Measuring the impact of agricultural research on Catalan agricultural productivity

Bouali Guesmi[1,2], José María Gil[1]

[1] Centre de Recerca en Economia i Desenvolupament Agroalimentari (CREDA-UPC-IRTA). Parc Mediterrani de la Tecnologia, Edifici ESAB, Avinguda del Canal Olímplic s/n, 08860 Castelldefels, SPAIN. Tel.: +34935521208; Fax: +34935521121. bouali.guesmi@upc.edu, chema.gil@upc.edu

[2] Department of Agricultural Economics, Mograne Agricultural High School, University of Carthage. 1121 Zaghouan , Tunisia. Tél.: (+216) 72 660 283; Fax : (+216) 72 660 563.

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Abstract

The main purpose of this article is to assess the impact of public agricultural research effort on agricultural total factor productivity in Catalonia. A complementary approach based on accounting and econometric techniques is applied to annual data over the period 1985–2015 to fit the relationship between agricultural total factor productivity (TFP) and agriculture research spending. The results show that TFP grows on average at an annual rate less than one percent. TFP growth was much faster during the tow first decades of the analysis, with a considerable slowdown in the last decade. Our empirical findings indicate that public agricultural research has statistically significant positive impact on Catalan agricultural productivity. Furthermore, from a cost–benefit perspective, our study reveals that the social marginal annualized real rate of return to public resources invested in agricultural research is about 15–28%.

Keywords: agricultural productivity, public agricultural research, knowledge stock, internal rate of return, Catalonia

***JEL Classification*:** C52, Q16, Q18

1. Introduction

Growth in total factor productivity (TFP) is a relevant indicator to assess the ability of the economy to generate gains. Thus, trends in agricultural TFP may provide valuable information about the performance of the sector. During the last five decades, productivity growth in agriculture has gained a substantial attention by the agricultural economist's community. The latter has focused their researches on the sources of productivity growth over time. The importance of productivity growth in the agricultural sector relies on ensuring a sufficient rapid growth of output to satisfy the increasing demands for agro-food products by the society.

Over the last decades, the Catalan agricultural sector has rapidly increased from €2041million in 1985 to reach €4310 million in 2015 presenting an annual productivity growth about 3% (The Spanish Ministry of Agriculture, Food and Environment; Agricultural Census; The Statistical Institute of Catalonia (Idescat), 2016). Technological advances are a main factor among others that may drive productivity growth. Hence, its role on productivity growth has recently received substantial attention. As a proxy to technological advances agricultural economists often use public and private agricultural research. The latter is shown to be a key factor of productivity gains. Moreover, Economic analyses have found reliable evidence that investment in agricultural research generate high returns per unit spent (Fuglie and Heisey, 2007). This finding of highly profitable investment suggests that research activity is consistently underfunded and that current government involvement may be insufficient (Alston et al., 1994).

The development of new technologies (e.g., new varieties and techniques, genetically enhanced livestock) and increased technological adoption allow producers to choose and combine inputs effectively in better ways which lead to improve yields. Agricultural productivity may increase through greater use of agricultural inputs, such as more fertilizers and machinery per ha of land or the same amount of output can be produced with lower inputs use. On the other hand, changes in TFP can be attributed to improvements in rural infrastructure (e.g., transport facilities). Indeed, it is of great importance to differentiate the contribution of changes in input use from that of other factors affecting the growth of the agricultural productivity. In particular, TFP index is often used as a reliable measure to this purpose.

Knowledge about productivity growth and its main factors would facilitate better decisions by policymakers who used investment and R&D policy as an instrument to promote agricultural development, farmers who try to optimize their production decisions by using less input, reducing costs and adopting new technologies as well as for nonfarm sectors of the economy. Furthermore, social concerns regarding the effectiveness of public agricultural research have been growing and need estimates of the expected returns of these investments. The relevance of this type of analysis has led many authors to evaluate the impact of public agricultural research investment on agricultural productivity.

