The Impact of Public R&D Investments on Agricultural Productivity

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Abstract: The present study aims at assessing the impact of the public agricultural research and development (R&D) on the total factor productivity in Catalonia. To do so, we use a complementary approach based on econometric and accounting techniques to examine the relationship between public investments in agricultural R&D and the productivity growth over the period 1985–2015. Results show that the productivity grew on average at an annual rate less than one percent. However, the growth was much faster during the tow first decades of the analysis. In addition, our empirical findings indicate that the public agricultural R&D has a significant and positive impact on the Catalan agricultural productivity. From a cost–benefit perspective, the estimates reveal a high return (15-28%) to R&D investments which has contributed to improve the productivity performance of the agricultural sector in Catalonia.

Keywords: R&D Investments, Knowledge Stock, Productivity Growth, Social Return.

1. INTRODUCTION

The productivity growth is a relevant indicator to assess the ability of economy to generate gains. Thus, trends in the total factor productivity (TFP) may provide valuable information about the performance of different economic sectors. In being a useful tool to diagnose economic problems, the assessment of productivity growth has drawn broad research interest. During the last decades, the academic literature has largely focused on the sources of productivity growth over time given its importance to ensure a sufficient rapid growth of output to satisfy the increasing demands for agro-food products by the society.

Previous studies advocated that technological advancements are a key factor that contribute to enhance the agricultural productivity growth (Khan et al., 2017). Agricultural research and extension expenditures have been commonly used as a proxy for technological advancements. Moreover, research studies provide supporting evidence that investments in the agricultural R&D generate high returns per unit spent (Fuglie & Heisey, 2007; Alston et al., 2010). However, this finding could indicate that some emergent research areas are underfunded due to a limited budget that represents less than 2% of the gross domestic product in both developed and developing countries. The recent coronavirus pandemic might witness this phenomenon demonstrating how important R&D innovations are to our society, health and economy (Soetan, 2021).

R&D innovations allow farmers to improve their competiveness, optimizing resources usage and increasing productivity, which in turn ensures the economic viability and sustainability of agricultural sector. The agricultural productivity may increase through greater use of agricultural inputs (e.g., more fertilizers and machinery per hectare of land) or the same amount of output could be produced with lower inputs use. In addition, changes in TFP may be also attributed to improvements in rural infrastructure (e.g., transport facilities). It is interesting to distinguish between the contribution of changes in input use and other factors that may affect the agricultural productivity growth. In this way, the TFP index is commonly used as a reliable measure to this purpose.

Knowledge about the productivity growth and its main factors is important as an analytical instrument that could assist policymakers' decisions in R&D investment policies to promote the agricultural development and enhance farmers' performance through using less input and reducing costs by adopting new technologies. Social concerns about the effectiveness of public R&D investments become more and more growing. Research impact assessment (RIA) is a key tool to provide insights into the effectiveness of science and research for learning purposes and the management of R&D impact within the public research organization (PRO) as well as for different stakeholders involved in the generation of the R&D impact. Four institutional 'As' purposes (advocacy, allocation, accountability and analysis) drive the evaluation of R&D impact of research organizations: (Morgan et al., 2017).

Given the social and economic importance of agricultural sector in Catalonia, an investigation of the R&D efforts on the productivity growth makes the analysis especially interesting. In this context, this article attempts to provide estimates of the social benefits of agricultural R&D investments.

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The remainder of this paper is structured as follows. The next section presents a literature review on R&D impact and our contribution to this research area. Next, we offer an overview of the evolution of agricultural productivity and public agricultural research in Catalonia. Then, we describe the empirical implementation of the model. Finally, the last sections outline and discuss the empirical findings.

2. LITERATURE REVIEW

During the last decades, research studies examining the agricultural productivity have significantly expanded. Early analyses of public agricultural research impacts on agricultural productivity date back to the pioneering work by Griliches (1958). The literature on the economics of agricultural R&D has been expanded due to mainly the availability of long time series data on R&D, the development of new RIA methods that provide robust and unbiased estimates and the need to evaluate the effectiveness of agricultural R&D programs (Alston et al., 2011). In this context, the "social rate of return" to agricultural R&D expenditures could be defined as a percent return on each euro spent on R&D. The literature suggested that the payoff from the government's investment in the agricultural research is very high.

