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Centro di ricerche in Analisi economica
e sviluppo economico internazionale

Working Paper 01/22

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FOREWORD

This Working Paper is part of CRANEC's (Research Centre for Economic Analysis and International Economic Development) ongoing research on "Science and Technology Platforms (STP) and their reference networks", which is funded by Fondazione Cariplo.

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This project is the natural, and innovative, continuation of previous research carried out by CRANEC in partnership with the Fondazione Edison and published in *Euro-platforms: Science, Technology and the Economy. A crucial connection for Italy* (Il Mulino 2020), which offers a snapshot of the state of the art of European technology platforms, European science policy and strategic connections between research and business.

The innovative aspect of the current research with regard to the previously mentioned one is that it aims to go beyond the systematic analysis of what presently exists, and attempts to foresee – starting from the current context, including its dysfunctional aspects – future scenarios and possible models in which the experience of European technology platforms and current science policy innovations contribute to defining the Italian and European science and technology panorama with optimal paradigms, both for existing and yet to be created infrastructures.

It is interesting to note that investment in the development of science and technology platforms often comes from public spending, and more specifically spending on research and development. Public R&D spending is a driver of economic growth. It is one of the few areas of consensus that crosses all of the literature, without discriminating against any school of thought.

In our case, starting from Italian macroeconomics, the paper tries to explain not only the type of impact (negative/positive), but also the possible magnitude by analysing the effect of public R&D spending on output.

The full findings of the research will be presented at a national conference in September at the Accademia Nazionale dei Lincei as part of the Edison Foundation-Lincei partnership, which began in 2003 and has already showcased various conferences on related subjects.

The research project is coordinated by Professor Alberto Quadrio Curzio, Professor Floriana Cerniglia and Dr Alberto Silvani. The members of the research group are Dr Giovanni Barbieri, Dr Santiago José Gahn and Dr Piera Magnatti.

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On the long-run relationship between R&D expenditures and GDP: some considerations for the case of Italy (1963-2013)

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Abstract

This paper analyses empirically the long-run relationship between 'pure' public expenditures on Research and Development and GDP for the case of Italy (1963-2013). The results show that a 1% increase in 'pure' public research and development expenditure increases output by 0.1%. This shows that, as the consensus in the literature indicates, this type of expenditure has a persistent effect on GDP and calls for a review of the austerity policies that have been pursued in Italy on this type of expenditures since 1991.

JEL classification: L16, N14, O30, O47

Keywords: Italy, research and development, Public Expenditures, public policy, structural change

“Innovation is the central
issue in economic prosperity”

Michael Porter

1. Introduction

The need for public spending in developed countries is based on the argument that the state is ultimately the institution that has the greatest capacity to exert a strong influence, through direct intervention and/or incentives, on the productive apparatus. For some authors, the state is, after all, the engine of innovation and technological change (Mazzucato, 2011; Block and Keller, 2015); if it is not directly productive, it can become so through large-scale financing. For other authors, it is the state that has the capacity to ‘lead the way’ through clear rules (Hausmann and Rodrik, 2003). There is a common element, a consensus, in the literature: public expenditure on research and development is an explanatory factor for economic growth.

This paper analyses the long-run impact of public expenditures on Research and Development on GDP for the Italian case. In order to do so, the importance of public expenditures on Research and Development is explored throughout the literature. The consensus on this type of policy is developed in the first section based, on the one hand, on an extended version of the *traditional view* that assumes the existence of Marshallian externalities, and on the other hand, on an alternative *demand-led view* that assumes compliance with the Kaldor-Verdoorn law (Verdoorn, 1949). Then, a brief history of public expenditures in Research and Development in Italy is provided. Finally, empirical evidence is presented for the period 1963-2013 on the possible impact of Research and Development’s public expenditures on GDP. The results indicate that these types of expenditures could become a key tool in the discovery of dynamic comparative advantages, and that they could become one of the sources of self-discovery through 'learning by doing', 'learning by interacting' and 'learning by exporting', among others, given its positive and significative impact on GDP.

