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# Productivity gains, evolution of productive performances, and profitability of organic ruminant farms: farm size and feed self-sufficiency matter

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**Abstract**

We analyzed the productive and economic performances of a constant sample of 58 organic ruminant farms between 2014 and 2018, in a mountain grassland area (French Massif Central). Over this 5-year period, these farms expanded without increasing their labor productivity or animal density per hectare of forage area. While animal productivity has been maintained, we observed a decrease in feed self-sufficiency, and thus, an increase in feed purchases. Over the period, the volume of inputs used has increased more rapidly than agricultural production, resulting in a decline in the productivity surplus (PS) at a rate of  $-2.6\%$ /year. As the prices of products and inputs were relatively stable, this decrease in PS was financed at 41% by an increase in public aid (drought aid, agri-environmental climate measures) and at 49% by a decrease in profitability for the farmer (the farm income per farmer fell by 40%). A binary choice estimation model, i.e., which variables determine the positive or negative sign of the PS, showed that farm size was a negative determinant of the PS, as was system specialization, while feed self-sufficiency was a positive determinant. More statistically robust references on price indices of organic farming (OF) products and inputs, as well as long-term follow-ups of OF farms, are needed to validate these original results, which were based on a small sample size and a short period of time.

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**Keywords (separated by '-')** Economics - Organic farming - Productivity Surplus - Ruminants - Technical efficiency

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## 2 Productivity gains, evolution of productive performances, 3 and profitability of organic ruminant farms: farm size 4 and feed self-sufficiency matter

5 Patrick Veysset · Edith Kouakou ·  
6 Jean-Joseph Minviel

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results, which were based on a small sample size and 35  
a short period of time. **AQ1**

**Keywords** Economics · Organic farming · 37  
Productivity Surplus · Ruminants · Technical 38  
efficiency 39

### Introduction 40

In 2021, 2.78 million hectares of farmland and 58,400 41  
farms were engaged in organic production in France, 42  
representing respectively 10% and 13% of the French 43  
farmland and farms. The productivity of organic 44  
farming (OF) systems has been questioned, mainly 45  
concerning crop yields per hectare of land (De Ponti 46  
et al., 2012) or animal productivity (Gaudaré et al., 47  
2021) by comparing these yields to those obtained in 48  
conventional farming (Seufert et al., 2012). A number 49  
of studies have looked at the technical efficiency of 50  
organic production systems. They all used frontier 51  
analysis methods by constructing efficiency frontiers 52  
(benchmark or maximum possible production 53  
level from a given combination of inputs) from 54

A1 **Supplementary Information** The online version  
A2 contains supplementary material available at [https://doi.](https://doi.org/10.1007/s13165-023-00422-9)  
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55 national statistical databases of OF farms (Lakner &  
 56 Breustedt, 2017). Most of these studies focused on a  
 57 comparison of organic versus conventional farming;  
 58 very few have investigated the main determinants  
 59 of OF productivity per se (Guesmi et al., 2012;  
 60 Karafillis & Papanagiotou, 2011; Paul et al., 2017).  
 61 Moreover, these few studies concerned field crops  
 62 or fruit crop production and, to our knowledge, the  
 63 papers about the analysis of the organic livestock  
 64 farming productivity are very scarce (Kostlivy &  
 65 Fuksova, 2019; Lakner et al., 2011). The performance  
 66 of organic livestock systems has been studied through  
 67 various multi-performance indicators (Liang et al.,  
 68 2018; Veysset et al., 2013), or through a specific  
 69 indicator such as resilience (Perrin et al., 2020) or  
 70 vulnerability (Bouttes et al., 2018). These studies  
 71 revealed that some characteristics were determinant  
 72 to maintain or improve these performances, mainly  
 73 feed self-sufficiency (Escribano, 2018; Faux et al.,  
 74 2022), crop-livestock integration (Liang et al., 2018),  
 75 or diversification as multi-specie livestock farming  
 76 (Martin et al., 2020). The evolution over time of the  
 77 efficiency and profitability of OF systems is a rare  
 78 topic in the scientific literature. Such studies require  
 79 a relatively constant panel of farms over time, or  
 80 statistically representative samples (Veysset et al.,  
 81 2015). Lansink et al. (2002) conducted a diachronic  
 82 study of the efficiency and productivity of Finnish OF  
 83 livestock farms over 4 years (1994–1997) using data  
 84 from the Farm Accountancy Data Network (FADN-  
 85 Finland). Over the 4 years of the study, the number of  
 86 farms in OF is not constant, as some farms converted  
 87 during these years, and the average number of farms  
 88 per year, 41, was relatively low; moreover, these farms  
 89 were classified as livestock farms without further  
 90 specification of the type of livestock: monogastric,  
 91 small ruminants, cattle, milk, or meat production. All  
 92 observations (farm years) were grouped into a single  
 93 sample. Lansink et al. (2002) concluded that OF  
 94 farms are more technology efficient than conventional  
 95 farms. None of these studies analyzed possible  
 96 productivity gains made by OF farms over time, nor  
 97 price changes and thus shares of productivity gains  
 98 (Veysset et al., 2019).

99 French Massif Central is one of France's largest  
 100 livestock production areas, with 85% of its territory  
 101 devoted to raising grazing livestock, including 38%  
 102 of beef cattle, 20% of dairy cattle, and 16% of sheep/  
 103 goat farms. The Massif Central concentrates 30% of

French ruminant livestock certified in organic farming  
 (OF). The objective of this work was threefold:  
 (1) to carry out an overall medium-term (5-year)  
 technical-economic analysis of OF ruminant farms  
 in the Massif Central, (2) to evaluate the productiv-  
 ity gains of these farms over the period, their forma-  
 tion and distribution, and (3) to evaluate the deter-  
 minants of productivity gains of these farms. After  
 presenting the network of farms and the technico-  
 economic database used, we explained the meth-  
 odological choices adopted. We then presented the  
 changes over the period in the main average char-  
 acteristics of the farms, as well as the productivity  
 surplus, its determinants, and the economic surplus  
 account. Finally, we discussed the changes observed  
 on these farms, before concluding on the conditions  
 for maintaining the technical efficiency of organic  
 livestock farms.