To assess productivity trends, the TFP is generally preferred to partial productivity indexes since it allows combining multiple outputs and inputs. Productivity analysis is mainly divided into two groups. While a first group used the index number theory to estimate productivity, the second one relied on econometric approaches namely, non-parametric (data envelopment analysis) and parametric methods (Stochastic Frontier Analysis). Regarding the former method, Tornqvist-Theil and Fisher ideal indexes are widely used and TFP growth is often expressed as a function of agricultural R&D spending. However, research capital measures derived from R&D expenditures are still at its early stage and often refer to Griliches (1958)'s work. Since then, public agricultural R&D expenditures have been used to proxy the "true" measure of agricultural R&D innovations that impact the productivity (Huffman & Evenson, 2006).

The effect of agricultural research is not immediate and requires a long time lag to generate benefits. Nevertheless, the production economics literature has recently debated on the proper specification of the total lag length as well as the appropriate measure of the economic benefits to be used in the case of public agricultural R&D (Hurley et al., 2017; Oehmke, 2017; Anderson, 2019). Evenson (2001) suggested that free-form lag estimates are unsatisfactory due to the high correlation between lagged research expenditures and hypothetical shape of timing weights. For instance, the pattern of R&D impact on productivity encompasses three principal periods: short gestation, blossom and obsolete periods (Huffman, 2017). This assumes that the contribution of research is insignificant at the beginning and its effects become progressively more important and positive over the next period followed a maturity phase during which weights are high and constant as innovations are completely integrated in the production process (Alston et al., 2010). After a long period of adoption, the impact of innovations becomes obsolete.

Previous research studies proposed the social rate of return to measure the direct benefits of additional public funds. Two main approaches have been widely used to determine the returns to agricultural research. While statistical techniques attempt to associate past expenditures on R&D to changes in productivity, project evaluation methods draw the development and dissemination of innovations. The former approach is mainly built upon the causal relationship to derive the return to research. The Griliches's pioneering empirical work proposed econometric techniques to assess the relationship between the productivity of maize and past investments in R&D. The author found high estimates of return to R&D investments of around 40%.

Only few studies examined the returns to agricultural research by different sources of funding (e.g., private vs. public; regional vs national, competitive grants vs other grants type). However, such information needs finer and detailed data on research expenditures. Huffman and Evenson (2006) analyzed the impact of public agricultural research and extension on productivity at the state level taking into account funding sources. Their findings indicated that the rates of return to agricultural research vary from 49 to 62% and a much higher rate to extension services. Consistent with Huffman and Evenson's results (2006), Jin & Huffman (2016) found a higher estimates of an internal rate of return (IRR) to public investments in agricultural research of 67% and to extension services over 100% for a panel of contiguous U.S. 48 states from 1970 to 2004. It is worth noting that the investments in public agricultural research and extension services exhibit different lengths of time lags for obtaining social benefits, being sooner for extension than for research (Huffman, 2016).

Bervejillo et al. (2012) used alternative models to measure the returns to public agricultural research in Uruguay over the period 1961–2010. They reported that the economic returns were stable across models with different lag structures, ranging from 23% to 27% per annum. Anderson & Song (2013) examined the impact of public agricultural research undertaken by USDA and SAESs on agricultural productivity using aggregated national-level data. They showed that elasticities of productivity with respect to knowledge stocks vary between 0.28 and 0.35 indicating IRR in the range of 8-10%. In another study, Anderson (2015) obtained a similar finding using the same data for the United States. The author found an annual real rate of return of 10.5% suggesting that reducing agricultural R&D spending in recent decades raises concerns about productivity growth in the future. Khan et al. (2017) investigated the dynamic relationships between R&D expenditure and productivity growth in the Australian broadacre agriculture based on aggregate time series data for the period 1953 to 2009. In line with previous studies, the authors revealed that an increase in the public expenditure in R&D is likely to lead to higher productivity growth in the long run.