The structure of the paper is as follows: in section 2, the theoretical controversy and common positions on public spending is discussed. In section 3, I analyse public spending on research and development in Italy. In section 4, I develop the econometric model and present the dataset, methodology and results. Finally some conclusions in section 5 are provided.

2. Economic growth and R&D in perspective

The impact of direct public policies on GDP has never played a prominent role in economic theory. Although writings on the subject could be traced back to Alexander Hamilton's 'Report on the Subject of Manufactures' written in 1791 and Friedrich List's 'National System of Political Economy' edited in 1841, the impact of these works on the theoretical corpus has been practically insignificant. This is mainly due to the fact that the bulk of the traditional literature has long held that any type of state intervention implies an inefficient allocation of resources and that public spending would not be desirable as it crowds out private investment.

This debate is directly linked to economic growth. The latter has been one of the most controversial issues in economic theory debated in the literature. At the risk of being profoundly simplistic, there are two major theories that, today, attempt to explain economic growth under different perspectives. First, the Marginalist/Neoclassical Theory, which takes as *given* the following *data*:

- Factor endowments: endowments of land, labour and capital.
- Consumers' tastes and preferences: consumers' subjectivity.

- Technique of production: infinite possible combinations.

Under this framework, growth is led by the rate of technical progress or the rate of savings. It was Robert Solow (1956) who tried to estimate, with a simple model, the sources of economic growth. His results were surprising: about 88% of growth was explained by a residual; in other words, growth could not be explained with the traditional 'factors of production', such as land, labour and physical capital. In this theory, growth is led by the supply side.

Later, stemming from the Cambridge Capital Controversies (Lazzarini, 2011), an alternative economic theory based on the Classical Theory started to consolidate. Under this theory, the *data* that is taken as *given* is the following:

- Level and composition of output: output is given.
- Distributive variable: the real wage as a given variable.
- Technique: generally, the most commonly used technique (dominant).

Classical authors did not have a theory of output (Mongiovi, 1990) due to Say's Law. Thus adding to the difficulty of reconciling the investment component as simultaneous supply and demand, demand-led growth models did not exist at all. It was thanks to the Sraffian Supermultiplier model, developed by Franklin Serrano (1995), that the Classical Theory became a real alternative to mainstream theory - at least in the sphere of quantities. Under this theoretical framework, the autonomous components of aggregate demand, including public expenditures, are the ones that mark the growth path of an economy, allowing it to be led by demand.

In the early 1990s, stimulated by the high growth rates of Asian countries, the traditional school of thought started to investigate public policies as a possible response to certain 'market failures' (Rodrik, 2000; Hausmann and Rodrik, 2003;) in the presence of sectors with Marshallian externalities (Krugman, 1991). In line with this school, public policy is defined as a set of selective actions aimed at increasing the productivity of the economy; it is generally associated with international insertion through the promotion of exports, or the development of dynamic comparative advantages (Amsden, 1989), since countries, in a context of uncertainty, may not know what their comparative advantages really are (Hausmann and Rodrik, 2003). Public policy recommendations, in this case, are supply-oriented.

On the other hand, other non-mainstream scholars, linked to Keynesian schools of thought, sustain the need for a supportive State but, unlike the traditional school, the objective is not to increase productivity, but rather to increase output. Productivity, in this case, would be the result of implementing policies that stimulate increased domestic production. Although there are many positions within this school that are based on export promotion, the bulk of the literature focuses on the combination of export promotion and import substitution. A set of selective actions should be pursued by the State, aimed at changing the productive structure in such a way as to achieve high rates of GDP growth. Public policies in this case, while considering supply-side factors, are demand-driven.