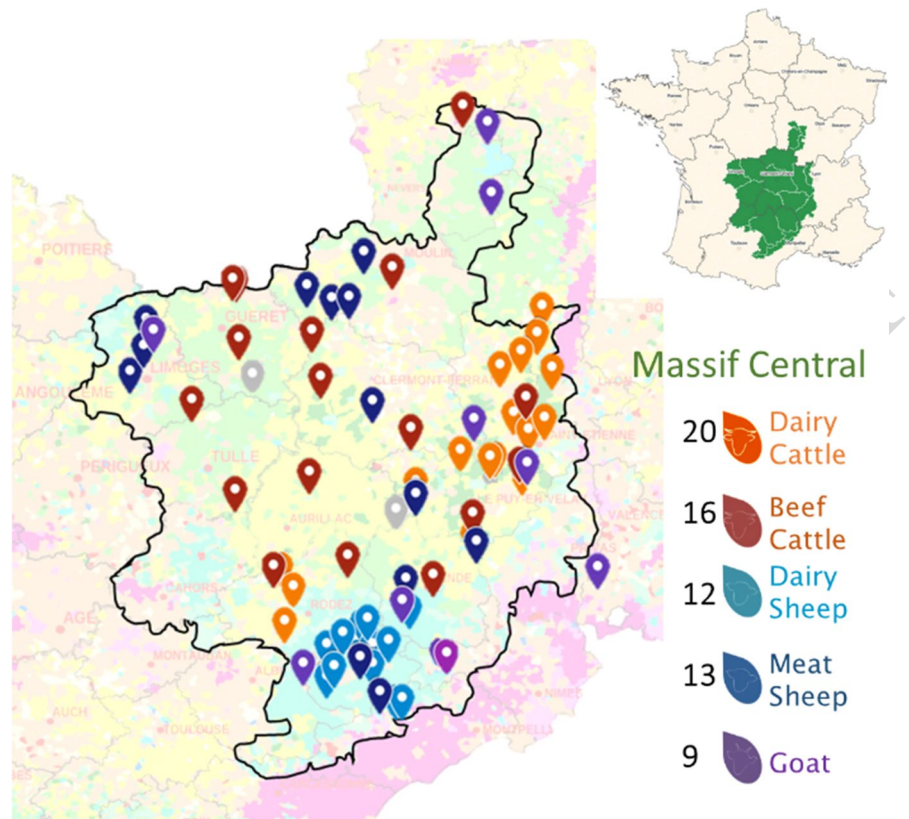
## Materials and methods

### The farm network and the database

The project's support farms are spread throughout the  
 Massif Central (Fig. 1) and include the three ruminant  
 species (cattle, sheep, and goats) and the two main  
 productions (milk and meat) of this mid-mountain  
 territory. The criteria for choosing farms respect the  
 desire of local stakeholders to have data from special-  
 ized farms that meet regional challenges in order to  
 produce references in OF (i) cow-calf-fattener suckler  
 cattle systems, (ii) dairy cattle systems with at least  
 6000 L of milk per cow per year, (iii) dairy sheep  
 systems with various production periods to meet the  
 needs of the downstream market, (iv) meat sheep sys-  
 tems in search of feed self-sufficiency, in particular  
 by using grass for lamb finishing, (v) finally, in dairy  
 goat production, there are no references on the scale  
 of the Massif Central on OF systems delivering milk  
 and making cheese on the farm, these two systems are  
 therefore present in the network set up. The farms in  
 the network have all been certified organic for at least  
 5 years at the start of the project (50% have been cer-  
 tified for more than 10 years).

Annually, 70 farms were monitored according to  
 the INOSYS-Réseaux d'Élevage methodology (Insti-  
 tut de l'Élevage and Chambres d'Agriculture, 2014)  
 in order to analyze their functioning. Structural data

**Fig. 1** Location of the 58 constant sample farms of the BioReference livestock farms network



149 (production means), technical data (global function-  
 150 ing of the herd and surfaces), zootechnical, and eco-  
 151 nomic data were recorded in the Diapason database  
 152 (Charroin et al. 2005) for each year from 2014 to  
 153 2018. Among these farms, we were able to build a  
 154 constant sample over the period of 58 farms: 16 dairy  
 155 cattle (DC), 13 beef cattle (BC), 11 dairy sheep (DS),  
 156 10 meat sheep (MS), and 8 goats (G). Our study  
 157 focused on this constant sample.

158 Descriptive analysis and evolutions of farm  
 159 characteristics

160 In order to characterize the sample, we performed an  
 161 analysis of the means of the variables:

162 • Structural: number of workers expressed in annual  
 163 work units (1 AWU = 1 full-time worker on the  
 164 farm), size of the farm in hectares (ha) of usable  
 165 agricultural area (UAA), annual crop area, grass  
 166 area, and herd size in number of livestock units (LU).

- Technical: animal productivity, consumption of  
 167 concentrates per LU, feed self-sufficiency. Some  
 168 technical variables, such as animal productivity,  
 169 depend on the type of production and are therefore  
 170 not common to all farms (litres of milk per cow,  
 171 ewe, or goat for dairy systems, kg of live-weight  
 172 produced per LU or ewe for suckler systems).  
 173 These variables were expressed for each farm in  
 174 base 100 with respect to the year 2014.  
 175
- Economics: gross farm product (animal products,  
 176 plant products, other products, and total aid),  
 177 intermediate consumption, depreciation, finan-  
 178 cial costs, labor costs, gross farm surplus, value  
 179 added, and farm income. All economic values  
 180 were expressed in constant 2018 Euros (Consumer  
 181 Price Index deflator, IPC given by the French  
 182 National Institute of Statistics and Economic Stud-  
 183 ies, INSEE).  
 184

In 2014, the 58 farms in the study sample operated  
 185 an average UAA of 89.9 ha ( $\pm$  46.5) with a work  
 186 collective of 2.08 AWU ( $\pm$  1.16) of which 0.34 ( $\pm$   
 187



0.84) AWU were salaried. The main forage area (MFA) occupied 87.8% of the UAA, with grassland (permanent and temporary meadows) constituting 99% of this MFA. Herds averaged 76.3 LU ( $\pm$  39.9). The average annual stocking rate (number of LU per ha of MFA) was 1.01 ( $\pm$  0.29). The 2014 animal productivity was 6400 ( $\pm$  690) L of milk per dairy cow, 281 ( $\pm$  42) kg live-weight per beef cattle LU, 246 ( $\pm$  31) L of milk per dairy ewe, 116 ( $\pm$  27) lamb per meat ewe, and 552 ( $\pm$  142) L of milk per goat. The consumption of concentrates per LU was 744 ( $\pm$  452) kg and the feed self-sufficiency of the herds (the proportion of the animals' energy needs covered by the resources of the farms) was 87.1% ( $\pm$  9). The gross farm product (GFP) per ha UAA and per AWU was respectively €2406 ( $\pm$  1071) and €97,940 ( $\pm$  35,535), the total subsidies represented 28.5% ( $\pm$  11.5) of this product. Total variable costs and fixed amounted to 26.6% ( $\pm$  8.7) and 50.1% ( $\pm$  10.7) of the GFP respectively. The value added (VA), the earnings before interest, taxes, depreciation and amortization (EBITDA), and the net farm income per ha UAA were respectively €813 ( $\pm$  286), €967 ( $\pm$  433), and €540 ( $\pm$  332). The economic efficiency of the farms, assessed by the ratio EBITDA/GFP was 41.0% ( $\pm$  9.3). Last, the net farm income per unit of family work was €27,462 ( $\pm$  21,244).