Over the last few years, there have been a few attempts to assess the effect of R&D investments on agricultural productivity in European countries. Butault et al. (2015) evaluated the effect of public agricultural research spending on the French agricultural productivity for the period 1959-2012.

They concluded an increasing in R&D expenditures would improve the productivity growth by 0.15% leading to obtain an average return around 30%. In another recent study, Ratinger and Kristkova (2015) examined the impact of R&D investments between 1993-2012 in the Czech Republic using the co-integration analysis. They found an estimated average return to knowledge of 40% which is much lower when R&D spillover is accounted for (30%). The bulk of the literature indicates that the rates of return to R&D investments are sensitive to function specification choices, estimation techniques, commodities and the period covered.

Despite the relevance of understanding the relationship between investments in public agricultural R&D and the productivity, there are very few empirical applications in the European countries. The present study contributes to fill this gap. In addition, to our best knowledge ours constitute the first study that assesses the social return to agricultural R&D expenditures in Catalonia (Spain). Finally, considering the social and economic importance of the agriculture sector in Catalonia, an investigation of the agricultural R&D impact on the productivity growth would have important implications for impact assessment and policymaking.

3. AGGREGATE INPUTS, OUTPUTS AND TOTAL FACTOR PRODUCTIVITY

This section sheds light on the role of the agricultural sector in the Catalan economy and gives an overveiwe of the productiviy growth over time. The agricultural sector continues to play a significant social and economic role in the economy. In 2020, the sector offers 64.5 thousand jobs for the rural community (IDESCAT, 2021). The number of farms is nearly 60 thousand distributed over almost one million hectares. These farms generate about €5043 million in 2020. Moreover, the agricultural revenue has grown at an annual rate of 2.62% during the period 1985-2020. In 2020, Catalonia accounts for about 10% of the Spanish agricultural gross domestic product (GDP) (up from a 7% share in 1986) using just 4% of the total country's UAA. The relevance of the agricultural sector in the Catalan economy makes this analysis especially interesting.

In order to derive the TFP index of Catalan agriculture, we use the Fisher ideal index. This indicator is computed as the ratio of aggregate outputs index to aggregate inputs index. The value of index is defined as 100 in the base year, 1990. To compute the aggregate outputs and inputs indices, our study relies on annual data on two outputs (crops and livestock production) and four categories of inputs (intermediate consumption (e.g., fertilizer, herbicides, pesticides, services and energy) capital, labor and land) over the 25-year period. This study offers the first estimates of the TFP growth for the agricultural sector in Catalonia.

Data are mostly obtained from Catalan national statistical agencies (Agricultural Census and IDESCAT). In addition, other official sources (e.g., The Spanish Ministry of Agriculture, Food and Environment; the National Statistics Institute (INE) are consulted to get a complete data for some missing observations. The rental cost of capital and the annual cost of capital services obtained from the Banco Bilbao Viscaya Argentaria have been used to compute the capital input. Labor inputs are measured in terms of the number of active adults employed primarily in agriculture. Labor wages are calculated as the annual cost of agricultural labor by the total number of jobs. Land input represents the total utilized agricultural area. Weighted rental prices of land are taken from Agricultural Census. Table **1** summarizes the growth rates of output, the input and the TFP over the period of analysis.

Table 1. Average Annual Growth Rate for Farm Output, Input, Total Factor Productivity (1990-2015).

Period	Average Annual Growth Rate: 1990–2015 (%)		
	Total Output Index	Total Input Index	TFP Index
1990-1995	0.67	-0.77	1.45
1995-2000	1.56	0.47	1.09
2000-2005	-1.91	-1.78	-0.13
2005-2010	-0.63	-2.07	1.47
2010-2015	0.10	1.30	-1.19
1990-2015	-0.05	-0.58	0.53

Source: own elaboration.