Considering the social and economic importance of the agricultural sector in Catalonia, an investigation of the agricultural R&D impact on TFP growth would be of great worth for impact assessment and policy making. In fact, the objective of this article is to provide estimates of the impact of public agricultural research funding on Catalan agricultural productivity. Furthermore, results are used to construct estimates of the internal rate of return (IRR) to public agricultural research. To do this, accounting and econometric approaches are used to time series data over the period 1985–2015.

The remainder of this paper is organized as follows. The next section presents a literature review and the contribution of this work to the previous literature. Sections 3 and 4 offer a brief historical overview of the evolution of agricultural multifactor productivity and public agricultural research in Catalonia, respectively. Then, the econometric technique used for the empirical application is described in section 5. The sixth section outlines and discusses the results of the empirical implementation. Finally, section 7 provides some concluding comments and policy implications.

2. Literature review

In the past five decades, the number of studies that focused on examining agricultural productivity levels and growth rates has significantly expanded. Early analyses of public agricultural research impacts on agricultural productivity back to Griliches (1958), Huffman and Evenson (1994), Alston et al. (1994) and Alston and Pardey (2001). The literature on the economics of agricultural R&D is large due to mainly the availability of data and other information, the development of new approaches that deal with this type of data and the need to evaluate the degree to which the agricultural R&D programs have improved agricultural productivity (Alston, 2010). Indeed, several economic assessments have attempted to determine the "social rate of return" to agricultural R&D expenditures which is defined as a percent return on each euro spent on research. They offered a range of estimates of returns to agricultural research indicating that the payoff from the government's investment in agricultural research is high.

Instead to measure individual productivity per unit of a particular input, TFP has been developed and expressed as aggregate output per unit of aggregate input. The latter allows combining all measurable inputs such as land, labor, capital, and purchased inputs. The literature on TFP measurement is mainly divided into two groups. While a first group used index number theory (economic accounting measure) to estimate productivity, a second group used econometric approach namely non parametric (data envelopment analysis (DEA)) and parametric methods (Stochastic Frontier Analysis (SFA)). Regarding the former method, Tornqvist-Theil and Fisher ideal indexes are the most likely used in the previous literature.

TFP growth is often expressed as a function of agricultural research investment. Studies on gathering research capital variables from research expenditures are still in its early stage and often refer to Griliches (1958)'s work. Since then, the scientific community used public agricultural research expenditures to proxy the "true" measure of agricultural research innovations that impact productivity (Huffman and Evenson, 2006).

The effect of agricultural research is not immediate and entails a long lag time to affect productivity. To capture the impact of R&D that possibly affects productivity over a period of several years, alternative specifications of shapes and lag length have been examined in the literature (e.g., gamma, trapezoidal, inverted U or V). Nevertheless, there is still some diverge in opinion regarding total lag length. Evenson (2001) suggested that free-form lag estimates are unsatisfactory due to a high correlation between lagged research expenditures and hypothetical shape of timing weights should be imposed. For instance, Griliches (1998) concluded that the pattern of the impact of research and development on productivity may pass by a short gestation, blossom and obsolete periods. The reason behind using such assumption is that initially the contribution of research is insignificant, but as research results become available and are adopted by more producers, its effects become progressively more important and positive over the next period followed by years of maturity during which weights are high and constant as innovations are integrated in the production process (Lyu et al., 1984). After a longer period, the impact of the innovations becomes obsolete.

With respect to the impact of agricultural R&D on productivity growth, previous literature proposed the social rate of return to measure the direct benefits of additional public funds. It is often used the net present value theory to determine this measure. Two main approaches have widely been used in the literature to estimate returns to agricultural research. While statistical techniques attempt to relate past expenditures on research to changes in productivity, project evaluation methods trace the development and dissemination of innovations. The former method is mainly a causal relationship which is a prerequisite step to derive the return to research. Griliches's pioneering empirical work in the 1950s developed econometric techniques to relate productivity or output to past investments in research and development (R&D). He determined the economic value of higher maize yield made possible from innovation versus the cost of research and extension. The author found an annual IRR of 35-40%.

