2020

THREE PERSPECTIVES ON INNOVATION IN EUROPEAN AGRICULTURE: FROM PUBLIC RESEARCH TO THE CIRCULAR ECONOMY

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Digital Object Identifier: https://doi.org/10.13023/etd.2020.433

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THREE PERSPECTIVES ON INNOVATION IN EUROPEAN AGRICULTURE: FROM PUBLIC RESEARCH TO THE CIRCULAR ECONOMY

DISSERTATION

A dissertation submitted in partial fulfillment of the
requirements for the degree of Doctor of Philosophy in the
College of Agriculture, Food and Environment
at the University of Kentucky

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2020

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ABSTRACT OF DISSERTATION

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The dissertation examines the idea that current and future challenges faced by the European agricultural sector call for a multidimensional approach combining the classical path of productivity growth with more stringent commitments to environmental protection, and more incisive mitigation and adaptation actions to mitigate climate change, all within a policy context of a transition toward the cyclical management of resources (inputs, outputs and wastes) inspired by the circular economy concept. The three essays of the dissertation aim to show: that agricultural productivity in Europe is supported by complementarities between public and private investments in agricultural research with remarkable results in terms of rates of return; that the processes of knowledge-based innovation adoptions improve the economic performance of farms, especially by focusing on higher quality and value-added of agricultural production; and that an innovative approach, based on a combination of policy coherence and targeted technological solutions, can trigger the circularity of water use across urban and agricultural economic sectors, providing a valid solution for improving the allocative efficiency of irrigation water, while safeguarding the status of the aquifers and the river basins.

The reading key for the dissertation is, *innovation* conditioned by *policy priorities*, and the three essays provide a perspective on the evolution of the role of agricultural innovation over time in the context of the changing policy priorities of the European Union. Since the 1950s innovation in agriculture has always been an engine of economic growth in Europe. Over time, patterns of the creation and diffusion of agricultural innovation in Europe changed notably, from improving farm productivity and intensification in the first periods, then to sustainable intensification and natural resource (environmental) protection in a second period, and most recently a new focus on implementing a more circular economy. The dynamics that lead from research to innovation, and from innovation to economic growth are changing as well. Europe is assisting a switch from the old linear transmission of knowledge approach (research-extension-farmer) to a more modern network-type agricultural knowledge and innovation system (AKIS) (Klerkx *et al*., 2009), as well in making transitions from the linear paradigm of economic growth to a more

circular economy system by *closing the loop* and guaranteeing productivity improvement *without impairing natural resources* (EC, 2015).

The objective of this dissertation is threefold: i) macro – to assess the economic impact of public investments in agricultural research on agricultural productivity in Europe through analysis of aggregate rates of return; ii) micro – to assess the impact of information, research *in primis*, at the farm level through the analysis of the effects of innovation adoption on individual farm profitability in one region of Italy; and, iii) environmental – to explore theoretical application of the circular economy concept to the reuse of water and irrigation management.

The first essay provides an evidence-based assessment of the impacts of publicly supported R&D and innovation of agriculture in Europe. A panel model framework is applied to 16 European countries. The impacts of R&D investments and agricultural patents on agricultural productivity (TFP) were estimated, and rates of return (RoR) from public expenditures have been computed. The results vary according to the length of the imposed lags, showing a positive but decreasing pattern of effects both on TFP and return rates. Although preliminary, the values are deemed consistent with the evolution of research productivity over the last three decades in Europe, which has been characterized by a shift of the CAP from productivity enhancing investments, to a public commitment to improving environmental sustainability.

The second essay aims at analyzing the determinants of farmers' adoption of innovations and studying their effect on profitability. Different from existing literature, beyond examining adoption behavior, I investigate whether the source of information and the connection of agricultural research with an adopted innovation influences the economic performance of farms. Relying on primary data collected in the Bologna province (Italy), an econometric analysis is conducted in order to assess determinants of adoption and to estimate the impacts of such decisions on farm profitability. The results indicate that a farmer having a connection to scientific research, although not determinant for the adoption decisions, triggers significant improvements in profitability, in terms of value-added and quality of production, but does not affect other profitability-related parameters.

The third essay proposes a framework for the Circular Economy (CE) concept to be applied to the water sector. The European Green Deal and the CAP post-2020 challenge the European agricultural sector by imposing stricter environmental cross-compliance measures linked to a strong demand for improved competitiveness, all within an overarching policy framework that pursues: the circularity of resources, climate neutrality, and economic growth decoupled from resource use. Although the agricultural sector has been excluded from the direct application of the CE concept, it remains highly subject to various requirements to pursue sustainable intensification, with frequent risks of: prosecution for environmental noncompliance, and of production and income losses, due to market volatility and climate change, especially related to the scarcity of water resources. However, a possible solution might be found in the proposal of a CE framework that is able to provide for a combined set of policy measures, coordinated across the urban and the agricultural sectors, and that mainly deal with specific technological improvements aimed at producing safe additional irrigation water from urban treatment plants and at optimizing the irrigation use, seemingly without consequences on levels of current water tariffs.

KEYWORDS: Europe, Agricultural productivity, Returns to public R&D investments, Innovation adoption, Circular Economy, Water management.

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DEDICATION

To *my grandparents, who donated me an exemplary way of living, to my parents, who allowed me to make my own personal and professional choices, to my wife and sons with whom I shared every single day of this wonderful experience and all the good people who trusted me and supported me in this journey.*

ACKNOWLEDGMENTS

The following dissertation, while an individual work, benefited from the insights and direction of several people. First, my Dissertation Chair, Dr. David Freshwater, exemplifies the high quality scholarship and human good qualities to which I aspire. In addition, Dr. Freshwater provided timely and instructive comments and evaluation at every stage of the dissertation process, allowing me to complete this project regardless of the time constraints. Next, I wish to thank the complete Dissertation Committee, and outside reader, respectively: Dr. Berry J. Barnett, Dr. Carl R. Dillon, Dr. William H. Hoyt, Dr. Jordan M. Shockley, and Dr. Anthony Creane. Each individual provided insights that guided and challenged my thinking, substantially improving the finished product.

In addition to the technical and instrumental assistance above, I received equally important assistance Dr. Tyler Mark and Janene Toelle, who smoothed the way for me till the end of my journey. My wife, Marianna Filosa, and my sons, Lucio and Davide, although receiving my full care and attentions, shared with me the burden of achieving this extraordinary result. Finally, I wish to thank all those sincere friends who happily encouraged me to keep hanging on.

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CHAPTER 1. AGRICULTURAL R&D AND INNOVATION IN EUROPE: INVESTMENTS, PRODUCTIVITY AND RETURNS

1.1 Introduction

The growth of agricultural production worldwide has been boosted by the adoption of innovations, which increasingly are derived from the implementation of research outcomes. The role of research as a fundamental driver of agricultural productivity has been widely acknowledged in the scientific literature of the last 60 years (Schultz, 1953; Griliches, 1957; Ball *et al*., 2001; Ball *et al*., 2010). Improved methodologies for quantifying research impacts on agricultural productivity, with the aim of precisely estimating the rate of return (RoR), is an issue that has been challenging economists for a long time, especially in developed countries. The first attempt by Griliches (1958) estimated the present value of research investments that allowed the introduction and diffusion of hybrid corn in the US. This was followed by many other studies confirming the high long-run profitability of agricultural research investments (Alston *et al*., 2000; Pardey *et al*., 2006; Piesse *et al*. 2010; Hurley *et al*., 2014). Such empirical evidence generated growing interest, especially in developed countries, in the roles of agricultural research conducted by public policy bodies, public institutions (universities) and private firms, each focusing on different dimensions of agricultural innovations, but with all having the objective of triggering growing rates of agricultural productivity, through more targeted investments (Sunding and Zilbermann, 2001). This pattern, however, recorded a turn in the last decades when governments in developed countries reduced their rates of investments in agricultural research, while developing countries, in contrast, initiated institutional and political reforms in order to sustain both agricultural research and productivity (Wang *et al*., 2012; Fuglie, 2016).

The reasons for reduced investment in agricultural research by developed countries remain objects of current discussion, both in academia and policy milieus. In fact, there is still disagreement about: the validity of agricultural productivity measurements, the reliability of RoR estimates (considered upward biased), and about the factors responsible for the reduction of interest in agricultural research, especially in Europe (Alston *et al*., 2000, Alston *et al*., 2010; Fuglie *et al*., 2012; Wang *et al*., 2012). Indeed, the shift of the European Common Agricultural Policy (CAP) from production-based supports to a growing environmentally sustainable policy framework, set forth with the MacSharry reform in 1992 and more fully imposed with the Agenda 2000 reforms, have reduced the stimulus for improving productivity and, instead provided incentives for the adoption of environmental-friendly practices (Matthews, 2013). This shift might have in turn induced a change in national research agendas of European countries, loosening the attention on agricultural productivity and turning the focus to the environmental sustainability of agricultural activities.

The consequences of this shift, in terms of productivity, are still evolving, given that in the last twenty years the CAP moved to a direct income support system decoupled from production and to a shift in funding to rural development measures. These changes contributed to a bifurcation of agriculture structure with the emergence, on one side, of capital-intensive, market-oriented large farms mostly devoted to the production of food and feed and, on the other side, the persistence of smaller farms that were incentivised: to contribute to the general economic development of rural territories, to the environmental sustainability of the agricultural activities, and to the production of ecosystem services and public goods (Pe'Er *et al*., 2019). However, the latest rural development programme (RDP)

2014-2020 of the CAP provided support for the establishment of *innovation operational groups*, aimed at stimulating the interaction among agricultural stakeholders and the research sector, with the direct involvement of farmers in the twofold guise of both developers and adopters of innovations. Such a new European context makes it harder on one hand to rely on TFP measures, and, on the other hand, to identify a direct connection among public research expenditure, private efforts and agricultural sector productivity.

The objective of this essay is to assess, through quantitative analysis, the contribution that public and private expenditure on agricultural research have had on the evolution of the agricultural sector in the Europe, in terms of agricultural productivity. Five objectives are targeted in this essay: i) to assess the effects of public research investments on agricultural productivity; ii) to compute the relative rates of return of this investment; iii) to estimate the effects of agricultural patents on agricultural productivity, iv) to quantify the effects of other factors on the agricultural productivity; v) to identify the impact of various lag lengths on the preceding objectives. Such aims concur, *inter alia*, with filling a gap in the recent literature, which has not included quantitative analyses of R&D impacts on European agriculture. The essay proceeds with a review section on the relevant literature, followed by the presentation of the data and methodology. Subsequently two sections on the description of the results and then related analysis follow. The essay is closed by a concluding section.

1.2 Literature review

Agricultural productivity growth is considered to be a principal driver of economic development of countries (Timmer, 1988; Gollin *et al.*, 2002; Tiffin *et al.*, 2006). Evidence of the connection between spending on research and development (R&D) and the performance of (agricultural) productivity has strong evidences in the academic literature (Shultz, 1953; Griliches, 1958; Parente, 2001; Hall *et al.*, 2010). Most studies (Ball *et al*., 2001; Fuglie, 2016) measure agricultural productivity by the means of Total or Multi Factor Productivity (TFP or MFP), as formally defined in the Solow model (the Solow residual) (Ten Raa *et al.*, 2011). Since the main objective of such studies is to obtain as realistic a representation as possible, the computational methods and estimation techniques for TFP have been considerably improved through several techniques, such as: the use of aggregation and index numbers, the dual approach and others (Hall *et al.*, 2010), while still remaining in the neoclassical framework of the Solow model. Consequently, technology advances – and their causes – remain exogenous elements of these models.

Such a framework, in fact, completely ignores the decision processes of agents and institutions for generating and adopting new technologies; and, hence, treats change in technology as a costless factor. However, Lipsey *et al*. (2000) strongly criticize the reliability of TFP as a truthful measure of productivity. Indeed, they reject the ability of TFP as commonly measured to catch all the productivity improvements stemming from technological changes, arguing that many other factors affect productivity in different patterns and that such factors are not fully accounted for in the usual computations of TFP. Similarly, Syverson (2011) highlights that productivity[1] measures at the firm level systematically neglect some factors proven to be responsible for productivity improvements. Some of these are the managers' experiences and training, and the general adoption of management best practices, such as, the creation of complementarities that improve the organization and coordination of inputs. Other elements not caught by usual

[1] Productivity is intended as changes in production isoquants and not as movements on isoquants, the latter being determined by changes in relative prices and factors' substitution.

computation techniques include, the role of increasing economies of scale of firms, related to capital-augmenting productivity driven by growth in labor productivity, and the role of price variabilities in non-competitive markets, that are mostly affected by product quality and market power. These biases are more pronounced in aggregate indexes, for which specific assumptions have to be imposed in the estimation procedures, such as constant return to scale and perfect competition[2]. Addressing R&D, for example, Lipsey *et al.* (2000) recognize its importance in advancing the progress of innovations and the improvement of productivity, but specify a remarkable difference between applied vs. fundamental R&D. Indeed, they argue that the latter is responsible for the generation of general purposes technologies, like electricity, which allow for the spurring of multiple subsequent innovations in all industries and sectors, that are mostly derived from applied R&D, for a very long time. These patterns, accounted for as *technological knowledge stock*, generate technological complementarities that improve productivity but are not fully accounted for in TFP.

A common objective of this type of study is to estimate the rate of return to public investments in agricultural research. Based on the neoclassical framework of the exogenous growth model, research expenditures are treated as an input (a production factor, in the same way as capital and labor) that affects the agricultural supply function (causing shifts in the supply) and, therefore, TFP. The contribution (effect) of public research expenditures on the agricultural productivity growth is then used as the basis for the computation of the RoR from this investment, under a framework of cost-benefit analysis (net present value of the benefits). These approaches, belonging to the exogenous

[2] Although the review of Syverson refers to these biases in the context of manufacturing firms, their results can be extended to the agricultural sector without loss of generality.

growth framework, are suited for public investments and differ from those employed for the estimation of (both private and social) RoR relative to private R&D investments. They are surveyed by Hall *et al.* (2010) and mostly pertain to the endogenous growth framework. The models, constructed in a private firm context (micro data), are flexible and able to account for the presence of market power, strategic behavior, variable return to scale (long-run RoR) and spillovers. Further, since the models are specified as maximizing expected firms' profits, the computation of private RoR is directly implied by the model (as internal short-run RoR) and conditioned on prior (*ex-ante*) earning expectations, investments levels and market power. However, this approach causes the emergence of measurement issues of RoR on private R&D investments as well as a manifold of possible interpretations of the estimates, due to the presence of endogeneity of the R&D variable.

Estimation and interpretation issues are also common when such models are used to represent country-level RoR from public R&D investments. Indeed, the quality and magnitude of the results, beyond the reliability of data, highly depends upon the analytical (quantitative) methodology applied for the estimation. Hall *et al.* (2010) confirm such estimation issues and explicitly relate them to the multiplicity (non-uniqueness) of different available and valid analytical methods, and their related effect on the measurement of RoR. In fact, as reported by Alston *et al*. (2000) in their meta-analysis, the RoR from different countries, obtained through different analytical methodologies, vary significantly from low (close to zero) to very high (over 50% yearly) levels. However, despite the efforts by Alston *et al*. (2011) and Hurley *et al.* (2014) in proposing a more cautious approach for estimating RoR (considering reinvestment factors) and for providing results more suitable for plausible interpretations, the issue of correctly estimating RoR remains unresolved.

The issue of plausible interpretation is further complicated by the fact that, despite very high returns on public sector R&D investment in agriculture, a reduction in public investment is observed along with a growing shift of R&D to the private sector. This has been especially true in Europe in recent decades. In this regard, Shimmelpfennig and Thirtle (1999) strongly suggest including information related to private investments in R&D, easily proxied by agricultural patents, in order to avoid upward biased estimates of RoR on public R&D expenditures. Beyond the test of innovative computational methods, in order to try to address such dilemma, it would be useful to consider other potential factors affecting returns to R&D in agriculture, such as: country level climate variability, the role of the structural transformation in aggregate productivity (Timmer, 1988), the role of policies for agricultural productivity (Gollin *et al.*, 2002; Restuccia *et al.*, 2008), and the effect of increased competitive pressure on the agricultural sector (Galdon-Sanchez *et al*., 2002; Schmitz, 2005; Duarte *et al*., 2010). However, given that most of these measures are either not available or only available as short time series at the country level in Europe, these elements largely remain absent from TFP models, and therefore can be considered to be part of our *ignorance*, as pointed out by Lipsey *et al.* (2000), with respect to explaining the variability of agricultural productivity. The measure of such ignorance is captured in models through the inclusion of unspecified cross-country averages, like the constant term and time.

Although the literature deduces that TFP alone is not able to fully explain the dynamics of agricultural growth - because it represents a measure of a *residual* - it remains a valid construct for proposing methodological improvements and testing more complex analytical frameworks. In the present essay, in fact, more variables are added with respect to the traditional approach and a more robust econometric technique is applied, consciously leaving room for unspecified and undetermined *ignorance* because of the impossibility of accounting for important determinants of agricultural growth in Europe.

1.3 Data selection

Time series of R&D expenditures[3] for agriculture by European countries are available in Eurostat from 1981 to 2016, according to two main categories of public investment: Gross Domestic Expenditures on R&D[4] (GERD) and Government Budget Appropriations or Outlays on R&D[5] (GBAORD). GBAORD data refer to all appropriations by central governments allocated to R&D in central government budgets. However, data in the GERD time series are missing for many years, especially before 1996, and several countries do not have any record[6]. The OECD recompiles the Eurostat data in US dollars, which makes the data more easily linked to production measures obtained from FAOSTAT. For the purpose of this essay, GBAORD data on agricultural

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[3] Data on public investment in R&D are collected at country level by public institutions (mainly statistical institutions or statistical offices of Ministries), based on criteria and standards set by EU regulations. The frequency of data collection is yearly, however the communication to Eurostat might be provided biennially as well (as in the case of Switzerland – a non-EU country).

[4] GERD includes intramural expenditure on R&D in Government (GOV), Higher Education (HE), Business Enterprises (BE) and Private non-Profit (PnP) sectors. I consider only public investments performed by GOV and HE, namely public sectors. GERD data are classified by "Field of Science" (FOS) and "Nomenclature for the Analysis and Comparison of Scientific Programmes and Budgets" (NABS).

[5] GBAORD are budget provisions and not actual expenditures. Data include both current and capital expenditures and cover not only government-financed R&D performed in governmental organizations, but also government-financed R&D performed in the business enterprise, private non-profit and higher education sectors. GBAORD data are classified by NABS.

[6] More details on data issues and criteria for selection has been omitted for space requirement and are available upon request.

R&D expenditures have been selected from the OECD database[7]. Data limitations result in the following 16 countries being selected: Austria (AT), Belgium (BE), Denmark (DK), Finland (FI), France (FR), Germany (DE), Greece (EL), Ireland (EI), Italy (IT), Netherlands (NL), Norway (NO), Portugal (PT), Spain (ES), Sweden (SE), Switzerland (CH) and United Kingdom (UK). For statistical and analytical purposes, the selected countries result in a reasonably complete representation of Europe, given the presence in the sample of Nordic, Continental and Mediterranean countries[8].

The series of agricultural GBAORD are fully available starting from 1981 until 2018. In order to align them with FAOSTAT production and productivity series, the time series are selected up to 2016.

Table 1.1 reveals that only six out of sixteen countries - FR, DE, IT, NL, ES and UK - record average agricultural GBAORD values largely over 100 M$ in the period considered. Apart from The Netherlands, this group also corresponds to those countries having the largest shares of both agricultural land (about 77%) and gross value of agricultural production (about 73.9%) in Europe (data from FAOSTAT). Including The Netherlands, the agricultural land share is about 78.5% (a 1.40% increase), while the value of agricultural production improves to about 79.6% (about a 6% increase).

Table 1.1 GBAORD for Agriculture

	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland
Average	47	64	91	95	574	593	56	72
St. Dev.	7.6	24	27.3	15.2	197.9	187.7	14	29.6
Average yearly	0.25%	-2.55%	1.21%	0.33%	-1.32%	2.59%	-0.53%	1.66%

7 OECD receives data from EUROSTAT and converts them in US dollars in order to operate international comparisons.

8 The sample includes Norway and Switzerland, which are not part of the EU. Eastern country coverage is still limited.

Table 1.1 (continued)

	Italy	Netherlands	Norway	Portugal	Spain	Sweden	Switzerland	United Kingdom
Average	344	194	143	73	394	53	65	531
St. Dev.	96.5	45.5	36.9	50.0	269.2	12.6	20.4	107.9
Average yearly growth rate	1.20%	-2.44%	2.56%	-2.35%	3.43%	0.49%	1.57%	-1.43%

Source: *own elaboration on OECD data; Million 2005 Dollars - Constant prices and PPPs (time averages)*

Based on this information, it is possible to suppose that public agricultural investments, at the country level, are proportional, on average, to both levels of agricultural fixed capital (mainly represented by agricultural land) and the value of agricultural production (which does not necessarily depend on land, as in the case of The Netherlands). Another factor emerging from the selected sample is the variability per country of investment in agricultural R&D over time. In the first decade (1981-1990), EI, NL and UK recorded diminishing levels of GBAORD, while BE and DE had a flat trend. All the remaining countries, on average, present a growing trend. During the next decade (1991-2000), however, most countries either continued to record diminishing spending or began a tendency towards a reduction in agricultural R&D investments – BE, CH, EL, FI, FR, IT, NL, NO, SE and UK. Only, AT, DE, DK, EI, ES and PT raised their spending in agricultural R&D. The third decade (2001-2010) shows a pattern very close to the previous one, except for FI, IT, NO and SE, which recorded a growth in GBAORD. The last period (2011-2016), characterized by the financial crisis, shows a general downturn or flatness in agricultural R&D spending. Exceptions are CH, DK, EL and NO, with sustained average growth of expenditure up to about 9%.

The next step is to present the evolution of agricultural productivity across European countries. For this task the TFP index constructed by the USDA-ERS using FAOSTAT data is considered to be most appropriate for the analytical purpose of this essay. Indeed, as suggested by Fuglie (2016), output growth can be decomposed into area and yield growth. The area (land) affects output growth only through expansion (extensification), while the effects of yield growth reflect both increased input usage per hectare (intensification) and TFP growth (efficiency of input transformation). In turn, as already indicated in the introduction section, TFP improvements depends upon multiple factors, including mainly: technological change, improved technical and allocative efficiency in resource use and economies of scale. Both components of yield growth are susceptible to increases directly linked to improvements in technology, which in the log-run are highly dependent on the complementarities brought about by investments in R&D. In effect, R&D investments provides for two expected outcomes: improvements in the production frontier through *technical change* (by increasing output levels) and increases in input productivity resulting from *technical* and *allocative efficiency* (by decreasing input levels).

Operationally, TFP is a relative and non-dimensional measure computed through the use of index number methodology in which $ values of (sectorial) products are related to $ values of production inputs. The TFP index is normalized in order to be comparable across observation units (countries in this case). I selected the series for which the reference value is 100 in the year 1961 (out of the sample period[9]). Table 1.2 shows the evolution of TFP for the sample countries over the period considered.

The first information to highlight is that the average level of the TFP index for some countries, such as NO, PT and CH, is very close to the starting level of 100 imposed for the year 1961.

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[9] For more details about the computational methodology see Fuglie (2012).

Table 1.2 Total factor productivity (TFP) (1961=100)

	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland
Average	149	199	184	144	157	191	153	141
St. Dev.	21.1	38.5	48.7	20.9	25.2	40.7	20.3	14.8
Average yearly growth rate	1.17%	1.63%	1.91%	0.30%	0.84%	2.41%	1.17%	0.67%

	Italy	Netherlands	Norway	Portugal	Spain	Sweden	Switzerland	United Kingdom
Average	200	186	120	99	227	139	118	151
St. Dev.	41.5	34.8	16.9	18.7	57.3	18.8	13.1	14.4
Average yearly growth rate	2.41%	3.43%	-0.08%	0.90%	2.53%	1.28%	0.43%	0.68%

Source: *own elaboration on USDA-ERS data*

The meaning of such an average is that productivity in those countries lagged behind other countries. Conversely, for some countries, such as BE, DK, DE, IT, NL and ES, the average TFP index is close to or greater than 200. The existence of such variability across countries suggests the value of investigating potential causes of these differences by developing an inferential procedure aimed at estimating the impact, *inter alia*, of R&D investments over years at country levels. Further, average yearly growth rates in the sample show notable variability across countries, from about -0.1% for NO to 3.4% for NL. Indeed, a deeper exploration of the yearly evolution at the country level reveals that some countries record a flat trend over the first decade and a steady growth afterwards (IT, NL, CH and UK), with NO flat until 2007. Other countries (BE, EL and EI), instead, show the opposite evolution with steady increase until 1997 and a flat trend afterward. The remaining countries show constant positive tendencies over the entire period, except for FI which, while keeping the same growth trend, records a decrease in 1998 (growth break).

These observed differences in the evolution of TFP growth across countries suggest the potential importance of country-specific factors, *in primis* the level of R&D investments, in affecting agricultural productivity over time. Indeed, for example, the steadiness of TFP growth within the first decade for some countries might be revealed to be a favorable factor in supporting the supposed role of increased R&D investments in inducing productivity growth over time. On the other hand, for those countries experiencing, after a steady growth, a flat trend of agricultural TFP might suggest that objectives or priorities for agricultural research may have shifted from productivity to other dimensions, such as improving the environmental sustainability of agricultural production. However, given that for all countries the trends of land use and gross agricultural production are stable over the considered period, and that some other inputs[10], such as fertilizer use, do not show flat trends, but rather decreasing ones, it remains plausible to suppose the continued role of research in affecting TFP in terms of improvements in allocation efficiency of inputs.

Among other factors potentially affecting the evolution of agricultural TFP at a country level, the literature includes: private investments in R&D, the spillover of R&D investments from other countries, weather effects, and policy improvements (or the combination of institutions and regulations). Although these factors are considered to be potentially important in isolating the specific effect of R&D investments, it is very difficult to collect the relevant data to obtain significant estimates for their individual effect. Indeed, systematic information about private investments in agricultural R&D (BERD in Eurostat), like GERD, are missing for many years and many countries. Further, the practice of private R&D investments in European agriculture is not widespread, at least at farm level. However, in order to account for private investments, I opted to include agricultural patents in the analysis. Patent data are available from the European Patent Office (EPO).

[10] Evolution of inputs used to construct the TFP index have been analyzed but not shown in the essay. Analysis are available upon request.

The data on agricultural patents have been extracted from the EPO Worldwide Patent Statistical database (PATSTAT Global, Autumn 2019) from 1980 to 2016 for the 16 selected countries and the United States of America. They provide the count of agricultural patents belonging to the International Patent Classification (IPC) classes A01 (*agriculture; forestry; animal husbandry; hunting; trapping; fishing*) and C05 (*fertilizers*, *manufacture thereof*). A01 and C05 data have been collected for *domestic* patents, where the country of residence of the patent owner (firm or public body) and the country in which the patents are registered is the same, and for *foreign* patents, where the country residence of the patent owner differs from the country in which the patents are registered. Specifically, for *foreign* patents, European and US agricultural patents have been collected. One category of foreign patents comprises European countries that are constructed by removing the *domestic* patents from total patents for each of the 16 countries, leaving only data for patents owned by foreign European firms that are recorded in that specific country. Similarly, agricultural patents owned by US firms that are registered in each European country are collected as well.

Examining patent data for the period 1981-2016 for all countries shows that on average, 96% belong to the A01 class, where 48% are domestic patents, 36% are foreign European and 16% are foreign US patents. The country with the highest shares of domestic agricultural patents, as shown in Table 1.3, are DE (48%) and FR (18%). Regarding the role of foreign patents for specific countries, the specific shares are: AT (20%), DE (27%), DK (16%), ES (9%) and PT (7%), which collectively account for almost 80% of European foreign patents. For US patents the shares by country are: AT (18%), DE (39%), DK

(12%), ES (10%) and PT (6%), which collectively account for almost 84% of USA patents in Europe.

Table 1.3 Domestic agricultural patents – 1981-2016

Country \ Patent	Domestic			Europe			USA		
	A01	C05	Total	A01	C05	Total	A01	C05	Total
AT	1,522	146	1,668	11,048	646	11,694	4,330	109	4,439
BE	327	23	350	167	12	179	15	-	15
CH	319	20	339	164	8	172	38	-	38
DE	34,776	1,708	36,484	14,760	707	15,467	9,528	282	9,810
DK	1,556	55	1,611	8,375	390	8,765	2,902	77	2,979
EI	536	24	560	932	47	979	388	8	396
EL	133	14	147	679	53	732	342	16	358
ES	3,770	269	4,039	4,870	278	5,148	2,406	69	2,475
FI	2,066	272	2,338	1,486	124	1,610	637	25	662
FR	12,829	557	13,386	2,567	78	2,645	459	20	479
IT	3,946	116	4,062	1,054	40	1,094	243	9	252
NL	3,008	82	3,090	626	22	648	87	3	90
NO	898	77	975	1,866	188	2,054	1,011	60	1,071
PT	237	11	248	3,855	227	4,082	1,543	49	1,592
SE	2,117	171	2,288	631	37	668	160	10	170
UK	4,186	192	4,378	1,089	41	1,130	666	23	689
Total	72,226	3,737	75,963	54,169	2,898	57,067	24,755	760	25,515

Source: *own elaboration on EPO data*

Several countries recorded, on average, a notable increase in the number of domestic patents over the period 1981-2016. Among these, as shown in Table 1.4, are BE, EL and NL with annual average growth rates of 19%, 20% and 9%, respectively.

Table 1.4 Domestic agricultural patents – 1981-2016

	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland
Average	46.33	9.72	44.75	64.94	371.83	1013.44	4.08	15.56
St. Dev.	10.75	14.18	16.19	19.66	92.58	322.31	10.45	9.00
Average yearly growth rate	-0.61%	18.75%	1.07%	2.80%	-1.62%	0.66%	9.08%	3.71%

	Italy	Netherlands	Norway	Portugal	Spain	Sweden	Switzerland	United Kingdom
Average	112.83	85.83	27.08	6.89	112.19	63.56	9.42	121.61
St. Dev.	103.24	71.37	9.92	3.28	36.24	39.71	6.89	72.06
Average yearly growth rate	-14.44%	20.27%	5.80%	0.00%	1.63%	-0.93%	-0.70%	5.89%

Source: *own elaboration on EPO data*

Other countries, in contrast, show a diminishing average growth rate, such as, AT (-1%), FR (-2%), SE (-1%) and CH (-1%). IT is a special case with a rate of -14.44%, due to a drastic reduction of domestic patenting activity since 2003. The remaining countries show modest positive growth rates of between 1% and 6%.