#### 215 Generation and distribution of productivity gains: 216 productivity surplus and surplus account

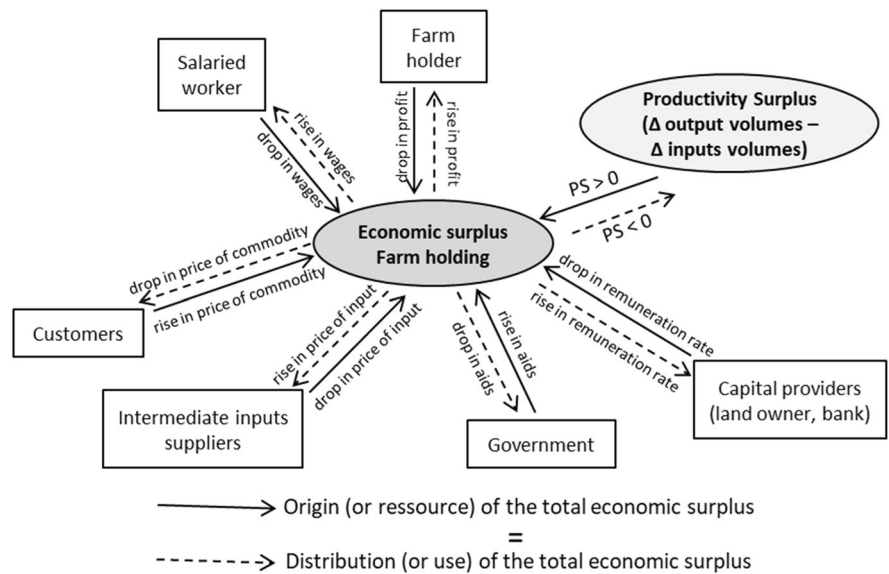
217 Between 2 years, productivity gains measure changes  
218 in the volume of production, net of changes in the  
219 volumes of factors of production (intermediate con-  
220 sumption, capital, land, labor) and make it possible  
221 to analyze the relative competitiveness of firms (Ball  
222 et al., 2010). The productivity surplus (PS) produced  
223 between two fiscal years is estimated by the respec-  
224 tive variations in the volumes of products and factors  
225 of production used between these two fiscal years.  
226 According to the hypothesis of product depletion in  
227 factor remuneration (the value of the various prod-  
228 ucts of a firm completely covers the value of all the  
229 factors of production used), we can show that there  
230 is equality between the evolution of the PS of a firm  
231 and the evolution of the prices of the various products  
232 and inputs, called price advantages (PA). It is then  
233 possible to determine by the surplus account method  
234 (Boussemart et al., 2012) who are the economic

agents that are direct partners of the farm (custom- 235  
ers, suppliers, capital providers, workers, managers, 236  
the State) that benefit from these productivity gains. 237  
The PS will be positive when, between two periods, 238  
the volumes of products increase faster than those of 239  
inputs, conversely it will be negative. An increase in 240  
the price of an input is considered a price advantage 241  
for its supplier (its remuneration increases), and a 242  
decrease in the price of a product is considered a price 243  
advantage for the customer (the price of the product is 244  
lower). We can construct a balanced economic surplus 245  
account (Fig. 2) between the resource of this surplus 246  
(or origin) and its distribution (or use). This method 247  
requires decomposing the variation in the value of all 248  
the farm's products and expenses between 2 years into 249  
a variation in price and a variation in volume. 250

We calculated the PS and applied the surplus account 251  
method to individual data from the 58 farms in our farm 252  
network. Changes in volume, price, PS, and PA were 253  
calculated each year  $t + 1$  by difference with year  $t$  for 254  
each farm, making four results per farm between 2014 255  
and 2018. An average of the annual PS and PA results 256  
was performed, and then we added these four averages 257  
to obtain the cumulative of productivity surplus and 258  
price advantages and thus achieve the balanced surplus 259  
account over the period considered (Veysset et al., 2019). 260

For all the farms, we had the volumes and real unit 261  
prices of the main products (cow, sheep, and goat 262  
milk; kg of sheep and beef meat) as well as the cere- 263  
als or other crops sold. Concerning the factors of pro- 264  
duction, we also had the volumes and unit prices of 265  
a certain number of expenses of the farm: purchased 266  
feed, salaried and family labor, rented land, and finan- 267  
cial expenses. For the other products and inputs for 268  
which we only had the economic value, the volume- 269  
price decomposition can be carried out using the price 270  
indices provided by INSEE: the IPPAP (indices of 271  
producer prices of agricultural products) and the IPP- 272  
MAP (indices of purchase prices of the means of agri- 273  
cultural production). By deflating the annual values of 274  
these products and inputs by their respective indices, 275  
the changes in the value obtained between 2 years cor- 276  
respond to changes in volume, and the change in the 277  
price index of an item corresponds to its price change. 278  
These indices reflect the evolution of prices observed 279  
on a national scale, they concern the evolution of the 280  
price of products and inputs of conventional agricul- 281  
ture, but cannot be used as such for certain products 282  
or inputs of OF that are not on the same markets and 283

**Fig. 2** Balanced economic surplus account. Distribution of the productivity gains and price advantages between the different economic agents that are direct partners of the farm



284 therefore do not follow the same evolution of their  
 285 respective prices (for example, meat by-products of  
 286 dairy farms, mineral feed additives, straw, soil improv-  
 287 ers, seeds, and crop protection products). For these  
 288 organic products and inputs, we had constructed our  
 289 own indices based on the prices available in some of  
 290 the network farms, by consulting the project’s field  
 291 experts and the reference systems produced within the  
 292 framework of the BioReference project.

293 Since subsidies were an important contributor to  
 294 the gross product of livestock farms, we had assumed  
 295 that they did not have a (variation in) volume, so the  
 296 variation in total value observed corresponded to the  
 297 variation in the price of subsidies.

298 We thus made our calculations based on 14 products  
 299 divided into 7 groups (including the subsidies) and 17  
 300 inputs grouped into 6 groups (including the manager)  
 301 (Table 1). The sum of the aids and gross products for  
 302 which we knew exactly the volumes and prices for each  
 303 farm, represented between 90 and 95% of the gross  
 304 operating product. The total expenses related to inputs  
 305 for which we have volumes and prices represent 30 to  
 306 35% of the total costs of the 58 farms in our sample.

307 Estimating the determinants of the productivity  
 308 surplus

309 We sought to explain the direction of change in the  
 310 PS between two consecutive years (variable to be  
 311 explained) by a set of variables (explanatory variables)

that were not included in its calculation: variables of  
 structure, practices, or operation of farms. To do so,  
 we used a binary-choice econometric model in which  
 the PS was transformed into a binary variable: value 0  
 when the PS was negative (loss of factor productivity),  
 value 1 when it was positive (productivity gain). From  
 a practical standpoint, the dichotomization of the PS  
 allows us to examine factors related to the probabili-  
 ty of obtaining positive productivity gains in order to  
 find levers to promote organic farming<sup>1</sup>.

The selected explanatory variables and their defini-  
 tions are presented in Table 2. The size of the farms  
 (economies of scale) was characterized by the utilized  
 agricultural area (UAA) expressed in hectares (ha).  
 We could have expressed the size of the farm by the  
 size of the herd (number of total LU), but these farms  
 being specialized in animal productions; the agricul-  
 tural surface and the size of the herds are strongly cor-  
 related ( $r^2 = 0.88$ ). Labor, in particular the use of hired  
 labor or service providers, is a determinant of technical  
 efficiency (Latruffe, 2010), which we characterized by  
 the share of salaried labor in the total workforce. Feed  
 self-sufficiency of farms plays an important role in

<sup>1</sup> Formal presentation of the econometrics model, including equations and additional motivations for the estimated model, were presented in the appendix of the manuscript Supplementary Information (SI A-Estimating the determinants of the productivity surplus: additional motivation for the estimated model).