Only few studies have tried to estimate 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. Lyu et al. (1984) evaluated the effects of agricultural research and extension expenditures on productivity in the United States during the period 1949-1981 using production function approach. They concluded that the total marginal product and IRR for the United States are $8.11 and 66%, respectively. Their findings indicated that the use of Cobb-Douglas production function would overestimate the IRR to agricultural research. Later, Huffman and Just (1994), using state productivity data for 1948–1982, found that federal formula funding has a greater impact on agricultural productivity than competitive grant funding, due to the high transaction costs associated with the latter.

In another study, Huffman and Evenson (2006) examined the impact of public agricultural research and extension on agricultural TFP at the state level paying attention to the composition of the funding sources. They found a statistically significant positive impact of public agricultural research and extension on state agricultural productivity which is larger with respect to formula funding than federal competitive grant funding. Furthermore, they showed that the social real IRR to public resources invested in agricultural research vary from 49 to 62%, and to public agricultural extension, the rate is larger.

Based on Alston et al's (2010) technique, Bervejillo et al. (2012) used different estimations to measure the returns to public agricultural research conducted in Uruguay over the period 1961–2010. They reported that the IRR was stable across models with different lag structures, ranging from 23% to 27% per annum. Anderson and Song (2013) examined the impact of public agricultural research undertaken by USDA and SAESs on agricultural productivity at the U.S. aggregate level. They assumed a short gestation period followed by a total lag length of 50 years to build a research stock variable. They reported that a productivity elasticity of public agricultural research capital varied between 0.28 and 0.35 and the IRR is on the range of 8-10%.

The availability of more updated data with a long lag length, improvement in measures of research returns to provide consistent estimates and other information motivate researchers to continue conducting such analysis. Recently, Jin and Huffman (2015) investigated the marginal product of public agricultural research and extension on state agricultural productivity for a panel of contiguous U.S. 48 states from 1970 to 2004. Their findings indicate a real IRR to public investments in agricultural research of 67% and to agricultural extension over 100%. More recently, Butault et al. (2015) evaluated the effect of public agricultural research spending on French agricultural productivity for the period 1959-2012. They found that the increase in R&D expenditures by 1% raises the average TFP growth rate by 0.15% leading to obtain an average social IRR around 30%. It is evident that the estimated rates of return are sensitive to specification choices, the methodology used in the analysis, commodities and coverage. Examples of results from recent studies are summarized in table 1.

Our contribution to the literature is of empirical nature. First, to our best knowledge, there is no study in Spain or in Catalonia that was interested in determining the social rate of return to agricultural R&D expenditures. The existing studies in this country only focused on the relationship between the R&D expenditures and productivity growth in the long run using cointegration and causality analysis (Alfranca, 1998; Fernández, 1999; Díaz and González, 2001). Second, while previous studies aimed at assessing TFP growth at national level, this work is the first study that deals with the Catalan agricultural TFP at macroeconomic level. Finally, the present work is of great importance to offer sound estimates to policymakers about agricultural research investments for the future.

3. Aggregate inputs, outputs and multifactor productivity

This section sheds light on the role of agriculture in the Catalan economy and reports statistically the growth in production and productivity over 1990-2015. Agriculture sector in Catalonia continues to play significant social and economic role in the economy. By 2015, it offers over 60 thousand jobs for the rural community which represents about 2% of the working population (Statistical Institute of Catalonia (Idescat), 2016). The number of farms is nearly 60 thousand distributed over almost one million ha. These farms generate about €4310 million around 1% of the total value of production in 2015 which is reduced compared to its share 2.3% in 1986. However, the agriculture revenue has grown at an annual rate of 3% during the period 1985-2015. In 2015, Catalonia accounts for about 8.5% of the value of Spanish agricultural GDP (up from 7% share in 1986) using just 4% of the total country's UAA. The relevance of the agriculture sector in the Catalan economy makes this analysis especially interesting.