Data on foreign agricultural patents show a different picture, with a prevalence of negative growth rates for both European and US patents. In fact, the number of registered patents by European foreign firms, shown in Table 1.5, was remarkably reduced in almost all countries, with magnitudes of between -16% and -4%, except for BE (8%), EL (6%), NL (6%) and UK (13%), while CH record an average growth of 0%.

Table 1.5 Foreign European agricultural patents – 1981-2016

	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland
Average	324.83	4.97	243.47	44.72	73.47	429.64	20.33	27.19
St. Dev.	193.86	7.97	77.80	47.46	71.63	238.06	41.80	42.60
Average yearly growth rate	-9.57%	7.92%	-6.73%	-14.05%	-7.04%	-3.99%	6.02%	-16.15%

	Italy	Netherlands	Norway	Portugal	Spain	Sweden	Switzerland	United Kingdom
Average	30.39	18.00	57.06	113.39	143.00	18.56	4.78	31.39
St. Dev.	41.06	15.86	32.61	48.87	101.13	16.37	4.26	16.33
Average yearly growth rate	-7.99%	6.46%	-12.22%	-11.99%	-7.97%	-7.86%	0.08%	12.99%

Source: *own elaboration on EPO data*

Registration of agricultural patents by US firms, shown in Table 1.6, also follows a negative trend in all countries, with the exception of BE and NL where the growth is close to 0%.

Table 1.6 Foreign USA agricultural patents – 1981-2016

	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland
Average	123.31	0.42	82.75	18.39	13.31	272.50	9.94	11.00
St. Dev.	93.21	0.87	34.67	17.99	18.25	179.08	21.48	17.55
Average yearly growth rate	-2.40%	0.00%	-10.84%	-12.45%	-7.51%	-2.15%	-7.54%	-10.39%

Table 1.6 (continued)

	Italy	Netherlands	Norway	Portugal	Spain	Sweden	Switzerland	United Kingdom
Average	7.00	2.50	29.75	44.22	68.75	4.72	1.06	19.14
St. Dev.	11.93	2.48	18.31	21.20	46.54	5.81	2.79	9.94
Average yearly growth rate	-10.94%	0.00%	-3.14%	-5.69%	-11.55%	-11.18%	-2.18%	-1.81%

Source: *own elaboration on EPO data*

These data suggest that, in the considered countries, and hence in Europe, the patenting of technology and innovation for agriculture show these specific features: i) domestic agricultural patenting has become much more intense in about 70% of the sample countries in the period 1981-2016; ii) the registration of foreign European patents was reduced in 75% of the sample countries; iii) agricultural patents by US firms diminished in the 90% of the countries; iv) the few positive increments of foreign European patents occur in countries in which domestic patenting improved the most (BE, EL, NL, UK – except NO); v) the smallest reduction in foreign US patenting occurred in the same countries identified in point iv (BE, NL and UK – except EL); vi) in DE and FR the count of domestic patenting is extremely high with respect to the other sample countries; vii) in DE the level of foreign patenting is the highest among the sample countries. Such a complex scenario seems to highlight that private agricultural R&D activities in richer and more developed countries, like DE, NL and UK, are carried out in a wide international framework, in which patenting by foreign countries are as important as domestic patenting. DE, UK and NL, indeed, have a long experience in the development of agricultural innovations and technologies, associated with strong multinational agri-business corporations. In other European countries, foreign patenting is more important than domestic, like in AT, DK, EI, EL, NO and PT.

Among foreign patents, data show a very high linear correlation between the European and US series (92%), and lower correlations between foreign and domestic patenting (56% European and 68% US). Such conditions may indicate, on one hand, that the development of agricultural innovation and technologies has a twofold scope: competition at international level for private R&D activities, occurring in a structured worldwide market, for agricultural innovations that are applicable worldwide; and, on the other hand, complementary private R&D activities at the local level focused on: developing, adapting and implementing innovations, even building on foreign patents, that meet specific requirements responding to local needs. Given this strong interconnectivity, both sets of foreign patent data cannot be used together in the models because of high multicollinearity, and choice between foreign European and US patents needs to be made. A suggestion is provided by Piesse *et al*. (2010) with a hypothesis, based on the findings by Schimmelpfennig *et al*. (1999), of the existence of a diffusion path from the US to less developed southern European countries, after first passing through northern Europe. They suppose that the new knowledge produced in USA moves first to Northern European countries, later to Southern European countries, and subsequently to other southern countries across the Mediterranean and to Asian areas. Based on the hypothesis of Piesse *et al*. (2010), I propose to use *domestic* and *foreign US* agricultural patents in order to account for both the primary sources of new knowledge, namely *foreign US* patents, and individual country level applications of innovation and technologies developed at the local level, namely *domestic* patents.

A further critical point of using patents as a proxy for private R&D activities and to capture spillovers from foreign countries is the inability to isolate productivity enhancing patents from other patent types or purposes, as well as to discriminate between patents owned by private firms from those produced by either public bodies or originating from public-private partnerships. Including this last category of patents might, however, cause an issue of endogeneity with respect to GBAORD, when they belong to the *domestic* domain[11].

Considering weather data, although largely available, are very difficult to aggregate at a country level and are very hard to use as representative of the evolution of climate as it affects agricultural production. Indeed, in the literature these data are typically either very simple variables, like annual cumulative rainfall, or are selected in term of simple indexes, like anomalies in yield growth rates of wheat, or are missing (Thirtle *et al*., 1989). Following Schimmelpfennig *et al*. (2000), I decided to use wheat yield anomalies data at the country level, provided by FAOSTAT[12]. The weather data are proxied by the annual average anomaly around the long-run trend of wheat yields at country level. Similarly, policy data are difficult to include in a relatively simple model, especially in Europe, where disaggregated data country on CAP influences are not available.

Preliminary evaluation of the available data suggests that the selected data series appear to be suitable for testing the hypothesis of a causal relationship between the evolution of public agricultural R&D expenditures and patents on the evolution of agricultural productivity. Although available data do not allow for separating TFP growth in terms of allocative efficiency and the production frontier, I propose to use the traditional

[11] The risk of endogeneity issues with GBAORD is greater in cases where the number of patents from own-country public institutions is large. In this essay, the separation between private and public entities' patents is not possible, because the EPO web platform does not allow for it.

[12] Other data have been tested with no success: two climate indexes, growing and cooling degree days indexes, estimated by the Joint Research Center (JRC) of the European Commission within the framework of AGRI4CAST Toolbox, specific for the agricultural sector.

methodological approach to estimate the overall impact of public investments in R&D on TFP. By assuming the improvement in the efficiency of input use as the primary hypothesis, I develop the analysis according to procedures commonly used in the literature and control for other covariates and country-specific features. For these controls I include in the models: patent variables to account for private *domestic* R&D and *foreign* country R&D spillovers, a *weather* variable (wheat yield anomalies) to account for TFP changes due to local weather conditions, a *time* variable and a *constant* term to account for remaining unspecified features, namely our *ignorance* in explaining the total variability of TFP.

1.4 Methodology

The study of the impacts of agricultural R&D on society, although it has matured over a long experience, has not converged to a well-established and agreed upon methodology. This is largely due to the theory of economic growth having evolved into two distinct approaches (academic currents/streams). These two approaches, exogenous and endogenous growth, are studied with different modeling frameworks, which in turn give origin to different methodological approaches. Despite this, most studies on the economic impacts of agricultural R&D are carried out by estimating connections between measures of productivity, *i.e.* total or multiple factor productivity, and measures of expenditures in agricultural research, in order to assess the contribution of research to productivity growth and to determine relative rates of return from research expenditures. The framework of exogenous economic growth treats technology as an external factor affecting the process of economic advancement and is computed as the residual of the production process. Endogenous growth models, instead, assume that progress in technology depends on the improvement of human capital in terms of (the production of) new knowledge and, hence, this new knowledge is considered directly as a factor affecting economic growth within the production process. Given the examination carried out by Parente (2001) on the merits of both approaches, I opted for the exogenous economic growth framework in the analytical work of this essay.

The exogenous growth model is a common approach for assessing the RoR from investments in agricultural R&D, where expenditures on R&D are used as a proxy for knowledge, or *technological knowledge* according to Lipsey *et al*. (2000). They treat these investments as an exogenous capital input in the estimation process. In particular, by being considered a capital variable the effect of the R&D investment is supposed to persist beyond the first year, thereby affecting more than one production cycle[13]. Further, economic growth models are necessarily implemented within the framework of time series analysis, because the intent of the study is to estimate long-run growth and returns. These factors imply the inclusion in the model of both contemporaneous and delayed effects of the R&D variable, namely *lags*, the presence of which allows accounting for the effects of investments in prior years on current productivity. Theoretically, the more lags that are included in the model, the more complete is the estimation of the long-run effect of R&D investments.

Such an approach, however, inevitably yields estimation issues (biases) due to multicollinearity among the lag variables, which leads to imposing limits on the length of the time-lag. Further, no rule of thumb is available for deciding how many lags to include in the model and, usually, researchers need to refer to the literature for choosing the most

[13] In this case the production cycle coincides with one year.

suitable lag. More precisely, the choice of the lag length is either directly imposed by the analyst or estimated by means of goodness-of-fit and information criteria. The former choice is related to specific assumptions regarding the nature of the research system present in a country (basic, experimental, adaptive, extension, *etc*…) as it is developed in existing literature. The other option, instead, relies upon the data to express information on the appropriate potential length of the causal relationship between R&D and productivity through the maximum Adjusted R^2 or other information criteria, such as, AKAIKE and Likelihood ratio tests. None of these approaches has a specific theoretical foundation associated with the appropriate R&D lagged impact on productivity, but they have the merit of bridging the assumptions of the exogenous models to the mechanics of the estimation methodology.

Once the lag length has been decided, the next step is to remove the issue of multicollinearity. One of two approaches can be adopted, both implying the construction of a unique R&D investment variable. One applies the perpetual inventory method (PIM) to construct a *knowledge stock* variable, considering a reasonable discount rate (between 5% and 6%), while the other imposes a polynomial distributed lag (PDL) function, shaped in various forms, such as, triangular, trapezoid, inverted U or others. The two approaches produce two conceptually different variables, in that the first is a proxy for the accumulation (stock) of new knowledge, while the second is a non-linear approximation of the distribution of the cumulative effects of R&D on productivity. In the same way, the spill-over effects (effects of domestic R&D investment on other countries' productivity) are modelled using PIM or PDL when expenditures are employed as proxy for investments in R&D. The most acknowledged literature contributions, especially from scholars such as Alston *et al*. (2000), Fan (2000) and Thirtle *et al*. (2008), consider a length of at least 50 years in lags, in order to assess the total effects of R&D expenditures on agricultural productivity, supposing that such a time span is required to capture the entire period going from the beginning of the research project to the complete obsolescence of the related technology.

However, while such an approach is deemed coherent within the American research system, which is mostly based on fundamental and applied research; as regards European countries a shorter length of years might be acceptable, in terms of quantitative analyses, given the more adaptive nature of R&D, not to mention more limited data. Such an assumption is reasonably supported by the argument made by Schimmelpfennig *et al*. (1999) and by Piesse *et al*. (2010), along with the recent findings of the FP7 project The Impact of Research on EU Agriculture (IMPRESA - Country reports on agricultural research expenditure). Confirmations of these hypotheses are shown in previous studies on European countries in which shorter lag lengths have been adopted based on estimation criteria, with the best estimation performance achieved within an average lag length between 9 and 12 years, with a minimum of 2 and a maximum of 16 years, on a PDL structure (Sumelius, 1987; Thirtle and Bottomley, 1988; Thirtle and Bottomley, 1989; Rutten, 1992; Shimmelpfennig *et al*. (1994); Thirtle *et al*., 1995)[14]. In order to bridge across the theoretical hypotheses and the literature results, I propose to run multiple

[14] The consulted publications from 1987 to 1995 (covering data between the periods 70's and 90's) about the determination of lags' length and structure in European countries reveal three main arguments: i) the conventional knowledge - or wisdom - about the lags' length and structure about the effects of R&D investment in agricultural research on evolution of TFP is confronted with empirical evaluation based on inferential methods; further, the results obtained by the application of inferential methods are considered more reliable than the conventional wisdom; ii) the lags have been evaluated to be between 9 and 12 years long (on average), with min 2 and max 16; iii) the best performance of the estimation models is got by imposing a polynomial distributed lag (PDL or Almond) structure (inverted "U"), through which a dynamic evolution of the effects can be considered.

estimation models, as many PDLs are built on lag lengths from a minimum of 3 to the maximum possible and are assessed by the Adjusted R^2 criterion. The choice of a minimum lag of 3 years is reasonable to catch the very first effects of research outcomes on TFP, supposing an average length between two and four years for producing and transferring research results to farms.

Beyond the public investments, the choice of lag length also concerns domestic private investments on R&D and the technological spillovers from external countries as well. In this essay, both are proxied by patents: private R&D by domestic country agriculture and fertilizer patents, and spillovers by US agriculture and fertilizers patents. According to Shimmelpfennig and Thirtle (1999), in their study on RoR in UK, the choice of appropriate lag lengths for patents pertains to the estimation performance, and they found significant effects for up to five years for domestic patents and up to 12 years for foreign patents. A further study by Thirtle *et al*. (2004) in UK found mechanical patents, in terms of the sum of domestic and foreign patents, having the highest effect at the 7th year lag, but no significant effects for chemical patents[15]. In order to choose the best lag length for the patent, following Thirtle *et al*. (2004), I apply the criterion of the best estimation performance by selecting the positive and significant lag lengths that, along with the best PDL estimate, optimize the whole model estimation.

It follows that, given the analytical constrains imposed by the reduced length of the series, the most common methodologies in the literature[16] are not applicable to the present study, since they require time series data longer than 50 years. There are however models

[15] The authors explain such different result in terms of complementarities between public bodies, focusing on biological research, and the private sector more interested in mechanical and other technologies.
[16] A specific reference has been produced by the authors and it is available upon request.

that are capable of dealing with pooled cross-section and longitudinal data sets where the time series has a relatively short duration. The most appropriate models in the literature with these characteristics are those proposed by Alene (2010). Such models proved to be able to manage relatively short time series and to provide for robust results by employing structured lagged variables for R&D expenditure. Further, a flexible analytical method is necessary in order to be able to manage simpler but more common estimation challenges, like the presence of correlations across countries and along the years, as well as the presence of heteroskedasticity. For such reasons, I opted to use a panel model employing the generalized least squares (GLS) estimator, including an autoregressive component of order one in the error term to account for potential biases due to country-level omitted variables (such as policy and other effects). The general form of the estimation model is based on the pooled panel specification: $y_{it} = \boldsymbol{x}'_{it}\beta + u_{it}$, in which the conditional variance of the error term $\mathrm{Var}[u|\mathbf{x}]$ is the unknown non-singular matrix $\boldsymbol{\Omega}$, estimated through the feasible GLS estimator. The model specification has the objective of estimating the effect of the expenditures on research on TFP, through the most efficient estimator of the panel models, conditional on having a panel where the number of years is greater than the number of individuals, $m < T$. The underlying analytical framework is based on a Cobb-Douglas production function in which expenditure on research is considered as a production factor. Such an approach is the most common analytical methodology found in the relevant literature (residual approach).

The following yearly data is used:

- dependent variable: TFP (Total Factor Productivity) index (USDA-ERS elaboration from FAOSTAT) in logarithmic terms;

- independent variables:
  - GBAORD R&D (2005 M$ - OECD.STAT) and lags, in logarithmic terms;
  - Number of agricultural (A01) and fertilizer (C05) patents originated in USA and registered in each European country (EPO), *foreign US*, in logarithmic terms;
  - Number of agricultural (A01) and fertilizer (C05) patens originated and registered in each European country (EPO), *domestic*, in logarithmic terms;
  - Anomalies in wheat yields in each European country (FAOSTAT);
  - Time.

In order to overcome the issue of multicollinearity of R&D lags, the following second order polynomial distributed lag (PDL) specification has been applied to the R&D lag variables:

$\sum_{j=0}^{J} \alpha_j ln(\text{GBAORD})_{t-j}$; $\alpha_j = \beta_0 + \beta_1 j + \beta_2 j^2$ with $j = 0,1,\cdots,J$ where J is the maximum lag;

$\sum_{j=0}^{J}(\beta_0 + \beta_1 j + \beta_2 j^2) ln(\text{GBAORD})_{t-j} = \beta_0 \sum_{j=0}^{J} ln(\text{GBAORD})_{t-j} + \beta_1 \sum_{j=0}^{J} j\, ln(\text{GBAORD})_{t-j} + \beta_2 \sum_{j=0}^{J} j^2 ln(\text{GBAORD})_{t-j}$. In order to avoid crossed effects between R&D and productivity (negative coefficients), an end-point restriction is applied, such that expenditures in years *t+1* have zero effects on productivity in year *t*, *i.e.* $\alpha_{-1} = \alpha_{J+1} = 0$. This restriction implies that only the β_2 coefficient has to be directly estimated, while all other coefficients can be obtained from the following equations: $\beta_0 = -\beta_2(J+1)$ and $\beta_1 = -\beta_2 J$. Once the coefficient of the *PDL*, namely $\beta_0, \beta_1, \beta_2$, have been obtained, the single effects $\alpha_j\ \forall j$ and the total effects $\sum_{J=0}^{J} \alpha_j$ can be estimated.

Before model estimation, the time-series properties of the variables were investigated. Data have been tested for the presence of unit roots for all possible specifications of the tests[17]. Augmented Dickey-Fuller and Philips-Perron, tests have been applied to each single series of the panel and the results were not uniform. Given the acknowledged low power (against relevant alternatives) of the Dickey-Fuller and Philips-Perron tests (Gutierrez *et al*., 2003; Oehmke *et al*., 2004; Wooldridge, 2015), further tests have been applied in order to check the stationarity of the entire panel. Fisher, Harris-Tzavalis, Breitung and Hadri Lagrange-Multiplier tests have been applied. These tests report inconsistent results, further confirming that not all panels have unit roots. It follows that not all the series composing the panel are non-stationary.

Further, test results for the *PDL* variable, which is a constructed variable, also appear to be non-stationary. This would imply the necessity to transform it in order to make it stationary. However, transforming the *PDL* variable, as well as TFP, would necessarily mean the loss of fundamental economic information required to compute rates of return (Wooldridge, 2015). Indeed, the literature is not in agreement regarding the appropriate approach. Some papers either test for co-integration (Gutierrez *et al.*, 2003; Andersen *et al*., 2013) or at least eliminate the time trend from the data, while some others papers face the same issue, but do not change the data (Schimmelpfennig *et al*., 2000) or, after employing the available tests with discordant results, decide to use the data in levels (Jin *et al.*, 2016).

[17] The presence of unit root indicates that a time series variable is not stationary, which implies that the process (variable) under analysis does not have a unique distribution over time. Such issue may produce biases in the estimation as well as results affected by spurious relationships.

In addition, it is well-known that co-integration techniques (specifically differencing the data) do not accommodate lag structures (Schimmelpfennig *et al.*, 1999) and that co-integration would make the data lose the economic meaning of their information (Oehmke *et al.*, 2004; Wooldridge, 2015). However, by following the suggestions provided by Gutierrez *et al*. (2003), Andersen *et al.* (2013) and Eberhardt *et al*. (2013), the data have been tested for co-integration by the means of Pedroni tests. The test results report the presence of co-integration between TFP and *PDL*. These results suggest of that both couples of series share the same stochastic trend and that in turn means the data become stationary series if a linear combination of the relative variables is applied. In such a case, the use of standard OLS econometric procedures yields super-consistent parameter estimates (Andersen *et al.*, 2013).

The main assumption for the analysis of the impact of R&D on agricultural productivity in Europe is that European R&D activity is mainly adaptive to existing knowledge and contributes in a lower proportion to creating new knowledge. This assumption follows the diffusion path hypothesized by Schimmelpfennig *et al*. (1999) and Piesse *et al.* (2010. Such an assumption also suggests the presence of yearly lags for *patent* data, with the appropriate length of lag to be quantified empirically using model results. Following the literature, a positive impact of public R&D expenditures on TFP is also assumed although data limitations necessitate shorter lags than the accepted ideal of 50 years (with peak on the 24th). However, a clear assumption about the potential effect of weather variability on agricultural productivity is difficult to formulate given the multiplicity of findings in the literature supporting both positive and negative impacts of climate change on agriculture that vary by area and specific agricultural activity (an example is the different impact of temperature increases brought about by increases in CO_2 which have opposite effects on C3 and C4 plants). Consequently, unknown/ambiguous signs are hypothesized for *weather* (wheat yields anomaly) and *time* variables. An expected result from the models' specification on TFP is a negative (by construction) sign for *PDL*, given by the β_2 coefficient which represents the inverted U curvature of the *PDL*. Similarly, positive sign for both *foreign US* (spillover) and *domestic* patents (private investments) are expected, reflecting their role in improving agricultural productivity.

Within the framework of cost-benefit analysis, by referring to several studies, especially to Griliches (1964) and Davis (1981), the computation of the RoR has been carried out according to the method of the marginal internal rate of return (MIRR). The MIRR has been computed according to the criteria adopted by Alene (2010): $\sum_{j=0}^{J} \frac{VMP_{t-j}}{(1+MIRR)^j} = 1$, with $J = "lag\ lenght"$ and $t = \{"1981 - 2016"\}$, where *VMP* stands for *value marginal product* of R&D. VMP_{t-j} is defined as the value of the marginal product at time $t - j$ and it is derived from the decomposition of α_j. In particular, given that $VMP_{t-j} = \frac{\partial TFP_t}{\partial RE_{t-j}} \cdot \frac{\Delta VA_t}{\Delta TFP_t}$ and $\alpha_j = \frac{\partial \ln TFP_t}{\partial \ln RE_{t-j}} = \frac{\partial TFP_t}{\partial RE_{t-j}} \cdot \frac{\overline{RE}_{t-j}}{\overline{TFP}_t}$, it implies that $VMP_{t-j} = \alpha_j \cdot \frac{\overline{TFP}_t}{\overline{RE}_{t-j}} \cdot \frac{\Delta VA_t}{\Delta TFP_t}$ for TFP in logarithmic terms. Given that the RoRs have been computed upon estimates from panel models, they are unique for all the countries.

1.5 Results and discussion

Applying the max $AdjR^2$ criterion, lags of up to 27 years for R&D expenditures were found to affect *TFP*, implying that the variable $\text{PDL} = \sum_{j=0}^{J}(R\&D_{t-j})$ should be computed with $j = 0, 1, \ldots, 27$. It follows that a total of 25 models, namely from 3 to 27 lags, have been run and the results are appended in the annex section. Similarly, each model has been estimated by letting lags for the two variables on patents vary up to seven years, for a total of $7^2 = 49$ combinations, but only those results in which estimates on both *domestic* and *foreign US* patents are positive and significant have been retained[18]. However, some models yield more than one feasible couple and, in this case, *ceteris paribus,* the signs and significance of other variables of the model associated with the lowest (highest in absolute value magnitude) significant *PDL* estimate has been selected for the subsequent RoR computation.

The first outcome to highlight is the robustness of the models employed for all the considered lag lengths. The FGLS estimator provides robust estimates of the panel regressors' coefficients, controlling for heteroskedasticity, cross correlation and serial correlation (autoregressive component of order one). In all models, the sign of the *PDL* estimator for β_2 is, as expected, negative, while for *time* it is positive. Both variables are statistically significant and show a decreasing pace, in absolute values, for increasing lag lengths, with *PDL* approaching zero very rapidly and *time* reaching zero at the 25th year lag. *time* variable remains null for the 26th and 27th year lags. The *weather* variable shows statistical significance over all lag lengths and a quite low magnitude of variability across all models.

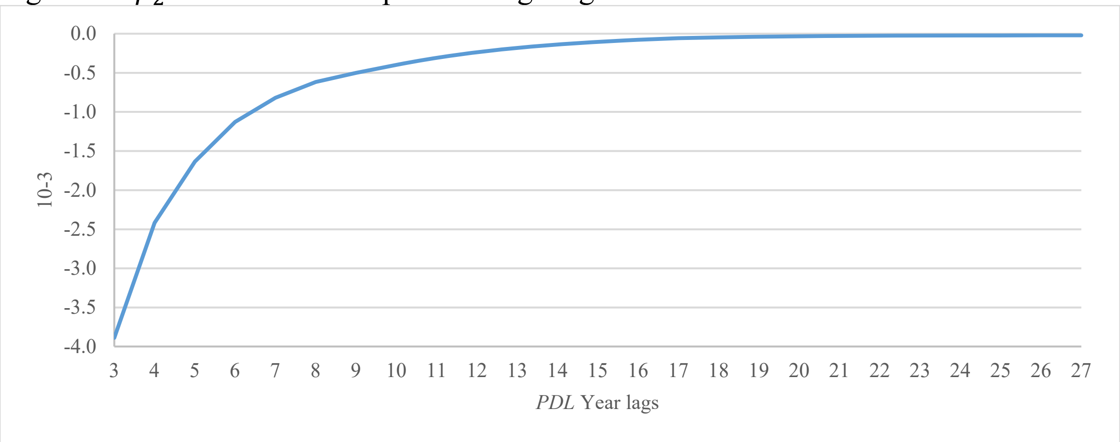
[18] Among the consulted literature, only few cases use patent variables to control for the effects of public R&D on TFP, like Schimmelpfennig *et al*. (1999) and Thirtle *et al*. (2004). The result of such exercises, for the latter, is a remarkable reduction of RoR of public R&D expenditures from 60% to 10% on average, when spillovers and patents are considered in the quantitative analysis. The role of patents is supposed – and found – to be a *complement* of public expenditure, in terms of private R&D investments focusing on or covering those research objectives not faced by the public institutions anymore, including traditional productivity technologies like mechanics, chemicals and genetics.

Each *PDL* estimate is the direct result of the estimation of the β_2 coefficient in each model, specified with a specific lag length, *i.e.* from 3 to 27 year lags, and it expresses a partial elasticity given that the *PDL* variables have been computed on logarithmic values of R&D expenditures. Their estimates are shown in Figure 1.1.

By plotting all the *PDL* estimates from all the models against the lag length it can be observed that they follow a hyperbolic shape, starting from a value of $-3.88 \cdot 10^{-3}$ at year lag 3, reaching quickly the value of $-1.11 \cdot 10^{-3}$ at year lag 6, curving slowly to $-0.104 \cdot 10^{-3}$ at year lag 14 and moving closer and closer to zero for the next lags, up to a value of $-0.0196 \cdot 10^{-3}$ at year lag 27.

The corresponding total effect $\sum_{J=0}^{J} \alpha_j$ represents the total elasticity of *TFP* with respect to *R&D* and, by construction, it is positive for each lag length and for each model specification.

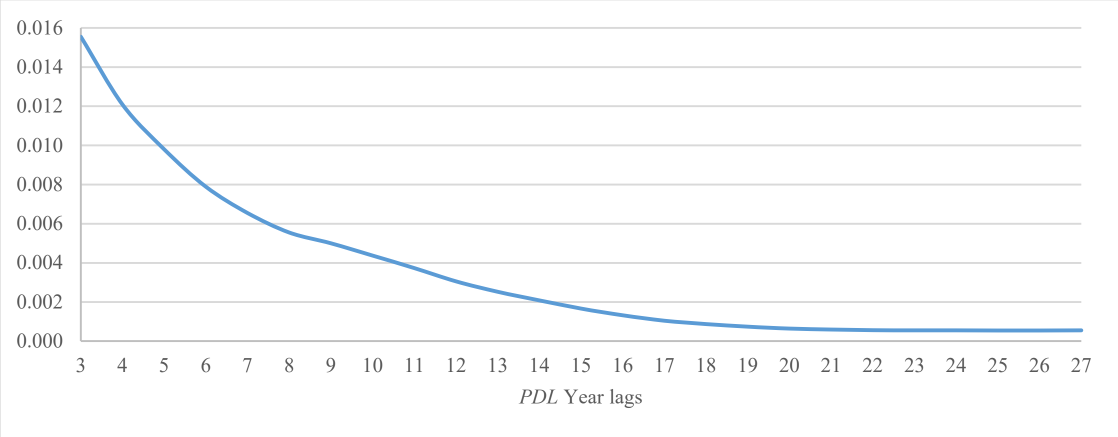
Figure 1.1 β_2 - *PDL* estimates per each lag length



Source: *own elaboration on estimation results*

The shape of *total effect*, shown in Figure 1.2, is hyperbolic, similar but reciprocal to the shape of β_2. It smoothly goes from a value of 0.0156 at year lag 3 to 0.00132 at year lag 16, getting close to zero over the next lags and reaching 0.00055 at year lag 27. These estimated values are used to compute the rates of return.

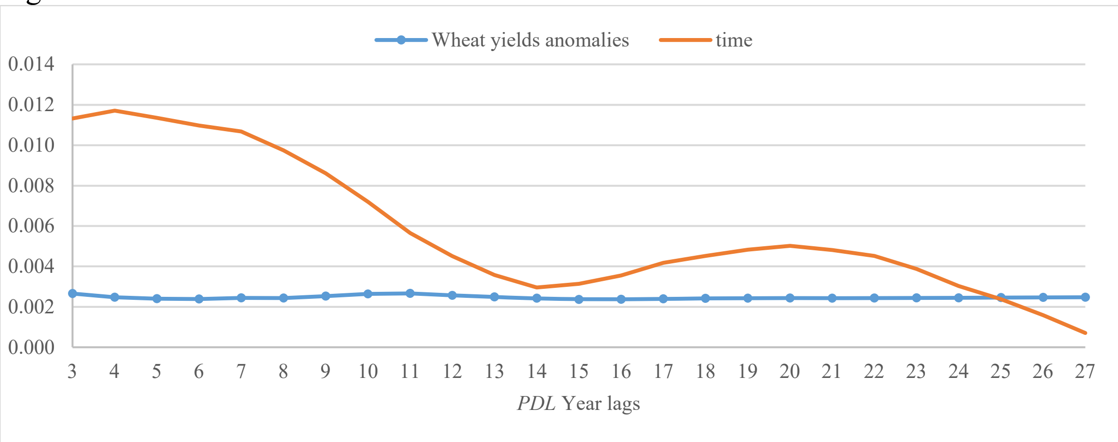
Figure 1.2 *Σα* – Total elasticity of *TFP* wrt *R&D*



Source: own elaboration on estimation results

The *weather* variable is a measure of yearly wheat yields anomaly in each country and it is employed in the models in dimensionless levels. For convenience it is represented in Figure 1.3 together with *time* variable estimates. *Weather* shows stability in the coefficient estimates across all the lag lengths, with max and min values of 0.00267 and 0.00237, respectively, with an average of 0.00247 and a variance of $6.81 \cdot 10^{-9}$.

