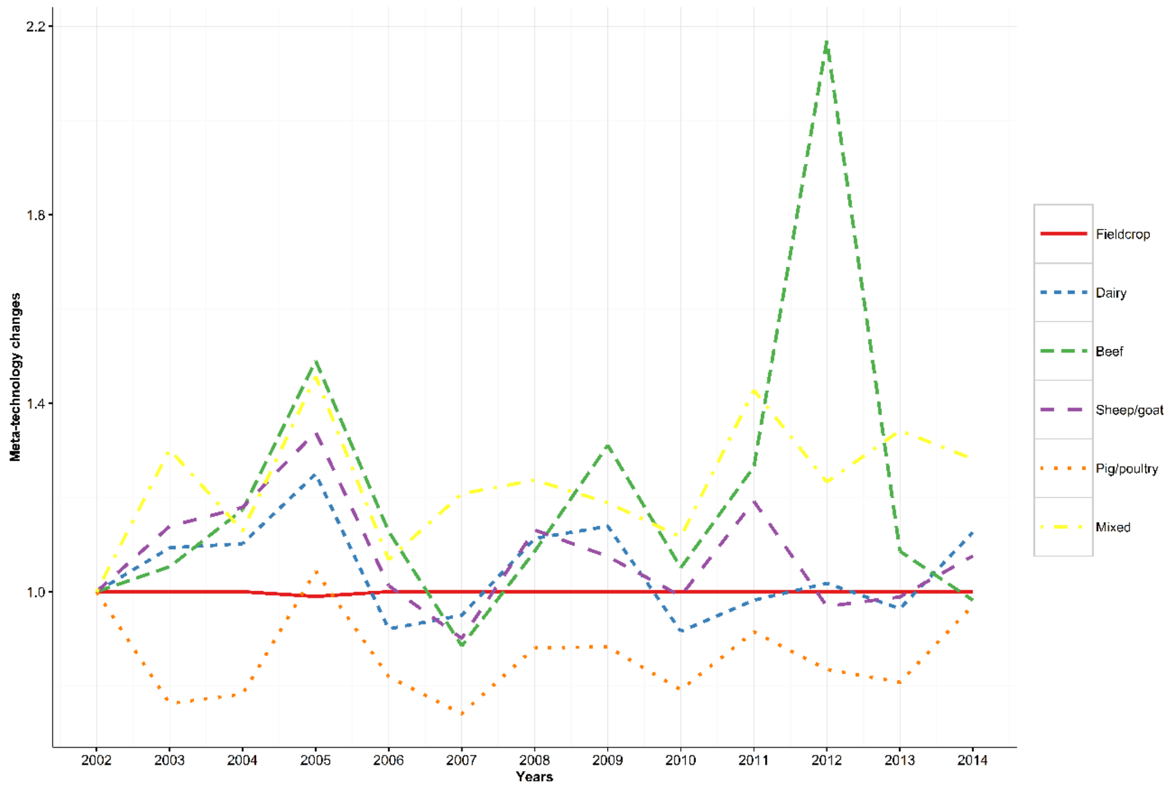
Source: Estimated by the authors, based on French FADN data and using R software.

Table 6: Technology gap ratio changes (TGRC) for French FADN farms in each year over the period 2002-2014

Years	Field crop farms	Dairy farms	Beef farms	Sheep and/or goat farms	Pig and/or 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: Estimated by the authors, based on French FADN data and using R software.

Figure 2: Evolution of the changes in technology gap ratios (TGR) for French FADN farms over the period 2002-2014



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

5. Conclusion

The objective of this article was to assess productivity change in French agriculture during 2002-2014, namely 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 change in technology gap between the six types of farming considered, we extended the Färe-Primont methodology to the meta-frontier framework.

Results indicated that during 2002-2014, all farms had a TFP progress. Pig and/or 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 (21.8%), suggesting that for these farms efficiency improved more than technology. Technological progress was rather concentrated in the 90's due to the introduction of advanced technologies, such as feed distribution equipment. In the 2000's, beef farmers managed to adjust their practices to the new technology and became highly efficient. Pig and/or poultry farms had the lowest change 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 impact depending on the type of subsidies. Latruffe *et al.* (2017) 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 and/or poultry farms was 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 progress was the highest for the whole French agricultural sector (under the meta-frontier) in 2010. When the different types of farming are considered separately, the peak of technological change lies within 2009-2011, while its strongest decline occurred in 2006-2008. This decrease occurred after the CAP reform that saw the introduction of decoupled payments (SFP), although one could have been expected that such payments may increase technological change (through enhancing investment) and, thus, productivity change. By contrast, the economic crisis in the subsequent 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, *i.e.* full time equivalents. Still, one AWU may have a different meaning in crop farming and 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. A further note is that 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. For example, Dakpo *et al.*, 2017b, 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 checks, 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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Appendices