1FL01  
 1FL02  
 1FL03  
 1FL04  
 1FL05  
 1FL06



**Table 1** Products, expenses, prices, or indices taken into account for the calculation of the productivity surplus and the balanced surplus account, divided into categories representing the various economic agents

AQ3

Economic agents	Products, costs (annual economic value)	Prices or price indices
Downstream meat	Gross meat product of beef cattle	Individual prices
	Gross meat product of dairy cattle	Individual prices
	Gross meat product of meat sheep	Individual prices
	Gross meat product of dairy sheep and goat	Price indices BioRéférences
Downstream milk	Gross milk product of dairy cattle	Individual prices
	Gross milk product of dairy sheep	Individual prices
	Gross milk product of goat	Individual prices
Downstream other herbivores	Gross product of other herbivores unit	IPPAP <sup>1</sup> equine
Downstream other animals	Gross product of monogastrics	Price indices BioRéférences
Downstream cash crops	Gross product of cereals	Individual prices
	Gross product of protein-oil crops	Individual prices
	Sales of forages and straw	IPPAP forages
Downstream other products	Gross product other activities	IPPAP general indice
Government	Total subsidies	Individual subsidies
Suppliers of intermediate consumption	Fertilisers	IPPMAP <sup>2</sup> organic fertilisers
	Soil improvers	IPPMAP lime, calco-magnesian amendments
	Seeds and planting stock	Price indices BioRéférences
	Concentrates purchased	Individual prices
	Forages and straw purchased	IPPMAP hay, straw, other feeding stuff
	Veterinary and breeding	IPPMAP veterinary expenses
	Fuel and lubricants	IPPMAP fuel and lubricants
	Maintenance of machinery and buildings, other goods and services	IPPMAP small production tools, maintenance of equipment
	Third-party work	IPPMAP overhead expenses
	Water, electricity, other services	
Capital providers	Depreciation—machinery	IPPMAP farm machinery
	Depreciation—buildings	IPPMAP farm buildings
	Depreciation—other	IPPMAP installations
	Financial expenses	Interest paid/debts, individual
Landowners	Land rent	Rent paid/ha UAA under tenancy, individual
Salaried workers	Employee-related expenses	Wages paid/salaried worker, individual
Social security	Farmers' social contributions	Social contribution paid/family worker, individual
Farmer, manager	Profit	$(\sum \text{output} - \sum \text{input})/\text{family worker, individual}$

<sup>1</sup>IPPAP: indices of producer prices of agricultural products<sup>2</sup>IPPMAP: indices of purchase prices of the means of agricultural production

335 their economic efficiency (Lebacq et al., 2015; Lherm  
336 & Benoit, 2003) and was characterized by feed self-  
337 sufficiency (share of concentrates and conserved fod-  
338 der produced on the farm out of the total concentrates  
339 and conserved fodder used). Straw self-sufficiency also  
340 reflects a certain degree of autonomy, but it also char-  
341 acterized a practice of connecting cereal and livestock

production, a source of agronomic efficiency (Sekaran 342  
et al., 2021). Crop-livestock integration was also char- 343  
acterized by the share of forage and non-fodder (poten- 344  
tially saleable) crops in the total UAA, dedicated to 345  
animal feed. The productive diversity (or specializa- 346  
tion) of farms was characterized by their degree of 347  
specialization (share of gross product excluding aid of 348

**Table 2** List, definition, and qualification of explanatory variables used in the semiparametric estimation model (SNP) of the sign of the productivity surplus (PS)

Variable name	Definitions	Qualification
UAA	Usable agriculture are, hectare (ha)	Size of the farm
S_AWUs	Share of the number of salaried workers (AWUs) on the number of total workers (AWUt)	Technical efficiency
Feed_self-suff	Feed self-sufficiency (%), T. feed produced on the farm / T. total feed consumption	Feed self-sufficiency
Straw_self-suff	Straw self-sufficiency (%), T. straw produced on the farm / T. total straw consumption	Crop-livestock integration
A_feed	Share of agricultural area used to produce animal feed (%)	
Spe	Level of specialisation, share of gross product excluding aids of the main unit on the total gross product excluding aids (%)	Farm and crop specialisation/diversification
Shannon	Crop diversity expressed by the Shannon index	
Aid	Total aid received per ha of UAA	Aids from government
Type of production	4 binary variables DC (1 if dairy cattle; 0 if no), BC (1 if beef cattle; 0 if no), DS (1 if dairy sheep; 0 if no), MS (1 if meat sheep; 0 if no)	Control variable

349 the main unit in the gross product excluding aid of the  
 350 farm), the diversity of resources and plant production  
 351 by the Shannon index characterizing the number and  
 352 relative share of the different plant cover (permanent  
 353 grasslands, temporary grasslands, forage corn, cereals,  
 354 other crops) in the UAA. Public aids received by farm-  
 355 ers can influence their production decisions (Minviel &  
 356 Latruffe, 2017); aids were taken into account via their  
 357 total amount received per hectare of UAA. Finally, in  
 358 order to determine whether the type of production (cat-  
 359 tle, sheep, goat, milk, or meat) influenced the sign of  
 360 the PS, four binary control variables are introduced  
 361 in the model (BC, DC, MS, DS), with goat produc-  
 362 tion (G) as the reference. The correlation coefficients  
 363 between these variables were relatively small, suggest-  
 364 ing that multicollinearity issues can be safely ignored  
 365 in our regressions (SI A, Table SII).

366 Our database counted 290 farm years (58 farms \*  
 367 5 years). This model was used with 232 farm years,  
 368 2014 being the base year for the PS calculation, the  
 369 latter is therefore equal to 0 and its first sign of evo-  
 370 lution appeared in 2015.

## 371 Results

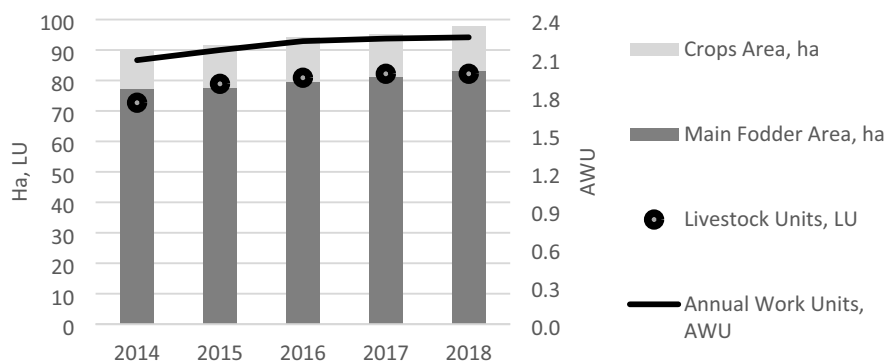
### 372 Farm characteristics changes over 5 years (2014–2018)

373 Between 2014 and 2018, farms expanded by 8.7%,  
 374 8.5%, and 7.8% in UAA, workforce, and herd size,  
 375 respectively (Fig. 3). Crop rotation (share of UAA,