In order to derive TFP index of Catalan agriculture, we use Fisher ideal index (i.e., a discrete approximation of a Divisia index). TFP index is computed as the ratio of the aggregate outputs index to the aggregate inputs index. The value of the index is defined as 100 in the base year, 1990. To compute the aggregate outputs and inputs indices, our study is based 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, 1990–2015. This study offers the first estimates of TFP growth for Catalan agriculture.

The Data for the application are collected primarily from Catalan national statistical agencies (Agricultural Census and Idescat). Also 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. Our database covers the period 1990-2015. The rental cost of capital and the annual cost of capital services obtained from data published by Banco Bilbao Viscaya Argentaria have been used to compute capital input. The labor input represents the total number of jobs created by the agricultural sector. The price of labor for every year is derived by dividing the annual cost of agricultural labor by the total number of jobs. Land input is represented by the total utilized agricultural area. Average rental prices of land are taken from Agricultural Census. This average is a weighted average of the annual rent paid to landowners for each type of land. Before 1998 rental prices of land are not available. We derive the rental rate using the ratio of paid rent to the sales value of the land observed during the period 1998-2015 which varies from 18% to 23%. The average ratio is used to determine the rental price for the entire period. Table 2 summarizes the growth rates of the three series output, input and TFP over the period of analysis.

Between 1990 and 1995 the aggregate output index represents an increase of about 0.7% per annum. This growth is accompanied by a decrease in application of fewer inputs. Indeed, the increase in output not due to additional input use can be attributed to productivity growth. The latter grew by 1.45% per year. Crops and livestock production increased at a faster rate (1.56%) during the second half of the 1990s than it did during the preceding period. This growth was achieved with only a 0.5 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. The highest productivity growth (1.5%) is reached between 2005 and 2010 resulting in decrease of both output (0.63%) and input use (2.1%). During the last sub-period of analysis, 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, positive input growth is associated with slow TFP growth. Indeed, the productivity index declined by 1.2% per annum representing the slowest rate compared to preceding sub-periods.

Over the period 1990-2015, Catalan agricultural output growth is almost stable while it is evident for input growth to be negative. TFP increases at an average annual rate of 0.53% from 1990. Therefore, since 1990 productivity growth have added €515 million to the value of output in 2015 (12.3% of €4187 million worth of total agricultural output). This productivity gain may be attributed to technological innovation resulting essentially from R&D investments realized by agricultural research institutes in Catalonia.

4. Public Agricultural Research in Catalonia

The pattern of total R&D spending in Catalonia shows clearly the effort realized by the Catalan government "Generalitat de Catalunya" to strengthen the system of technology in order to improve productivity and increase market competitiveness and farmers' revenues. In 2014, total R&D expenditures reached €2938 million of which 43% are funded by public funds (Idescat 2016). However, total expenditures in R&D are still low representing less than 2% of the Catalan GDP.

The Department of Agriculture, Livestock, Fisheries, Food and Natural Environment (DAAM) allocated around 12.5% of its budget to R&D activity, which is the second important effort in R&D behind the Department of Economics with 40%. During the period 2008-2010, the agricultural department spends in R&D, on average, €56 million which is among the highest investments by the Catalan government behind the Department of Economics (€640 million) and the Department of Health (€246 million). Public spending on agricultural research is rapidly growing and reached €87 million in 2010. Since 2008 this expenditure has increased by 159% with an annual growth of 40 % between 2008 and 2009 and 85% between 2009 and 2010. Statistics data on private agricultural research are not available which make the assessment of its relevance within the general context difficult. In 2009, the contribution of private sector is equivalent to €69 million.

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 Government of Catalonia and ascribed to the DAAM. The main goal of the IRTA is to become the strategic ally of the agro-food sector, to conduct original research on agriculture and to be the locomotive of innovation and technology transfer for this field. IRTA is composed of ten centers and field stations of its own and also 3 associated centers spread across different locations in Catalonia. The total number of employees at the IRTA is 636 of which 188 are researchers and the remaining are support personnel. Accounting for employees at the associated centers the total number of workers is expanded to reach 1016 people.