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

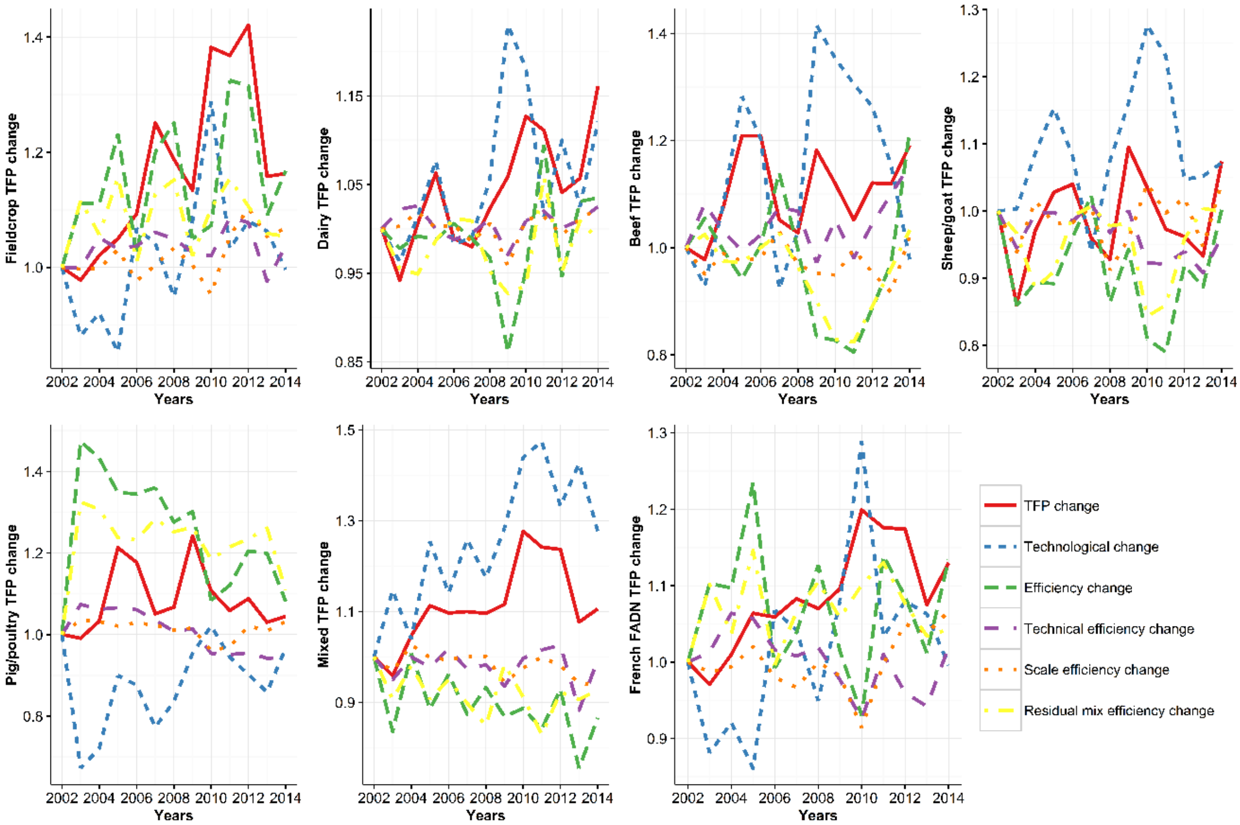
Years	TFP change	Technological change (TC)	Efficiency change (EC)	Technical efficiency change	Mix-efficiency change	Residual scale efficiency change
Field crop farms						
2002	1.000	1.000	1.000	1.000	1.000	1.000
2003	0.978	0.881	1.112	0.999	0.961	1.159
2004	1.021	0.921	1.110	1.052	0.973	1.084
2005	1.050	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 and/or 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 and/or 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: Estimated by the authors, based on French FADN data and using R software.

Appendix 2: Evolution of the change in TFP and components over the period 2002-2014 for French FADN farms



Notes: The six first panels show the evolutions of changes calculated with respect to the separate (group) frontiers, namely for field crop farms, dairy farms, beef cattle farms, sheep and/or goat farms, pig and/or poultry farms and mixed crop and livestock farms; while the last panel shows the evolutions of changes calculated for all farms with respect to the meta-frontier.

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

Appendix 3: Average change in TFP and components for 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 French FADN data and using R software.

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