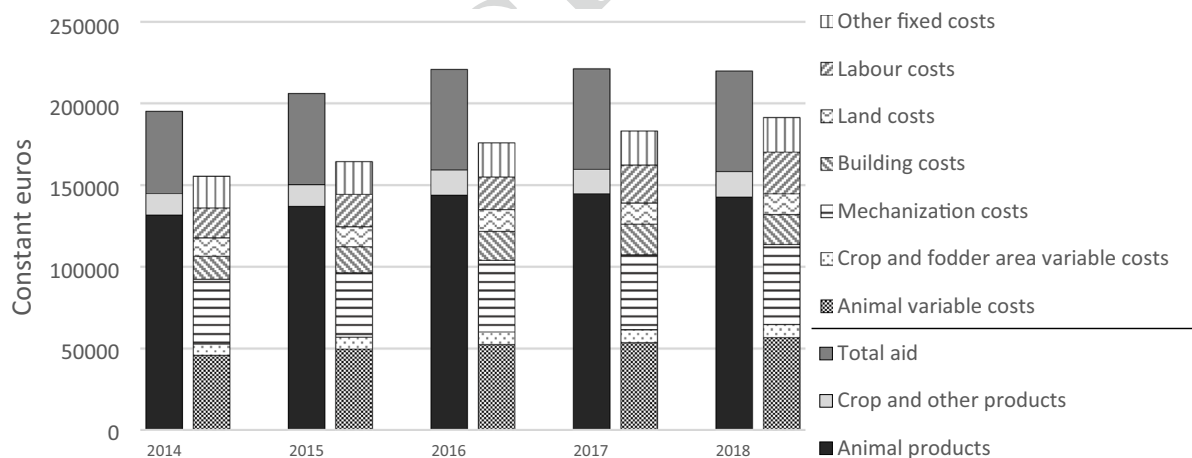
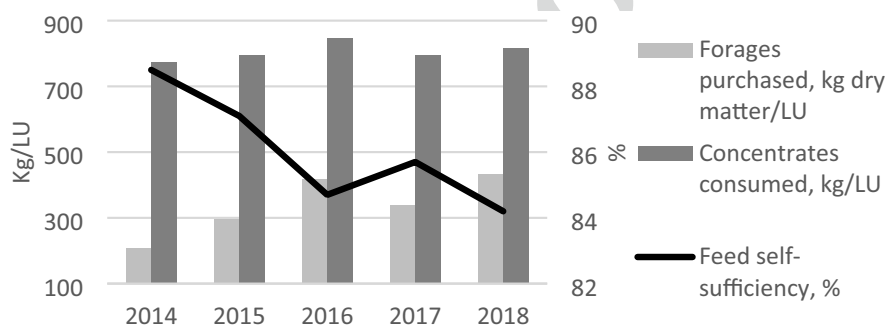
grass, and annual crops in UAA) remained stable  
 overall, as did physical labor productivity (number of  
 ha of UAA or LU per AWU), and stocking rate (num-  
 ber of LU per ha of MFA).

The average animal productivity (kg of milk  
 produced per female dairy per year, or kg of live-  
 weight produced per LU for meat herds) for the  
 entire sample remained stable with a very slight  
 downward trend (−1.28%). The stability of the  
 stocking rate over the period showed that the for-  
 age area offered per animal remained stable, so  
 any variation in forage supply was related to vari-  
 ations in the yield of this forage area. The years  
 2016 and 2018 were marked by a rainy spring  
 (which disrupted the hay harvest) and a dry sum-  
 mer and fall, which limited grazing and fall grass  
 regrowth, of varying severity depending on the  
 geographical area. Forage purchases tended to  
 increase (Fig. 4), with two peaks in 2016 and  
 2018 (respectively 420 and 430 kg of dry matter  
 of forage purchased per livestock unit (LU) for a  
 five-year average of 340 kg/ LU). The quantities  
 of concentrates distributed per LU also tended to  
 increase, from 775 kg/livestock unit in 2014 to  
 815 kg/livestock unit in 2018 (Fig. 4). Stagnant  
 animal productivity over 5 years, along with an  
 increase in the purchase of fodder and the con-  
 sumption of concentrates per animal, has resulted  
 in a decrease in the feed self-sufficiency of the  
 herds (the proportion of the animals' energy needs  
 covered by the resources of the farms).

**Fig. 3** Changes in the main average structural characteristics of the 58 BioReferences constant sample farms between 2014 and 2018



**Fig. 4** Evolution of the average quantities of forages purchased per livestock unit (LU), concentrates consumed per LU, and feed self-sufficiency of the 58 BioReferences constant sample farms between 2014 and 2018



**Fig. 5** Changes in product value and expenses, in constant euros, for the 58 farms in the BioReferences constant sample between 2014 and 2018. For each year, the left bar represents the product value's decomposition and the right bar the costs' decomposition

407 Over these 5 years, the average selling price of  
 408 animals and animal products increased very slightly  
 409 (+ 3.8%). Due to the increase in herd size and the  
 410 maintenance of animal productivity, the quantities  
 411 sold increased by 10.1%, resulting in an increase  
 412 in the animal gross output value of 13.3% (Fig. 5).  
 413 In addition to this increase in animal gross output

414 value, there was a 22% increase in total aid due to  
 415 the increase in the size of the farms as well as an  
 416 increase in aid from the 2nd pillar (agri-environ-  
 417 mental measures) of the Common Agricultural Pol-  
 418 icy (CAP) and the allocation of exceptional drought  
 419 aid. The gross farm product increased by €24,626,  
 420 i.e., +12.6% (Fig. 5).

421 Total variable costs increased by €11,913, or  
 422 +22.6% (Fig. 5). This increase is linked almost  
 423 entirely to the increase in animal costs, +€10,786 due  
 424 to the growth in purchases of fodder and concentrates.  
 425 Total fixed costs increased by 23.2% between 2014  
 426 and 2018, or +€23,890 (Fig. 5). The item of fixed  
 427 costs that increased the most in value is mechanization  
 428 (+€9361), mechanization expenses represented 38%  
 429 of fixed costs in 2014, they represent 40% in 2018.

430 Overall, over the 5 years, total expenses have  
 431 increased more rapidly (+€35,803, +23%) than  
 432 gross farm product. The value added (VA), the earn-  
 433 ings before interest, taxes, depreciation and amor-  
 434 tization (EBITDA), and the net farm income have  
 435 decreased respectively by 11.1% (−€6,577), 5.6%  
 436 (−€4,547€), and 25.3% (−€11,231). Per hectare of  
 437 UAA, the gross farm product only increased by €110  
 438 (+4.6%) while total expenses increased by €229  
 439 (+13.2%), resulting in a decrease in VA/ha UAA,  
 440 EBITDA/ha UAA and net farm income/ha UAA of  
 441 18.2% (−€120), 13.1% (−€118), and 31.3% (−€154)  
 442 respectively. The value added (or wealth created) per  
 443 total labor unit loses 21.5%. The net farm income  
 444 per unit of family work unit falls from €27,462 in  
 445 2014 to €17,725 in 2018, or −39.8%.

446 Beyond these averages, there was considerable  
 447 variability within the sample. However, this vari-  
 448 ability remained stable over the years and was much  
 449 higher for structural and economic characteristics  
 450 than for technical ones (Table 3). The coefficient of  
 451 variation (CV) of structural characteristics and eco-  
 452 nomic performance varied from 0.50 to 1.50 and  
 453 more, while that of animal productivity was between  
 454 0.15 and 0.30. Feeding practices were relatively vari-  
 455 able between farms, especially the use of purchased  
 456 fodder (CV between 1.15 and 2.10); however, total  
 457 feed self-sufficiency was not very variable between  
 458 farms and years (CV close to 0.20). The detailed  
 459 technical and economic results for each species  
 460 and production and for each year were published in  
 461 annual reports (Pôle Bio Massif Central, 2022).