IRTA represents the predominant form of public agricultural research activity in Catalonia. Between the period 2008 and 2010, it administrated 1405 noncompetitive research projects (€27.5 million) of 4528 research projects (€51.3 million) (DAAM, 2016). Thus, it plays a significant role to enhance the system of agricultural technology in Catalonia. Its strategy on R&D would contribute to the modernization and promotion of competiveness and sustainable development in the agriculture sector especially in increasing domestic and international market competiveness. Thus, innovation effort may lead agriculture sector to provide safe, quality foods to the final consumer and generally to improve human welfare. IRTA has continuously built up the stock of agricultural technological knowledge specifically in crop systems and soil management, dairy, wheat and barley breeding, fertilization and plant protection, animal nutrition, and integrated pest management for fruits and vegetables.

The research activity is usually long-run term of nature and need times to generate social and private benefits, for this reason research institutes need help to support them (Alston et al., 1994). In Catalonia, public agricultural research is primarily undertaken by IRTA which amounts to about €61 million accounting for 32% of the total during the period 2008-2010.

In 1986, IRTA spent €4.1 million on agricultural research 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, IRTA research 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 growth of R&D spending pattern evolves unevenly over time. It slowed considerably from 13.6% during 1986-1995 period, to 10.2% between 1995-2005 and to become less than 3% over the last decade. It is noteworthy to stress that the growth of expenditures on agricultural research turned negative (-10%) from 2010 to 2014. This is mainly due to the consequences of 2008's financial crisis which results in a reduction in Spanish government support for agricultural research. In 2015, agricultural research spending presented some renewed growth in 2015.

Table 3 summarizes the sources of funds and its distribution for IRTA research over time. The composition of funds is not uniform over time and varies significantly. In 2015, the 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 funded by the Catalan government. IRTA has been successful in obtaining competitive grants funds which represent on average 16% of the total spending during the period of analysis. 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. Also, it is worth noting that the 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 operating costs continue to occupy the lion share of total IRTA spending, representing 70.4% and 73% in 1986 and 2015, respectively.

Public agricultural research expenditures can be considered as an investment. Hence, it is crucial to know to what extent these investments yield a favorable and profitable return for the society.

5. Econometric model of agricultural productivity

As discussed earlier, 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 fit as a function of past investments in agricultural R&D which in turn show a notable progress over the period of our study. It is worth noting that public agricultural research capital is one important determinant of total factor productivity in agriculture. The annual average growth in public agricultural research expenditures over 1985–2015 is high, at over 8%. Changes in technologies which in turn are linked to past R&D expenditures by public sector (IRTA) in Catalonia could reasonably be expected to affect agricultural productivity growth.

In order to provide a sound and empirically comprehensive assessment of the effect of trends in R&D expenditures on Catalan agricultural productivity, and the social returns to these investments, a complementary approach based on accounting and econometric approaches has been used. The evaluation of this effect involves relationship between increased productivity flows and benefits in which long lag times that agricultural research takes to affect productivity have to be accounted for properly.

To achieve the aforementioned objective, TFP growth at time period t is assumed to be a function of stock of public agricultural research with a lag length of 10 years, K_t. Private agricultural research and technology spillover (from other countries) and spill-in (in other provinces) are also expected to affect agricultural productivity gains as found in previous literature. However, like other many studies that are constrained by availability of such data type unfortunately currently they are not included in our model and the assessment of their importance is not possible.