Between 1990 and 1995, the aggregate output index represents an increase of 0.7% per annum, while the aggregate quantity of inputs decreased at an average annual rate of 0.8%. Indeed, the increase in output not due to additional input use could be attributed to the productivity growth with an average annual rate of1.45%. Crops and livestock production increased at a faster rate (1.56%) during the second half of the 1990s than the previous period. This growth was achieved with only one half times increase in application of more inputs leading to an annual increase in TFP of 1.1%. In contrast to the preceding period, the output as well as the input use shrank representing a negative annual increase of 1.9% and 1.8%, respectively. TFP reached the highest growth (1.5%) between 2005-2010 resulting from a decrease of both output (0.63%) and input use (2.1%). During the last sub-period, the aggregate quantity of output presented a slight recovery and some renewed growth of 0.10% with a more substantial increase in agricultural inputs (1.3%). Nevertheless, a positive input growth is associated with slow TFP growth conducting to a 1.2% decline in the productivity which represents the slowest rate compared to previous sub-periods. Over the period 1990-2015, the Catalan agricultural output growth is almost stable while it is evident for the input growth to be negative. TFP increases at an average annual rate of 0.53% from 1990. This productivity gain could be explained by the contribution of technological advancements resulting essentially from R&D investments realized by the agricultural research institutes in the region.

4. PUBLIC AGRICULTURAL RESEARCH IN CATALONIA

The pattern of total R&D spending in Catalonia shows clearly the efforts made by the Catalan government "Generalitat de Catalunya" to strengthen the system of technology in order to improve the productivity and to increase both the market competitiveness and farmers' revenues. In 2019, the total

R&D expenditures reached €3597 million of which 40% are funded by public funds (IDESCAT, 2021) representing 1.44% of the Catalan GDP.

In 2019, the Agricultural R&D spending represents 6% of the total budget allocated to R&D activities in Catalonia, being the fourth most relevant share (IDESCAT, 2021). During the period 2017-2019, the agricultural department spends in R&D, on average, €200 million while the health sector reaches the highest amount of investments in R&D (€1186 million). Since 2010, the agricultural R&D expenditures have rapidly increased by 138% indicating the relevant role of the Catalan government in supporting and promoting innovations in the agricultural research area.

The Institute of Agro-food Research and Technology (IRTA), among others like The Spanish National Research Council (CSIC) and public universities, represents the leading system of public agricultural research activity in Catalonia. IRTA was created in 1985 as a public organism of the Catalan Government. The main goal of IRTA is to transfer knowledge and innovations to the agro-food sector. IRTA composed of ten centers and field stations and three associated centers spread across different locations in Catalonia. In 2019, the total number of employees at the IRTA reached 839 of which 180 were researchers and the remaining are mainly support staff.

In Catalonia, the public agricultural research is primarily undertaken by IRTA, which amounts to about €135.3 million accounting for 23% of the total during the period 2017-2019. In addition, IRTA was able to manage 1405 noncompetitive research projects (€27.5 million) representing the most relevant share (54%) of the total projects (€51.3 million) (DAAM, 2013). Thus, it plays a significant role to enhance the system of agricultural technology in Catalonia through contributing to increase the Catalan market competiveness at both national and international levels and promote sustainable development in the agricultural sector. On the other hand, the innovation efforts help meet the consumer demands for high-quality products, ensure food safety and security, and improve human welfare. IRTA has continuously built up the stock of agricultural knowledge specifically in the following areas: crop systems and soil management, dairy, wheat and barley breeding, fertilization and plant protection, animal nutrition, and integrated pest management for fruits and vegetables.

In 1986, IRTA spent €4.1 million on agricultural R&D of which one million euros or 20% of the total was its own resources while the remaining was mainly structural funds (70%) provided by the Catalan Government and credits (10%). Since its foundation, the R&D expenditures fluctuated around an increasing trend through the 1980s and early 2000s until it dropped from €57.4 million in 2006 to €40.7 million in 2007. Total research spending has significantly grown recording an average annual rate of 8.5%, or just 5% per year when expressed in real terms. The R&D spending pattern evolves unevenly over time. It slowed considerably from 14% during 1986-1995 period, to 10% for the 1995-2005 period, to become less than 3% over the last decade. It is worth noting that the growth of expenditures on agricultural research became negative (-10%) from 2010 to 2014. This came from severe cuts in the agricultural R&D funds mainly due to the consequences of the 2008's financial crisis. In 2015, agricultural research spending presented some renewed growth. Table **2** summarizes the sources and the distribution of the R&D funds over time.