#### 462 Changes in productivity gains, productivity surplus

463 The cumulative productivity surplus (or cumulative  
 464 change in factor productivity) between 2014 and  
 465 2018 is negative (−€21,640, Table 4), declining at

a rate of 2.65% per year. For a cumulative increase  
 in the volume of output equivalent to €10,061  
 between 2014 and 2018, the cumulative increase in  
 the volume of intermediate consumption is equiva-  
 lent to €17,155, with purchased feed being the item  
 that has increased the most (+€5,558), followed  
 by mechanization (fuel, equipment maintenance,  
 and third-party work, +€4991). The increase in the  
 need for mechanization and equipment resulted in  
 a cumulative increase in the volume of fixed capi-  
 tal used equivalent to €7427. As the average num-  
 ber of total workers increased, this additional vol-  
 ume of labor corresponds to +€6150. Overall, the  
 change in input volume between 2014 and 2018  
 was greater than the change in output volume. For  
 €1 more input volume, the output volume only  
 increased by €0.32, resulting in a decrease in the  
 overall factor productivity of these 58 OF livestock  
 farms over the 5-year period, 2014–2018.

#### Surplus account: origin and distribution of the cumulative economic surplus

Over the 5 years, the cumulative productivity sur-  
 plus and the absolute value of negative price advan-  
 tages represented, in constant euros and on aver-  
 age per farm, a total economic surplus of €28,636  
 (Table 5). This economic surplus came mainly  
 from the decrease in the remuneration of the farm-  
 ers or profitability of the farms (49%) and from the  
 government (41%) due to the increase in subsidies  
 (Table 5). The need to finance the decline in the  
 productivity surplus (PS < 0) accounted for 75%  
 of the economic surplus generated over the period,  
 while the increase in farmers' social contributions  
 accounted for 13% (Table 4). There was a slight  
 increase in the prices of intermediate consump-  
 tion, land rent, and salaried labor, which took 5%,  
 3%, and 4% respectively of the economic surplus.  
 The prices paid to producers for milk and crops  
 increased very slightly (respectively 3% and 6% of  
 the economic surplus) while those for meat stag-  
 nated. The price advantage obtained for crops was  
 beneficial for the farmers who sell them, and disad-  
 vantaged the purchase of concentrated feed, whose  
 price increase was partly responsible for the price  
 advantage of suppliers of intermediate consumption.

**Table 3** Main structural, technical, and economic characteristics of the 58 BioReferences constant sample farms for each year from 2014 to 2018. Mean values and coefficient of variation (standard deviation / mean)

Variables	2014	2015	2016	2017	2018
<b>Structural characteristics</b>					
Total annual work units (AWUt)	2.08 (0.56)	2.16 (0.53)	2.23 (0.57)	2.25 (0.53)	2.26 (0.52)
Family workers (AWUf)	1.74 (0.45)	1.79 (0.42)	1.84 (0.43)	1.86 (0.43)	1.83 (0.43)
Salaried workers (AWUs)	0.34 (2.45)	0.36 (2.36)	0.39 (2.51)	0.39 (2.10)	0.43 (1.95)
Usable agricultural area (UAA), ha	89.9 (0.52)	91.7 (0.54)	94.4 (0.54)	95.3 (0.53)	97.7 (0.53)
Main fodder area (MFA), ha	77.2 (0.48)	77.8 (0.50)	79.7 (0.50)	81.4 (0.50)	83.2 (0.49)
Including grass area, ha	76.6 (0.85)	76.5 (0.88)	78.8 (0.91)	80.3 (0.90)	82.1 (0.88)
Including maize forage area, ha	0.62 (3.07)	0.8 (2.71)	0.9 (2.48)	1.0 (2.43)	1.1 (2.61)
Crop area, ha	12.7 (1.11)	13.9 (1.09)	14.7 (1.11)	13.9 (1.05)	14.5 (1.13)
Number of livestock units (LU)	76.3 (0.52)	78.9 (0.53)	80.9 (0.54)	82.2 (0.54)	82.2 (0.55)
Stocking rate, LU/ha MFA	1.01 (0.28)	1.05 (0.29)	1.05 (0.28)	1.05 (0.28)	1.02 (0.28)
<b>Technical performances</b>					
Dairy cow productivity, litre milk/cow	6406 (0.11)	6312 (0.15)	6166 (0.16)	6106 (0.15)	6022 (0.16)
Beef cattle productivity, kg live-weight/LU	281 (0.15)	287 (0.14)	265 (0.23)	278 (0.19)	283 (0.18)
Dairy ewe productivity, litre milk/ewe	246 (0.13)	257 (0.13)	271 (0.20)	271 (0.18)	267 (0.19)
Meat sheep productivity, lambs/ewe	1.16 (0.23)	1.06 (0.22)	1.13 (0.21)	0.98 (0.32)	1.00 (0.27)
Goat productivity, litre milk/goat	552 (0.26)	551 (0.28)	552 (0.28)	530 (0.24)	590 (0.28)
Concentrates, kg/LU	774 (0.58)	795 (0.58)	845 (0.60)	794 (0.60)	815 (0.58)
Purchased forage, kg dry matter/LU	207 (1.34)	295 (1.23)	419 (2.16)	338 (1.33)	432 (1.14)
Feed self-sufficiency, %	88 (0.10)	87 (0.13)	85 (0.17)	86 (0.14)	84 (0.16)
<b>Economic performances</b>					
Gross farm product (GFP), k€ <sup>1</sup>	199.6 (0.65)	210.0 (0.65)	225.8 (0.66)	225.6 (0.69)	224.1 (0.67)
Animal gross output, k€	131.6 (0.81)	137.0 (0.79)	143.9 (0.80)	144.7 (0.85)	142.7 (0.82)
Crop and other gross output, k€	17.8 (1.21)	17.4 (1.20)	20.5 (1.15)	19.4 (1.16)	19.9 (1.12)
Total aids and subsidies, k€	50.2 (0.49)	55.7 (0.50)	61.5 (0.53)	61.5 (0.54)	61.5 (0.51)
Total aids and subsidies, % GFP	28.4 (0.41)	29.6 (0.38)	30.4 (0.40)	31.2 (0.45)	31.4 (0.42)
Variable costs, k€	52.7 (0.68)	57.1 (0.74)	60.2 (0.69)	61.4 (0.67)	64.6 (0.69)
Animal variable costs, €	45.8 (0.71)	49.7 (0.76)	52.3 (0.69)	53.6 (0.68)	56.6 (0.71)
Including purchased feed, €	26.8 (0.86)	28.6 (0.84)	29.7 (0.85)	30.2 (0.85)	31.5 (0.89)
Including veterinary, €	3.2 (0.66)	3.5 (0.68)	3.7 (0.69)	3.3 (0.71)	3.6 (0.69)
Crop and fodder area variable costs, €	6.8 (0.74)	7.2 (0.91)	7.8 (0.89)	7.8 (0.85)	8.0 (0.89)
Fixed costs, k€	102.8 (0.78)	107.6 (0.78)	115.9 (0.82)	121.9 (0.80)	126.7 (0.81)
Including mechanization costs, k€	39.6 (0.80)	39.4 (0.66)	43.7 (0.69)	45.9 (0.69)	49.0 (0.75)
Including building costs, k€	14.1 (0.91)	16.0 (1.26)	17.8 (1.28)	18.8 (1.26)	18.4 (1.22)
Including land costs, k€	11.3 (0.95)	12.2 (1.22)	13.4 (1.41)	12.9 (1.48)	12.8 (1.47)
Labor costs, k€	18.3 (1.40)	19.9 (1.37)	20.0 (1.45)	23.3 (1.20)	25.6 (1.18)
Including other overhead costs, k€	15.4 (0.58)	16.4 (0.59)	17.0 (0.56)	17.7 (0.59)	18.2 (0.57)
Value-added, k€	59.3 (1.17)	58.1 (1.13)	61.9 (1.12)	59.8 (1.32)	52.7 (1.28)
Value-added, €/ha UAA	813 (0.35)	645 (0.67)	673 (0.76)	627 (0.89)	561 (1.00)
Value-added, k€/AWUt	24.9 (0.60)	24.3 (0.61)	24.2 (0.71)	22.0 (0.92)	19.1 (0.96)
EBITDA <sup>2</sup> , k€	81.0 (0.67)	82.6 (0.65)	91.0 (0.65)	85.7 (0.77)	76.5 (0.70)
EBITDA, €/ha UAA	966 (0.45)	973 (0.53)	1,057 (0.54)	962 (0.56)	862 (0.68)
EBITDA, k€/AWUf	50.2 (0.53)	50.0 (0.54)	52.6 (0.43)	47.4 (0.53)	42.4 (0.48)
Economic efficiency, EBITDA/GFP %	41.0 (0.23)	39.9 (0.30)	40.9 (0.24)	37.1 (0.31)	34.1 (0.32)
Net farm income, k€	44.3 (0.71)	45.6 (0.76)	45.9 (0.80)	42.5 (0.96)	33.1 (0.92)