Figure 1.3 *Weather* and *time* estimates



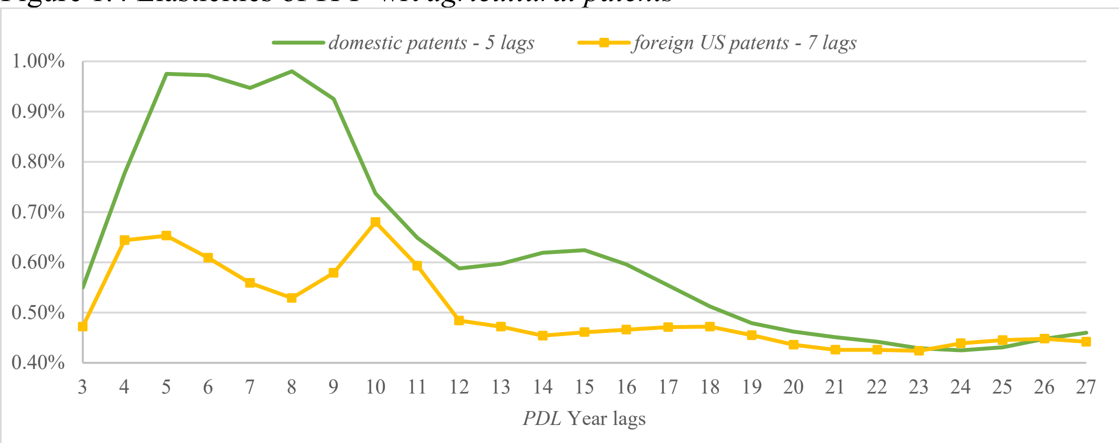
Source: *own elaboration on estimation results*

Time coefficient estimates follow a diminishing pattern, with a local minimum at lag length 14, a subsequent rise to lag length 20 and a fall till lag length 27. The coefficient estimates of *time* are not significantly different from 0 beyond lag length 24 (and are numerically smaller than the estimates for the *weather* variable).

From all the model specifications, namely for all lag lengths from 3 to 27, a constant pattern emerges over the length of patent lags. Agricultural patents are the sum of A01 (agricultural sector) and C05 (chemical fertilizers) patents expressed in logarithmic terms. The most significant estimates of all the variables in all models always corresponds to a lag of five years for *domestic* agricultural patents and to a lag of seven years for *foreign US* agricultural patents. These coefficient estimates can be interpreted as elasticities of TFP with respect to agricultural patents. In Figure 1.4 the estimates of *domestic* patents has the shape of a left-skewed distribution, with peaks between 5 and 9 year lags, in which the average elasticity is 0.0096, followed first by sharp fall up to year lag 12 and an elasticity of 0.0059 and then by a smooth decline to values of elasticities around 0.0044 in the last year lags.

A different pattern is shown, instead, for *foreign US* patents, with elasticities fluctuating around the average value of 0.0058 from 3 to 12 year lags, followed by a more stable average value of 0.0045 up to the last year lag.

Figure 1.4 Elasticities of *TFP* wrt *agricultural patents*



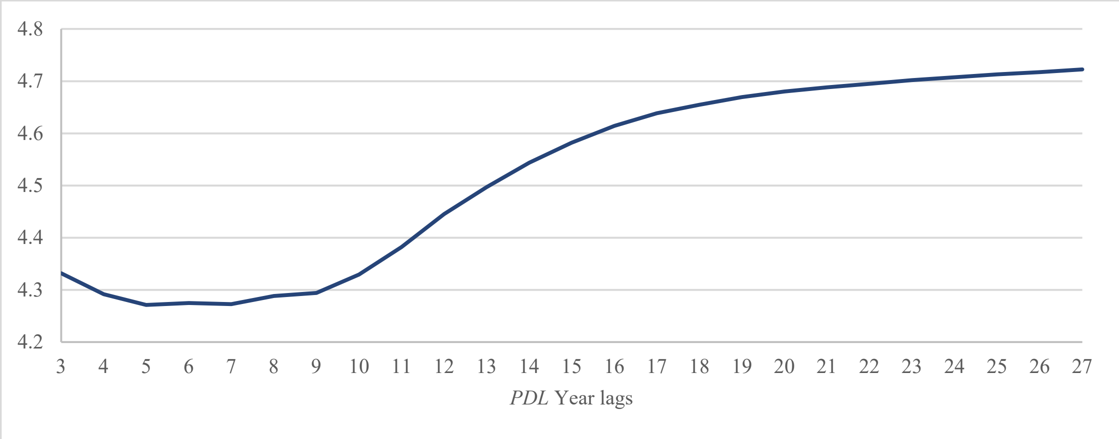
Source: *own elaboration on estimation results*

It appears clear from Figure 4 that both elasticities converge from year lag 15 to the end of the series. These results are in line with the hypothesis proposed by Piesse *et al.* (2010), suggesting the presence of differentiated lagged impacts on TFP, with *foreign US* agricultural patents having 7 period lags, and *domestic* agricultural patents having 5 period lags[19]. The latter show a more pronounced impact on TFP in shorter timespan (5 year lags), which is consistent with the suggested sequence of adoption-diffusion scheme, proposed by Levins and Cochrane (1996), commonly known as the *technology treadmill* hypothesis, that affects competitiveness and profitability at the farm level. The 5 year lags, indeed, might be interpreted as corresponding to an initial lag of 2 years from the registration of the patent through its introduction and early adoption, then followed by a diffusion over the next 3 years among later adopters.

Estimates of the constant term are all significant and show a very low variability across model specifications. The pattern in Figure 1.5 indicates that the constant term follows an inverse parabolic pace with an average value around 4.29 from year lag 3 to 9, a smooth growth to 4.65 up to year lag 18 and a final flatting pattern with an average level around 4.70. The overall shape of the constant term estimates resembles a cumulative logistic curve, with an average value of 4.52 and a variance of $3.23 \cdot 10^{-2}$.

[19] The direct effects of *foreign US* on *domestic* agricultural patents have not been explicitly addressed, but as mentioned before their linear correlation of 68% is indicative of a close relationship between them. This information, associated to the estimation results, might suggest the presence of a specific path from US to Europe and, finally, to domestic patenting activity.

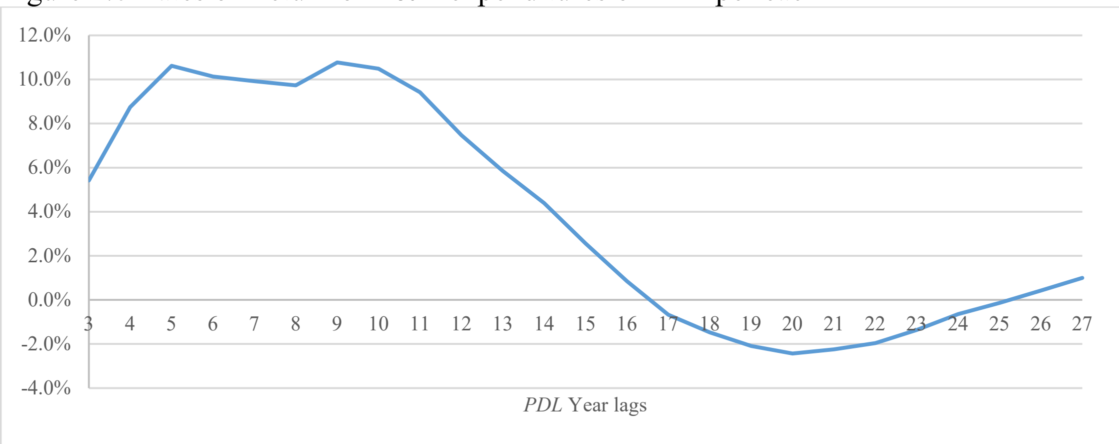
Figure 1.5 Pattern of *constant term* estimates



Source: *own elaboration on estimation results*

The RoR result, shown in Figure 1.6, is positive for lag lengths 3 to 16, then negative from lag lengths 17 to 25, and then positive again up through lag lengths 27.

Figure 1.6 Rates of Return of R&D expenditures on TFP per each PDL

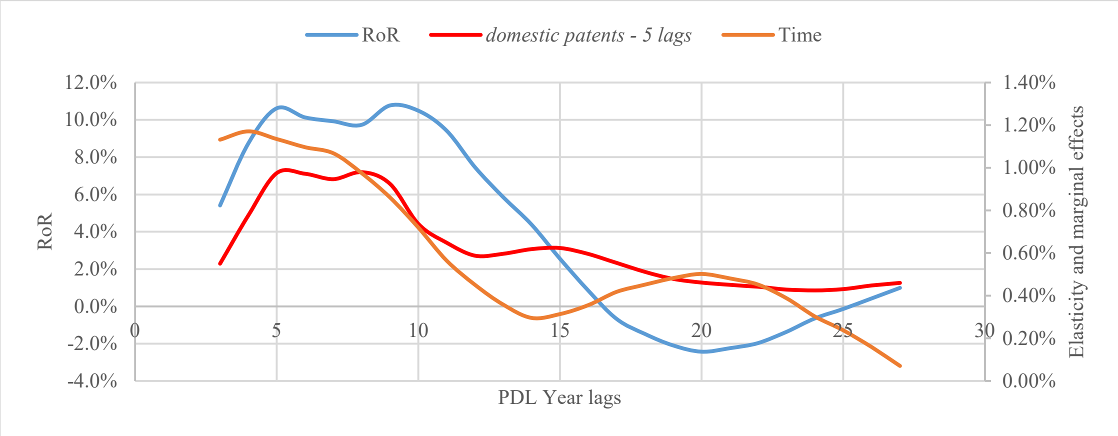


Source: *own elaboration on estimation results*

Within the positive range (year lags 3-16), the computed RoR follows a parabolic pattern, with a rapid growth from 5.4% to 10.6% over the interval of year lags 3 to 5, reaching stable values for the interval year lags 5 to 10 with average returns around 10.15% and the highest value of 10.8% at year lags 9, then followed by a quick and smooth decline to 0.85% at year lags 16. Within the negative range, the RoR values diminish smoothly reaching a minimum of -2.4% at year lags 20, followed by a constant rise to year lags 27, becoming again positive in year lags 26 and 27 with an average value of 0.7%.

A more careful inspection of the graphical pattern of the RoR in Figure 7 reveals that it closely follows the pattern of *domestic* patents effects (5 lags) graph. Indeed, the Pearson correlation test between both series indicates an $r = 0.88$, statistically significant at 1% level, indicating a very strong association. A similarity between the RoR pattern and the shape of the estimates of the *time* variable is evident as well in Figure 1.7. For them, the Pearson correlation parameter $r = 0.79$, statistically significant at 1% level, indicates again a strong link.

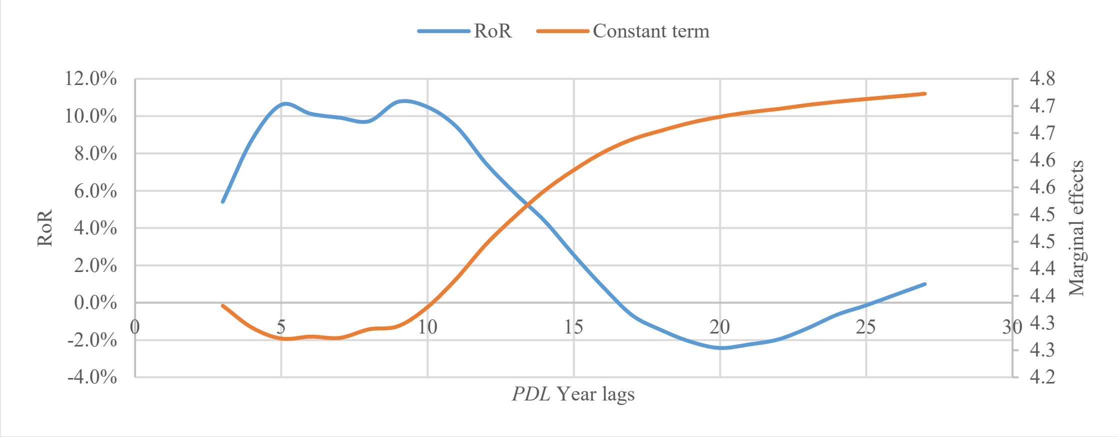
Figure 1.7 Comparative pattern of RoR, *domestic patents* and Time effects



Source: *own elaboration on estimation results; Estimates of domestic patents and time are shown on the right.*

Further, the pattern of the constant term estimates appears to have a shape resembling an inverse of the RoR pattern as shown in Figure 8. In fact, the Pearson correlation test provides an $r = -0.90$, statistically significant at 1% level, indicating a very strong inverse association between them.

Figure 1.8 Comparative pattern of RoR and constant term estimates



Source: own elaboration on estimation results; Estimates of constant term are shown on the right.

The observed similarities among the shapes of *domestic* patents, *time* and the inverse of the *constant term* might indicate the presence of a common direct marginal contribution of these covariates on TFP variation over time. The graph of RoR shares the same shape of *domestic* patents, *time* and the inverse of the *constant term* (Figures 7 and 8), but, differently from them, it is not a direct marginal effect but rather an indirect one built on the *total elasticity α*[20]. This observed commonality might also indicate that RoR, although representing an indirect measure, expresses an *inner* pattern of marginal effects on TFP variability (same as shown by the other covariates) or an *underlying* (non-observed) characteristic of TFP variation over time, represented by the peaks between the year lags 5 and 10 and a decreasing tendency afterwards.

This estimation exercise, along with the previous discussion about the similarity between the RoR computed series and the *domestic* patent shape across *PDL* year lags, provides interesting clues for discussing the impact of R&D expenditure on agricultural

[20] In fact, as indicated in the methodology section, the RoR is the outcome of a calculation based on the marginal value product of R&D on TFP, based on the parameter α, computed through PDL, TFP, GAP and R&D expenditures.

productivity in Europe, and the complementarities between public research activities and private R&D initiatives in the European agricultural sector. Firstly, public research might act as a background framework providing: new knowledge, innovation development settings, the transfer of improved and updated abilities, basic and professional education, and other costly and time consuming endeavors, like environmental, biological and genetic research, for which the RoR estimate captures only the lagged *magnitude* of these impacts on TFP, that first appear in the third year after the outlay. Secondly, the private sector is continuously fed by public research outcomes and it acts as an economic agent pursuing short-run profits by investing to improve their own production systems and commercial networks, especially at local levels, for which the lagged *patents* shape the direct contribution to TFP over the years. In particular, this ability of the private sector: to employ, to adapt to, and to develop complementary innovations that build on public R&D for their own benefit is much more evident at the country level and is captured by lagged *domestic agricultural* patents in specific industries, like mechanics, automation, chemicals, precision agriculture, logistics and others — and it is caught by the *shape* of the RoR series.

These conditions determine a precise interpretation of the results in terms of the impact of lagged public research expenditure on the evolution of TFP. This impact, together with positive effects of private R&D and research spillovers from the USA, represents the complementary contribution of European public R&D sector on TFP at the country level. It is positive for up to 16 year lags and it reaches an average of 10% in terms of RoR when computed as a *PDL* of length between 5 and 10 year lags, with a peak of about 11% when employing a *PDL* with a 9 year lag length.

The evident contribution of *domestic* patents to TFP might suggest the prevalence of new innovations and technologies that induce positive productivity impacts, mainly realized by big, competitive and market-oriented farms. On the other side, the direct impact of public R&D, computed to account for private R&D *complementarities*, results in lower, on average, effects in Europe when compared to results for other countries in the literature (for example the USA). This, more limited impact, might reflect the wider scope of the public research system in European countries which goes beyond increasing farm productivity, to incorporate other objectives - supporting "greener" growth of the agricultural sector, characterized by a "sustainable intensification" path; and the development of rural territories based on environmental stewardship; the provision of ecosystem services, and enhancing public goods provided by small and marginal farms. Such impacts are in line with those estimated in previous studies in Europe, or in European countries, especially those including proxies or measures of private R&D, like Shimmelpfennig and Thirtle (1999) and Thirtle *et al.* (2004).

However, the results presented in this paper should be accepted with caution, because of potential flaws coming from data shortcomings, particularly, GBAORD which are not a measure of actual expenditure, and from the omission of unavailable information, such as agricultural policy effects, and the unavailability of private expenditures on agricultural R&D. Finally, the complexity of the CAP evolution makes the integration of its impacts into the models a non-trivial task. Indeed, from 1980 to 2010, CAP reform has followed a multifaceted path. In the early '90s, increasing interest was placed on environmental concerns related to agriculture, so that several measures devoted to reducing production (set aside), and different agro-environmental schemes were employed that tended to intensify agriculture. However, during this decade, changes were gradual when compared to the period ranging from 2000 to 2010. During this latter period, a rapid evolution brought about stricter agro-environmental schemes and the total decoupling of direct aid. This evolution, by fostering the openness of the agriculture sector towards markets, was able to change research objectives within the European context and reorient funds for research. At the same time, market evolution in Europe, and the economic and political dynamics in the energy and oil sectors, as well as the implementation of European climate policies, have further complicated the overall picture for agriculture. All these aspects and their dynamics require a deep analysis and should be object of further investigations in the years to come. Therefore, although acknowledging their importance, their analysis is left for future research.

1.6 Conclusions

In this essay I analyze the impact of European research expenditures on agricultural productivity at the aggregate level. The analysis has limitations especially related to data availability concerning research expenditure. The main limitations concern the length of the time series available, and the level of standardization (comparability over time and space) of expenditure data. The analytical results are, however, consistent with the hypothesis of a relevant contribution of national public research to productivity increases. The time lag of research effects on agricultural productivity is estimated to be up to 27 years. The same qualifications apply to the derived estimates of the research payback that shows positive values of a Marginal Internal Rate of Return (MIRR) up to year lag 16, with peaks averaging about 10% between 5 and 10 year lags and with a maximum of about 11% at year lag 9. Beyond the discussion about the magnitude and implications of the results, the main message that can be drawn from the analysis carried out in this paper is that the impact of agricultural research on productivity in Europe is positive and builds upon a strong complementarity with private R&D activity at the country level.

The results can be considered as representative at the European level, given the countries included in the analysis. Information about the rates of return to agricultural R&D expenditure in Europe was not available before, except from a previous study analyzing the return of agricultural research on ten EU countries across the twenty-year period 1973-1993 by Schimmelpfennig *et al*. (1999). In particular the MIRRs, are to be interpreted as an average indication of the impacts of agricultural research. Indeed, the contribution of each country to the estimate of the MIRR has to be considered as being different from the others. Such country-level information, however, is not always retrievable, or even traceable, given that it depends upon the specific estimation methodology employed. Resolving such challenges might represent a valid research proposal for continuing the exploration and developing a better understanding of the impacts of research on agricultural productivity, both at the country and EU levels. In particular, taking into account the diversity that characterizes the research policies of individual EU countries is an important consideration.

CHAPTER 2. FARMERS' ADOPTION OF AGRICULTURAL R&D

2.1 Introduction

Agricultural innovation is considered a key factor for agricultural competitiveness and socio-economic growth (Feder *et al.*, 1993; Basley *et al.*, 1993). Research studies have demonstrated that the effects of agricultural innovations on agricultural competitiveness and socio-economic growth come through processes of adoption and diffusion of available innovations (Levins *et al.*, 1996; Ruttan, 1996; Ghadim *et al.*, 1999; Sunding *et al.*, 2001; Marra *et al.*, 2003). Given relatively high investment costs, farmers have very limited chances to engage directly in agricultural R&D activities to design and develop their own innovations (Sunding *et al.*, 2001; Diederen *et al*., 2003). Instead they typically turn to, extension, external and market services to gain information on available innovation choices. These services are mostly supported by European policy funding, including the rural development plans (RDP) of the Common Agricultural Policy (CAP). Within this framework of a linear transfer of agricultural knowledge from public research to the farm, available agricultural innovations are mostly exogenous to the farms' production processes.

However, in response to new global challenges posed by: climate change, increasing food demand, and demands for better environmental and natural resources stewardship of the agricultural sector; along with more specific pressures, such as, modulation of direct support from the CAP; the European Union has proposed creating an agricultural knowledge system (AKS) aimed at developing a new information framework better able to support the participation of farmers in the stages of innovation development, together with other actors including, research, education and advisory sectors, as well as public and private stakeholders. In such a context, farmers are supposed to be able to better align the innovation development process with their own farms' needs and their multiple farm objectives. Indeed, innovation adoption in European agriculture has become a complex process that presumes the existence of single, contemporaneous or repeated choices undertaken to pursue different aims, including: competitiveness, profit, risk management, environmental compliance, labour safety and others.

In this context, the study of innovation adoption in agriculture needs to be grounded in an analytical framework involving not only the determinants of innovation choice(s), but also a wider understanding of the full choice process: i) that looks back to the origin of the innovation and the prior knowledge of it, as well as, ii) linking the choice(s) to effects on the performance of the adoption at farm level. Moreover, the role of the farmers needs to be approached as *users* of available *information* instead of as *users* of available *innovations*. Such a perspective allows a wider perspective on identifying farmers as: innovation decision makers where they are: actual developers, in cases where the innovation has been developed by the farmers them-selves, adopters in cases where farmers acquired the necessary information before taking the adoption choice, or non-adopters, in cases where farmers decided not to innovate.

Within this theoretical/analytical framework, it is possible to formulate the following hypotheses about innovation choices: 1) single and sequential innovation choices are determined by structural characteristics of farms, such as: size, specialization, labour, mechanization, *etc*; 2) single and sequential innovation choices are conditioned by farmers' characteristics, such as: education, experience, attitude towards innovation, income from farming activities, legal status of farms, *etc*…; and 3) prior knowledge and information acquired by farmers, *i.e.* learning process, represented in terms of attitude, information sources, links to R&D, positively affect the economic performance of adopted innovations.

The essay continues with a review of the literature and of the links between R&D and innovation in section 2 and 3. The methodology and the analytical models are outlined in sections 4 and 5, followed by presentation of the case study area (Province of Bologna, Emilia-Romagna) and data in section 6. Section 7 illustrates the results, and is followed by a discussion in section 8, and concluding remarks in section 9.

2.2 Literature review

Early studies on innovation adoption at the farm level focused mostly on disentangling the innovation adoption process through a micro-economic approach, by relying on the basic assumption of profit maximisation as the main economic driver for adoption (Sunding *et al*., 2001). The literature on innovation in agriculture then evolved by focusing more on *elements* determining the adoption, as well as on its diffusion, but this approach overlooked the *process* of innovation adoption. In fact, on the one hand, economists argued that innovation adoption is a *survival* reaction to changes in economic (market) factors, such as, prices, technology, credit and more, undertaken to maintain farms' short-run profitability, while, on the other hand, sociologists focused on the role of the adopter's characteristics and their social environment as determinants of diffusion. Different studies report diverse results for the relative importance of determinants of adoption (Ghadim *et al.*, 1999), such as: education, credit constraints, land size and more (Feder *et al.,* 1993). One reason for result discordance can be attributed to difficulty in relating model hypotheses to the conceptual/theoretical framework in which the adoption of innovations in agriculture takes place (Lindner, 1987; Basley *et al.*, 1993). Further evolutions of micro-level studies on the topic progressed by testing alternative models of adoption and diffusion patterns as a sequence of adoptions, through the inclusion of new farm level factors mainly, information, as it is related to uncertainty and risk, and time, as affecting the diffusion process.

Information played a major role in affecting the risk attitude and risk aversion behaviour of innovators facing uncertainty and in modelling the uncertainty concerning the adoption decision. Indeed, in a context of incomplete information, the degree of perceived risk is assumed to be reduced by more or better knowledge, as it reduces uncertainty concerning the adoption choice (especially the downside production risk) (Marra *et al.*, 2003; Koundouri *et al.*, 2006). Similarly, time is the other factor characterizing the speed and rate of diffusion (aggregate adoption) (Sunding *et al.*, 2001), especially if considered from a twofold perspective: the first as a delay following adoption by others, *i.e.* waiting in order to learn from others' actions, and second as influencing the frequency of sequential adoption, *i.e.* learning from one's own actions as well. However, although new insights have come from these theoretical evolutions, empirical results still provide rather different explanations of adoption (Ghadim *et al.*, 1999). Despite this, by looking at the topic from a wider perspective, it is possible to deduce that the evolution of both theoretical and empirical approaches has led to a convergence in identifying the *learning behaviour* of individuals as one of the most important factors in the innovation adoption process, which, in turn, influences the diffusion pattern (rate of adoption), as hypothesized by Ruttan (1996).

With the inclusion of informational attributes and learning behaviour into the models, the theoretical framework progressed, by conceiving the innovation adoption as a *dynamic process* (Feder *et al.*, 1993; Basley *et al.*, 1993; Ghadim *et al.*, 1999; Sunding *et al.*, 2001; Koundouri *et al.*, 2006). Within this research line, the latest advances in the literature concern the adaptation of the technology acceptance model (TAM), proposed by Davis (1989), to the farming sector (Flett *et al.*, 2004; Rezaei-Moghaddam *et al.*, 2010). Through TAM, innovation adoption is explained as a process depending upon the perceived usefulness and perceived ease of use of the technology which, in turn, affects the acceptance (and the adoption) of the innovation. Such a theoretical framework mainly adds a psychological perspective to the analysis of the innovation adoption process and imputes more importance to individual beliefs and perceptions, beside risk and uncertainty, underlying the learning behaviour involved in the adoption process.

2.3 Linking R&D to adopted innovation

So far, the evolution of studies on innovation adoption has demonstrated that knowledge proves to have a positive role, in terms of information and learning behaviour, in the process of innovation adoption, as long as it is referred to (or limited to) innovations already available in the market (Marra *et al.*, 2003). It follows that, according to the (old) AKS framework, learning behaviour is mostly considered a skill that allows the farmer (the innovator) to be able to reduce the downside risks of innovation adoption, and to improve the performance of adopted innovations through a process of adaptation to his/her farm's peculiar characteristics. Viewed from another perspective, the underlying adoption process relies upon the farmer's best guess of likely economic performance improvements brought about by adopted innovations, conditional on his knowledge and experience. This implies that the adopter's learning behaviour is considered to be detached from the path leading from initial research to innovation development. Therefore, the adoption choice, namely the *final* stage, is considered as detached from the initial stage, namely the R&D *origin* of the innovation. This is reasonable for most agricultural innovations because the relatively high costs of internal R&D activities do not allow for an easy and affordable development of innovations within the farm (Sunding *et al.*, 2001; Diederen *et al.*, 2003). Alternatively, if a farmer were involved into an R&D process, beyond developing the innovation, he would acquire new knowledge which would facilitate him to make more aware adoption choices. In such a case, the adoption process could be intended as a wider concept integrating a learning process as well and for which the adoption choices are no more based on "best guesses" but are the outcome of a process linking R&D to farm performance.

Indeed, another step forward in the analysis of innovation adoption, however, might be realized by considering the adoption choice as a final stage of a wider learning process that takes place through a multiplicity of information channels, in which farmers know – directly or indirectly – the entire process leading to the generation of the innovation, including the prior steps of creation and development, as far back as the research stages. This holds true especially under the recent changes of the European CAP context which provide increasing incentives for more market-oriented productions and stricter environmental cross-compliances.

Moreover, a further evolution of information and knowledge management, resulting in the process of *learning behaviour*, might support the argument that adoptions choices can be intended also as complex strategies in which, depending on his/her own subjective perception of risks, profit maximization is not the unique aim of a farmer. Indeed, within a context of expected higher returns, farmers might decide to invest in specific innovations tailored to their own farm's needs in order to minimize production or market (or both) risks. This might be the case, for example, of irrigation infrastructures embedding technological advanced fertilization systems, called "fertirrigation", that can mitigate the effects of droughts thereby avoiding reduction in production levels, but also improving the quality of the products, and improving the capability of farms to comply with environmental constraints imposed by the CAP. On the other side, choices to forgo the adoption of innovations while continuing farming might arise due to expected higher off-farm income opportunities and by accepting relatively lower farm profits that result from renouncing *de facto* new investments in farm production. This might be the case, for example, for relatively small farms whose size and, hence, production potential might not allow access to credit, because of insufficient collateral, or that might not experience sufficient short-run returns from investments in innovative equipment, machinery or production methodologies, such as a combine harvester for cereals.

This *wider* framework would allow testing the proposed hypothesis that farmers make a much more aware adoption choice and employ a more complex innovation strategy, by applying a "reciprocal fine tuning" between the adopted innovation and the production process, the aim of which is higher expected economic profitability by transferring some production risks to the marketing stage (returns risk). This hypothesis hinges upon recent changes, perceived and reported in the literature regarding the paradigm of production and transfer of agricultural knowledge to the final users. The new paradigm although, on one hand, makes the study of approaches of innovation adoption more complex, but, on the other hand, widens the research perspectives by allowing the inclusion of latent or hidden elements in modelling innovation adoption in agriculture, such as multiple information channels and R&D, for which the literature contribution is still limited.

At the basis of the new paradigm, indeed, there is a new idea for which the development and realization of innovations are not limited to a pre-defined and unidirectional process (path-dependence, demand-pull or technology-push), as in the case of AKS, but rather are fed by a multitude of processes characterized by the continuous interaction and cooperation of stakeholders in an innovation network, called an agricultural knowledge and (information) innovation system (AKIS) (Röling, 1994; SCAR, 2012). In this context, Hall (2012) clearly sketches how the modern innovation adoption process goes largely beyond the (public) function of introducing technology to farmers, conceiving innovation in agriculture as a system in which partnerships, alliances and network actors work together to develop and spread the innovation. The European Union supported such paradigm by introducing, in the last CAP programming period 2014-2020, explicit funding to create the so-called *innovation operational groups* (IOG), financed under Measure 16 – cooperation – of the RDP. It follows that both the literature and EU policy agree in identifying the farmer as a pivotal actor for boosting the impact of innovation in agriculture by fostering the leverage of both the (economic) determinants of the innovation choice and other dimensions of the choice process, such as those related to the acquisition and elaboration of information, as well as the specific learning behaviour of adopters.

Given that learning ought not to be considered as an activity strictly limited to the choice action, but also affects the adoption performance, there might be room for widening the role that knowledge has in the process of innovation adoption, by allowing the inquiry to consider multiple information channels, as well as the inclusion of information concerning the *generation* of the innovation as additional determinants of adoption, and as a means to reduce production risks and improve economic performance. Innovation adoption processes are not necessarily restricted to examining only available innovations, but rather may be approached as a continuous process of information acquisition/gathering that, given the proper educational, practical and learning skills, might improve both the adoption choice and the economic performance of the adopted innovation.