Table 2. Funding Distribution by Major Sources for IRTA, 1986–2015.

Expenditure Source	Contribution to the Total			
	1986	1995	2005	2015
Structural Funds : Catalan government & Deputation	0.70	0.64	0.43	0.41
Credits	0.10	0.00	0.01	0.00
Specific Grants	0.00	0.00	0.13	0.00
National competitive grants: INIA & National Plan	0.00	0.07	0.09	0.05
UE funding	0.00	0.03	0.04	0.08
Contracts, services and product sales	0.08	0.10	0.14	0.34
Other funds	0.11	0.16	0.16	0.12

Source: IRTA, 2019.

The composition of funds is not identical and varies significantly over time. In 2015, IRTA had total financial resources of €43.5 million. Own resources of IRTA continues representing the lion share of funds accounting for 61% of the total. The rest of expenditures (39%) are obtained from the Catalan government. IRTA has been successful in obtaining competitive grants funds that represent on average 16% of the total spending. Funds from national sources, mainly The National Institute for Agricultural and Food Research and Technology (INIA) and National Plan, have remained generally stable and constant (6% on average). Funds received from UE are increasing which account for about 8% of the total research spending while it was about one percent in 1988. In addition, IRTA has been successful to catch grants and contracts funding from other sources. It obtains part of its funds from selling products and services to farmers and from industry grants and contracts. Their contribution to the total IRTA spending grew significantly over the last decades representing the most rapid increase from 8% in 1986 to 39% in 2015. Permanent staff and research division training costs continue to occupy the lion share of total IRTA spending, representing 70% and 73% in 1986 and 2015, respectively. In this context, it is crucial to know to what extent these R&D investments yield a favorable and profitable return for the society.

5. MATERIAL AND METHODS

As discussed earlier, the Catalan agriculture productivity has annually grown by 0.53% from 1990. This growth involves a significant annual variation in productivity gains during the period of analysis. This evolution has been expressed as a function of past investments in agricultural R&D, which in turn show a notable progress. The annual average growth in agricultural R&D expenditures over 1985–2015 is high, at over 8%. Changes in technological innovations associated to past R&D investments made by public sector (IRTA) could reasonably be expected to affect the agricultural productivity growth. In order to provide a comprehensive assessment of this relationship, a complementary approach based on accounting and econometric techniques has been used. The evaluation of R&D impact examines the relationship between increased productivity flows and benefits taking into account that the agricultural research takes long time to affect productivity and generate social and economic benefits (Anderson, 2019).

To achieve the aforementioned objective, the TFP growth at time period t is assumed to be a function of stock of the public agricultural research with a lag length of 10 years, Kt. the knowledge stock is built using total expenditures on agricultural research carried out by IRTA over the period 1985–2015. To do so, we assume a gamma lag distribution model following Alston et al. (2010) defined as follows:

$$K_t = \sum_{k=0}^{L_R} \beta_k \times R_{t-k} \text{ , where } \sum_{k=0}^{L_R} \beta_k = 1 \qquad (1)$$

LR represents the total lag length and β_k are lag weights applied to agricultural research investment kt over the past 10 years, R_{t-k}. Weights are normalized and sum to one. During the first period the impacts of R&D are assumed to become progressively more important, positive and represented by increasing weights. Then, the effects follow declining weights and go to zero eventually as innovations become obsolete (Anderson, 2019). In short, the research lag weights (β_k) can be derived from the following expression:

$$B_k = \frac{(k+1)^{(\delta/1-\delta)}\lambda^k}{\sum_{k=0}^{L_R}\left[(k+1)^{(\delta/1-\delta)}\lambda^k\right]} \text{ for } L_R \geq k \text{ ; otherwise } B_k = 0 \qquad (2)$$

δ and λ are parameters that determine the shape of the distribution ($0 \leq \delta < 1$ and $0 \leq \lambda < 1$).