**Table 3** (continued)

Variables	2014	2015	2016	2017	2018
Net farm income, €/ha UAA	540 (0.61)	543 (0.86)	597 (0.80)	486 (0.86)	395 (1.20)
Net farm income, k€/AWUf	27.5 (0.77)	27.1 (0.87)	28.3 (0.62)	22.6 (0.79)	17.7 (0.95)

<sup>1</sup>Constant 2018 Euros (Consumer Price Index deflator)<sup>2</sup>Earnings before interest, taxes, depreciation, and amortization**Table 4** Details of the productivity surplus (volume effect) accumulated over the period 2014–2018, in average constant euros per farm

Changes in output volumes	10,061	Changes in the volumes of production factors	31,701
Milk output	9023	Intermediate consumption	17,155
Live-weight (meat) output	869	Purchased feed and fodder	5558
Other output	169	Animal and area variable costs	3012
		Mechanisation (fuel, maintenance)	4991
		Other supplies and services	3593
		Capital	7427
		Land	969
		Family and salaried work	6150
Productivity surplus = -21,640 €			

**Table 5** Cumulative economic surplus account, average per farm in constant euros, and as % of resources and uses

Distribution or use	Euros	%	Origin or resources	Euros	%
Downstream-meat	68	0	Downstream-milk	1861	6
Suppliers of intermediate inputs	1 373	5	Downstream-cash crops	833	3
Landowners	751	3	Downstream-other output	190	1
Farmer social contributions	3670	13	Bank	166	0
Waged labor	1134	4	Government	11,695	41
Productivity surplus	21,640	75	Farmers' profit	13,891	49
Total uses	28,636	100	Total resources	28,636	100

## 511 Determinants of the productivity surplus

512 Four explanatory variables among the eight selected  
 513 had a significant effect on the sign (positive or neg-  
 514 ative) of the PS: farm size, feed self-sufficiency,  
 515 productive specialization, and the subsidies they  
 516 received (Table 6). The type of animal species raised  
 517 and animal production, as well as the diversity of  
 518 the crop rotation, straw self-sufficiency, the share of  
 519 UAA dedicated to animal feed and the share of sala-  
 520 ried workers in the work group did not have a signifi-  
 521 cant impact on the sign of the PS. The variable with  
 522 the greatest impact was feed self-sufficiency. Feed  
 523 self-sufficiency was positively associated with the  
 524 probability of having a positive PS. An increase of  
 525 1 percentage point in farm feed self-sufficiency was

associated with the probability of having a positive 526  
 PS by 0.66 percentage points. Increasing farm size 527  
 had a negative effect: increasing UAA by 1 ha was 528  
 associated with the probability of having a negative 529  
 PS by 0.22 percentage points. Similarly, productive 530  
 specialization (share of gross product excluding aid 531  
 of the main production unit on the total gross farm 532  
 product excluding aid) had a negative effect on the 533  
 probability of increasing the productivity surplus 534  
 (-0.32). The amount of aid received per ha of UAA 535  
 had a positive effect, but it was very small and sig- 536  
 nificant at the threshold of only 0.10. 537

Results from other type of models (standard panel 538  
 model, probit panel model) were similar to ones of the 539  
 main model estimated in terms of the direction of the 540  
 effect of the explanatory variables (SI B, Table SI2). 541



**Table 6** Marginal effect of variables on the probability of having a positive or negative productivity surplus (PS), significance of effects, standard error

Variables	Marginal effect of the variable (percentage points)	P-value	Standard error
Usable agricultural area (UAA)	-0.2219	***	0.0669
Share of salaried workers (S_AWUs)	-0.0387	ns	0.0924
Feed self-sufficiency (feed_self-suff)	0.6648	***	0.1791
Straw self-sufficiency (straw_self-suff)	-0.0446	ns	0.0466
Agricultural area used to produce feed (A_feed)	0.0194	ns	0.0684
Productive specialisation (Spe)	-0.3246	**	0.1634
Crop diversity (Shannon)	5.4105	ns	7.8192
Total aid received per ha of UAA (Aid)	0.0162	*	0.0085
Dairy cattle (DC)	-5.2016	ns	7.6055
Beef cattle (BC)	8.0797	ns	8.5649
Dairy sheep (DS)	15.7365	ns	11.0944
Meat sheep (MS)	-2.7517	ns	7.8380

P-value: \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$ ; ns, non significant

## 542 Discussion

543 Like all methods, the surplus accounts method  
 544 was sensitive to the starting hypotheses, and the  
 545 results obtained depended on the sample analyzed.  
 546 The decomposition of changes in economic value  
 547 into volume and price effects using the volumes  
 548 and prices actually observed for each farm limited  
 549 the bias associated with the use of average  
 550 price indices for an entire sector over a vast geographical  
 551 area (Méraud, 1979). Similarly, using  
 552 individual farm data allowed us to more accurately  
 553 trace changes in factor productivity established at  
 554 a sectoral and/or regional level, rather than using  
 555 aggregated data from regional or national statistics  
 556 (Veyssset et al., 2019). However qualitative the  
 557 information we used (harmonized method of monitoring  
 558 Inosys-Réseaux d'Élevages and the Diapason database),  
 559 some intermediate consumption did not have volumes  
 560 and was only known by its economic value, hence,  
 561 the use of price indices. As INSEE did not publish  
 562 specific indices for organic agriculture, we had to  
 563 establish them based on the information available to  
 564 us. The size of our sample was therefore a limitation,  
 565 and our indices and results did not claim to be  
 566 exhaustive, but they gave indications of trends  
 567 observed in organic farming systems in the Massif  
 568 Central. In order to study in detail the production  
 569 and economic strategies of organic farmers in a given  
 570 territory, as well as their

evolution, variability and dispersion, it would be  
 essential to have data from statistically representative  
 long-term technical and economic networks.