In practice, the innovation adoption process might be understood not only in terms of determinants of adoption, as in the classical approach, but also in terms of economic performance conditional on a prior learning process. More specifically, learning affects not only the adoption choice, but also its consequences in terms of profitability. This supposition is supported by the concept according to which better knowledge implies better performance and better knowledge is acquired through continuous learning. Indeed, such a supposition is supported by theoretical frameworks and empirical evidence that highlight how the cognitive elements of the innovator, in particular his/her educational background and attainments (successful experiences), positively affect both the adoption and performance of adopted innovations (Lin, 1991; Foster *et al.*, 1995; Reimers *et al.*, 2012). Moreover, this hypothesis easily accommodates the theoretical framework pertaining to AKIS proposed by the SCAR (2012), according to which the process of generating and diffusing innovation is a proper function of agricultural stakeholder networks. In this essay I consider knowledge about the R&D generating the innovation and the multiplicity of information sources of the farmers - intended in terms of learning process - as potential factors affecting both the adoption choice and the economic performance of the adopted innovation.

2.4 Methodology

This essay aims at contributing to the innovation adoption literature through a micro-level perspective study of *classical* innovation adoption determinants combined with the potential impacts of the underlying learning process of farmers, with both leading to an adoption choice that has subsequent effects on the economic performance of farms, through the inclusion of attitudinal, informational and research factors.

The study approach is based on the conjecture that the adoption of innovations allows farmers to improve the productivity of both capital and labour employed in the farm production processes, in turn leading to improvements in farm profitability, mainly through reduction of costs and/or increases in yields (Hayami and Ruttan, 1985; Levins *et al.*, 1996). Improvements in agricultural productivity are realized mainly through the adoption of new available technologies capable of raising the technical efficiency of production and/or of optimizing the allocative efficiency of the resources used in the production process (Fuglie, 2016). However, Cochrane (1958) demonstrated that the profitability gains brought about by the adoption of new technologies benefits mainly the early adopters - because they have a competitive advantage on the market – and lasts until laggards catch up, by adopting the same technology, causing a reduction in market prices. This paradigm, better elaborated by Hayami and Ruttan (1985) through a deeper understanding of the role played by market prices and technological development in inducing the adoption of agricultural innovations, is cyclical, driven by new possibilities of profitability gains that come about by the adoption of new technologies. These repeated cycles are described as a *treadmill*, for where sequential innovation adoption is required for continuity in a farm's economic viability. Although the principles of such *technology treadmills* are still pertinent for analysis of modern dynamics in the agricultural sector, the treadmill concept seems to have evolved by adding knowledge to technology, thereby switching the focus from the technology to the innovation. Better knowledge about an innovation might improve profitability not just through the reduction of costs and rise in yields, namely the market price determinants, but also by improving the dimensions of profitability that depend upon market dynamics, such as value-added and product quality, namely the causes of price mark-ups. Further, beyond the determinants of innovation adoption, this study tries to verify whether prior knowledge about an adopted innovation affected the economic performance of the farm. Such prior knowledge is proxied by information sources and the R&D origin of the innovation.

Within this analytical framework, the proposed methodology is grounded on the *induced technical change* theory of Hayami and Ruttan (1985), in which innovation adoption is responsive to both economic conjuncture and technical evolution brought about by R&D; and the *evolutionary model* (Nelson and Winter, 1982), according to which farmers put effort into searching for better techniques and the selection of successful innovations (local searches for innovations, imitation of the practices of others and satisficing economic behaviour).

Using a rather well-established approach to the topic, I first assess which factors and processes influence farmers' decisions to adopt /not adopt available new technologies, including sequential adoptions, and then I investigate to what extent the link between adopted innovation and specific information sources and scientific research affects both the adoption decision and the economic performance of the farm. I apply a demand-driven approach, as proposed by Walker *et al*. (2010), which, together with the *recall* technique (Basley *et al*., 1993), will allow me to set an impact pathway, going backward from the present, in order to trace back the evolution of the effects of successful innovation adoption on economic performance.

A qualitative assessment of the data collected is carried out, to define: the structural and market aspects of surveyed farms, the subjective elements of the farmers, and all relevant features related to adopted innovations; and to quantify the variables used in the subsequent quantitative analysis. A two-stage conceptual framework is employed in the quantitative analysis. The first stage concerns farmers' choice to adopt an innovation and the second concerns the profitability of the adopted innovation. The underlying process is composed of a participation stage and an outcome stage, where the outcome depends on participation: the first stage is about the choice to adopt or not, and, conditional on this first decision, the second stage examines the economic performance resulting from the adoption decision.

An expected utility maximization framework is used to examine farmers' choice to adopt, including sequential adoptions as well. Assuming that farmers are profit oriented and that their expected utility depends on the level of profit earned, the objective function of the farmers will be to maximize expected utility through maximizing expected profits (posed that utility is monotonically increasing in expected profit). It follows that a higher profit implies a higher expected utility for farmers.

Thus, for the i_{th} farmer: $U_i = U\big(\pi_i(I_i, X_i, S_i)\big)$, where U_i is expected utility of farmer i, π_i is expected profit of farmer i, I_i is the innovation adopted (that guarantees the highest performance) by farmer i, X_i is vector of determinants of adoption decisions of farmer *i* that impact expected profits of production, and S_i is a vector of other factors affecting the ability of farmer *i* of generating profit.

According to Lynes et *al.* (2016), the choice to adopt an innovation occurs if the expected utility U_i, expressed in terms of expected profit from the adoption of I_i, is greater than the expected utility of no adoption, namely $no\ I_i$. Assuming that the choice of I_i depends on X_i and S_i as well, $I_i(X_i, S_i)$ and by simplifying the notation, so that U_i is stated as a function of I_i, the following condition applies: $U_i(I_i) > U_i(no\ I_i)$, such that $U_i(I_i) - U_i(no\ I_i) = \Delta(U_i) > 0$.

Expected higher profits, *i.e.* the *outcome*, is dependent on the choice of adopting, *i.e. participation*. The outcome stage can be identified according to two different specifications. On one hand, the outcome of adopting an innovation, as suggested by Cochrane (1958) and Levins *et al*. (1996), can be understood as a continuous choice or a sequence of adoptions, namely more than one adoption, in order to guarantee, according to the *technology treadmill*, the competitiveness and profitability of the farm. On the other hand, the outcome stage can be thought of as the level of profitability conditioned on the adoption of a specific innovation, namely the realized economic performance resulting from the introduction of the innovation into the farm.

In both cases, it is assumed that farmers who choose to adopt know that their specific outcome is affected by adoption determinants, such as: structural factors (farm size, specialization, mechanization, market), and subjective characteristics of the farmer (education, experience, off-farm income, business motivation, entrepreneurial attitude). Farmers also know that, to maximize profitability, innovations need to be introduced after undertaking a learning process, and after other elements have been scrutinized and evaluated accurately, such as: the ability of self-developing the innovation, trial and error approaches, sources of information from others, and links with R&D providers. Expected higher profit can, therefore, be considered as an indirect function of: adoption determinants, the farmers' subjective characteristics and the learning process leading to the adoption of a specific innovation. Stage two can be represented as follows: $\pi_i[I_i(X_i, S_i)] > 0$, for which $\frac{\partial I_i}{\partial S_i} > 0$, $\frac{\partial \pi_i}{\partial I_i} > 0$ and, in turn, $\frac{\partial \pi_i}{\partial S_i} > 0$, while $\frac{\partial I_i}{\partial X_i}$ is ambiguous.

2.5 Analytical models

The analytical models chosen to analyse such decisions belong to the class of limited dependent variable models. In the general case, the choice to adopt is observed as a binary action, representing the underlying outcome of the utility maximization: if $Y_{ai} = 1$ means that $\Delta(U_i) > 0$, while in the opposite case $Y_{ai} = 0$. That is, $Y_{ai} = 1$ when farmer *i* chooses to adopt the innovation, and $Y_{ai} = 0$ otherwise. Determinants of (X_i) and other factors (S_i) are assumed to linearly affect the adoption decision related to the farmers' choice to adopt. Let $Z_{ai}(Z_{a1}, \dots, Z_{ak})$ be the set of both the determinants of (X_i) and the other factors (S_i) affecting the adoption choice, and let $\alpha_{ai}(\alpha_{a1}, \dots, \alpha_{ak})$ be a vector of parameters, and ε_i be a mean zero IID error term.

Then, the adoption choice can be modelled as: $\Delta(U_i) = \alpha_{ai}Z_{ai} + \varepsilon_i, Y_{ai} = \begin{cases} 1\ if\ \Delta(U_i) > 0 \\ 0\ otherwise \end{cases}$.

These choice models are named *adoption models*. The choice variable is simply the record of adoptions, recorded as a single choice (in the case of one innovation) and as a sequence of choices (in the case sequential adoptions). The determinants include, the technical and commercial characteristics of the farms and the subjective, socio-demographic characteristics of the farmers. Other factors include the innovation adoption attitude of the farmers. This part of the analysis was carried out by evaluating determinants of both the propensity to innovate and the number of innovations introduced, by employing a *Probit* and a *Poisson* model, respectively. In addition, a *double-hurdle* model has been used. This type of model has the advantage of making it possible to analyse the number of adoptions (single or repeated) that are conditional on analysis of the choice to innovate (participation), which potentially follows a different data generating process (or, rather, that may be affected by different explanatory variables). The additional contribution of the *double-hurdle* regression is the capacity to clearly discriminate between the factors mainly affecting the choice (participation) from those mostly affecting the adoption (magnitude). This approach integrates a two-step analysis. The determinants include the technical and commercial characteristics of the farms and the subjective, socio-demographic characteristics of the farmers. Other factors include the motivations of farmers to innovate, namely their attitude.

Following the same rationale, the profitability induced by the adopted innovation is observed as a binary outcome as well: if $Y_{bi} = 1$ means that $\frac{\partial \pi_i}{\partial I_i} > 0$, while in the opposite case $Y_{bi} = 0$. That is, $Y_{bi} = 1$ when the adopted innovation yielded an improvement in profitability and $Y_{bi} = 0$ otherwise. Even in this case, determinants of (X_i) and other factors (S_i) are assumed to linearly affect the improvement in profitability. Let $Z_{bi}(Z_{b1}, \ldots, Z_{bk})$ be the set of both the determinants of (X_i) and the other factors (S_i)

affecting the profitability (they do not need to be the same employed in step one), $\alpha_{bi}(\alpha_{b1}, \dots, \alpha_{bk})$ be a vector of parameters and ξ_i be a mean zero IID error term.

Then, profitability can be modelled as: $\pi_i(I_i) = \alpha_{bi} Z_{bi} + \xi_i, Y_{bi} = \begin{cases} 1 \; if \; \pi_i(I_i) > 0 \\ 0 \; otherwise \end{cases}$.

These other models are named *performance models*. Profitability is the measure of the realized gains, based on farmers' declarations, resulting from the introduction of the innovation, in terms of: *cost reduction*, *production increase, value-added increase* and *quality increase*. The first three have been collected in per cent terms, while the last is specified in ordinal categorical terms (*not at all*, *low*, *high*, *very high*). However, they have all been transformed into binary variables in order to evaluate solely the presence (not the magnitude) of the declared (positive) effects of the introduced innovation. The determinants are the same as those applied in the previous models, while other factors include: the motivations of farmers to innovate, their knowledge of the adopted innovation prior to its adoption, the sources of information that farmers consulted, including the origin of innovation from scientific research, as well as whether farmers developed the innovation by them-selves.

The most suitable model for testing the proposed hypotheses are the Tobit model and the Heckman sample selection model, which corrects for the potential self-selection bias of the innovators (differently from the Tobit as it considers the dependent variable as incidentally censored) However, given that the variables have been transformed from percentage to binary, only a *probit* specification of the Heckman model, called *Heckit*, is applied to the analysis of the economic performance of adopted innovation.

2.6 Data

The agricultural territory of the province of Bologna is composed of plain, hilly and mountain areas. According to the last agricultural census, carried out in 2010 by the Italian Institute of Statistics (ISTAT), Bologna province accounts for about 10,800 agricultural units over an UAA[21] of about 173,000 Ha. The agricultural system of the province of Bologna reflects that of its region Emilia-Romagna and is mainly based on livestock and cereal farms. As shown in Table 2.1, the agricultural sector is mainly based on cereal and other arable crops, involving about 7,000 farms and about 141,000 Ha of UAA. The second major type of farming is livestock and related activities, involving about 800 cattle-holding and 33,000 head as well as 150 swine-breeding with 75,000 head. The largest livestock farms are based in the plain areas. Arable crop farming is mainly farms growing cereals (about 4,000) and forage (about 2,000), whose UAA shares are 53% and 27%, respectively.

Table 2.1 Agricultural census data per specialization (type of farming) and altitude level.

Specialization	**Plain**	**Hill**	**Mountain**	**Total**	
Cattle farms (Milk, Beef, ovine-caprine and mixed)	295	454	369	**1118**	10%
Cereal crops (wheat, maize, oats, barley)	3177	633	187	**3997**	37%
Other arable crops (horticultural, mixed and grain pulses crops)	1284	849	608	**2741**	25%
Fruit (orchards, olives and grapes)	1529	1082	90	**2701**	25%
Non-classifiable	65	109	28	**202**	2%
Total	**6350**	**3127**	**1282**	**10759**	
	59%	29%	12%		

Source: *own elaboration on ISTAT data*

The average size of farms producing cereal and forage crops is 12 and 10 Ha, respectively, and more than half are located in plain areas. Regarding fruit cultivation, about 2,700 farms have orchards over an UAA of about 16,000 Ha. The majority of farms (over 80%) are individual farms, but the number of companies is increasing (Chamber of

[21] UAA stays for Utilized Agricultural Area

Commerce of Bologna, 2015). During the last years, the land dedicated to agricultural activities decreased, as did the number of active farms: this is consistent with the national trends and the gradual abandonment of marginal agricultural activities.

The agriculture of Emilia-Romagna is one of the most advanced, quality-oriented, and productive of the Italian peninsula. Some of the most renowned food products in the world are produced in this Region, for example: Parmigiano-Reggiano, Grana Padano, Prosciutto di Parma, Culatello di Zibello, traditional Balsamic Vinegar of Modena, Mortadella Bologna, and many other quality products worthy of label of origin protection by the European Union. This primacy is due to favourable geographical and climatic conditions (the southern part of the territory is mountainous, while the northern part belongs to the Po river valley, which is a very fertile zone), and the presence of highly specialized enterprises. Emilia-Romagna is particularly active in the production of cereals, wheat, fruits and wine, and animal breeding (mainly pigs, bovines, and poultry). Five percent of all Italian farms are located in Emilia-Romagna; they account for 8% of the Italian UAA and employ around 200,000 people (of whom 14% are foreigners) (Agricultural Census 2010). Regional seed production represents one third of the national total, while 90% of Italian production of orchard and horticultural crops are from Emilia-Romagna. Around 37,000 hectares and 70 enterprises are involved in this production (Fanfani and Pieri, 2016), mainly in the Province of Bologna and the provinces of Ferrara, Ravenna, and Forlì-Cesena. Wine products are also extremely important: Lambrusco is one of the best-selling wines nationwide, and the second most exported in the world. Emilia-Romagna accounts for 11% (around 650,000 animals) of the total number of bovines in Italy. The percentage rises to 15% if we consider only dairy cows, meaning that dairy-oriented bovine farms characterize this Region. Milk production reached 1.9 million tons in 2015, an increase with respect to the previous five years. Emilia-Romagna also accounts for 17% of the total number of Italian breeding pigs, but in absolute terms the number of animals has decreased by 10% since the early 2000s. Last, but not least, regional poultry breeding is extremely relevant: in Emilia-Romagna are located the biggest European enterprises in this industry, and the region produces 17% of Italian poultry (Fanfani and Pieri, 2016).

Data were collected through a survey of farmers in the province. The structure of the questionnaire is illustrated in Table 2.2. The questionnaire is introduced by a section that briefly presents the objectives of the survey.

Table 2.2 Structure of the questionnaire

SECTION	AREA	TOPICS
Introduction		
A	Farm structure	- altitude - production specialization - ancillary economic activities - land, labor, machines - use of sale contracts
B	Types of innovation/s	- typology (agronomic, biological/genetic, livestock, diversification, automation, informatics, marketing, energy-water saving) - most important innovation (in terms of profit) in the last 20 years - reasons for no introduction (high costs, ethics, bureaucracy, risk, plan to close, negative past experience, traditions)
C	Most important innovation	- reasons (risk reduction, diversification, costs reduction, increase production) - timing for introduction - selection of one innovation based on profitability (revenue and product quality) - year of introduction - knowledge about innovation origins (external source of information, knowledge of the innovation producer, need of consultancy for introducing the innovation) (based on the Nelson and Winter approach (1982)) - knowledge of the research giving origin to the innovation - difficulties faced (lack of knowledge, bureaucracy, adapt farm structure) - need of training courses; introduction of the self-developed innovations by others - need of complementary innovations - role of prices variation (products and factors) in inducing innovation adoption (based the approach developed by Hayami and Ruttan (1985))
D	Costs for the introduction of the innovation	- types of financing - costs for the farmer
E	Effects of innovation' adoption	- relevant changes (in terms of costs, production, value added, quality) - changes in combination of factors of production - satisfaction - expected duration of the innovation

Table 2.2 (continued)

F	Future behaviors	- continuing farming activity - intention to introduce new innovations - reasons for introducing (or not) new innovations - statements about the CAP
G	Socio-demographic characteristics	- type of farm - family labor - employees - instruction - income from agricultural activities - memberships - municipality

Source: *own elaboration on questionnaire structure*

The first versions of the questionnaire were preliminary and were tested through direct interviews during the spring-autumn period in 2015. It was then modified and reduced in size to be suitable for phone interview formats. In the winter of 2016, the questionnaire was administered via phone to a target population composed of approximately 11,000 farms located in the Province of Bologna. The sample list is the one used for the 2010 Agricultural Census. The collection process was completed in late January 2016 with about 900 farms contacted and 300 complete phone interviews (of approximately 15 minutes) (32.2% success rate). The contacted farms were sequentially selected to be representative of the agricultural sector at the provincial level according to territorial distribution, characterized by plain, hill and mountain areas.

The collected data consist of 300 farms, distributed according to altitude levels and specialization. As shown in Table 2.3, the sample includes 87 farms located in hilly areas, 35 in mountains and 178 in plain areas. According to their main specialization[22], the sample is composed of 20 cattle farms, 116 cereal farms, 69 (arable) crop farms, 77 fruit farms (including olives and grapes), 11 nursery and 7 non-classifiable farms. Cereal crop

22 A comparative pairing of the specializations considered in the questionnaire with FADN classification is listed in the annex section.

is the most frequent specialization with about 39% of the total farms, followed by fruit farms (about 26%), arable crop farms (22%) and cattle farms (7%).

Table 2.3 Number of farms per Specialization and Altitude

Specialization	**Plain**	**Hill**	**Mountain**	**Total**
Milk-beef cattle			2	**2**
Beef cattle	1	2	2	**5**
Milk cattle	4	3	3	**10**
Mixed cattle, mainly pastern		1		**1**
Ovine-caprine and pastern cattle		1	1	**2**
Cereal crops (wheat, maize, oats, barley)	86	21	9	**116**
Open field crops	12	7	5	**24**
Mixed crops	2	4	1	**7**
Horticultural crops	12	5	2	**19**
High protein crops (grain pulses)	6	4	7	**17**
Combination of crops and cattle	1	1		**2**
Fruit	23	22	3	**48**
Olives		1		**1**
Grapes	17	11		**28**
Nursery	9	2		**11**
Non-classifiable	5	2		**7**
Total	**178**	**87**	**35**	**300**
	59.3%	29.0%	11.7%	

Source: *own elaboration on sample data*

As shown in Table 2.4, the collected sample accounts for about 8,000 ha of utilized agricultural land, of which about 5,000 are owned by the farm. The largest share of land use is by cereal crop farms with about 36% of total land, followed by cattle farms (27%), (arable) crop farms (18%) and fruit farms (15%).

Table 2.4 Utilized Agricultural Area per Specialization and Altitude

Specialization	**Plain**	**Hill**	**Mountain**	**Total**
Milk-beef cattle			52	**52**
Beef cattle	50	520	155	**725**
Milk cattle	510	280	110	**900**
Mixed cattle, mainly pastern		60		**60**
Ovine-caprine and pastern cattle		40	1	**41**
Cereal crops (wheat, maize, oats, barley)	1877	475	483	**2835**
Open field crops	368	155	101	**624**
Mixed crops	9	24	35	**68**
Horticultural crops	493	57	49	**599**
High protein crops (grain pulses)	143	29	61	**233**

Table 2.4 (continued)

Combination of crops and cattle	9	300		**309**
Fruit	184	356	17	**557**
Olives		3		**3**
Grapes	371	219		**590**
Nursery	97	4		**101**
Non-classifiable	97	17		**114**
Total	**4208**	**2539**	**1064**	**7811**
	53.9%	32.5%	13.6%	

Source: *own elaboration on sample data*

If compared to the 2010 general agricultural census in the province of Bologna (53.3% in plain, 32.5% in hilly and 14.2 in mountain areas), the sampled farms can be considered as representative of the province. The sampled agricultural area, however, presents differences with respect to the census distribution of the UAA (61.9% in plain, 29.3% in hilly and 8.8% in mountain areas).

The sampled farms own 1.024 tractors and 944 operational machines. Cereal farms have more than a third of the tractors and other machines, followed by fruit farms, crop farms and cattle farms. On average, cereal farms and fruit farms have the highest shares of tractors per farm, about 3.42 and 2.98 respectively (corresponding to 0.24 and 0.4 in *per ha* terms), showing them to be the most mechanized specializations in the province.

2.7 Survey results: descriptive statistics

Farmers were asked whether they believe there had been important innovations in their field of specialization, in terms of impacts on profitability, in the last 20 years[23]. This question tries to collect information regarding the *attitude* towards innovation adoption. Almost 47% (140 out of 300) of the interviewees believe there have been important

[23] For "innovation" is meant: new products, new inputs and new processes. The interviewees were asked to choose among the following options: biological/genetical; diversification/manufacturing; agronomic/livestock; mechanical/automation; informatics; energy and water savings; marketing; managerial; other.

innovation. Then, farmers were asked whether they had adopted any innovations and what type in the last 20 years. About 40% of respondents (121 out of 300) replied positively. The joint distribution of the replies to the questions regarding the attitude and the adoption, shown in Table 2.5, revealed a concordance of *No-No* answers for 125 interviewees and of *Yes-Yes* answers for 86 farmers. Off-diagonal answers (cross-answer) were expected for those farmers who believe there have been important innovations in the last 20 years but that have not adopted any (54 out 300). Less expected were off-diagonal answers of farmers who do not believe in the presence of important innovations in their sector, but that did adopt innovations (35 out of 300).

Table 2.5 Joint distribution of attitude and innovation adoption in the last 20 years

Important innovations in the last 20 years	**Introduction of at least one innovation in the last 20 years**		**Total**
	No	**Yes**	
No	125	35	**160**
Yes	54	86	**140**
Total	**179**	**121**	300

Source: *own elaboration on sample data*

The 125 *No-No* answers are composed by 50% of cereal, 26% of other arable crop and 17% of orchard growers. With respect to the total of each specialization, cereal growers represent the 54% (63 out of 116), other arable crop the 49% (33 out of 67) and the orchard growers the 25% (19 out of 77). These 125 respondents are small farms with a low agricultural income. In fact, on average, 83% of them operates on less than 20 hectares and 76% of them receive an income from agricultural activities less than 30% of family income. Such conditions are consistent with the declared reasons of no adoption, mainly related to high costs.

The 54 *Yes-No* answers indicate no adoption despite the belief of the existence of important innovations in the sector of specialization. These 54 are composed by 41% of cereal, 24% of other arable crops and 30% of orchard growers. With respect to the total of each specialization, cereal growers represent the 19% (22 out of 116), other arable crop the 19% (13 out of 67) and the orchard growers the 21% (16 out of 77). This group also is composed of small farms with a low agricultural income, and these figures are similar to but only slightly smaller than those of the previous group. In fact, on average, 72% of them operate on less than 20 hectares and 71% of them receive an income from agricultural activities that is less than 30% of family income. In this case also, such conditions seem to be consistent with the declared reasons of no adoption, mainly related to high costs, quitting soon the activity (cereal) and keeping traditional production methods (cereals and orchard).

The 35 *No-Yes* replies indicate adoption despite the declaration that there have been no important innovations in the sector of specialization. These 35 are composed by 17% of livestock, 43% of cereal, 9% of other arable crops and 26% of orchard growers. With respect to the total of each specialization, breeders represent the 30% (6 out of 22), cereal growers the 13% (15 out of 116), other arable crop the 4% (3 out of 67) and the orchard growers the 12% (9 out of 77). This group of innovators is characterized by operating larger farms with higher agricultural income. In fact, on average, only 47% of them operates on less than 20 hectares, while 49% of them receive an income from agricultural activities less than 30% of family income. These figures clearly differ from the ones of the previous two groups and the declared motivations for having introduced at least one innovation (with positive effects on profitability) mostly refer to reducing costs and increasing production. The logic behind this cross-answers may be counter-intuitive, given that they have declared that there have been no important innovations in the last 20 year, but anyway they adopted at least one innovation. However, this is compatible with innovations that occurred earlier than 20 years ago and were adopted later on, or with the perception of lack of novelties for the sector but not for the farm. The declared motivations for having introduced at least one innovation (with positive effects on profitability) in the last 20 years refer mostly to cost reduction and production increase. This group of innovators could be identified as laggards who adopt only when replacing obsolete technologies.

In the last group, the 86 *Yes-Yes* replies consist of 12% of livestock, 19% of cereal, 21% of other arable crops and 38% of orchard growers. With respect to the total of each specialization, livestock represent the 45% (10 out of 22), cereal growers the 14% (16 out of 116), other arable crop the 28% (18 out of 67) and the orchard growers the 43% (33 out of 77). This other group of innovators operates on farms with sizes similar to the ones of the previous group, but with higher agricultural income. In fact, on average, 43% of them operates on less than 20 hectares and only 27% of them receive an income from agricultural activities that is less than 30% of family income. Similar to the previous group, this last group also indicates as main motivations for adopting at least one innovation (with positive effects on profitability) cost reduction and production increases, with the addition of other motivations pertaining to the improvement of labour conditions, such as, reducing fatigue and improving safety of workers. This group of innovators could be identified as early adopters and followers who innovate in order to sustain the profitability of their farms.

The number of innovations introduced in the last 20 years is more than 200 for the 121 innovators (an average rate of about 2 innovations per farmer), while the farmers that adopted more than one innovation is 48, for a number of adoptions (beyond one) of 139 (an average of 3 innovation per farmer). The distribution of adoptions, shown in Table 2.6, reveals that mechanical innovations are the most adopted (32%), followed by energy-water saving (21%), diversification (15%) and biological, agricultural and informatics (about 8% each).

Table 2.6 Number of innovations introduced in the last 20 years and selection of the most important in terms of profitability.

Type of adopted innovations	**All adoptions**	**Share of adoptions**	**Unique most-important**	**Share of most-important**	**Sequential adoption**	**Share of sequential**
Biological-Genetic	18	8.5%	8	7.5%	13	9.4%
Diversification or Manufacturing	32	15.0%	15	14.0%	16	11.5%
Agricultural-Zootechnic	18	8.5%	7	6.5%	12	8.6%
Mechanical-Automation	68	31.9%	45	42.1%	44	31.7%
Informatics	17	8.0%	2	1.9%	2	1.4%
Energy-Water saving (irrigation plants, solar panels, biogas)	44	20.7%	27	25.2%	40	28.8%
Marketing strategies (quality systems, production protocols)	5	2.3%	2	1.9%	9	6,5%
Operational (cooperatives, associations, logistics)	2	0.9%		0	0	0
Other	9	4.2%	1	0.9%	3	2.2%
Total adoptions	**213**	**100%**	**107**	**100%**	**139**	**100%**
Does not know			14			

Source: *own elaboration on sample data*

The distribution of type of innovations changes if considering the single most important innovation that, according to farmers, yielded the highest impact on profitability. In fact, the shares of mechanical (42%) and energy-water saving (25%) innovations increases, while the others are slightly reduced. Sequential adoptions, instead, tend to be more frequent for energy-water saving (29%), while other typologies are in line with the shares of all adoptions. Most sequential adoptions occur in livestock and fruit specializations and relate to innovations in fields of mechanization, energy-water saving and diversification. As regards the reasons, the adoption of these type of innovations are mainly motivated by: the needs to reduce costs, to increase production and to face new climatic challenges affecting the availability of natural resources, such as water. The same reasons are behind the choices of sequential adoptions and mostly for cereal crops, fruit and grapes. The main reasons motivating the adoption of the most important innovation are concentrated in cost reduction (35%) and production increase (30%) (122 replies out of 187)[24]. However, out of 122 replies (66+56) 31 result to be joint, indicating a willingness to strengthen the motivations indirectly related to the increase of profitability[25].

Other motivations, beyond the ones directly addressing profitability, have been collected in open format and resulting in profitability improvement and reduction of workers' fatigue. The main motivations of cost reduction and production increase are most frequent for cereal (25%), fruit (19%) and grape farms (16%). In particular, by looking at the most important innovations, mechanical-automation and energy-water saving results are the most frequent with 32 and 20 replies out of 66 for cost reduction, and 19 and 10 out of 56 for increasing production, respectively. Further questions about the motivations underlying the adoption of innovations were asked of farmers in relation to market price variations of both inputs and products. In particular, the questions asked whether farmers have adopted the innovation in order to react to increases in input prices and to reductions in output prices too. For both questions, about 50% of respondents replied positively, with 27% and 22% represented by cereal and fruit farms, and 42% and 18% indicating mechanical and energy/water saving innovations, respectively.

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[24] The replies are more than the number of adopters because the inquiry was set as a multiple-choice question.
[25] The link has not been explicitly asked, but, in the explicit list, we included also the reduction of risks and the diversification of the activity in order to evaluate the motivations directly related to profitability. Very few replies have been collected.