Public agricultural knowledge stock is built using data on total expenditures on agricultural research by IRTA over the period 1985–2015. To do so, we approximate the pattern of timing weights assuming a gamma lag distribution model proposed by Alston et al. (2010) which is represented as follows:

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

L_R represents the total lag length and the β_k parameters are lag weights applied to agricultural research investment k_t over the past 10 years, R_{t-k}. The weights are normalized and sum to one. Lag effect distribution may present two periods. During the first one the impacts of public agricultural research expenditures on productivity are assumed to become progressively more important, positive and are represented by increasing weights. Then, during the second period the effects follow declining weights and go to zero eventually as innovations become obsolete. By assuming a gestation period of zero (Alston et al., 2010), the research lag weights (β_k) can be derived from the following expression:

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

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 the growth rates of public agricultural research spending are reflected in research capital stocks. Total agricultural research expenditures are used as a measure of capital research including the subset of all public agricultural research expenditures undertaken by the IRTA. Since the latter has been founded in 1985, availability of data on agricultural R&D before this year is not possible. Indeed, we assume 10 years total lag length following gamma distribution. Under this assumption we obtain a smooth series for the stock of public agricultural research. The resulting lag distribution allows getting 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 productivity growth, a weather variable has been also included in the model. Regarding the weather variable (C), following Butault et al. (2015) it is defined as the difference between precipitation and potential evapotranspiration. As explained above, it is important mention 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 before 2010 and takes the value of one after this year. We expect the variable to be significantly negative, which means that reducing R&D spending will affect negatively the productivity growth. Table 4 provides a brief summary of the variables used in the empirical productivity model.

A Ln–Ln productivity function is commonly used (Huffman and Evenson 2006; Alston et al. 2010, 2011; Bervejillo et al., 2012; Anderson and Song, 2013; Butault et al., 2015). The Cochrane-Orcutt procedure has been used to deal with the time series nature of the data. This model allows correcting for first order autocorrelation assuming that the error term follows a first-order autoregressive process. The econometric model of agricultural productivity growth is specified as follows:

$$LnTFP_t = \alpha_0 + \alpha_1 LnK_t + \alpha_2 C_t + \alpha_3 D + \mu_t \quad (3)$$

Where the error term is defined as follows :

$$\mu_t = \rho\mu_{t-1} + \varepsilon_t \quad (4)$$

and ε_t is an error term assumed to be independent and identically distributed. α_1 represents the elasticity of TFP with respect to change in capital stock of research. The elasticity of productivity growth of public research is of considerable interest in computing the rate of return to investments. Given a maximum lag length of 10 years, and data on research expenditures that started from 1985, data on TFP allows to estimate the model only for 1995-2015 period. To construct the research stock variable, a grid-search procedure has been used to assign values for the parameters of the gamma lag distribution (δ and λ). The choice of the optimal values for δ and λ is based on the parameters that best fit the data. Given a fixed maximum lag of 10 years, 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 is developed using the estimated parameters of productivity growth model. The gross annual research benefit (GARB) in year t is calculated using the following approximation:

$$GARB_t = \Delta\ LnMFP_t \times V_t \tag{5}$$

where V_t , expressed in constant 1990 prices, represents the real agricultural output in year t, and $\Delta LnMFP_t$ denotes the proportional variation in agricultural productivity in year t, induced by a simulated increase in public agricultural research spending. This variable is computed as the difference between the predicted LnMFP given the actual research spending and the predicted LnMFP with the increased (hypothetical) research expenditures. Furthermore, the present value in the year 2015 of accumulated benefits (PVB) is derived based on an annual real interest rate of r = 5% (values of r = 3% and r = 10% have been used for comparison purpose).

$$PVB = \sum_{t=1995}^{2015} GARB_t \times \left(1+r\right)^{2015-t} = \sum_{t=1995}^{2015} \Delta LnMFP_t \times V_t \times \left(1+r\right)^{2015-t} \tag{6}$$

Following previous studies, an estimate of the average annual IRR to the public investment is also deduced by solving the following expression:

$$\sum_{n=0}^{N} B_{t+n} \times (1+r)^{N-n} - I_t (1+m)^N = 0 \tag{7}$$

where I_t represents an investment at time t, B_{t+n} is a flow of benefits which would be reinvested at the interest rate, r over the N years and m indicates the IRR.