Farms enlargement, volumes of input used, and  
 financing of these inputs

These organic livestock farms followed an expansion  
 trend, with the notable fact that labor productivity  
 remained stable. Despite the constancy of labor  
 productivity, the increase in the volume of variable  
 factors of production used (excluding labor) has been  
 faster than that of agricultural production, resulting  
 in a drop in the productivity surplus. From a technical  
 efficiency point of view, these OF farms in the Massif  
 Central did not differ from the major trends observed  
 in the whole European agriculture, of which OF is  
 a part. Within the whole EU-28 agricultural sector,  
 capital productivity showed a general downward  
 trend, while there were no gains on intermediate  
 consumption productivity; technical efficiency had not  
 increased since the early 2000s (European Commission,  
 2016). The development of farm size on organic  
 farms was observed by Langer et al. (2005) and was  
 linked to the debate on the “conventionalization” of  
 OF. The question of the conventionalization of OF is  
 often observed via the evolution of structures, but the  
 evolution of practices, the intensification of the use  
 of intermediate consumption must also be considered  
 (Darnhofer et al., 2010).

599 The prices of agricultural products and interme-  
600 diate consumption remained relatively stable within  
601 the sample studied, and the volumes of intermediate  
602 consumption and capital acquired by OF livestock  
603 farmers in the Massif Central were financed by a drop  
604 in their remuneration as well as by an increase in the  
605 total aid received.

#### 606 Mechanisation costs

607 Among the inputs, all of the costs of mechanization,  
608 i.e., fuels and lubricants, work by third parties, equip-  
609 ment maintenance (intermediate consumption) as  
610 well as the depreciation of owned equipment (capita-  
611 l), constituted the item that had increased the most  
612 over the 5 years studied. We did not observe any dilu-  
613 tion of equipment use costs in the volume of products  
614 or in a larger UAA (Veysset et al., 2019). In addition,  
615 tax policy may induce farms with good economic  
616 performance to invest in equipment and over-equip,  
617 in order to limit taxable income, and thus reduce the  
618 amount of social contributions. The search for feed  
619 self-sufficiency can lead to a higher cost of mechani-  
620 zation of the forage harvesting and distribution chain  
621 than for our European competitors who more easily  
622 contract feed purchases (Chatellier et al., 2020). But,  
623 we observed that the mechanisation costs increased  
624 while the feed self-sufficiency decreased; part of this  
625 increase in mechanization costs can be explained by  
626 an increase in mechanized actions to try to cope with  
627 climatic hazards and preserve a certain degree of feed  
628 self-sufficiency: additional mown areas to build up  
629 stocks, reseeding of degraded grasslands, and distri-  
630 bution of fodder during the summer. This strategy  
631 was not necessarily a winning one in the event of  
632 severe drought and thus a sharp drop in forage yields,  
633 farm equipment can then be seen as a response by  
634 farmers to their risk aversion, and not as a source of  
635 improved productivity and economic performance  
636 (Sheng et al., 2016).

#### 637 Feed self-sufficiency and specialization/ 638 diversification

639 Feed self-sufficiency on organic livestock farms was  
640 seen as a factor in reducing the vulnerability of these  
641 systems to climatic hazards (Bouttes et al., 2018).  
642 This autonomy also improved the economic effi-  
643 ciency of farms (Lebacqz et al., 2015). The increase

in feed purchases was indeed the primary cause of 644  
the decrease in surplus productivity, and income, of 645  
the OF farms in our sample over the 5 years of study. 646  
But the low availability of certified OF feeds on the 647  
market, and thus their high price, was a limitation 648  
to non-autonomous OF systems (Escribano, 2018). 649  
The search for feed self-sufficiency for livestock at 650  
the farm scale was therefore a productive, economic, 651  
and environmental necessity (Soteriades et al., 2016), 652  
feed self-sufficiency in pasture-based grazing systems 653  
also improved the resilience of organic dairy farms 654  
(Perrin et al., 2020). In the case of our sample of 58 655  
farms, the adaptation strategy of farmers to climatic 656  
hazards (drought 2016 and 2018) was to buy fodder; 657  
in the face of these increasingly frequent (drought, 658  
rainy spring, late frosts) and localized hazards, farm- 659  
ing practices will have to be adapted locally (date of 660  
grazing of animals, fodder stocks, fodder crops, etc.) 661  
in order to guarantee real feed self-sufficiency and to 662  
limit the need for purchases (Sidam, 2019). The feed 663  
self-sufficiency of livestock farms was reinforced by 664  
the diversification of forage resources cultivated on 665  
mixed crop-livestock farms (Bell et al., 2018; Havet 666  
et al., 2014) although crop diversification did not 667  
significantly affect productivity gains in our sam- 668  
ple. This may be due to the fact that grasslands and 669  
their management (mowing, hay, silage, grazing) are 670  
considered as a single crop in the calculation of our 671  
Shannon index. Productive specialization decreased 672  
the probability of achieving productivity gains, so we 673  
can assume that the production of several agricultural 674  
goods on the same farm would improve the productiv- 675  
ity of the system. Diversification on the farms in our 676  
sample mainly took the form of mixed crop-livestock 677  
farming, with the production of cereals or cereal/pro- 678  
tein mixtures for animal feed in order to reinforce feed 679  
self-sufficiency. The integration of crops and live- 680  
stock on mixed crop-livestock farms reduced the need 681  
to purchase inputs thanks to the recycling of nutrients 682  
within the system (Peyraud et al., 2014), and the pro- 683  
ductivity of these diversified production systems was 684  
thus improved (Sekaran et al., 2021). Some farms 685  
combined a second animal unit with their main ani- 686  
mal unit (mainly cattle-sheep associations); the ani- 687  
mal mix on pasture allowed to improve animal pro- 688  
ductivity thanks to the feeding complementarity and 689  
parasite dilution (D'Alexis et al., 2014). But feed self- 690  
sufficiency in organic livestock farming systems was 691  
not sufficient to achieve a good economic efficiency 692

693 (Faux et al., 2022), compromises must be made with  
 694 the mechanization costs of producing, harvesting, and  
 695 distributing feed produced on increasingly large areas  
 696 of the farm.

## 697 Conclusion

698 Organic ruminant production systems, from a con-  
 699 stant sample of 58 farms in the French Massif Cen-  
 700 tral monitored for 5 years, seem to follow the same  
 701 structural and technical trends as those observed in  
 702 the agricultural sector as a whole. We observed an  
 703 increase in the size of the utilized agricultural area,  
 704 a decrease in feed self-sufficiency, and an increase in  
 705 mechanization costs, hence, a decrease in technical  
 706 efficiency. They were also characterized by relatively  
 707 stable product prices (at least until 2018), the decline  
 708 in farm profitability was therefore due to the decline  
 709 in factor productivity (volume effect). More statisti-  
 710 cally robust references on price indices for organic  
 711 products and inputs, as well as long-term monitor-  
 712 ing of OF farms, are needed to validate these original  
 713 results, which were based on a small sample size and  
 714 a short period. The question of feed self-sufficiency  
 715 is central to the productivity of these farms, but also  
 716 to their resilience to climatic hazards. The resil-  
 717 ience, vulnerability, and adaptability of farms to haz-  
 718 ards and/or shocks require further work to study the  
 719 trade-offs between increasing the agricultural area,  
 720 diversifying resources, securing stocks, combining  
 721 production factors and mechanization costs, and thus  
 722 consuming non-renewable energy.

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 730 econometric model and performed this analysis. The first draft  
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 protected by statistical confidentiality. They were not deposited 739  
 in an official repository. 740

**Declarations** 741

**Conflict of interest** The authors declare no competing interests. 742

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