Having explored the distribution of adopters, the attention turns to the share of the sample composed by those farmers who declared to have adopted no innovation in the last 20 years, followed by the description of their reasons for not innovating. Out of 179, 85 non-adopters are cereal farms, 46 crop farms, 35 fruit farms and 6 cattle farms. Such data imply that, compared to the entire sample, the share of non-adopters per specialization is about 73% for cereal farms, 69% for crop farms, 45% for fruit farms and 27% for cattle farms. Among the 179 non-innovator farmers, 108 (about 60%) declared to receive less than 30% of family income from farming activities and 126 (about 71%) less than 50%. Of these, 62 (about 49%) are cereal farms. I asked these farmers to explain why they have not adopted any innovation according to two groups of reasons, obstacles and intentional choice. Among the obstacles, I proposed as obstacles: high costs, bureaucracy and risks, while for intentional choice I asked about personal reasons - the intention to quit the business, negative past experiences and the desire to follow traditional production processes. As shown in table 2.7, 84 out of 179 replies[26] considered the excessive costs for adopting innovations as the main hurdle, while 16 and 18 answers declared to quit the business soon and to keep traditions in production, among the intentional choice group, respectively. For those choosing not to innovate, about three-fifth of the interviewees (179 farmers) decided not to innovate because of economic and managerial hurdles that reduce the capacity of farmers to get new technology and adopt innovations[27]. Therefore, the sample revealed that the main reason for not having adopted innovations in the last 20

[26] The replies are more than the number of non-adopters because the inquiry was set as a multiple-choice question.
[27] Detailed descriptions of such data have been omitted in order to save text. These are, however, available by authors upon request.

years is excessive cost, highlighting economic barriers and the lack of managerial skills for gaining access to new technology[28].

Table 2.7 Reasons for non-adopting, per specialization

Specialization	Costly	Bureaucracy	Risky	Ethical	Quit	Past failure	Tradition	Other	Total	
Milk-beef cattle	1							1	**2**	1.0%
Beef cattle	1								**1**	0.5%
Milk cattle	1		1						**2**	1.0%
Mixed cattle, mainly pastern									**0**	0.0%
Ovine-caprine and pastern cattle					1				**1**	0.5%
Cereal crops (wheat, maize, oats, barley)	32	3	2	2	8	2	9	**33**	**91**	**47.2%**
Open field crops	6	1	4		1		1	3	**16**	8.3%
Mixed-crops	4	2				1	1		**8**	4.1%
Horticultural crops	6	1	1					2	**10**	5.2%
High protein crops (grain pulses)	7	1	1		3		3	2	**17**	8.8%
Combination of crops and cattle								1	**1**	0.5%
Fruit	15		1		1		4	4	**25**	**13.0%**
Olives									**0**	0.0%
Grapes	6	1						5	**12**	6.2%
Nursery	3								**3**	1.6%
Non-classifiable	2				2				**4**	2.1%
Total	**84**	**9**	**10**	**2**	**16**	**3**	**18**	**51**	**193**	
	43.5%	4.7%	5.2%	1.0%	8.3%	1.6%	9.3%	**26.4%**		100%

Source: *own elaboration on sample data*

However, since for 33 out of 51 (65%) other reasons have been expressed by cereal farms, we deduce that for about two-third of respondents such choice is due to a disinterest in innovation; given that they possess less than 20 hectares and have no weeding and harvesting machines, and therefore possibly opted to obtain these services from other companies. This is an important point in light of recent structural trends, as it points to a dichotomy between larger professional farms, for which innovation remains important,

[28] I have not explored whether such barrier would depend upon credit constraints. Further, I did not ask to specify the other reasons.

and small farms keeping land ownership but cultivating using contractors to carry out farm operations, whereby innovation is carried out or adopted by the contractors, *i.e*. outside the farm. For the remaining third, I equally deduce that they have not been interested in adopting innovations, but differently from the previous farmers, because the technology they possess is considered still effective and so it does not need to be replaced or upgraded.

Beyond the motivations underlying the choice of the selected innovations, the survey investigated the selection and adoption processes followed by the farmers. Indeed, farmers were asked whether they designed and/or developed the (adopted) innovation themselves or got information regarding the introduced innovations from external sources (and in turn, who informed the farmer about the existence of such innovation).

In this respect, farmers who declared to have designed and/or developed an innovation by them-selves are denominated "self-developer" and are considered to be their *internal source of information* as opposed to other innovators who declared to have learned about the innovation from an *external source of information*. Such specification is meant to indicate also that self-developers are proactive in searching for information leading to the development of the innovation. Farmers who positively replied to the option of *external sources of information* were also asked whether they knew the origin of the research for the innovation they adopted.

The data about the sources of information, shown in Table 2.8, indicates self-developed innovation in the first column (the source of information is the farmer him-self, *i.e. internal*) and the list of proposed external sources. Such questions mainly focused on revealing the importance of public and associative (public-like) institutions responsible for developing and diffusing innovations (agencies having the role of intermediaries between the research and agricultural sectors). *Internal* source (self-developed innovation) information was declared by 31% of innovators, with prevalence for cereal, fruit and nursery farms. It follows that the remaining 69% knew about the innovation from external sources and, in particular, mostly from sources other than public institutions and unions/farmer associations. Indeed, 37% of the innovators declared they acquired information about the innovation they decided to introduce from consultants, courses, and local or abroad visits to other farms. The other large share, in decreasing order, is the 17% represented by sources of information from people belonging to the sphere of personal relationships of farmers such as, friends, relatives and neighbours.

Table 2.8 Sources of information for innovation adopted, per specialization

Source of information	**Internal**	**External**					
Specialization	**Farmer**	**Institutions (University, Region, Province, Ministry)**	**Unions, associations**	**Acquaintances, friends, relatives, neighbours**	**Other sources (consultants, refresher courses/trainings, visiting…)**	**No reply**	**Total**
Milk-beef cattle							
Beef cattle	1			1	2		**4**
Milk cattle	3		2		2	2	**9**
Mixed cattle, mainly pastern	1						**1**
Ovine-caprine and pastern cattle					1		**1**
Cereal crops (wheat, maize, oats, barley)	**12**		3	6	**10**		**31**
Open field crops	2		1	1	4		**7**
Mixed crops							
Horticultural crops	2		2	2	3	1	**10**
High protein crops (grain pulses)				2	1		**3**
Combination of crops and cattle					1		**1**
Fruit	**9**	1	2	4	**9**		**25**
Olives					1		**1**
Grapes	3	1		2	**10**		**16**
Nursery	**5**		1	2			**8**
Non-classifiable			1		1	1	**3**
Total	**38**	**2**	**12**	**20**	**45**	**4**	**121**
	31.4%	1.7%	9.9%	16.5%	**37.2%**	3.3%	

Source: *own elaboration on collected data*

Unions and sectorial associations cover 10% of the external sources of information and their relative frequency appears to be uniformly distributed across specializations. Only a residual share, of about 2%, represents public institutions devoted to research and development in agriculture as external sources of information. Such a result highlights a level of disconnect between sectors that ideally should constitute the main pillars of the agricultural innovation system.

As a follow up question, farmers were asked to declare their knowledge about the maker/producer of the innovation. Beyond the group of self-developers (31%), about 26% of the innovators do not know the producer/maker of the innovation, while 3% and 4% know that the innovation has been produced by public institutions and by acquaintances, respectively. About 24% of innovators stated that innovations have been produced by private companies, while the remaining 12% indicated as "other" the category of innovation producers. By considering the inquiry according to the type of innovation, it comes out that, concerning mechanical innovations (the most frequent type with 39 out of 83 replies), 16 declare knowing that the producer is a private company out of 29 (about 50%), while14 do not know the maker out of 31 (about 50%). Concerning energy/water saving innovations (21 out of 83 replies), one-third of respondents declare knowing it comes from a private company, about one-third do not know the producer, while the remaining replies mostly indicate. know the producer but without specifying (as "other").

By excluding self-developers, this inquiry reveals that the majority of adopters (about two-thirds), who learnt about the existence of the introduced innovation from external sources, is also aware of the innovation source. This might indicate that farmers operate a careful decision process for adopting the innovation that ought to meet at best their own profit expectations, by relying upon trusted external sources of information and acquaintance of the producers[29]. Or, it may be that the innovation has the name of a manufacturer on it and farmers assume the manufacturer is the source of the innovation. Overall, the sample reveals that most of farmers either strictly rely on their own ability to develop an innovation, or, on their own initiative, search around for information and get cues from someone else's experience in order to make the best choice.

Another question to reveal whether interviewees needed support in the process of innovation adoption was asked of both self-developer and other farmers. Responses reveal that about 62% did not require any support, while the remaining respondents declared to have been assisted mainly by the innovation producer or by an expert. Self-developers mainly asked producer organizations and professionals in agriculture (supposedly agronomists and mechanical engineers). In particular, assistance was asked for innovations developed in cereal, fruit and nursery farms, and mainly for diversification-manufacturing, mechanical-automation and energy-water saving types of innovation.

In order to explore the connection between innovation adoption and research at the farm level, farmers were asked whether they knew that the innovation they adopted was created from specific agricultural research. This question was only addressed to those farmers that previously declared knowing about the innovation from an external source of information. Self-innovators were excluded because it is supposed that they engage in a process of introducing the innovation, mainly based on development of their own ideas,

[29] For some types of innovation, such as mechanical ones, farmers have a better knowledge of the major brands/producers because of the presence, in the Emilia-Romagna region, of a wide district of mechanical manufacturers operating from the beginning of the last century. Farmers in Bologna province possess a deep knowledge of the evolution over time of mechanical technologies as well as a wide culture of mechanical manufacturing, which provides them with a sufficient ability to develop mechanical innovations by themselves.

which is completely different from the process followed by other interviewed innovators. The sample audience receiving this question is consists of 83 innovators with 53 respondents (about 64%) stating that the introduced innovation derived from specific research in agriculture. In particular, 29 out of these 53 (about 55%) concerned mechanical innovations, mainly related to cereal, grape and fruit farms.

Concerning the timing of introduction, responses reveal that about 70% of farmers introduced the innovation since 2005 (included), while about 46% did so between 2010 and 2015 (included). Data indicate that about 65% of the mechanical innovations were introduced within the 2010-2015 period, while about 66% of the energy-water saving technologies were adopted in the 2005-2015 period. The adoption timing of the other types of innovation are smoothly spread across the time span (1995-2015).

Regarding costs for introducing the innovation, farmers were asked if they received financial support through a European Union Program or other credit lines. About 55% of the adopters (67 out of 121) did not make use of external financial sources for introducing the innovation, 16% (19 out of 121) used loans or credit facilities, and 12% (15 out of 121) used funds from the EU Regional Rural Development Program 2007-2013. In terms of absolute investments, about one third stated that they spent more than 50.000 euros on a specific innovation (in particular mechanical and energy-water savings), while another 37% stated that they spent between 10,000 and 50,000 euros (in particular for mechanical innovations). According to Table 2.9, mechanical and energy-water saving are the most "expensive" innovations, because they account for almost the total of respondents who paid more than 50,000 euros to introduce their innovation. Also, the majority of the people paying between 10,000 and 50,000 euros introduced a mechanical innovation, while the lowest category of costs ("Less than 5,000 euros") show a wide range of answers (marketing, informatics, and agronomic innovations).

Table 2.9 Cost of introduction and type of (the most important) innovation in terms of profits

	Types of innovation								
Cost	**B - G**	**D - M**	**A - Z**	**M - A**	**INF**	**E - W**	**MKT**	**OTR**	**Total**
<5,000 €	2	4	1	7	1	1	1		**17**
5,000-10,000 €		2	3	2		4	1		**12**
10,000-50,000 €	3	2		16		9			**30**
>50,000 €		3		14	1	8		5	**31**
Total	**5**	**11**	**4**	**39**	**2**	**22**	**2**	**0**	**90**

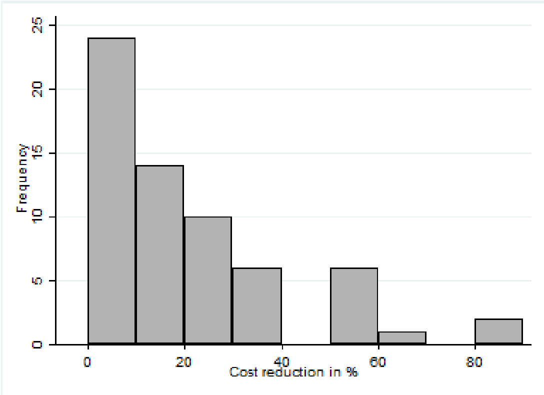
Source: *own elaboration on collected data*
Note: *B-G stays for biological-genetic; D-M diversification-manufacturing; A-Z agronomic-zootechnics; M-A mechanical-automation; INF informatics; E-W energy-water saving; MKT marketing; OTR other. Missing values are not included.*

Data for evaluating the effects on economic performances of the introduced innovation come from decomposing profitability into four elements: *Cost Reduction, Production Increase, Value-Added Increase and Quality Increase.* The importance of these variables within the context of the innovation adoption process lies in their potential to reveal the mechanism by which the adopted innovation contributes to the overall farms' economic performance and, in turn, to profit. The first three are measured by eliciting the percentage increases, while the last, quality increase, is determined by collecting four categorical levels (not at all, low, high and very high) from introduction of the innovation. Given the way they are measured, the four elements are best presented through a graphical (histogram) representation in Figure 2.1. The number of observations of these variables do not correspond to the number of innovators' sub-sample (121), because not all respondents have provided a reply to each of the four questions. This implies that the zero answers correspond to actual observation of the performance by the farmer, while a missing reply might be justified by the lack of expectation of any impact on that specific component of profitability (in fact many farmers declared not knowing the specific performance effect).

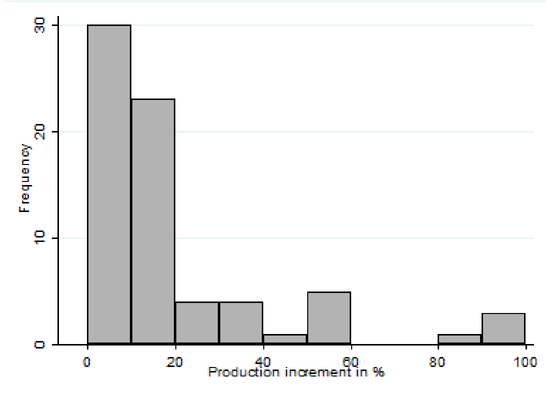
Since the answers were not mutually exclusive, respondents could choose to indicate more than one positive effect.

Figure 2.1 Frequency distribution of Cost Reduction (A), Production Increase (B), Value-Added Increase (C) and Quality Increase (D)

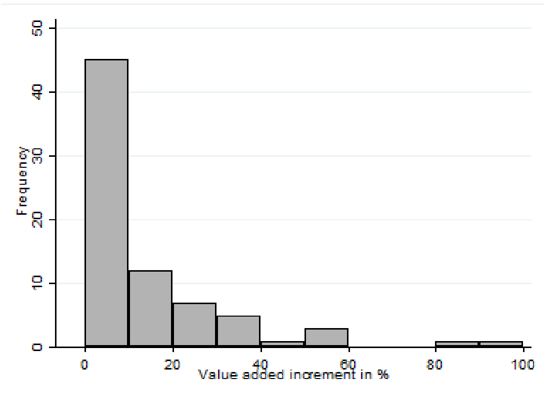
A (63)



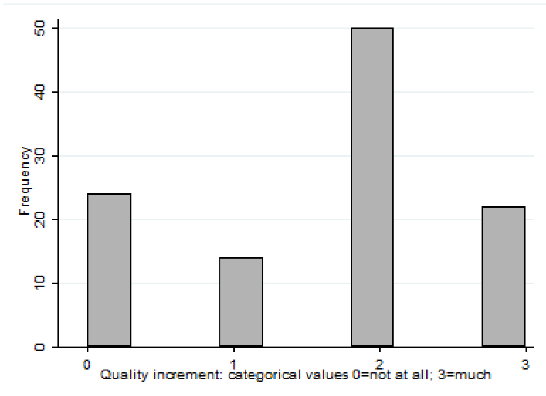
B (71)



C (75)



D (121)



Source: *own elaboration on collected data; number of observations in parenthesis.*

Cost Reduction (A), *Production Increase* (B), *Value-Added Increase* (C) show a noteworthy frequency of zeros. This was expected, since it is unlikely that one innovation might yield positive profitability outcomes on all four of the considered components at the same time. The effect on *Cost* presents a concentration of positive outcomes within the range of 10-60% cost reduction (with the highest share on the lower boundary of the interval, and no case recorded between 40% and 50%), while *Production* and *Value-added* are more frequently within the 10-40% interval of increase. *Production Increase* also shows a fairly high frequency around the 50-60% range. As far as *Quality increase* is concerned, it is observed that about 60% of the replies indicate an improvement in profitability due to high and very high-quality increases, while only about 25% show no quality increases at all.

2.8 Results of econometric analysis

Results obtained from the quantitative analyses are reported in two groups: the first pertains to the adoption of innovation, and the second concerns the linkage between adopted innovation and sequential adoptions and performance. In order to avoid potential confusion across analyses and models, the first groups have been denominated *adoption models*, while the second are *performance models*. The list of variables and relevant descriptive statistics are provided in the Annex.

The results of the *Poisson* and *Probit adoption* models, shown in Table 2.10, indicate which factors are most important in determining both the number of innovations and the chance (propensity) of introducing an innovation, respectively. This group of results are related to hypotheses 1 and 2.

The ability of both models to explain the survey data is quite good, as indicated by Wald χ^2 statistics. The results from both models indicates that the propensity to innovate, in particular to adopt more than one innovation, or to be a *sequential adopter*, is highly determined by the economic size and other structural characteristics of the farm, as well as by some individual and behavioural characteristics of the respondents. The positive role of the share of rented - over total - land may be connected to both the structural characteristics of the farm, likely conditioned on a rent-based land expansion, and to the overall size in terms of land area.

Table 2.10 *Poisson* and *Probit adoption* models

		Number of introduced innovations (Poisson)		Introduction of innovation (0-1) (Probit)	
Characteristics		Coefficient	Marginal effect	Coefficient	Marginal effect
Attitude	Important innovations (last 20 yrs)	0.91***	0.66***	0.78***	0.21***
Farm	Share of rented over total land	0.73***	0.53***	1.00***	0.26***
	Number of tractors	0.05***	0.03***	0.03	0.01
	Livestock specialization	0.22	0.16	0.42	0.11
	Cereal specialization	-0.54***	-0.39***	-0.59***	-0.16***
Socio-economic	Education > than mid-school	0.64***	0.47***	0.57***	0.15***
	Family income from Agric<30%	-0.58***	-0.42***	-0.53***	-0.14***
	Number of family labor	-0.16**	-0.11**	-0.11	-0.03
	Individual farm	-0.38*	-0.28*	-0.59***	-0.16***
	Constant	-0.70**			
	Observations	244		244	
	Wald χ^2	146***		80***	
	AIC	478.6		248.4	
	BIC	513.6		283.4	

Note: *robust standard errors*; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The number of tractors is positively and significantly correlated to the number of innovations (but not to respondent attitude) and shows that multiple innovations are more likely on large and capital-intensive farms. The positive and significant coefficient of the share of agricultural income shows a higher propensity to innovate on more professional farms focused on agricultural activity. These results suggest that a *technology treadmill* paradigm is consistent with the observed sample.

In contrast, more family labourers and a tenure status of individual farm, reflecting the common structure of small farms, indicates a reduced propensity to adopt innovations (these are also correlated with the specialisation, given the remarkable share of small cereal farms). As concerns personal and behavioural features, instead, more educated farmers and those showing a positive attitude towards innovation adoption - declaring that, in the last 20 years, important innovations in terms of profitability have been released - show a higher propensity to innovate and, in particular, to adopt sequentially - more than one innovation.

In order to further support these first results, and to better explain the process, a two-step model has been applied by employing a double-hurdle regression. This type of model has the advantage of allowing analysis of the phenomenon of adoption, both single and sequential, conditional on analysis of the decision to innovate (participation), which is supposed to follow a different data generation process. The additional contribution of the double-hurdle regression is its capacity to clearly separate those factors mainly affecting choice from those mostly affecting adoption, including the sequential ones. The results are shown in Table 2.11.

Table 2.11 *Double-Hurdle* model

		Number of introduced innovations
Characteristics	*Quantity equation (Q)*	
Farm	Number of tractors	0.09^{**}
	Breeder specialization	1.15^{**}
	Cereal specialization	-0.64^{*}
	Fruit specialization, including grape and olives	0.29
Socio-economic	Specialized Ag education	-0.47^{*}
	Family income from Ag <30%	-0.63^{**}
	Family workers per ha	1.00^{*}
	Constant	1.21^{**}
	Participation equation (P)	
Innovation	Important innovations in last 20 yrs	1.01^{***}
Farm	Location: plain=1; hill=2; mountain=3	-0.22^{**}
	Total Land	0.01^{***}
Socio-economic	Education superior than middle school	0.75^{***}
	Family workers per ha	-0.65^{**}
	σ_Q	1.86^{***}
	$\sigma_Q\sigma_P$	-1.69^{***}
	Observations	245

Note: *robust standard errors;* $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$*;* σ_Q *is the estimated value of the standard deviation of the error term of the quantity equation;* $\sigma_Q\sigma_P$ *is the the estimated value of the covariance between the error terms of the quantity equation and the participation equation.*

Results obtained from the double-hurdle model confirm those from the *Poisson* and the *Probit* estimates. Further, they indicate that the choice to innovate highly depends upon: location, especially plain and hill, total size of farm and operator education. Larger farms and higher education contribute to increases in the probability of adoption. Attitudes about the existence of *important innovations in the last 20 years* notably affects adoption choice, but it does not contribute to explaining the number of adoptions. On the other hand, what seems to determine increases in the number of adoptions are factors related to the type of farming (and relative physical and economic size of the farm). In fact, larger farms with higher agricultural income, particularly livestock, or farms with more family labour and higher mechanization (number of tractors) are more prone to adopt more than one innovation. Further, the results of the two-step procedure are consistent with the presence of the *technology treadmill* paradigm.

As regards the analysis about the effects of adopted innovations on economic performance, as related to hypothesis 3, specific attention is devoted to the contribution of a self-learning process, carried out independently by the farmer through the acquisition of information, especially on the research-innovation link and sources of information for each of the four components of the farm's profitability. The results from the *probit performance* model, shown in Table 2.12, indicate whether the source of information and knowledge about the research-innovation link improves the likelihood for innovators, of obtaining positive economic performance.

The analysis on economic performance has the same specification as the *probit adoption* regression, with the inclusion of the variables accounting for knowledge of research-innovation link and source of information (hereafter "information variables").

Table 2.12 *Probit performance* models

Characteristics		Cost reduction [yes=1; no=0]	Production increment [yes=1; no=0]	Value added increment [yes=1; no=0]	Quality increment [very high, high=1; otherwise=0]
		Economic performance			
Innovation	Research-innovation link	0.21	0.77*	0.76*	0.83**
	Source of innovation [ext=1; self =0]	-0.93	-1.22*	-1.59**	-0.87**
	Age of innovation	-0.01	0.04	0.06**	0.05*
	Important innovations (last 20 years)	-0.73	-1.13**	0.05	-0.07
Farm	Cereal specialization	0.65	0.53	-0.67	-0.05
	Share of rented land over total land	-0.42	-0.27	-0.42	0.18
Socio-economic	Individual farm [yes=1; no=0]	-0.20	0.11	0.67*	0.10
	Family income from Ag <30%	-0.91*	-1.72***	-1.37***	-0.32
	Education > than mid-school	0.34	-0.11	0.52	-0.28
	Constant	1.98**	1.88**	0.25	0.41
	Observations	50	56	62	88
	Pseudo R^2	0.176	0.245	0.317	0.115
	Wald χ^2	12.1	14.9*	30.4***	11.7
	AIC	71.7	76.6	78.7	123.9
	BIC	90.8	96.9	100.0	148.7

Note: *robust standard errors*; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Specifically, the *research-innovation link* is the variable expressing whether the farmer is informed about the research that led to the adopted innovation, while *source of information* indicates whether the farmer learned about the innovation from external sources or developed the innovation independently. The third variable, *age of innovation,* is a measure of time distance between the year of introduction and 2015 (maximum 20 years) and is a proxy of the experience of farmers in using such an innovation (fine-tuning of innovation usage), as well as for the innovation to fully express its effects in terms of economic performance. The dependent variables used in the *probit performance* models are, *cost reduction*, *production increase*, *value added increase* and *quality increment*, all expressed as binary variables. Given the application of the *performance* models to each measure of performance, the number of observations for each group of regressions is reduced from the size of the entire sample.

The *probit performance* models applied to *cost reduction* and *quality improvement* proved to have little capacity to explain the likelihood of positive performance. In the first model (*cost reduction*) only one regressor out of nine is significant and the sample is relatively small, while in the last model only the group of information variables, taken as a whole, contributes to explaining variability in *quality improvement*.

On the contrary, the *probit performance* model proved to perform better when applied to *production* and *value-added increment*. In fact, for the latter models, the results show significant contributions from both groups of variables. From all significant results, a common pattern can be identified in terms of a positive contribution from the *research-innovation link* and a negative effect from *source of innovation* on the likelihood of obtaining a positive economic performance.

These results suggest that farmers who learned about the innovation from external sources have lower chances to obtain positive economic performance, especially in terms of *value-added* and *production*, when compared to *self-innovators*. On the other hand, the positive contribution of *research* on economic performance is more pronounced in terms of *quality*. It is important to recall that the variable *research-innovation link* is only available for farmers who declared they learned about the innovation from *external sources*. This implies that the variable *research-innovation link* improves, in terms of a positive additive effect, the likelihood of getting positive economic performance for those farmers who acquire information about the innovation from external sources.

However, although the *probit performance* analysis provides interesting results, its specification might be affected, beyond the reduced number of observations, by selection bias in that only farmers who expect higher economic performance, on the basis of the information they possess, might decide to effectively adopt the innovation. In order to evaluate this hypothesis, a *Heckit* model, specifically a *probit* model with sample selection, is run by formally dividing the variables into two groups, namely the selection (*adoption*) and outcome (*performance*) variables. Results from the *Heckit* estimation, illustrated in Table 2.13, indicate the presence of a self-selection process of innovation introduction related only to positive expected gains in *value-added*, as indicated by the significance of ρ, while the other model specifications indicate that both processes are essentially independent[30].

Table 2.13 *Probit performance* model with sample selection

		Economic performance			
Characteristics		Cost reduction [yes=1; no=0]	Production increment [yes=1; no=0]	Value added increment [yes=1; no=0]	Quality increment [very high, high=1; otherwise=0]
Innovation	*Outcome equation (O)*				
	Research-innovation link	0.31	0.53	0.58*	0.79**
	Source of innovation [external=1; self =0]	-1.20*	-1.16**	-1.16***	-0.91**
	Age of innovation	-0.01	0.03	0.04	0.05*
	Constant	1.36**	0.98**	0.98**	0.30
Innovation	*Selection equation (S)*				
	Important innovations (last 20 years)	0.41*	0.48*	0.48**	0.84***
Farm	Breeder specialization	0.52	-0.11	-0.20	0.56
	Cereal specialization	-0.47**	-0.32	-0.64***	-0.52**
	Share of rented over total land	1.15***	0.76**	0.99***	1.03***
	Number of tractors	0.04	0.05	0.05	0.02
Socio-economic	Education > than mid-school	0.44*	0.49**	0.53***	0.52**
	Family income from Ag <30%	-0.22	-0.62***	-0.44**	-0.55***
	Family labor	-0.26**	-0.29***	-0.22**	-0.09
	Individual farm [yes=1; no=0]	-1.13***	-0.75***	-0.77***	-0.71***
	arctan(ρ)†	0.05	-0.27	-1.13*	-0.14
	Observations	241	243	240	232
	Uncensored Obs	50	56	62	88
	AIC	272.5	301.6	308.7	344.3
	BIC	321.3	350.5	357.4	392.5
	Wald χ^2 (O)	3.76	4.55	8.42**	10.2**

Note: *robust standard errors; t statistics in parentheses*; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$;
† *arctan*(ρ) *indicates the correlation coefficient between output and selection equations*.

[30] Indeed, a check on such results has been performed by running a *probit* regression on the performance variables by solely employing the information variables. The results confirm the ones obtained in the output equation of the *Heckit* model.

This suggests that the *Heckit* models appear to be more appropriate for explaining the effects of the information variables on economic performance. Indeed, these models, on one hand, confirm the results about *research* and *source of information* from the previous *probit performance* models, and, on the other hand, report the same results as the *introduction* models, except for the variable *number of tractors*.

2.9 Discussion

The outcome of the analyses highlights a picture that reflects the current dichotomy of the modern agricultural sector in developed countries worldwide: the coexistence of a large share of farmers operating on small non-commercial or semi-subsistence farms and a relatively small share of farmers operating on larger commercial and profitable/competitive farms who produce the majority of output (Freshwater, 2017). As regards the former, in the sample considered, there is a considerable share of farmers who, due to several reasons, decided to not adopt innovations in last 20 years. What emerges from the analyses is that most of these farmers operate on relatively small farms, grow cereal crops, possess limited machinery and receive less than 50% of family income from agricultural activities. This is a type of farmer whose family income is not derived primarily from agricultural activities and whose objectives are not necessarily, or uniquely, directed on profit maximization of the farm, but on other dimensions of the agricultural activities and/or family preferences, such as, off-farm allocation of family labour, hobby land tenure, conservation of resources (*e.g.* local cultivars) and of cultural values, credit collaterals, additional family income, CAP subsidy receipt *etc* (Salvioni *et al.*, 2014; Freshwater, 2017). However, it might be argued that for this type of farm a xonscious choice to substitute the on-farm innovation adoption process with the purchase of services from contractors was made. Although reasonable and noteworthy, this topic would deserve a specific focus regarding the relative profitability of innovating vis-à-vis turning to third party service providers, but it is beyond the scope of the dissertation. On the other side, within the group of innovators, there is a noteworthy share of farmers who are actively innovating, which is partly explained by the long-time horizon they take into account. Most frequent innovations are in the field of mechanical innovations and innovation aimed at water-energy saving. This is consistent with the fact that mechanisation is a widespread need across farm specialisations, on the one hand, and with the current need to save resources in a context characterised by climate change; the latter issue is potentially emphasised by the location of the study area in a Mediterranean region. Sequential innovations are frequent among innovators, which may be explained by both the existence of connections among innovations (innovation packages) and the tendency of most active farm(er)s to innovate continuously (Läppe *et al.*, 2015) in order to preserve farms' competitiveness (Levins *et al.*, 1996).