The effects of a long-term change in growth rates of public agricultural R&D spending are reflected in the knowledge stock. As suggested by previous studies, the total R&D spending is used as a measure of the research capital. We assume a maximum research lag of 10 years following gamma distribution to build the knowledge stock. The lag distribution allows obtaining positive contributions of the current research knowledge stock over the previous 10 years implying a peak lag weight at year t depending on the parameters δ and λ.

In order to capture the effect of other factors that could affect the productivity growth, a weather variable has been also included in the model. Following Butault et al. (2015), we define the weather variable (C) as the difference between the precipitation and the potential evapotranspiration. As explained above, we stress that during the last five years the agricultural research spending showed a decreasing trend. To control for this effect, we include a dummy variable (D) that takes the value of zero and one before and after 2010, respectively. We expect a negative impact, which means that reducing R&D spending will negatively affect productivity growth (Anderson (2015). Table **3** provides a brief summary of the variables used in the empirical productivity model.

Table 3. Summary Statistics for the Variables used in the Analysis.

Variable	Definition	Unit of Measure	Minimum	Maximum	Average
Total factor agricultural productivity (TFP_t)	Ratio of Fisher index of aggregate output to aggregate input in year t	Index (1990=100)	102.50	121.20	111.54
Stock of public agricultural knowledge (K_t)	Built using 10 years of public spending on R&D and preferred gamma lag distribution (λ=0.9, δ=0.6)	Million 1990 euros	7.236	23.40	13.22
Weather index (C_t)	Measured as the difference between precipitation and potential evapotranspiration	mm	-496.00	106.00	-161.57

Source: own elaboration.

A logarithmic functional form is commonly used to model productivity gains and R&D investments (Huffman & Evenson 2006; Alston et al. 2010, 2011; Bervejillo et al., 2012; Anderson & Song, 2013; Butault et al., 2015). The Cochrane-Orcutt procedure has been used to deal with time series problems assuming that the error term follows a first-order autoregressive process. The econometric model of agricultural productivity growth is specified as follows:

$$LnTFP_t = \alpha_0 + \alpha_1 Lnk_t + \alpha_2 C_t + \alpha_3 D + \varepsilon_t \qquad (3)$$

Where ε_t is an error term assumed to be independent and identically distributed. α_1 represents the elasticity of TFP with respect to a change in the knowledge stock. Given a maximum lag length of 10 years and limited data on research expenditures that started from 1985, we estimate the R&D model for the period 1995-2015. To build the research stock variable, a grid-search procedure has been used to assign values for the parameters of gamma lag distribution (δ and λ). The choice of the optimal values for δ and λ relies on the parameters that best fit the data. We obtain 49 possible combinations of values for both λ and δ (0.60, 0.65, 0.70, 0.75, 0.80, 0.85, and 0.90). The economic approach for estimating rates of return to research depends on the parameters of productivity growth. Then, the gross annual research benefit (GARB) in year t can be calculated using the following approximation:

$$GARB_t = \Delta LnMFP_t \times V_t \qquad (4)$$

where V_t, expressed in constant 1990 prices, representing the real agricultural output in year t, and $\Delta LnTFP_t$ denotes the proportional variation in the agricultural productivity in year t, induced by a simulated increase in the public agricultural research spending. The simulated proportional change in TFP is simply calculated as the difference between the predicted *LnTFP* given the actual research spending and the predicted *LnTFP* with the increased (hypothetical) research expenditures. Furthermore, the present value in the year 2015 of accumulated benefits (PVB) assuming a real interest rate of r = 5% (values of r = 3% and r = 10% have been used for comparison purpose) can be obtained from the following expression:

$$PVB = \sum_{t=1995}^{2015} GARB_t \times (1+r)^{2015-t} = \sum_{t=1995}^{2015} \Delta LnMFP_t \times V_t \times (1+r)^{2015-t} \quad (5)$$

The modified internal rate of return (MIRR) to the public investment is deduced by solving the following expression:

$$\sum_{n=0}^{N} \beta_{t+n} \times (1+r)^{N-n} - I_t(1+m)^N = 0 \quad (6)$$

where It represents an investment at time t, Bt+n is a flow of benefits which would be reinvested at the interest rate, r over the N years and m indicates the MIRR.