6. Results

Using the aforementioned methodology and $LnTFP_t$ in year t as the dependent variable, various 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 5.

Results show that the top four models accounts for 53% of the variation in TFP from 1995 to 2015. As expected, the inclusion of R&D stock in the specification has a positive impact on productivity gains. On the other hand, results suggest that the shape of gamma distribution does not affect the parameter estimates very much across different models. The preferred model is obtained with values for δ = 0.60 and λ = 0.90. Moreover, the other alternative specifications display 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 highly significantly different from zero at the 1% significance level. The elasticity estimate shows a relatively low value at around 0.15. However, it is close to those obtained from previous studies that suggest elasticities between 0.16 and 0.30 (e.g. Alston et al., 2010; Sheng et al., 2011, Butault et al., 2015). Besides, results show a significant and negative impact of financial crisis on R&D spending after 2010 indicating that reducing investment in scientific knowledge leads to sluggish productivity growth of the Catalan agricultural sector.

Based on the preferred estimation, with an incremental investment in 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 the 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 the marginal effect (benefit-cost ratio which is defined as the ratio of the PVB to PVC). The marginal benefit-cost ratio is of 32 indicating that the annual flow of simulated benefits from productivity growth since 1995 is many times greater than the annual flow of research costs.

Table 6 provides estimates of the marginal benefit-cost ratio and IRR for our preferred model and the three alternative specifications as well. With an assumed real interest rate of 5% and for a marginal increase in agricultural research spending in 1995 the annual IRR to public research investment is about 24%. Rates of return are essentially identical across different model specifications. Our findings are somewhat similar compared with many of the estimates in the literature for returns to public-sector agricultural research (e.g., Alston et al. 1994; Bervejillo et al., 2012; Butault et al., 2015). The difference in estimates may be mainly ascribed to the comparatively short lag length, the omission of some variables such as private agricultural research and the case study itself of the present work. An annual rate of return of 28% is plausible indicating a good social rate of return on the IRTA investment for society. Rates of return are computed using different real interest rates (see table 6). Results show that the estimates of IRR range from 22% to 28% per year. They are relatively insensitive to different lag structure and relatively stable across different model specifications.

The low values of R^2 suggest some problem with the specification of the model, such as omission of some variables that may affect productivity growth in Catalonia. Among these variables are private research effort and spill-ins/over effects of research from national and international research institutes. The omission of unmeasured factors on productivity tends to overestimate the public research impact. Thus, the public knowledge stock coefficient is likely to be biased upward. To overcome this shortcoming we suppose different share of benefits attributed to public agricultural R&D while the remaining benefits would be attributed to omitted variables. A second IRR has been derived by using 100%, 75%, 50% and 25% of the values for measured benefits and a reinvestment rate of 5% per year. Accounting for other variables that may be behind some of the measured benefits reduce the estimated annual IRR to 15-26% per annum. In general, results show that the estimated annual rate of return varies from 15% to 28% with whether the stream of estimated benefits are totally attributed to IRTA or cut in different share of contribution. Indeed, it is clear of evidence that the IRTA investment on agricultural R&D is profitable for society through improving productivity performance of agriculture sector in Catalonia.

7. Conclusion

Over the period of the present study, the TFP analysis indicates that TFP index of agricultural sector in Catalonia increased from 100 in 1990 to about 114 in 2015. A part of this growth is used to be attributed to conventional inputs use. Holding productivity constant, 12.3% of the output in 2015, worth €515 million, is due to productivity growth since 1990. This productivity gains could be accounted for by other factors such economies of scale, improved managerial skills, improvements in rural infrastructure, transport facilities and other technological innovation. Hence, the latter is of considerable importance to improve farming skills.