The results from the adoption models, mainly testing the adoption determinants, are largely consistent with previous findings in the literature in terms of the role of structural characteristics of the farms, such as, farm size, mechanization, labour and production type, and subjective characteristics of the farmers, such as farmer education, experience and off-farm income (Feder *et al.*, 1984; Lin, 2001; Diederen *et al.*, 2003; Dimara *et al.*, 2003; Kounduri *et al.*, 2006; Läppe *et al.*, 2015). The main novelty arises from the consideration of the judgement of farmers regarding the existence of important innovations in their field of specialisation, which I consider as an *innovation attitude*, which helps to distinguish between cases in which the innovation choice by the farm results from the need of keeping up with general technology shifts (*e.g.* replacing obsolescence), as in the technological treadmill; and from cases in which innovation is more a choice tuned to the specific production and marketing needs of the farm.

The approach also helps to explain the two different profiles of non-innovators, namely those for whom no-innovation is linked to the absence of innovation in the sector, in contrast to those foregoing innovation for personal or farm reasons, in spite of the progresses of innovations in the sector. The second group of models, namely the performance models, represent, to my knowledge, the first attempt to evaluate whether an innovation choice, corroborated by the farmer's ability of improving farm production with the adopted innovation, has an impact on farm's economic performance. The first results support the hypothesis of differential impacts on profitability, depending on farmers' attitude towards innovations, information sources and their prior knowledge of the link between the innovations and the research behind them. The impacts on profitability stemming from the *research-innovation link* are more likely realized as value-added and quality improvements, while those arising from external information sources are less likely. On the contrary they do not appear connected to improvements in productivity or cost reduction, which seem to be largely affected by the same elements identified as determinants of innovation adoption, such as education and farm size. This further result allows for deducing that the determinants of innovations adoption are linked to improvements in farms' economic performance in terms of cost reduction and production increase, which remains in the classical framework of the technology treadmill of Cochrane (1958) and Levins *et al*. (1996) as well as the induced innovation adoption framework of Hayami and Ruttan (1985). Likely improvements from i*nnovation attitude* are positive for each performance indicator.

2.10 Caveats

However, the present work it is also affected by some limitations that may affect the robustness and the generalisation potential of the results. First, the sample is rather small, especially looking at the adopters' subsample and considering the heterogeneity brought about by the large coverage of different farm specialisations. This may have contributed to the low significance of some of the models and some difficulty in estimation. Small sample size has also made potential additional explanatory variables difficult.

Second, the case study relies on a specific province in Italy, which, while benefiting from an internal heterogeneity (in terms of farm specialisation and altitude), still represents a specific context in terms of general ecological and legal conditions (including specific priorities *e.g.* for investment).

A third limitation concerns the way the data were collected. Due to a lack of better information (*e.g.* from accounting data) and funding limitations, most of the variables are based on statements made by farmers. Farmer assessments of impacts can be problematic, in particular with respect to the estimation of the impact of innovation on profitability parameters, which also implies a difficult judgement on the part of the farmers, as does farmers' understanding of the origin of an innovation, especially with respect to its research base, that incorporates a mix of actual information about the origin and level of documentation by the farmers. The origin of innovations and knowledge about it, in turn, relate to each other and are almost impossible to distinguish because of the way in which the survey was conducted. Based on other questions and statements by farmers on their own level of information, we can interpret this information mostly as revealing the true origin of innovation, however, there is certainly some level of (unmeasurable) approximation.

Fourth, and connected to the above, using stated information coupled with resource constraints implied the need to collect this information in a simplified way (*e.g.* using qualitative or dichotomous variables) and, in some cases, using categories in the data treatment in order to account for "perceptive discontinuities" (such as round numbers in per cent statements). This, however, implies some further difficulty in the estimation and interpretation of the models.

These limitations, associated with the promising results achieved, highlight the relevance of the topic and suggest more precise hypotheses for further investigation on this issue. This would require, however, a larger sample, wider territorial coverage and would benefit from linkages to structural and performance data not available for this study.

2.11 Conclusions

An important message arising from the essay, in spite of its limitations, is that the role of farmers is crucial for innovation development and that farmers who are willing to innovate are often engaged in a continuous learning process, which includes, beyond acquiring practical knowledge about available innovations, the knowledge and awareness of the process leading from research to the realisation of the innovation as well. This evidence supports the paradigmatic change of the innovation process from AKS towards the AKIS and multi-actor concepts, by providing additional insight into the proactive role of farmers in the management of external information coming from different sources, including research, and of own-knowledge within the innovation adoption process (Klerkx *et al.*, 2009; SCAR, 2012; Läppe *et al.*, 2015). Such proactivity might represent a relative competitive advantage for the improvement of farm performance and a key feature of entrepreneurship. In terms of *treadmill*, the current era might be described as *knowledge treadmill* in which those who knows more and better than others have a competitive advantage. On the other side, in terms of *managerial capabilities*, the farmer who has a dynamic understanding of markets and anticipates innovation should do better than those with more limited skills. However, the "anatomy" of the proactivity process would need to be better analysed in future studies, with the collection of more specific information about on-farm processes leading to innovation adoption or implementation on the farm.

The results of this essay show the importance of innovation for a large share of farms considered over a substantial time frame of 20 years. The most common innovations are in the field of mechanical innovations and innovation aimed at water-energy saving. Sequential innovations are frequent among innovators. Classical factors, such as proxies related to farm size, remain the most suited variables to explain the adoption of innovations, while motivations for innovation adoption are largely related to the combination of cost reduction and production increases.

The process of innovation development and adoption in agriculture follows two main pathways: self-development by farmers and external development by mostly private companies. Agricultural research is generally known to be in the background, but rarely seems to lead directly to technology development and even less to adoption. This may also be connected to the prevailing technologies that are considered to be relevant in the area (mechanisation and water/energy saving), which require important steps in terms of ‘engineerisation’ of knowledge and fine tuning to suit local conditions (including machinery set-up and feedback from users). In either case, the mediation between research and farmers has an important industry component or, in any case, involves different layers of actors.

Farmer knowledge of the existence of research activities in developing an innovation seems to be associated with better performance only for the specific but important cases of improving the value-added and of achieving very high-quality production. This suggests that farmers can have a specific role in terms of linking scientific research to different performance-improving strategies, and, in particular, that this can contribute comparatively more to quality, while traditional determinants of innovation adoptions, self-development or industry-led technology adaptation can have a larger role in cost reduction.

These results also yield relevant insights in terms of research policy. In particular, when promoting multi-actor approaches, innovation policies should better consider different regional/sector objectives in terms of quality, productivity or cost reduction, and related to this, more explicitly evaluate the potentially different roles that private and public research and innovation players. In addition, while it can be expected that economic incentives linked to factor and product prices mainly affect cost reduction through self-innovation, a stronger role has anyway to be attributed to direct and on-farm research and innovation incentives if quality objectives are to be pursued.

In spite of its limitations, the study hints at the need to further explore the co-existence and interplay among different innovations, different innovation pathways and different innovation impacts. Moreover, the interaction between awareness of technology development pathways and actual technology performance at the farm level is an issue that was only partially untangled in this essay, and one that is undoubtedly worthy of further investigation.

CHAPTER 3. AGRICULTURE AND WATER IN EUROPE: INSIGHTS FROM A CIRCULAR ECONOMY ANGLE

3.1 Introduction

Starting from the MacSharry reform of the Common Agricultural Policy (CAP) in 1992, the preservation of relatively high levels of supports to the European agricultural sector has been politically traded-off in favor of additional and stricter environmental compliance, which, in absence of a structured and systematic environmental policy at the EU level, has been pursued by imposing *ad hoc* constraints on farm input use, through specific Directives and Regulations, such as sewage and fertilizers, with the Nitrate Directive in 1991, land use with the Natura 2000 Directive in 1992, irrigation water with the Water Framework Directive in 2000, and seeds with the GMO Directive in 2001. The objective of such constraints has been an improvement in environmental sustainability of the agricultural sector, which has affected the CAP, both directly, through the modification of the Statutory Management Requirements (SMRs), and indirectly, by conditioning the direct payments and the Rural Development Programmes (RDP) payments to meeting additional Good Agricultural and Environmental Conditions (GAEC). In turn, the technical and economic adaptation of farms to evolving market conditions and to additional environmental "cross-compliances" has, over time, mostly been in the form of interventions designed to tackle new and specific constraints and to provide supports for maintaining the profitability of larger commercial farms and the viability of smaller farms.

From a backward perspective, although favoring a growing commitment towards elevated environmental standards of the economic sectors at the EU level, such a policy paradigm augmented existing mismatches between environmental and economic policy objectives, creating an apparent dichotomy in which environmental and economic sustainability are traded-off and, therefore, treated as alternatives to each other (EC, 2019). This condition holds as long as an imbalance between specific environmental (social) goals and the profitability of the (private) use of a specific resource persists (SWD, 2017). Generally, the reason for this imbalance can be found in the fact that the goal of environmental sustainability is pursued through technology enhancement and technical efficiency, whereas the goal of economic sustainability is reached by allocation efficiency and valorisation of resources, used as inputs or outputs.

This is more pronounced in cases where these type of constraints apply to cross-sectoral natural resources, like water, characterized by growing imbalances between supply and demand across economic sectors, all of which have been further exacerbated by the recent evolutions of climate change negatively impacting on water availability; and for which divergencies in policy design and governance problems at national and sub-national level persist (Charbit, 2011).

An opportunity to reconcile these economic-policy mismatches on ways that favor improvements in the *multilevel governance* of environmental and natural resources, *in primis* water, is provided by the *European Green Deal* (EC, 2019) which represents the new policy framework of the European Union (EU) for the new 2021-2027 programming period. With the European Green Deal (EGD) the EU intends to steer its entire policy framework towards the environmental sustainability of production and consumption patterns in all economic sectors of the Union.

The main objective of the EGD is to provide a policy framework and specific supports for fostering a transition towards a European economic system focused on total environmental sustainability but that remains able to guarantee *inclusive*[31] economic growth. It also represents a turn in policy priorities of the EU, by setting the minimization of environmental impacts of all economic sectors as the basic principle underpinning all European policies. These priorities in turn hinge upon concepts of: *climate neutrality*, *circular economy* and *decoupling economic growth from resource use*, which will overarch the European policy agenda for the next seven years (EU, 2020).

Achieving such an ambitious policy framework will require the successful *harmonization* of various sectorial policies and achieving *coherence* in their implementation across overlapping different economic sectors and across national and sub-national governments. However, even with this, the crucial question still remains of how to reconcile *de facto* economic growth with the core goal of total environmental sustainability. These two domains are not easily coordinated with each other, and each responds to different external impulses, such as policies or markets, in different ways, depending upon the specific incentives provided and the targeted objectives.

Introducing such a novel European policy context as the EGD will require rebalancing the trade-off between environmental and economic sustainability through the application of the *circular economy* concept. Indeed, it provides the right presuppositions for harmonization of distinct policies that currently embody a dichotomy, especially in those economic sectors competing for natural resources, like water, in the urban and the agricultural sectors. Further, the *circular economy* approach might contribute to fill the *gaps*, especially the policy, objective, information and capacity gaps, characterizing the

[31] Without leaving anyone behind.

multilevel governance of decentralized water policies in many developed countries (Charbit, 2011).

Specifically, this essay intends to provide insights and contributions to the current development of the European policy setting for the 2021-2027 period by assessing opportunities for harmonizing two important European policies, namely the CAP and the Water Policy (WP), within the framework of the European Green Deal. In detail, the essay approaches the topic from a *circular economic-policy* perspective applied to the water sector, in way intended to serve as the *trait de union* between the urban and the agricultural sectors, seen as water *producer* and *consumer*, respectively.

The essay proceeds with two sections: the first refines the concept of *circular economy* within the context of the EU. This requires a discussion of the normative framework of the EU, followed by a section on the relevant policy literature and on the recent evolution of the European CAP. The second section assesses the potential of the *circular economy* concept to be applied to the water sector (urban and agriculture), and the essay closes with final remarks.

3.2 The Circular Economy concept: environmental vs economic sustainability

Although the *circular economy* (CE) approach is now widespread in academics, it has been used in different contexts and with multi-fold meanings. Korhonen *et al*. (2018) refer to the circular economy concept, in terms of *scientific and research content*, as *superficial and unorganized*. They suggest referring to the WCED[32] (1987) for defining

[32] WCED stands for World Commission on Environment and Development. The main document of the WCED is *Our Common Future*, also called the Brundtland report, published in 1987 in which, for the first time, the concept of sustainable development is introduced.

the CE concept. Further, Geissdoerfer *et al*. (2017) affirm that *the relationship between the concepts* [CE and sustainability] *is not made explicit in literature, which is blurring their conceptual contours and constrains the efficacy of using the approaches in research and practice*. According to the WCED (or Brundtland Report) (1987) *the overriding policy objective must be to reduce the amount of waste generated and to transform an increasing amount into resources for use and reuse* and *[...] promoting the reclamation, reuse, or recycling of materials can reduce the problem of solid waste, stimulate employment, and result in savings of raw materials*. It appears clear that the concept of CE, according to the Brundtland Report, can be considered to be a methodology (*the reclamation, reuse, or recycling of materials*) to support environmental sustainability. According to Geng *et al*. (2016), the CE concept has evolved from a tool supporting sustainability, mainly based on waste reduction, into a new paradigm of economic growth, based on the concept that *production and consumption processes should focus more on holistic transformation to incorporate quality-of-life while dealing with emergent environmental issues*.

The CE concept is gaining more and more interest by actors in different societal spheres. The main motivation seems to be an interest in reducing production and consumption wastes that negatively impact natural resources, water *in primis*. It follows that the main objective of implementing a CE approach is improving environmental sustainability (Korhonen *et al.*, 2018; Geissdoerfer *et al.*, 2017; Ghisellini *et al.*, 2016). A secondary objective is the necessity of making the CE approach, in terms of production and consumption patterns, economically sustainable as well. These two aspects of the CE concept seem to be, at the moment, not well integrated, and such a situation creates a dichotomy between environmental and economic sustainability in which the two domains remain alternatives to each other (EC, 2019). Indeed, while, on one side, improvements in environmental sustainability are achieved by improving technology and technical efficiency; on the other side economic sustainability is pursued by increasing allocative efficiency and improving the pricing of resources. As pointed out by Sauvé *et al.* (2016) and Korhonen *et al*. (2018), integration of the two goals will require advances in trans-disciplinary research, as well as the harmonization of concepts and epistemological interactions among different disciplines.

Within the conceptual framework of sustainability and CE set out in the Brundtland report, research on the application of the CE concept to the agricultural sector, in terms of agricultural and resource economics, has mainly focused on economic evaluations of using reclaimed urban wastewater as irrigation water (Tsagarakis, 2005; Hernandez-Sancio *et al*., 2010; Zucaro *et al.*, 2012; Orsini *et al.*, 2016; Arborea *et al*., 2017). An extension of water reuse is the economic evaluation of the reuse of residues from the process of water treatment, such as phosphorus (Dockhorn, 2009; Molinos-Senante *et al.*, 2011; Vollaro *et al.*, 2016). Such examples of academic interest in CE can be categorized as studies of economic feasibility analysis that focus on the employment of reclaimed raw material resources from wastes, obtained through newly available technologies, that can be used as substitutes or complements for scarce primary raw materials.

Conversely, much of the non-economic academic literature referring to CE in agriculture research focuses on the technical feasibility of production processes favouring the reduction of pollution and/or the reduction of waste (Sauvé *et al.*, 2016; Geissdoerfer *et al.*, 2017), which pertains mainly to environmental sustainability. Integration of both these literature streams would be beneficial in speeding up the diffusion of the CE approach as applied to agriculture. A further useful research dimension might be developing a set of policy supports able to foster the balancing between specific environmental (social) goals and the profitability of the (private) use of a specific resource (SWD, 2017), while providing incentives for *closing the loop* (EC, 2015) and for addressing the challenges posed by the impacts of climate change on natural resources (EU, 2020).

3.3 The environmental normative framework at EU level

The European normative governance framework is based on two blocks of EU legislation: primary and secondary. Primary legislation is the set of formal European treaties which are the basis for all EU actions. Secondary legislation is the set of legal actions created by the European Commission, the European Parliament, Court of Justice and/or the Council, the most important of which are Regulations, Directives and Decisions, all deriving from principles and objectives set out in the treaties. Some of these acts are binding on Member States (MS) and others are not, while some apply to all MS and others do not.

Regulations

A *regulation* is a binding legislative act created by the Commission. It must be applied in its entirety across the EU. Examples are the common safeguards on goods imported from outside the EU and the production standards of organic agriculture.

Directives

A *directive* is a legislative act that sets out a goal that all EU countries must achieve. It is established by the Commission after a majority of MS approve the idea through a decision by the Council. However, it is up to the individual countries to devise their own laws on how to reach these goals. An example is the directives pertaining to environmental protection for which each country determines the areas, resources, targets and standards that will satisfy the environmental requirements set out in the directives.

Decisions

A *decision* by the Commission or the Court of Justice is binding on those to whom it is addressed (*e.g.* an EU country or an individual company) and is directly applicable those specific entities. An example is the Decision No 529/2013/EU — accounting rules on greenhouse gas emissions and removals resulting from land use, land-use change and forestry.

Recommendations

A *recommendation* by the Commission or Parliament is not binding. It allows these institutions to make their views known and to suggest a line of action, without imposing any legal obligation on those to whom it is addressed.

Opinions

An *opinion* is an instrument that allows the institutions to make a statement in a non-binding fashion, in other words without imposing any legal obligation on those to whom it is addressed. An opinion is not binding. It can be issued by the main EU institutions (Commission, Council, Parliament), the Committee of the Regions and the European Economic and Social Committee. While laws are being made, the committees give opinions from their specific regional or economic and social viewpoint. For example, the Committee of the Regions issued an opinion on the clean air policy package for Europe.

Among the environmental Directives and Regulations directly affecting the agricultural sector there are:

- Directive 2008/105/EC setting environmental quality standards in the field of water policy (including pesticides)
- Directive 2000/60/EC – framework for Community action in the field of water policy (WFD)
- Directive 91/676/EEC – protection of waters against pollution caused by nitrates from agricultural sources
- Directive 2009/28/EC — promoting the use of energy from renewable sources
- Directive 2004/35/EC on environmental liability with regard to the prevention and remedying of environmental damage (polluter-pays principle)
- Regulation (EU) 2018/848 — rules on organic production and labelling of organic products
- Directive 2009/31/EC on the geological storage of carbon dioxide
- Directive 86/278 - soil protection when sewage sludge is used in agriculture
- Regulation (EU) No 1143/2014 on the prevention and management of the introduction and spread of invasive alien species
- Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (Natura 2000)
- Directive 2009/147/EC on the conservation of wild birds

- Directive 2001/18/EC on the deliberate release into the environment of genetically modified organisms

So far, the definition of the EU policy in each programming period (every seven years) is based upon an evolving set of issued Regulations, Directives and Decisions that shape the policy mix of each sector, like the CAP and others. However, the set of norms shaping environmental protection is not systematic (in the sense of not defining the environment as a sector) and norms are formulated as *ad hoc* constraints to bend economic sectors towards the environmental sustainability in their actions.

This is the reason why, as stated before, the European Green Deal represents a drastic change in the EU policy process, - posing environmental protection as an overarching goal for the formulation of sectoral policies. In this context, for example, mitigating climate change and protection of water resources become a priority and are treated as *sectors* (*i.e.* water sector) for which specific policy objectives are set (*i.e.* water policy). The consequence of this approach is that the full set of social and sectoral policies are then defined subject to meeting these overarching environmental objectives and greater coherence across sectoral policies is necessary for the attainment of these ambitious objectives.

3.4 Policy literature review: conciliating economic growth with environmental protection

An important stream of literature, mainly developed within the field of economic and policy analysis, refers to the impacts of normative frameworks that establish environmental constraints on wastes and pollutants. These can have the unintended effect of creating a barrier to the transformation of waste into new sources of raw materials and, hence, can limit the *closing the loop* objective. A clear example is the set of European Directives aimed at protecting water and related resources, including soil, biodiversity and coasts, from point and non-point pollution, as well as from excessive or unregulated water abstraction and coastal saline intrusion (Graversgaard *et al.*, 2018). These Directives act as environmental constraints (prohibitions and limitations) applied: to specific activities, to economic sectors, or to territories. Since they must be transposed into national laws in each MS, they directly affect the economic profitability of local businesses, by requiring the internalization of environmental compliance costs, and indirectly force firms to invest in order to improve the environmental sustainability of their production processes. This policy setting creates market imbalances, in terms of costs and output price shocks, leading, in the worst case, to the market exit of small and less competitive firms, which are unable to apply fast and timely improvements needed to acheive allocative efficiency for farm resources, and the consequent abandonment of land (Matthews, 2013).

Referring to irrigation water used in the agricultural sector, for instance, the constraints posed by the Water Framework Directive (WFD) to address frequent droughts and increased competition with urban and tourist water consumption, likely lead to higher production risks and income losses, unless accurate and targeted supports are not properly put in place. Recently, several studies applied to European contexts explored experiences in complying with article 9 and 11 of the WFD by using market, or market-like, mechanisms to improve the allocation of scarce irrigation water. These WFD articles refer to the *polluter pays* principle and *pricing as a basic measure*, respectively, and aim at reducing the amount of irrigation water used by agriculture by better aligning the marginal value of water with the marginal value of the output (Vollaro *et al.*, 2015). However, on the other side, the miscalibration of support schemes has in some cases led to the unintended consequence of increases in water use, due to a mis-alignment of private incentives, namely profit, with intended public outcomes, namely qualitative and quantitative improvement of water bodies (river basins, reservoirs and aquifers) (Rey *et al.*, 2019).

Both outcomes, an intended reduction or an unintended increase, in water use that occur as a consequence of the application of constraints and/or incentives, seem to have a short-run scope and feature *spot* interventions. However, the present climate and environmental challenges call for long-run policy initiatives that are more able to stabilize the private economic behaviour in the direction of the common goal of protecting the quantity and quality of water resources. Such initiatives are more likely if the agricultural sector is recognized as *multifunctional* (OECD, 2008) and, as such, is acknowledged as actively contributing to the provision of public goods and ecosystem services. An opportunity in this direction is provided by supporting the use of treated and reclaimed water for agricultural irrigation. However, at present the Directives represent a barrier, more than an opportunity, because of the very stringent standards related to safeguards of public health, and the relatively high investment costs for allowable reclamation technologies at Wastewater Treatment Plants (WWTP).

From a *circular economy* perspective, this *loop* should be closed but, in order to realize it, a harmonization of policies is needed, as is coherence across specific implementation measures. Indeed, Smol *et al.* (2020) support the idea that implementing the *circular economy* framework in the water sector, calls for both investments in technology, to overcome technical barriers, and a strong commitment to realize supporting institutional (organizational) and societal changes. At present, the European Green Deal seems to exclude this opportunity. Indeed, on one side, water policy, through the latest WFD and Urban Waste Water Treatment Directive (UWWTD), push improving the ecological status of water bodies, conditional on the *polluter pays principle*; while, on the other side, the CAP provides support schemes for protecting and improving the incomes of farmers, but imposes more, and more stringent environmental cross-compliance requirements. Although contact points for coordination have been set, the clear integration of these two policies, especially in the light of the promising *circular economy* standpoint proposed by the Green Deal, still appears far off.

Indeed, according to the European Commission (EC), the CAP should be restructured to accommodate all the sustainability objectives - pertaining to its sector - proposed in the *European Green Deal*: *climate change*, *water* and *biodiversity* (SWD, 2020). Within the latest CAP reform documents, along with the proposed nine specific objectives , the eco-schemes (Pillar I) and the agri-environment-climate payments of the rural development plans (RDP) (Pillar II), this *accommodation* would be accomplished by including the WFD as an additional statutory management requirement (SMR) and by sharpening the Good Agricultural and Environmental Conditions (GAEC)[33] requirements (SWD, 2020). This would occur without additional targeted financial support and without any reference to the *circular economy* policy proposal. Rather, it appears that CAP reform would be shaped according to the *decoupling of economic growth from resource use* proposal, whereby the agricultural sector will be incentivized to simultaneously improve, farm competitiveness, rural development and multifunctionality, while being constrained

[33] Good Agricultural and Environmental Conditions defined by Council Regulation (EC) No 1306/2013

to internalize higher environmental sustainability costs, and to improve profitability by reducing input use, including water. This setting actually contradicts current scenarios for climate change in Europe, which forecast changes in precipitation patterns, that reduce water availability and increase the frequency of droughts in the Mediterranean countries. These scenarios put at risk the objectives of the WFD and seem to require the provision of additional water sources. One concrete possibility in this direction would be increasing the use of reclaimed water as an additional irrigation source, which could be easily framed within the *circular economy* proposal of the European Green Deal.

3.5 EU policy development: environment, agriculture and water

A specific environmental policy does not now exist at the EU level. So far, the environment, in its largest meaning, is being protected by a sequence of norms that impose constraints on the use of resources. This is a reason why, from a policy perspective, the interest in CE is quite remarkable in the European Union (EU). The new European policy course, launched in 2014 with the Europe 2020 strategy, has set the ground for driving the EU toward a circular economy framework and it continued in this direction with the release of the European Green Deal in 2019. Indeed, the EU adopted a first *circular economy package* in 2015 based on the recovery and reuse of waste materials, with the twofold objective of reducing the production of primary materials and their impact on the environment. In 2020, a *circular economy action plan* was developed, with the ambition of changing the paradigm of consumption and production patterns at the EU level towards the circularity of resource use. Major policy weight and flexibility, indeed, has been attributed to the capacity of MS to reduce the pressures and impacts of economic and social activities on natural resources, especially soil and water.

This choice represents a natural evolution of a fragmented policy path for facing single issues, initiated decades ago, but which has evolved with the emanation of several directives and regulations concerning environmental protection (or the limitation of environmental pollution). As stated by the EC (2015) and EC(2019), a new paradigm for enhancing the competitiveness of the EU economy without impairing the environmental and natural resources – *achieving climate neutrality by 2050 and decoupling economic growth from resource use* - is supported by the objective of "closing the loop" and starting a transition process towards *a more circular economy* and to *double its circular material use rate in the coming decade*. Indeed, these statements introduce the circular economy plans adopted in 2015 and in 2020 with the specific objectives of reducing EU dependence upon the production and import of raw materials, that are highly subject to both scarcity of resources and price variability, as well as strongly reducing *consumption footprints*.

The intention to drive an economic system towards the circularity of materials (especially secondary raw materials) largely relies upon the innovation capacity of the EU, based on: vast existing technological know-how, the enhancement of research potential (through the Horizon 2020 and Horizon Europe programmes) and the financial support for knowledge-based investments through dedicated structural funds (Vollaro *et al.*, 2016). It also calls for a deep revision of sectoral policies in order to accommodate the new circularity paradigm. However, even though the *circularity* approach within the European Green Deal focuses on *re-designing* the production and consumption processes to favour a transition towards long-run *use* and *reuse* and reducing *wastes* and *disposals*, it seems that the agricultural sector is excluded from such a *circular approach* and is instead asked, once again, to internalize more stringent environmental cross-compliance.

In fact, the European CAP, born with the purpose of improving the food security of the European population and the living standard of farmers, since its outset has been designed to promote productivity improvement and modernization of the agricultural sector. Only later, starting from the 1990s, has the CAP been subject to continuous and growing environmental constraints[34]. The environmental bending of the CAP initiated in 1992 with the MacSharry reform which, *inter alia*, replaced price supports with coupled payments and introduced severe mandatory measures, including the set-aside of productive land by large farms and various agro-environmental measures. In this period, the European Union adopted a series of environmental Directives targeted to reduce the environmental pressure of agricultural production, among which the most important are the Nitrates Directive (1991), the Pesticides Regulation (1991) and the Habitats Directive (1992). The intent of these Directives was to protect natural resources, like water and soil, from excess usage of chemical inputs, and to reduce negative impacts on the natural environment, especially on wild animals and birds, by forcing the agricultural sector to reduce intensification practices (abuse of fertilizers and pesticides). Subsequent CAP reforms gradually replaced the coupled payment systems with decoupled direct payments and started to condition the receipt of these payments on observing the environmental constraints set in the environmental Directives, through environmental cross-compliance requirements.

Agenda 2000 reforms introduced Pillar II of the CAP by introducing Rural Development Plans (RDP) whereby voluntary measures, devoted to reducing intensification practices with the support of compensatory payments, were set. The basic

[34] For a thorough examination of the environmental evolution of the CAP, see Matthews (2013).

structure of the CAP has not changed since then, but the degree of environmental bending increased with the introduction of Statutory Management Requirements (SMRs) and the GAEC. The former applies to all farmers, while the latter apply only to farmers receiving support under the CAP. In the following period, since 2006, the CAP reduced the use of direct supports while strengthening environmental conditionality in Pillar I and improved, through a modulation mechanism, the financial resources of the agro-environmental measures (AEM) of Pillar II. In this period, on one side, the WFD (Directive 2000/60/CE) for the first time shaped a comprehensive water policy for the EU linking the issues of, climate change, drought and water scarcity, that became part of the international policy agenda; while, on the other side, the agricultural sector was *under accusation* (as a scapegoat) as the European sector responsible for the highest absolute consumption of water resources. Since then, the agricultural sector has been challenged by pressing requests to improve the environmental sustainability of production and, at the same time, to improve its competitiveness at the global level. This corresponds to steering agriculture towards both *sustainable intensification* (Pretty, 1997) and *sustainable competitiveness* (Dwyer *et al*., 2012), which are conflicting objectives.

Subsequently, the last CAP reform put in place the *greening* payment in Pillar I (with scarce success) and a new set of measures in Pillar II, beyond the AEM, based on: innovation (cooperation with the research sector and stakeholder interactions), interventions for mitigation and adaptation to climate change (reduction of GHG emissions), and a greater emphasis (in terms of land and financial support) on organic agriculture. The post-2020 CAP proceeds along this path by: reinforcing what is already in place and favouring wider flexibility of the implementation stages at the MS level, further modulation to make Pillar I schemes less attractive to large farms and more subject to environmental cross-compliance (now called "eco-schemes"), and encouraging more voluntary participation in the AEM schemes of Pillar II. For these Pillar II changes, traditional measures for fostering the *improved management of* ***natural resources*** *used by agriculture, such as water, soil and air*, organic agriculture and innovation will take a more prominent role[35]. It is important to highlight that, since the Agenda 2000 reform, a growing emphasis on supporting the generational turnover of farms has been given in Pillar I and II of the CAP. The underlying idea of this turnover is to make the agricultural sector more attractive for *educated* farmers who are thought to be more likely to adopt more *science-* and *innovation-based* management practices that are better able to successfully face environmental and climate challenges. The novelty of the CAP post-2020 is that the WFD will be integrated into the CAP, becoming the first SMR, although once again the trade-off between private profitability and environmental (social) outcomes has been chosen over the option of *closing the loop* through the approach of the *circular economy*.