6. RESULTS

Using the aforementioned methodology, alternative regression models have been estimated depending on the parameters that depict the gamma lag distribution. Estimates of these models using TFP data for 1995-2015, and research expenditures back to 1985, are reported in table **4**.

Table 4. Summary of Results for Alternatives to the Preferred Model.

Model Details	Model Results			
Rank[1]	1	2	3	4
R^2	0.533	0.527	0.528	0.521
Lag Distribution Characteristics				
δ	0.60	0.60	0.65	0.65
λ	0.90	0.85	0.85	0.80
Peak Lag Year[2]	12	8	10	7
Parameters				
Constant	-0.241** (0.084)	-0.227** (0.082)	-0.242** (0.085)	-0.228 (0.083)
Public knowledge stock (K)	0.149*** (0.035)	0.142*** (0.034)	0.150*** (0.036)	0.142*** (0.035)
Weather index (C)	3.590E-05 (5.460E-05)	3.210E-05 (5.460E-05)	3.490E-05 (5.480E-05)	3.090E-05 (5.480E-05)
Dummy variable (D)	-0.091** (0.030)	-0.086** (0.029)	-0.093** (0.030)	-0.087** (0.029)

Source: own elaboration.

Notes:

Standard errors in parentheses; ***Significant at 1% and **significant at 5%.

[1]Rank: Model rank by the sum of squared errors (SSE) and R2.

[2]Peak lag is the number of years until the current investment has its maximum impact on the research stock.

As expected, the inclusion of R&D stock in the specification has a positive impact on productivity gains. On the other hand, our findings suggest that the shape of gamma distribution does not affect significantly the estimates across different TFP estimation models. The preferred model is specified assuming values for δ = 0.60 and λ = 0.90. Moreover, other alternative specifications show similar results and do not differ substantially in terms of their goodness of fit. In all four estimations, the elasticity of TFP with respect to the public knowledge stock is around 0.15 and significantly different from zero at the 1% significance level. The elasticity estimate indicates that a 1% increase in the agricultural R&D spending would lead to approximately a 0.15% increase in the productivity. However, the results reveal a significant and negative impact of the financial crisis on the R&D spending after 2010 suggesting that reducing investment in scientific knowledge leads to raise concerns about the productivity growth of the agricultural sector in Catalonia.

Based on the preferred model, with an incremental investment in the public agricultural research of one million euros in 1995, the PVB can reach €86.33 million in 2015. On the other hand, we have determined the present value of costs (PVC), assuming (r = 5%), which amounts to €2.65 million (i.e., 1 million× (1+r) 20). The streams of PVB and PVC expressed in constant prices, allow deriving a benefit-cost ratio of 32 indicating that the annual flow of simulated benefits from the productivity growth is many times greater than the annual flow of research costs.

Table **5** provides estimates of the marginal benefit-cost ratio and MIRR for our preferred model and three alternative specifications using different real interest rates. Assuming a real interest rate of 5% and for a marginal increase in agricultural R&D spending in 1995, the annual MIRR to the public research investment is about 24%. Rates of return are relatively similar across different model specifications. An annual rate of return of 24% is plausible indicating a profitable social rate of return to the IRTA's investment. Results suggest that MIRR estimates range from 22% to 28% per year. They are relatively insensitive to different lag structures and relatively stable across different model specifications.

Table 5. Benefit-Cost Ratios and Internal Rates of Return.