IRTA, among other public research institutes and universities, plays a relevant role to strengthen the system of agricultural technology in Catalonia. Since its creation, IRTA has continuously built up the stock of agricultural technological knowledge and research expenditures fluctuated around an expanding trend through the period of analysis. Total research spending has significantly grown recording an average annual rate of 8.5%. In this sense, it is so relevant to know to what extent these investments are profitable for the society. The aim of this paper is to assess the impact of agricultural research realized by IRTA on Catalan agricultural productivity. Two complementary accounting and econometric approaches, recently proposed by Alston et al. (2010), have been use to conduct this analysis covering period 1985-2015.

The econometric analysis reports a positive and significant impact of agricultural R&D on productivity gains across different model specifications. The preferred model is obtained with values for $\delta = 0.60$ and $\lambda = 0.90$ and shows an elasticity of TFP with respect to the public knowledge stock relatively low at around 0.15. However, it is in line with previous findings (e.g. Alston et al., 2010; Sheng et al., 2011, Anderson and Song, 2013; Butault et al., 2015).

Consistent with previous studies, empirical results support previous literature that agricultural R&D is a highly profitable investment. However, some of important unmeasured factors (i.e., private research and spill-in/over) to explain productivity gains are omitted in the empirical model due to unavailability of such data type. The social return to public R&D ranges from 15 to 28% per annum depending on different lag structure and real interest rate. Results are somewhat insensitive to different parameters of gamma distribution as well as to assumptions to account for potential impacts of omitted variables in the model.

Assessing the relationship between public R&D and productivity growth would offer several policy implications for public strategies for investing in agricultural research. Our empirical findings confirm that part of current productivity of Catalan agricultural sector is obviously related to agricultural research effort over the past years. Thus, according to the estimated IRR increasing investment on scientific knowledge and research techniques would enhance productivity gains which in turn may lead to improve technical, economic and environmental performance of farms. In fact, a sustained long-term public-sector support for Catalan agricultural research would be required to keep the relevant impact of such investment on society at whole.

Public agricultural R&D is a profitable investment and an effective tool to promote agricultural productivity growth. Based on our empirical findings, R&D policies design will significantly affect productivity growth in the long run as long as public research institutes like IRTA continue to maintain its current effort or allocate more funds to agricultural R&D. IRTA investment in R&D is of clear strategic importance in terms of transferring new technologies and spreading the adoption of existing knowledge between farmers. Increase in IRTA expenditure could help to improve the performance of farms in Catalonia. Moreover, it seems that the contribution of private sector would have a positive impact on productivity gains in agricultural sector. Thus, it is important for decisions makers to seek alternative ways for financing agricultural R&D, including private-public partnerships which would be very valuable.

The present work presents some shortcomings should be kept with cautions when interpreting and using these estimates. First, some assumptions regarding shapes and length of lag have been made to conduct this analysis. Second, since the private research and spill-over/ins are crucially important, further work to explore the effect of these variables on Catalan productivity gains will be very important once they are available on hand. Finally, there is still likely to improve the analysis significantly with more extended data and better measures of the effects of spillover/ins, and private research. This merits further attention in future research.

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Table 1. Summary estimates of the rate of return to agricultural research

Authors	**Country**	**Period**	**Social rate of return**
Alston et al. (1994)	USA : UCD	1949-1985	17.10-21.40%
Alston et al. (2011)	USA	1949-2002	9.00-10.00%
Bervejillo et al. (2012)	Uruguay : INIA	1961-2010	23.00-27.00%
Anderson & Song (2013)	USA	1949-2002	8.00-10.00%
Jin and Huffman (2015)	USA	1970-2004	67.00%
Butault et al. (2015)	France : INRA	1959-2012	27.40-28.10%

Table 2. 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

Table 3. 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, 2016

Table 4. 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 Fisher index of 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 agricultural research (in) 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

Table 5. 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)

Notes:
Standard errors in parentheses; ***Significant at 1% and **significant at 5%.
[1]Rank: Model rank by the sum of squared errors (SSE) and R^2.
[2]Peak lag is the number of years until the current investment has its maximum impact on the research stock.

Table 6. 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