In adopting the WFD, the European Union (EU) started a process of policy interventions to safeguard water resources with the first important step being oriented toward the reduction of pollutants in water bodies. While improvements in water quality imply increases in water availability they do not guarantee, *per se,* meeting water needs. However, water needs, intended as water demand, also may not precisely correspond to actual crop water requirements, especially when water is provided at low cost, inducing inefficiencies in relative use, as it traditionally is in Mediterranean agriculture. Such conditions generate practices that treat water as a cheap input and interpret water demand

[35] For a thorough examination of the environmental setting of the CAP post-2020, see SWD(2020) 93 final.

as "water needs at quasi-null costs" (Arrojo, 1999), implying the establishment of a vicious circle of rising demand – inadequate supply – leading to increased (perceived) scarcity (Dosi and Easter 2000). In Article 9, the WFD invites each MS to recover costs related to water (scarce) resources and their respective uses according to *polluter pays* and *user pays principles*. In this respect, the WFD represents the first concrete attempt to associate an economic value to water resources, by encouraging a MS to apply adequate tariff systems and water price levels that can guarantee the financial sustainability of water management and incentivize more efficient use of water resources to yield a reduction in water use.

To strengthen the quantitative aspects of water policy and tackle the risks of drought and water scarcity, the European Commission (EC) since 2006 has been working on the formalization of a guideline document in the form of a collection of recommendations for better quantitative management of water resources at the EU level. The goal is to improve water use efficiency and reduce water losses, without meddling with the objectives of the WFD. Most relevance has been given to proven effective measures applied at different EU territorial levels for the agricultural sector, like: the increase of water supply (in the spirit of art. 4.7 of the WFD), the application of water price schemes and water metering (by backing art. 9 of the WFD), the implementation of more efficient water allocation mechanisms, *e.g.* water use rights trading/exchange, as well as, the integration of water related compliance measures with CAP subsidies. These outcomes are collected in the document *Blueprint to safeguard Europe's water resources* (EC, 2012b), which is an orientation policy document aimed at evaluating existing EU water policies, and analysing obstacles that likely hamper the implementation of the proposed measures. As regards the issues of drought and water scarcity in the agricultural sector, the Blueprint proposes to enforce the application of art. 9 of the WFD (pricing and metering) and to foster actions for water use reduction as a pre-condition for accessing Rural Development and Cohesion funds. In addition, the EC is developing another guidance document for the development of trading schemes for irrigation water use rights. According to Maia (2017), however, current implementation of the WFD is insufficient and, as regards economic aspects, much more clarity is required for cost-benefit analyses, especially regarding resource and environmental costs. Overall, *less than five years from the end of the second management cycle, it is clear that MSs still have many challenges to overcome to be able to achieve the very ambitious goals set by the WFD* (Maia, 2017).

With the introduction of the *new circular economy package* (EC, 2015) the EU is examining the option of reusing treated and reclaimed water for irrigation purposes and MS have been warmly invited to include the option in their national River Basin Management Plans (RBMPs), according to the *water hierarchy* set in the EU Water Scarcity and Droughts Policy (EC, 2007). Indeed, the option of turning to the use of treated and reclaimed water sources is increasingly relevant whenever the risk of scarcity (demand higher than supply) persists even after all other measures aiming at improving the efficiency of water use have been implemented, *from water saving to water pricing* (EU Water Directors, 2016). From the document *Guidelines on Integrating Water Reuse into Water Planning and Management in the context of the WFD* drafted by the EU Water Directors (2016) it appears clear that the policy implementation path begins with tackling the water scarcity issue by improving knowledge and the reliability of quantitative information for water management, namely supply (cyclical availability) and demand (use trends in all sectors). Then MSs can act to reduce water demand in all sectors, mainly through application of the polluter pays and full cost recovery principles of the WFD, by imposing specific tariff systems - like the block tariffs - or raising prices.

The results are encouraging and validate the potential of the WFD[36] to improve both the quality and quantity of water resources. But acting only on the demand (polluter) side might not prove be sufficient to guarantee future availability of water resources for all economic sectors, especially in view of growing pressure on water resources by future development in the urban, tourist, industry and agricultural sectors, especially with growing uncertainty of future water availability posed by the climate change. Another option, improving the supply of reliable and safe water, might be pursued by reducing water abstraction (in line with WFD), but also by constructing small scale artificial basins (able to catch and retain precipitation waters) and by improving the treatment performance of the WWTP (in order to divert treated and reclaimed water to non-potable uses, like recreational, industrial and agricultural ones). The EU is fully aware of such options, as well as of their great benefits in terms of coping with drought and scarcity, but technical and social barriers have prevented this option from being realized and effectively *closing the loop* (BIO by Deloitte, 2015; EU Water Directors, 2016).

There is a current and ongoing discussion within EU institutions about modifications to the UWWTP[37] Directive and introduction of a Regulation in order to set minimum qualitative standards for effluent[38] reuse in economic sectors (EC, 2018). The main issues, indeed, pertain to social acceptability by both consumers and producers of such options, conditional on *subjective perceptions* about health and environmental risks

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[36] https://ec.europa.eu/environment/water/quantity/good_practices.htm
[37] UWWTPD stays for Urban Water Water Treatment Plants Direcive (Directive 91/271/EEC).
[38] *Effluent* is the treated water leaving the WWTP.

and on safety conditions (Alcade-Sanz *et al.*, 2017; Ricart *et al*., 2019). Specifically, these relate to recent technical possibilities, given by advances in reclamation technologies and to related retrofitting of existing WWTP (Vollaro *et al.*, 2016), as well as to their related investment and operational costs, and to appropriate tariff levels with respect to the *full cost recovery* requirement (art. 9) of the WFD (Voulvoulis, 2018). Despite this, some EU countries have allowed the practice of water reuse for decades and recently more countries have started to plan water reuse activities (Lavrnić *et al*., 2017). However, a common framework for guiding and regulating such practices is far from being designed at EU level (Fawell *et al*., 2016; Lavrnić *et al.*, 2017; Rizzo *et al.*, 2018), in part because the optimal level of cost-effective water reuse is a *local issue* (BIO by Deloitte, 2015; Rizzo *et al*., 2018).

For the above reasons, since 2000, within the European policy context, the management of water resources and the agricultural sector characterized by the overlapping of: the WDF, the UWWTPD, and the SMRs and GAEC applied to the CAP, the only actions taken to increase the quantitative improvement of irrigation water for farms has been from support under the pillar II of the CAP for construction of *micro* artificial reservoirs and for the adoption of water saving technologies at the farm level (irrigation systems).

The opportunity for the realization of a *closed loop* exists, but it depends on the implementation of a well-defined policy mix involving the "water sector", which in turn depends on the harmonization and coherence of various sectorial policies. At the moment, however, the development of future policies in such a direction appears unrealistic and is instead constrained to the reduction of environmental pressures by the policy "path dependence" of each sector, (Pantzar *et al.*, 2020).

3.6 Potential coordination of actions for *closing the loop* on water in the agricultural sector

The European Green Deal is proposed as an overarching policy framework, intended to condition future economic development in the EU upon environmental, social and economic sustainability. The EGD relies on the concept of the *circular economy,* which represents a disruptive departure from the *linear economy* paradigm that has shaped the European policies so far. The transition toward a *circular economy* will not be smooth and, will likely be hindered by resistances to change from MSs and stakeholders in all sectors. However, a clear presentation of the *circular economy* framework, as well as its implementation stages, would be beneficial for reducing the uncertainty characterizing perceived policy risks of stakeholders, and for identifying practical solutions to accommodate the interactions among different policies and sectors in order to achieve sustainability objectives.

The *circular economy* concept calls for interaction, collaboration and coordination among interested parties, and involves a series of, combined, joint and matched actions and decision processes at all governance levels. Given its novelty and the lack of consolidated experiences, the *circular economy* framework is seen from different perspectives by different interests, with each trying to shape its management in ways that best suit that group's interests. These characteristics easily accommodate the policy prescriptions summarized and reported by Charbit (2011) to tackle the multilevel water governance issues in OECD countries. Indeed, Charbit (2011) invokes *innovative policy* and the design of *institutional responses* to meet the challenges risen with the decentralization of the water policies in many development countries: […] *water governance can be improved by means of better integration of territorial specificities and better co-ordination between public actors in charge of designing, regulating and implementing water policies across ministries, public agencies and between levels of government. Promoting co-ordination and capacity-building is a large and critical step toward bridging multilevel governance gaps in water policy*.

The key feature of the *circular economy* framework is to reduce *waste* by as much as possible: by limiting the wearing out or obsolescence of products; by supporting the reclamation, the recycling and the reuse of resources; and by fostering the transformation of resources exhausted in one use (mainly waste) into new secondary raw material for another use. This concept, necessarily, involves the overlapping of actions by different actors, like, firms, sectors and institutions at different level, from local to global, which share across the life process of a product (cradle-to-grave).

A variety of proposals of settings for CE frameworks can be found, and each is developed from a different angle, either, sectoral, resource-based, institutional or other. Ghisellini *et al.* (2016) differentiate the application of the *circular economy* concept into three distinct levels, mainly related the context of the process being considered: *micro* (company or consumer level), *meso* (ecoindustrial parks) and *macro* (nations, regions, provinces and cities) for production, consumption and waste management sectors. Smol *et al*. (2020) propose a framework tailored to the total management of water resources. Their CE framework expands the existing paradigm of *reduction* of qualitative and quantitative pressure on water resources and focuses on the improvement of the WWTPs by proposing expanded efforts at *reclamation,* characterized by the technical possibilities offered by the most advanced available technologies, and by the *rethinking* of the uses of water resources along the overall cycle (Smol *et al*., 2020).

Another perspective on the application of the CE concept to the management of water resources in the EU might be considered in terms of the relationship between the agricultural sector, other economic and social sectors, and the institutional/policy process. Borrowing from Ghisellini *et al*. (2016) and Smol *et al.* (2020), three levels can be identified in the management of water resources: an overarching *macro* level, including institutional and policy settings; the *meso* level, represented by the interactions and overlaps (linkages and contact points) between sectors; and the *micro* level composed of the sectors directly managing water, namely, urban, agriculture and industry.

At the *macro* level, policy boards could improve the level of interaction in order by elaborating coordinated and coherent policy packages across the implementation of the various European Structural and Investment Funds (ESIF) (ERDF, ESF, CF, EAFRD, EMFF and ETC)[39] at the national and local levels. This is possible through reductions of frictions among institutions having operating authority over the sectors actually managing water resources at local level, for example between the River Basin Authorities governing water policy under the WFD, and national and regional administrations governing economic sectors using water resources. The approach would coordinate programs serving urban, industrial and agricultural sectors, such as those under: the CAP, the Operational Program for Cohesion Policy, and the Regional Operational Programmes (ROP) of the

[39] ERDF: European Regional Development Fund; ESF: European Social Fund; CF: Cohesion Fund; EAFRD: European Agricultural Fund for Rural Development; EMFF: European Maritime and Fisheries Fund; ETC: European Territorial Cooperation (Interreg Fung).

ERDF. What is needed at the *macro* level is a coherent set of constraints and incentives, coordinated at both the *meso* and *micro* levels, able to allow the production of, and stimulate the use of, reclaimed water across the involved sectors.

Given the set of existing and prospective environmental constraints and water pricing systems already in place, the overarching *macro* level should provide economic instruments that offer better incentives for water management and that are designed to align individual behaviour with public objectives of achieving a reliable quantity and quality of water resources, and that mitigate water-related risks (Delacámara *et al.*, 2014; Lago *et al.*, 2015; Gómez, *et al.*, 2017) and are able to guarantee unimpaired profitability. In the case of the reuse of reclaimed water in agriculture, this can be done by: i) setting minimum qualitative standards for using reclaimed water in order to guarantee health and safety; ii) stimulating the adoption of innovation in the urban and industrial sectors, through the ROP, to upgrade the WWTPs and in the agricultural sector, through the CAP, to improve the management of irrigation practices; iii) supporting R&D and extension investments through ROP and CAP in order to stimulate cooperation among stakeholders and to awaken the population and economic agents about both economic development and sustainability opportunities provided by the CE approach; and iv) investing in public infrastructure for the delivery of reclaimed water (irrigation networks) through the ROP, CAP and CF.

At the *meso* level, a clear quantification of the potential supply and, particularly, the potential for supplementary reclaimed water for irrigation purposes is needed in order to evaluate the scope for both the design of local policy interventions and the magnitude of the required investments. The expected benefits of the implementation of a *circular* *economy* paradigm have to be considered at level of society but calibrated with respect to their cost-effectiveness at the local level. Therefore, *ex-ante* evaluations in terms of cost-benefit analysis of the technical, social and economic aspects are necessary in order to evaluate the optimal level of hypothesized interventions. These need to be supported by economic feasibility analyses related to required private investments in the urban and agricultural sectors, and by analysis of subsequent market conditions evaluated in terms of changes in the aggregate supply and demand due to the introduction of reclaimed water (Zucaro *et al.*, 2012; Arborea *et al.*, 2017). Recent technical evaluations suggest that remarkable benefits might accrue, especially in those rural territories surrounding large urban areas, for which the size of the WWTPs is higher than 2000 inhabitant equivalents and where the volume of treated water might represent an important supplementary source (B.I.O. by Deloitte, 2015).

A further fundamental point to be addressed at the *meso* level is the degree of involvement of the population whose territory is interested in implementing the *circular economy* paradigm to its water sector. Indeed, the management of water resources is a sensitive issue for Europeans, especially for those populations affected by high risk of water shortages and droughts located in the Mediterranean territories. Such interest is in part motivated by effects of the recent application of the WFD at local levels, for which a rise in the investment costs and, subsequently, in water tariffs occurred, as did frequent privatization of water services (involving private investments as well). The higher tariff (price) signals triggered greater concern, not only with respect to the use and consumption of water resources, but also to the entire water management processes. Social acceptance of likely more costly water resources is essentially motivated by a *sharing* of the intended environmental objectives, especially regarding the social benefits accruing from: the qualitative preservation, the optimal management of scarce water resources, and the reduction of perceived uncertainties of future water availability caused by climate change (Vollaro *et al.,* 2015; Michetti *et al*., 2019).

As regards the involvement of stakeholders, specific interventions can be designed to support their collaboration and cooperation in the development of innovative solutions and best practices at different territorial levels within the European Innovation Partnership (EIP), by taking advantage of opportunities provided for the formation of research consortia from grants under the Horizon Europe (HE) programme, as well as through the establishment of Innovation Operational Groups (IOG) funded by ROP and CAP (all involving the research sector and private-public partnerships).

At the *micro* level, firms need to be stimulated and supported in the adoption of innovations. This is another key factor that requires, on one side, high managerial skills able to fine-tune the proper adjustments of the firms' production processes with the innovation choice and, on the other side, a push on quality improvement of products (see second essay). This holds for both the urban and the agricultural sectors if they are considered as producer and consumer, respectively, of reclaimed water.

In order to *sell* reclaimed water to the agricultural sector, the urban sector needs to improve the treatment and reclamation capacity of WWTPs. The most modern technologies are now actually able to both reclaim mineral resources, like heavy metals, nitrogen and phosphorous, and purify urban wastewater up to the "tertiary" level (with a strong abatement of pathogen microorganisms). This is possible by, retrofitting the existing WWTPs, and by expanding them with modular innovations enabling new stages of treatment, reclamation and sterilization, regardless of facility size (Vollaro *et al.*, 2016). According to the national standards of the US Environmental Protection Agency (EPA), *treated* water (obtained by a secondary treatment) is suitable: for use in orchards and industrial crops not intended for human and animal consumption, for recharging non-potable water-tables, and for the preservation of humid habitats and minimum vital flows of rivers; while *reclaimed* water (obtained by a tertiary treatment) would be suitable: for all irrigation purposes, including crops intended for human consumption, for the recharge of water bodies for bathing (or more generally for recreational uses), and for the recharge of potable water-tables (UNEP, 2011). The employment of such technologies would make the supply of irrigation water more elastic and less dependent solely upon the natural water cycle, with an expected positive consequence of guaranteeing a more stable supply of irrigation water.

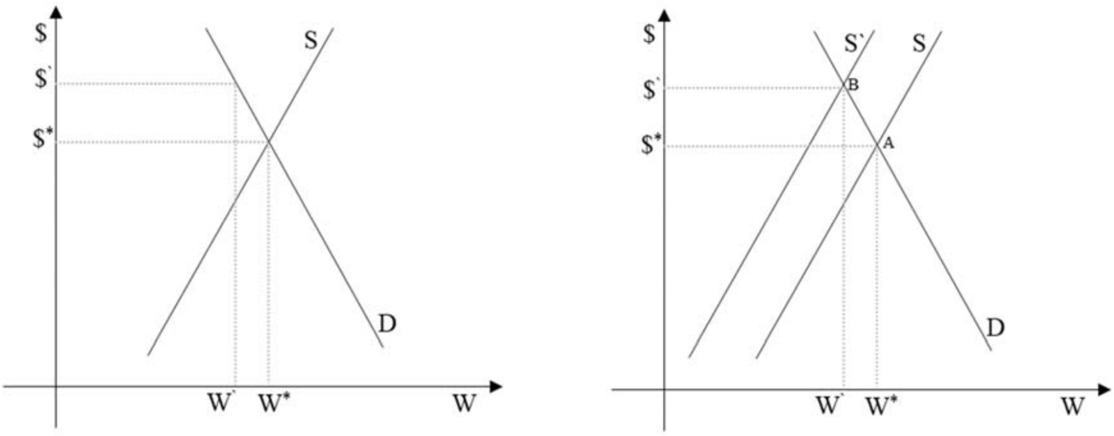
In order to apply this reclaimed water, the agricultural sector needs to be able to adapt to risks of water scarcity by adopting specific technologies and know-how. Indeed, the turn to reclaimed water sources presupposes the existence of a structural condition of water scarcity, as identified in the water hierarchy (EC, 2007), for which the agricultural sector should react by adopting water saving technologies as well as by improving farmers' skills related to on-farm water management. As mentioned, the European agricultural sector is subject to environmental cross-compliance and it is obliged to obey to the precepts of Directives imposing strict limits on inputs and operational choices, with likely negative consequences for production and economic performance. This happens because the Directives, often are rarely transposed in the correct manner at the MS level and are applied without suitable targeting in the implementation stages. This can lead to farmers being unaware of their obligations, or to strategic misconduct. Several studies confirm the effectiveness of the EU control agencies in identifying noncompliance, but sanctions are not applied because the agencies are aware that, most of the time, it is difficult for farmers to comply with the Directives, and the related sanctioning costs are high (König *et al.*, 2014).

On the other side, since the Agenda 2000 reform, Pillar II of the CAP is supporting both inter-generational turnover and modernization of farms, along with providing compensation for the voluntary adoption of AEM and pushing for the improvement of a knowledge-based agriculture. In terms of reduced pressure on water resources, the RDPs largely support farmers with funds for the adoption of sustainable agricultural practices, like organic agriculture, and for other measures concurring to the application of both SMRs and GAECs. However, these alone might not be enough to address future challenges of water scarcity and droughts. In fact, even without a comprehensive water management approach, farmers are adopting water saving technologies in response to higher water tariffs, by replacing surface irrigation with sprinklers and drip irrigation systems. Indeed, a major contribution to adoption is provided by the development of integrated digital innovations leading to the spreading and cost-effective implementation of precision agricultural technologies. These technologies also work as decision support systems (DSS), based upon networks of interconnected devices, able to provide accurate and detailed information about: the timing, the calibration and specific locations for optimal on-farm agricultural operations, like: the application of fertilizers and pesticides, irrigation, ploughing, seeding, harvesting, and so on. Most digital innovations are based upon satellite sensing and imaging technologies which, beyond providing traditional weather and climate data, are able to enhance other agricultural information related to the agronomic status of soils, the phenological stages of the observed (screened) crops and their agricultural needs, included water requirements (Vuolo *et al.*, 2015). Precision irrigation technologies help farmers develop tailored farm-based management practices that better cope with water scarcity by further optimizing agronomic operations, including the use of ordinary (freshwater) and supplementary (reclaimed) irrigation.

The realization of such an innovation scheme is conditioned on the actual ability of farmers to manage the new technologies and, hence, there is a need to provide farmers with support for specific training and practical experiences. These can be designed within the existing EIP framework, which supports knowledge and innovation capacity building of stakeholders in the water and agricultural sectors. The result would be a more elastic water demand, and a reduction in the risks of sudden adjustments due to water shortages (quantity shocks), and therefore to a stabilization of both water tariffs and production quantities.

For sake of simplicity, a graphical representation of the effects of the described measures is provided in the figures below. Figure 3.1 represents the market equilibrium condition (A; W^*, $\$^*$) of both an inelastic quantity supply (S) of, and demand (D) for ordinary irrigation water, and a supply adjustment (B; *W*\`, *\$*\`) either to a tariff increase or to the likely evolution of water scarcity due to climate change following a supply shock (S\`).

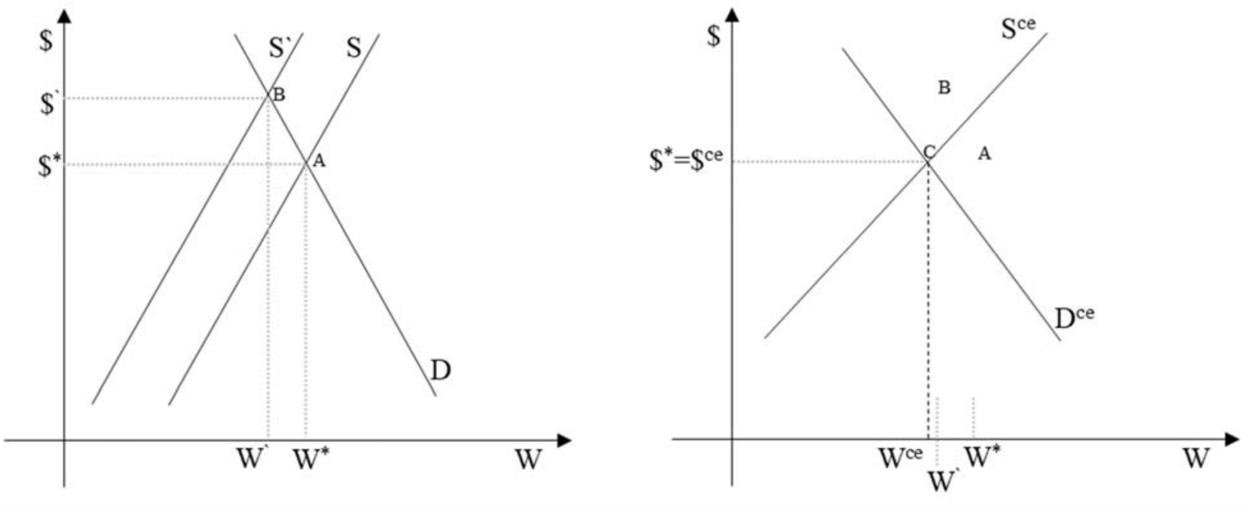
Figure 3.1 Market equilibrium conditions for ordinary irrigation water



Source: *own elaboration*

Figure 3.2 represents the market equilibrium condition (W^{ce}, $\$^{ce}$) with a more elastic quantity supply of (S^{ce}) and demand (D^{ce}) for ordinary irrigation water, integrated with supplementary reclaimed water following the implementation of the measures provided for by the *circular economy* framework and compared to the previous situations of Figure 1 keeping the tariff level $\$^*$.

Figure 3.2 Market equilibrium conditions for ordinary irrigation water supplemented with reclaimed water



Source: *own elaboration*

From Figure 3.2 it appears clear how, tariff *paribus*, the improved elasticity of both supply and demand of water quantity, resulting from coordinated technological improvements in the urban and agricultural sectors, yields a further reduction of the use of irrigation water, associated with guaranteed safety and a reduced risk of scarcity of the water resource.

3.7 Conclusion

The present essay provides a perspective on the management of irrigation water resources from the angle of an innovative *circular economy* framework, tailored to the water sector, that aims to accommodate a potential interplay between the European Green Deal and the CAP post-2020. The introduction of the *circular economy* concept in Europe is proposed in the European Green Deal, together with the objectives of zero emissions and a decoupling of future economic growth from increases in natural resource use. Although this plan is ambitious, the implementation of the *circular economy* in most economic sectors appears well set and is supported by the new Circular Economy Action Plan (CEAP). However, the current plan does not link to the CAP post-2020 because of the strong path-dependence of the CAP regarding how financial support is provided to farms, even though more stringent cross-compliance requirements are imposed because of strengthened environmental Directives. Among these, a prominent role will be played by the WFD, which will become the first SMR, and which will constrain the agricultural sector to further reduce the pressure it places on natural resources, water *in primis*.

However, as proposed in this essay, a possible route for the implementation of the *circular economy* concept to the water sector, supported also by the multilevel governance analytical framework proposed by Charbit (2011), is possible through an implementation framework composed by a *macro* level, focused on policy harmonization and institutional coordination, a *meso* level, that better coordinates overarching activities in the urban and agricultural sectors, and a *micro* level, that provides better incentives for the adoption of innovations fostering both qualitative improvements of wastewater treatment and promoting the adoption of digital technologies through precision agriculture. The scope of application of the proposed framework needs to be calibrated to local specificities and should be subject to an *ex-ante* economic feasibility analysis to provide a cost-effective estimate of the volume of treated/reclaimed water and the relative size of the potential demand.

This theoretical exercise suggests that the proposed combination of interventions, beyond providing a safe and reliable additional water source, might prove effective in helping to optimize the use of irrigation water, with the implication of no, or negligible, impact on current water tariff levels; and therefore providing, an alternative, and innovative, solution to the general objectives proposed in the European Green Deal that is perfectly aligned with current CAP post-2020 proposals.

APPENDIX 1. REGRESSION RESULTS FROM SELECTED MODEL SPECIFICATIONS

dep var logTFP									
Year Lags	3	4	5	6	7	8	9	10	11
PDL (log*GBAORD*)	-0.00389***	-0.00242***	-0.00163***	-0.00113***	-0.00082***	-0.00062***	-0.00050***	-0.00040***	-0.00031***
Total elasticity - α	0.01556***	0.01208***	0.00980***	0.00788***	0.00655***	0.00555***	0.00500***	0.00437***	0.00373***
Time	0.01132***	0.01171***	0.01135***	0.01097***	0.01068***	0.00975***	0.00861***	0.00720***	0.00565***
Wheat yield anomalies	0.00266***	0.00248***	0.00241***	0.00239***	0.00245***	0.00244***	0.00253***	0.00264***	0.00267***
Log *domestic patents*									
5 year lags	0.00550**	0.00777***	0.00975***	0.00972***	0.00947***	0.00980***	0.00925***	0.00737***	0.00649***
Log *foreign US patents*									
7 year lags	0.00472***	0.00644***	0.00653***	0.00609***	0.00559***	0.00529***	0.00579***	0.00680***	0.00593***
Constant term	4.3319***	4.2916***	4.2714***	4.2751***	4.2728***	4.2885***	4.2944***	4.3296***	4.3825***
Observations	464	464	464	464	464	464	464	464	464
Wald X^2	408.52***	500.44***	504.67***	447.83***	417.99***	416.63***	462.90***	480.59***	448.18***
Rate of return	5.41%	8.74%	10.62%	10.13%	9.92%	9.73%	10.77%	10.49%	9.42%

Note: * $p < 0.10$. ** $p < 0.05$. *** $p < 0.01$; patents are the sum of A01 and C05

APPENDIX 1. (CONTINUED)

dep var logTFP								
Year Lags	12	13	14	15	16	17	18	19
PDL (log*GBAORD*)	-0.00023***	-0.00018***	-0.00014***	-0.00010***	-0.000078***	-0.000058***	-0.000046***	-0.000037***
Total elasticity - α	0.00305***	0.00252***	0.00208***	0.00166***	0.00132***	0.00104***	0.00087***	0.00074***
Time	0.00451***	0.00358***	0.00296**	0.00314**	0.00356***	0.00418***	0.00452***	0.00483***
Wheat yield anomalies	0.00257***	0.00249***	0.00243***	0.00237***	0.00238***	0.00240***	0.00242***	0.00243***
Log *domestic patents*								
5 year lags	0.00588***	0.00597***	0.00619***	0.00624***	0.00596***	0.00554**	0.00512**	0.00479**
Log *foreign US patents*								
7 year lags	0.00484***	0.00472***	0.00454**	0.00461**	0.00466**	0.00471**	0.00472**	0.00455**
Constant	4.4452***	4.4970***	4.5439***	4.5821***	4.6144***	4.6385***	4.6549***	4.6694***
Observations	464	464	464	464	464	464	464	464
Wald X^2	387.13***	340.48***	308.81***	290.91***	285.65***	288.32***	296.96***	305.22***
Rate of return	7.47%	5.85%	4.38%	2.56%	0.85%	-0.67%	-1.48%	-2.09%

Note: * $p < 0.10$. ** $p < 0.05$. *** $p < 0.01$; patents are the sum of A01 and C05

APPENDIX 1. (CONTINUED)

dep var logTFP								
Year Lags	20	21	22	23	24	25	26	27
PDL	-	-	-	-	-	-	-	-
(log*GBAORD*)	0.000031***	0.000027***	0.000024***	0.000023***	0.000022***	0.000021***	0.000020***	0.000019***
Total elasticity - α	0.00064***	0.00059***	0.000559***	0.000549***	0.000553***	0.000545***	0.000546***	0.000550***
Time	0.005021***	0.00481***	0.00452***	0.00388***	0.00303*	0.00238	0.00159	0.00071
Wheat yield anomalies	0.00244***	0.00243***	0.00244***	0.00245***	0.00245***	0.00246***	0.00247***	0.00248***
Log *domestic patents*								
5 year lags	0.00462**	0.00451*	0.00442*	0.00429*	0.00425*	0.00431*	0.00448**	0.00460**
Log *foreign US patents*								
7 year lags	0.00436**	0.00426**	0.00426**	0.00424**	0.00439***	0.00445**	0.00448***	0.00442**
Constant	4.6801***	4.6884***	4.6947***	4.7019***	4.7078**	4.7130***	4.7175***	4.7227***
Observations	464	464	464	464	464	464	464	464
Wald X^2	313.73***	322.88***	334.28***	345.27***	356.92***	365.75***	371.40***	372.76***
Rate of return	-2.43%	-2.24%	-1.96%	-1.36%	-0.64%	-0.14%	0.43%	0.99%

Note: * $p < 0.10$. ** $p < 0.05$. *** $p < 0.01$; patents are the sum of A01 and C05

APPENDIX 2. DESCRIPTION OF THE VARIABLES

Structural data		Description of data for the subsample of innovators	
breeder	Zootechnics specialisation	nb_inn_intro	Number of introduced innovations
fruit	Fruit specialization, including grape and olives	inn_intro	Introduction of innovation: yes=1; no=0
cereal	Cereal specialization	yrs_intro	Year of introduction of the innovation
prot	Protein crop specialization	yr_intro	Age of innovation wrt to introduction
crop	Arable crop specialization, including horticultural crops	risk_red	Intro for reducing risks = 1
anc_activ	Presence of ancillary activity: yes=1; no=0	farm_diver	Intro for diversifying ag activity = 1
sale_contr	Sale contracts	costs_red	Intro for reducing costs = 1
rent_tot	Share of rented land over total land	prods_inc	Intro for increasing production = 1
land_own	Own land	other	Other reasons (most increasing profitability and reducing labour)
land_rent	Rented land	inc_pr_inp	Reaction to increase in input prices
land_tot	Total Land	red_pr_outp	Reaction to reduction in output prices
tract_nbr	Number of tractors	ant_mkt_inp	Anticipate inputs markets trend
oper_mach	Number of operational machines	ant_mkt_outp	Anticipate outputs markets trend
Demographic data		ext_help_inn	External help from private or seller
altitude	Plain=1; Hill=2; Mountain=3	pub_help_inn	External help from public institutions
az_ind	Individual farm: yes=1; no=0	help_self_dev	Help for self-developed innovations
az_fam	Family farm: yes=1; no=0	no_supp	No external financial support for introducing innovation
fam_lab	Family labour	priv_supp	Level of self-financing: 0=less than 5.000; 3=more than 50.000
fam_lab_ft	Family labour Full Time	priv_supp_cat	Level of private support
fam_lab_pt	Family labour Part Time	Type of innovations	
edu_inf_med	Education inferior than medium school=1	bio_gen_inn	Biological and Genetic innovations
edu_sup_elem	Education superior than elementary school=1	agr_zoo_inn	Agronomical and Zoological innovations
edu_sup_dipl	Education superior than high school=1	mecc_inn	Mechanical innovations
edu_ag	Specialized Ag education=1	info_inn	Informatics innovations
inc_inf30	Family income from Ag <30%=1	enr_wat_inn	Energy and water saving innovations
inc_inf50	Family income from Ag <50%=1	diver_inn	Diversification innovation
Considerations		mkt_inn	Market strategies innovations
inn_imp	Important innovations in last 20 years: yes=1; no=0	Origin of innovation and prior knowledge of research giving origin to the innovation	
cont_5yrs	Continue farming in 5 years: yes=3; maybe yes=2; maybe no=1; no=0	ext_sourc	Source of information about innovation: external=1; self produced=0
inn_5yrs	Introduce innovation in next 5 years: yes=1; no=0	inn_maker	Innovation maker
inn_imp_comp	Innovation important for competitiveness: category values 0=not at all; 3=much	res_orig	Prior knowledge of innovation origin from research
cap_help_innov	CAP help innovation adoption: category values 0=not at all; 3=much	Effects on introduced innovation	
cap_supp_agr	CAP necessary for supporting agriculture: 0=not at all; 3=much	effects	All effects: presence of (positive) effect=1; otherwise=0
Description of data for non-innovators (reasons for not innovating)		red_cost	Cost reduction in %
no_intro	No introduction = 1	red_cost_d	Cost reduction: yes=1; no=0
high_cost	No intro for high costs = 1	inc_prod	Production increment in %
ethic_reas	No intro for ethical reasons = 1	inc_prod_d	Production increment: yes=1; no=0
too_bureau	No intro for too bureaucracy = 1	inc_va	Value added increment in %
too_risk	No intro for high risks = 1	inc_va_d	Value added increment: yes=1; no=0
quit_act	No intro for quitting activity soon = 1	inc_qual	Quality increment: very high, high and low=1; nothing=0
neg_past_exp	No intro for negative past experiences = 1	inc_qual_h	Quality increment: very high, high=1; otherwise=0
keep_trad	No intro for keeping traditions = 1	inc_qual_cat	Quality increment: categorical values 0=not at all; 3=much
other_no_intro	No intro for other reasons = 1		

REFERENCES

Alcalde-Sanz, L., and Gawlik, B. M. (2017). Minimum quality requirements for water reuse in agricultural irrigation and aquifer recharge. *Towards a Legal Instrument on Water Reuse at EU Level*.