	Model			
	1	**2**	**3**	**4**
Benefit-Cost Ratio				
Interest rate				
3%	36.51	35.20	36.62	35.25
5%	32.54	31.64	32.61	31.65
10%	24.92	24.72	24.90	24.66
Internal rate of return				
Reinvestment rate				
3%	22.07	22.16	22.07	22.16
5%	23.65	23.78	23.64	23.78
10%	27.62	27.88	27.59	27.85

Source: own elaboration.

The private research effort and spill-ins/over effects of research from national and international research institutes cannot not be included in the present analysis due to data availability. The omission of these factors could lead to an upward bias of the knowledge stock parameter which overestimates the public research impact. To overcome this limitation, we suppose different share of benefits attributed to the public agricultural R&D while the remaining benefits would be attributed to omitted variables. A second MIRR has been derived assuming 100%, 75%, 50% and 25% of the values for measured benefits and a reinvestment rate of 5% per year. These scenarios would reduce the annual MIRR to 15-26% per annum. In general, results support that the economic return to R&D investments varies from 15% to 28% with whether the stream of estimated benefits is totally attributed to IRTA or cut in different share of contribution. In line with previous literature, we find evidence that the agricultural R&D investment is profitable for society through improving the productivity performance of agricultural sector in Catalonia.

7. DISCUSSION AND CONCLUSION

Over the period 1990-2015, the TFP index of agricultural sector in Catalonia increased from 100 in 1990 to about 114 in 2015. Hence, if the aggregate input had been held constant at the 1990 quantities, output would have increased by a factor of 1.14:1. 12.3% of the actual agricultural output, worth €515 million in 2015, could be accounted for the productivity growth using 1990 technology. Productivity gains are likely driven by economies of scale, improved managerial skills, improvements in rural infrastructure, transport facilities and other technological innovations. The latter plays a key role, through the public agricultural research and extension services, in improving farmers' skills and the competitiveness of agricultural sector.

IRTA, among other private and public research institutes and universities, has been contributing to strengthen the system of agricultural technology in Catalonia. Since its creation, IRTA has constantly built up the stock of agricultural knowledge and research expenditures fluctuated around an expanding trend over time. In this context, it is important to know to what extent these investments are profitable for the society.

Our empirical findings report a positive and significant impact of the agricultural R&D on productivity gains across different model specifications. The preferred model suggests an elasticity of TFP with respect to the public knowledge stock at around 0.15 which is in line with previous findings looking at the economic performance of R&D investments (e.g. Alston et al., 2010; Sheng et al., 2011; Bervejillo et al., 2012; Anderson & Song, 2013; Butault et al., 2015). Consistent with previous studies, empirical results support that the agricultural R&D is a highly profitable investment. The social return to public R&D ranges from 15 to 28% per annum depending on different lag structures and real interest rate.

Assessing the relationship between the public R&D and the productivity growth would offer several policy implications for investing in the agricultural research. Our empirical findings confirm that part of the current productivity of the Catalan agricultural sector could be contributed to the agricultural research effort over the last decades. Therefore, according to the MIRR estimates increasing investments in the scientific knowledge and extension services would enhance productivity gains, which in turn may lead to improve the technical, economic and environmental performance of farms. In this way, a sustained long-term support for the Catalan agricultural research would be required to keep the relevant impact of the R&D investment on the society.

Public agricultural R&D is an effective tool to enhance the agricultural productivity growth. Empirical findings suggest that R&D policies will significantly affect the productivity growth in the long run as long as the public research institutes like IRTA continue to maintain its current effort or allocate more funds to the R&D activities to transfer new technologies and spread the adoption of existing knowledge between farmers. On the other hand, it is important for decisions makers to find alternative ways for funding the agricultural research and extension, including private-public collaboration through more inter-exchange of scientific resources, skills, and financial instruments.

The present work presents some shortcomings should be kept with cautions when interpreting empirical findings. First, the analysis relies on assumptions regarding shapes and length of lags. Second, since the private research and spill-over/ins are important factors that could affect the agricultural productivity growth, further investigations are still needed to determine the effect of these variables on productivity gains. Last but not least, there is still room for further lines of research to improve the analysis through using longer time series data and better measures of the effects of spillover/ins, and private research.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

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