Alene, A. D. (2010). Productivity growth and the effects of R&D in African agriculture. Agricultural Economics, 41(3-4): 223-238.

Alston, J.M., Norton, G.W., Pardey, P.G. (ed.) (1995). *Science under Scarcity: Principles and Practice for Agricultural Evaluation and Priority Setting*. Cornell University Press: Ithaca, NY

Alston J. M., Chan-Kang C., Marra M. C., Pardey P. G., and Wyatt T. J. (2000). A meta-analysis of rates of return to agricultural R&D: Ex pede Herculem?, (Vol. 113), International Food Policy Research Institute (IFPRI). Washington DC: IFPRI.

Alston, J. M., and James, J. S. (2002). The incidence of agricultural policy. In: Gardner, B. L., and Rausser, G. C. (Eds.), *Handbook of agricultural economics*. Elsevier, 2A: 1689-1749.

Alston J. M., Babcock B. A., and Pardey P. G. (2010). Shifting patterns of global agricultural productivity: Synthesis and conclusion. In: Alston J. M., Babcock B. A., and Pardey P. G. (eds.), *The shifting patterns of global agricultural production and productivity worldwide*. The Midwest Agribusiness Trade Research and Information Center. Iowa State University, Ames, IA.

Alston, J. M., Andersen, M. A., James, J. S., and Pardey, P. G. (2011). The economic returns to US public agricultural research. *American Journal of Agricultural Economics*, 93(5): 1257-1277.

Andersen, M. A., and Song, W. (2013). The Economic impact of public agricultural research and development in the United States. *Agricultural Economics*, 44(3): 287-295.

Arborea, S., Giannoccaro, G., de Gennaro, B. C., Iacobellis, V., and Piccinni, A. F. (2017). Cost–Benefit Analysis of Wastewater Reuse in Puglia, Southern Italy. *Water*, *9*(3), 175.

Ball, V. E., Bureau, J. C., Butault, J. P., and Nehring, R. (2001). Levels of farm sector productivity: An international comparison. *Journal of productivity Analysis*, 15(1): 5-29.

Ball, V. E., Butault, J. P., Juan, C. S., and Mora, R. (2010). Productivity and international competitiveness of agriculture in the European Union and the United States. *Agricultural Economics*, 41(6): 611-627.

Besley, T., and Case, A. (1993). Modeling technology adoption in developing countries. *The American Economic Review*, 83(2): 396-402

B.I.O. by Deloitte (2015). Optimising water reuse in the EU–Final report prepared for the European Commission (DG ENV), Part I. *collaboration with ICD and Cranfield University*.

Cavallo, E., Ferrari, E., Bollani, L., and Coccia, M. (2014). Attitudes and behaviour of adopters of technological innovations in agricultural tractors: A case study in Italian agricultural system. *Agricultural Systems*, 130: 44-54

Charbit, C. (2011). Governance of public policies in decentralised contexts. *The Multi-level Approach: OECD*.

Choo, C. W. (1998), The Knowing Organization, Oxford University Press, New York, NY.

Cochrane, W. W. (1958). *Farm prices: myth and reality*. U of Minnesota Press.

Daberkow S. G., (2001). Oral presentation 3rd European Conference on Precision Agriculture 2001, Montpellier.

Daberkow, S. G., and McBride, W. D. (2003). Farm and operator characteristics affecting the awareness and adoption of precision agriculture technologies in the US. *Precision agriculture*, 4(2): 163-177

Davis, J. (1981). A comparison of procedures for estimating returns to research using production functions. *Australian Journal of Agricultural Economics*, 25(1): 60-72.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS quarterly*, 13(3): 319-340

Diederen, P., Van Meijl, H., Wolters, A., and Bijak, K. (2002). Innovation adoption in agriculture: innovators, early adopters and laggards. *Cahiers d'Economie et de Sociologie Rurales*, 67: 29-50.

Diederen, P., van Meijl, H., and Wolters, A. (2003). Modernisation in agriculture: what makes a farmer adopt an innovation? *International Journal of Agricultural Resources, Governance and Ecology*, 2(3-4): 328-342

Dimara, E., and Skuras, D. (2003). Adoption of agricultural innovations as a two-stage partial observability process. *Agricultural Economics*, 28(3): 187-196.

Dockhorn, T. (2009). About the Economy of Phosphorus Recovery. In Ashley, K., Mavinic, D. and Koch, F. (eds), International Conference on Nutrient Recovery from Wastewater Streams, London, IWA Publishing, 145-158.

Duarte, M., and Restuccia, D. (2010). The role of the structural transformation in aggregate productivity. The *Quarterly Journal of Economics*, 125(1): 129-173.

Dwyer, J., Ilbery, B., Kubinakova, K., Buckwell, A., Menadue, H., Hart, K., ... and Erjavec, E. (2012). How to improve the sustainable competitiveness and innovation of the EU agricultural sector. *Brussel: European Parliament*.

Eberhardt, M., Helmers, C., and Strauss, H. (2013). Do spillovers matter when estimating private returns to R&D? *Review of Economics and Statistics*, 95(2): 436-448.

EPO - https://www.epo.org/index.html

Esposti, R. (2012). Knowledge, technology and innovations for a bio-based economy: lessons from the past, challenges for the future. *Bio-based and applied economics*, 1(3), 235-268.

European Commission (2007). Addressing the challenge of water scarcity and droughts in the European Union. COM(2007) 414.

European Commission (2015). Closing the loop - An EU Action Plan for the Circular Economy. COM(2015) 614.

European Commission (2018). Proposal for a regulation of the European Parliament and of the Council on minimum requirements for water reuse. COM(2018) 337 final.

European Commission (2020). The European Green Deal. COM(2019) 640.

European Union (2020). New Circular Economy Action Plan, https://ec.europa.eu/environment/circular-economy/pdf/new_circular_economy_action_plan.pdf

EU Water Directors (2016). Guidelines on Integrating Water-reuse into Water Planning and Management in the context of the WFD. *Common Implementation Strategy for the Water Framework directive and the foods directive*.

Evenson, R. E., Waggoner, P. E., and Ruttan, V. W. (1979). Economic benefits from research: an example from agriculture. *Science*, 205(4411): 1101-1107.

Fan, S. (2000). Research investment and the economic returns to Chinese agricultural research. *Journal of Productivity Analysis*, 14(2): 163-182.

Fanfani, R., and Pieri, R. (Eds.). (2016). *Il sistema agro-alimentare dell'Emilia-Romagna*. Osservatorio Agro-Alimentare, Unioncamere e Regione Emilia-Romagna Assessorato Agricoltura, caccia e pesca.

Fawell, J., Le Corre, K., and Jeffrey, P. (2016). Common or independent? The debate over regulations and standards for water reuse in Europe. *International Journal of Water Resources Development*, 32(4), 559-572.

Feder, G., and Slade, R. (1984). The acquisition of information and the adoption of new technology. *American Journal of Agricultural Economics*, 66(3): 312-320.

Feder, G., and Umali, D. L. (1993). The adoption of agricultural innovations: a review. *Technological forecasting and social change*, 43(3): 215-239

Flett, R., Alpass, F., Humphries, S., Massey, C., Morriss, S., and Long, N. (2004). The technology acceptance model and use of technology in New Zealand dairy farming. *Agricultural Systems*, 80(2): 199-211

Folorunso, O., and Ogunseye, S. O. (2008). Applying an enhanced technology acceptance model to knowledge management in agricultural extension services. *Data Science Journal*, 7: 31-45

Foster, A. D., and Rosenzweig, M. R. (1995). Learning by doing and learning from others: Human capital and technical change in agriculture. *Journal of Political Economy*, 103(6): 1176-1209.

Fountas, S., Pedersen, S. M., & Blackmore, S. (2005). ICT in Precision Agriculture–diffusion of technology. *ICT in agriculture: perspective of technological innovation, E. Gelb and A. Offer (eds),* *http://departments.agri.huji.ac.il/economics/gelb-main.html*

Freshwater, D. (2017). The Importance of Improving Incentives and Employment Opportunities for Farm Households in Poland. *Wieś i Rolnictwo*, 176(3), 11-33.

Fuglie, K. (2016). Accounting for Growth in Global Agriculture. *Bio-based and Applied Economics*, 4(3): 201-234.

Fuglie, K., and Wang, S. L. (2012). Productivity growth in global agriculture shifting to developing countries. *Choices*, 4th Quarter, 27(4): 1-7.

Galdon-Sanchez, J. E., and Schmitz Jr, J. A. (2002). Competitive Pressure and Labor Productivity: World Iron-Ore Markets in the 1980's. *American Economic Review*, 92(4): 1222-1235.

Geissdoerfer, M., Savaget, P., Bocken, N. M., and Hultink, E. J. (2017). The Circular Economy–A new sustainability paradigm?. *Journal of Cleaner Production*, *143*, 757-768.

Geng, Y., Sarkis, J., and Ulgiati, S. (2016). Sustainability, well-being, and the circular economy in China and worldwide. *Science*, *6278*(Supplement), 73-76.

Ghadim, A. K. A., and Pannell, D. J. (1999). A conceptual framework of adoption of an agricultural innovation. *Agricultural Economics*, 21(2): 145-154

Ghisellini, P., Cialani, C., and Ulgiati, S. (2016). A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production*, *114*, 11-32.

Gollin, D., Parente, S., and Rogerson, R. (2002). The role of agriculture in development. *American Economic Review*, 92(2): 160-164.

Graversgaard, M., Hedelin, B., Smith, L., Gertz, F., Højberg, A. L., Langford, J., ... and Stelljes, N. (2018). Opportunities and barriers for water co-governance—A critical analysis of seven cases of diffuse water pollution from agriculture in Europe, Australia and North America. *Sustainability*, 10(5), 1634.

Griliches, Z. (1957). Hybrid corn: an exploration in the economics of technological change. *Econometrica*, 25(4): 501-522.

Griliches, Z. (1958). Research costs and social returns: hybrid corn and related innovations. *Journal of Political Economy*, 66(5): 419-431.

Gutierrez, L., and Gutierrez, M. M. (2003). International R&D spillovers and productivity growth in the agricultural sector. A panel cointegration approach. *European Review of Agricultural Economics*, 30(3): 281-303.

Hall, A. (2012). Partnerships in agricultural innovation: Who puts them together and are they enough? In OECD (Eds.): *Improving Agricultural Knowledge and Innovation Systems: OECD Conference Proceedings*, OECD Publishing. http://dx.doi.org/10.1787/9789264167445-en. pp 219-236.

Hall, B. H., Mairesse, J., and Mohnen, P. (2010). Measuring the Returns to R&D. In: Hall, B. H., and Rosenberg, N. (eds.). *Handbook of the Economics of Innovation*. Elsevier, 2: 1033-1082.

Hayami, Y., and Ruttan, V. (1985). *Agricultural Development: An International Perspective*. Johns Hopkins University Press, Baltimore.

Hernandez-Sancho, F., Molinos-Senante, M. and Sala-Garrido, R. (2010). Economic Valuation of Environmental Benefits from Wastewater Treatment Processes: An Empirical Approach for Spain. *The Science of the Total Environment* 408(4): 953-957

Hsiao, T. C., Steduto, P., and Fereres, E. (2007). A systematic and quantitative approach to improve water use efficiency in agriculture. *Irrigation science*, 25(3): 209-231

Hurley, T. M., Rao, X., and Pardey, P. G. (2014). Re-examining the reported rates of return to food and agricultural research and development. *American Journal of Agricultural Economics*, aau047.

IPC – International Patent Classification: https://www.wipo.int/classifications/ipc/en/

ISTAT (2014). Symbola, Secondo Rapporto sulla Meccanizzazione Agricola Verde

Jin, Y., and Huffman, W. E. (2016). Measuring public agricultural research and extension and estimating their impacts on agricultural productivity: new insights from US evidence. *Agricultural Economics*, 47(1): 15-31.

Kidd, A. (1994), 'The Marks are on the Knowledge Worker', in Proceedings of CHI '94, ACM Press, Boston, MA., pp. 186-191.

Klerkx, L., Hall, A., and Leeuwis, C. (2009). Strengthening agricultural innovation capacity: are innovation brokers the answer?. *International Journal of Agricultural Resources, Governance and Ecology*, 8(5-6): 409-438.

König, T., and Mäder, L. (2014). The strategic nature of compliance: An empirical evaluation of law implementation in the central monitoring system of the European Union. *American Journal of Political Science*, 58(1), 246-263.

Korhonen, J., Honkasalo, A., and Seppälä, J. (2018). Circular economy: the concept and its limitations. *Ecological economics*, 143, 37-46.

Koundouri, P., Nauges, C., and Tzouvelekas, V. (2006). Technology adoption under production uncertainty: theory and application to irrigation technology. *American Journal of Agricultural Economics*, 88(3): 657-670

Läpple, D., Renwick, A., and Thorne, F. (2015). Measuring and understanding the drivers of agricultural innovation: Evidence from Ireland. *Food Policy*, 51: 1-8.

Lavrnić, S., Zapater-Pereyra, M., and Mancini, M. L. (2017). Water scarcity and wastewater reuse standards in southern Europe: focus on agriculture. *Water, Air, & Soil Pollution*, 228(7), 251.

Levidow, L., Zaccaria, D., Maia, R., Vivas, E., Todorovic, M., and Scardigno, A. (2014). Improving water-efficient irrigation: prospects and difficulties of innovative practices. *Agricultural Water Management*, 146: 84-94

Levins, R. A. and Cochrane, W. W. (1996). The treadmill revisited. *Land Economics*, *72*(4), 550-553.

Lin, J. Y. (1991). Education and innovation adoption in agriculture: evidence from hybrid rice in China. *American Journal of Agricultural Economics*, 73(3): 713-723

Lindner, R. K. (1987). Adoption and diffusion of technology: an overview. In *ACIAR proceedings series*

Lipsey, R. G., and Carlaw, K. (2000). What does total factor productivity measure?. *International Productivity Monitor*, 1,31-40.

Maia, R. (2017). The WFD implementation in the European member states. *Water Resources Management*, 31(10), 3043-3060.

Marra, M., Pannell, D. J., and Ghadim, A. A. (2003). The economics of risk, uncertainty and learning in the adoption of new agricultural technologies: where are we on the learning curve? *Agricultural systems*, 75(2): 215-234

Mairesse, J., and Mohnen, P. (2010). Using innovation surveys for econometric analysis. In Hall, B. H., and Rosenberg, N. (Eds.). (2010). *Handbook of the Economics of Innovation* (Vol. 2). Elsevier. pp 1129-1155.

Matthews, A. (2013). Greening agricultural payments in the EU's Common Agricultural Policy. *Bio-based and Applied Economics*, 2(1), 1-27.

Michetti, M., Raggi, M., Guerra, E., and Viaggi, D. (2019). Interpreting Farmers' Perceptions of Risks and Benefits Concerning Wastewater Reuse for Irrigation: A Case Study in Emilia-Romagna (Italy). *Water*, 11(1), 108.

Molinos-Senante, M., Hernandez-Sancho, F., Sala-Garrido, R. and Garrido-Baserba, M. (2011). Economic Feasibility Study for Phosphorus Recovery Processes. *Ambio* 40(4): 408-416.

Nelson, R. R., and Winter, G. S. (1982). An evolutionary theory of economic change. Cambridge: Harvard U. Press

OECD. (2008). *Multifunctionality in agriculture: evaluating the degree of jointness, policy implications*. OECD Publishing, Paris.

Oehmke, J. F., and Schimmelpfennig, D. E. (2004). Quantifying structural change in US agriculture: The case of research and productivity. *Journal of Productivity Analysis*, 21(3): 297-315.

Orsini, F., Accorsi, M., Luz, P., Tsirogiannis, I. L., and Gianquinto, G. (2016). Sustainable Water Management in Green Roofs. In *Sustainable Water Management in Urban Environments* (pp. 167-207). Springer, Cham.

Pantzar, M. and Suljada, T. (2020). Delivering a circular economy within the planet's boundaries: An analysis of the new EU Circular Economy Action Plan. *Institute for European Environmental Policy (IEEP) and Stockholm Environment Institute (SEI)*: Brussels and Stockholm.

Parente, S. (2001). The failure of endogenous growth. *Knowledge, technology & policy*, 13(4): 49-58.

Pardey, P. G., Alston, J. M. and Piggott, R. R. (Eds.). (2006). Agricultural R&D in the developing world: Too little, too late? International Food Policy Research Institute (IFPRI). Washington DC: IFPRI.

Pe'Er, G., Zinngrebe, Y., Moreira, F., Sirami, C., Schindler, S., Müller, R., ... & Hansjürgens, B. (2019). A greener path for the EU Common Agricultural Policy. *Science*, 365(6452), 449-451.

Pedersen, S. M. (2003). *Precision Farming–Technology Assessment of variable rate Treatment in Cereals* (Doctoral dissertation, Ph. D. Thesis. Technical University of Denmark, Lyngby, 343pp).

Piesse J., and Thirtle C. (2010). Agricultural R&D, technology and productivity. *Philosophical Transactions of the Royal Society B: Biological Sciences*, n. 365(1554).

Pretty, J. N. (1997). The sustainable intensification of agriculture. In: *Natural resources forum*. Oxford, UK: Blackwell Publishing Ltd. p. 247-256.

Restuccia, D., Yang, D. T., and Zhu, X. (2008). Agriculture and aggregate productivity: A quantitative cross-country analysis. *Journal of Monetary Economics*, 55(2): 234-250.

Rey, D., Pérez-Blanco, C. D., Escriva-Bou, A., Girard, C., and Veldkamp, T. I. (2019). Role of economic instruments in water allocation reform: lessons from Europe. *International Journal of Water Resources Development*, 35(2), 206-239.

Rezaei-Moghaddam, K., and Salehi, S. (2010). Agricultural specialists intention toward precision agriculture technologies: integrating innovation characteristics to technology acceptance model. *African Journal of Agricultural Research*, 5(11): 1191-1199

Ricart, S., and Rico, A. M. (2019). Assessing technical and social driving factors of water reuse in agriculture: A review on risks, regulation and the yuck factor. *Agricultural water management*, 217, 426-439.

Rizzo, L., Krätke, R., Linders, J., Scott, M., Vighi, M., and de Voogt, P. (2018). Proposed EU minimum quality requirements for water reuse in agricultural irrigation and aquifer recharge: SCHEER scientific advice. *Current Opinion in Environmental Science & Health*, 2, 7-11.

Rogers, E. M. (1983). *Diffusion of innovations*. Simon and Schuster.

Röling, N. (1990). The agricultural research-technology transfer interface: a knowledge systems perspective. In Kaimowitz, D. (Eds.) *Making the link: Agricultural research and technology transfer in developing countries.* Westview Press Boulder, San Francisco & London.

Röling, N. G. (1994). Agricultural knowledge and information systems. In Blackburn, D.J. (Eds.): *Extension handbook: Processes and practices*. Thompson Educational Publ. Inc., Toronto, Canada.

Ruttan, V. W. (1996). What Happened to Technology Adoption-Diffusion Research? *Sociologia Ruralis*, 36(1): 51-73

Salvioni, C., Papadopoulou, E., and Santos, M. D. (2014). Small farm survival in Greece, Italy and Portugal. *EuroChoices*, 13(1), 52-57.

Sauvé, S., Bernard, S., and Sloan, P. (2016). Environmental sciences, sustainable development and circular economy: Alternative concepts for trans-disciplinary research. *Environmental Development*, *17*, 48-56.

SCAR, E. U. (2012). Agricultural knowledge and innovation systems in transition–a reflection paper. *European Commission, Standing Committee on Agricultural Research-*

Collaborative Working Group on Agricultural Knowledge and Innovation System (CWG AKIS), Brussels.

Schimmelpfennig, D., and Thirtle, C. (1999). The internationalization of agricultural technology: Patents, R&D spillovers, and their effects on productivity in the European Union and United States. *Contemporary Economic Policy*, 17(4): 457-468.

Schimmelpfennig, D. E., and Thirtle, C. G. (2000). Significance of International Spillovers from Public Agricultural Research. In: Fuglie, K. O., and Schimmelpfennig, D. E. (eds.). *Public-Private collaboration in agricultural research: New institutional arrangements and economic implications*. J. Wiley & Sons: 245-268.

Schmitz Jr, J. A. (2005). What determines productivity? Lessons from the dramatic recovery of the US and Canadian iron ore industries following their early 1980s crisis. *Journal of Political Economy*, 113(3): 582-625.

Schultz, T. W. (1953). *The Economic Organization of Agriculture*. New York: McGraw-Hill pp. 374.

Staff Working Document (2017). Agriculture and Sustainable Water Management in the EU. *European Commission Staff Working Document*. SWD(2017) 153.

Staff Working Document (2020). Analysis of links between CAP Reform and Green Deal. *European Commission Staff Working Document*. SWD(2020) 93.

Strauss, J., Barbosa, M., Teixeira, S., Thomas, D., and Junior, R. G. (1991). Role of education and extension in the adoption of technology: a study of upland rice and soybean farmers in Central-West Brazil. *Agricultural Economics*, 5(4): 341-359

Sunding, D., and Zilberman, D. (2001). The agricultural innovation process: research and technology adoption in a changing agricultural sector. In: Gardner, B. L., and Rausser, G. C. (eds.). *Handbook of agricultural economics*. Elsevier, 1: 207-261.

Syverson, C. (2011). What determines productivity?. *Journal of Economic literature*, 49(2), 326-65.

Ten Raa, T. and Shestalova, V. (2011). The Solow residual, Domar aggregation, and inefficiency: a synthesis of TFP measures. *Journal of Productivity Analysis*, 36(1): 71-77.

Thirtle, C., Piesse, J., and Schimmelpfennig, D. (2008). Modeling the length and shape of the R&D lag: an application to UK agricultural productivity. *Agricultural Economics*, 39(1): 73-85.

Tiffin, R., and Irz, X. (2006). Is agriculture the engine of growth? *Agricultural Economics*, 35(1):79-89.

Timmer, C. P. (1988). The agricultural transformation. In: Chenery, H and Srinivasan, T. (Eds.) *Handbook of development economics*, 1: 275-331.

Tsagarakis, T.K. (2005). Recycled water valuation as a corollary of the 2000/60/EC water framework directive. *Agricultural Water Management* 72(1):1-14.

UNEP (2011): Technologies for Climate Change Adaptation – The Water Sector, TNA Guidebook Series

USDA (2016). https://www.ers.usda.gov/data-products/international-agricultural-productivity/documentation-and-methods/

Vollaro, M., Sardonini, L., Raggi, M., and Viaggi, D. (2015). Water Tariffs in Agriculture: Emilia Romagna Case Study. In *Use of Economic Instruments in Water Policy* (pp. 121-134). Springer, Cham.

Vollaro, M., Zavalloni, M., Raggi, M., and Viaggi, D. (2015). Adapting to climate change: the social perception of voluntary water transfers in the Italian context. *International Journal of Sustainable Agricultural Management and Informatics*, 1(1), 26-48.

Vollaro, M., Galioto, F., and Viaggi, D. (2016). The circular economy and agriculture: new opportunities for re-using Phosphorus as fertilizer. *Bio-based and Applied Economics*, *5*(3), 267.

Vuolo, F., D'Urso, G., De Michele, C., Bianchi, B., and Cutting, M. (2015). Satellite-based irrigation advisory services: A common tool for different experiences from Europe to Australia. *Agricultural water management*, 147, 82-95.

Voulvoulis, N. (2018). Water reuse from a circular economy perspective and potential risks from an unregulated approach. *Current Opinion in Environmental Science & Health*, 2, 32-45.

Walker, T., Ryan, J., and Kelley, T. (2010). Impact assessment of policy-oriented international agricultural research: Evidence and insights from case studies. *World Development*, 38(10): 1453-1461.

Wang, S. L., Schimmelpfennig, D., and Fuglie, K. O. (2012). Is agricultural productivity growth slowing in Western Europe? In: Fuglie, K. O., Wang, S. L., & Ball, V. E. (eds.). *Productivity growth in agriculture: an international perspective*. CABI, 109-125.

WCED (1987). Our Common Future: Report of the World Commission on Environment and Development. Oxford University Press, Oxford 1987

Wooldridge, J. M. (2015). *Introductory econometrics: A modern approach*. Nelson Education.

Zucaro, R., Rago, C., and Vollaro, M. (2012). Valutazione tecnico-economica delle potenzialità di riutilizzo irriguo dei reflui depurati: il caso della Valpadana. *Proceedings of the Towards a Sustainable Bio-economy: Economic Issues and Policy Challenges, Trento, Italy*, 4-5.

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Vollaro, M., Raggi, M., & Viaggi, D. (2019). Innovation adoption and farm profitability: what role for research and information sources?. *Bio-based and Applied Economics*, 8(2), 179-210.

Cronin, E., Selten, M., Van Galen, M. A., Bijman, J., Viaggi, D., Arevalo, I., ... & Vollaro, M. (2018). *Study on producer organisations and their activities in the olive oil, beef and veal and arable crops sectors*. European Union.

Vollaro, M., Galioto, F., & Viaggi, D. (2016). The circular economy and agriculture: new opportunities for re-using Phosphorus as fertilizer. *Bio-Based and Applied Economics*, 5(3), 267-285.

Vollaro, M., Zavalloni, M., Raggi, M., & Viaggi, D. (2015). Adapting to climate change: the social perception of voluntary water transfers in the Italian context. *International Journal of Sustainable Agricultural Management and Informatics*, 1(1), 26-48.

Vollaro, M., Sardonini, L., Raggi, M., & Viaggi, D. (2015). *Water Tariffs in Agriculture: Emilia Romagna Case Study*. In Use of Economic Instruments in Water Policy (pp. 121-134). Springer, Cham.

Vollaro, M., Raggi, M., & Viaggi, D. (2014). Water Management and Institutional Adaptation Strategies in the Irrigation Sector: Two Experiences in Emilia-Romagna. *Economics of Water Management in Agriculture*, 26.

Vollaro, M. (2012). The impact of the Single Farm Payments on the expenditure on fertilizers and crop protection inputs: a comparative study of the Italian agriculture. *Food Economics*, 9(1-2), 66-77.

Zucaro, R., Pontrandolfi, A., Dodaro, G. M., Gallinoni, C., Pacicco, C. L., & Vollaro, M. (2011). *Atlante nazionale dell'irrigazione*. INEA.

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