Table 1: Public policies in the literature

Model	Traditional	Alternative
Objective	Productivity	Output
Application	Supply-side	Demand-led
Output	Exogenous	Endogenous

Nowadays, there is a general consensus in the literature that public expenditures on Research and Development can contribute, through different channels, to an increase in output. Some authors, linked to the traditional perspective, think that the appropriate channel is training and increasing human capital embodied in labour (Lucas, 2015). Even under a tradition in which growth is considered exogenous by factor endowments and technology, the existence of hysteresis in the long run could imply that small deviations from the equilibrium growth path could have an impact even in the long run (Fatás and Summers, 2018; Gechert et al., 2019). Aggregate demand, or any of its components, could be such a trigger. If GDP is a variable that does not have a rigid growth trend given exogenous factors (Nelson and Plosser, 1982; Libanio, 2009), a one-tantum increase in one component of aggregate demand could change the long-run level persistently.

In the second line of thought, I refer here, in particular, to models that include autonomous components of aggregate demand - see, for example, Serrano (1995). If there is a permanent increase in autonomous demand, for example in R&D expenditures, first capacity utilisation increases and then, following the accelerator mechanism, entrepreneurs invest in new facilities: capacity adjusts in the long-run. Following this reasoning, this model revert Say's Law in the long-run. One of the arguments is based on the idea of *super*multipliers. Deleidi & Mazzucato (2021) actively claim that *mission-oriented* policies produce a larger positive effect on GDP than the ones generated by more generic public expenditures.

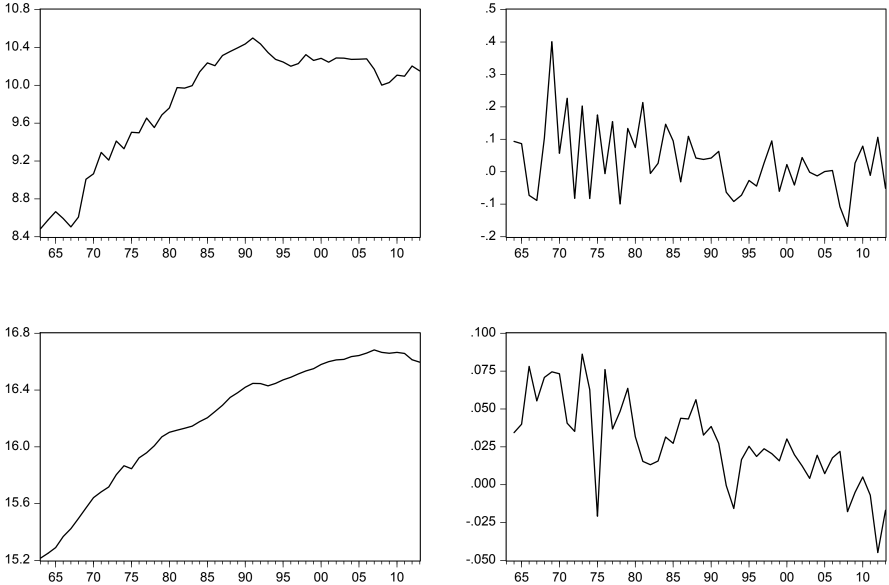
Given that there is a certain consensus in the literature that public spending on R&D could be a driver of growth, in this paper, rather than focusing on the theoretical models and their respective criticisms (see Petri, 2001), I will analyse the case of public spending on research and development for the Italian case. Theoretical work, from different perspectives, abounds, as does empirical work. However, for the case of Italy, I found that an aspect was not covered: the analysis of whether public spending on R&D has any impact on output.

3. Public R&D in Italy

From 1963 to 1991, R&D spending by public institutions and financed by public institutions - what I called here 'pure' public R&D[1] - grew at an average annual rate of 8.15%. However, from 1991 on-wards, its average growth rate was negative by -1.36% per year. Could this explain, in some way, the performance of the Italian economy over the last 20 years? This question has been assessed both in analytical and practical terms.

[1] R&D expenditures of public universities and public enterprises are not taken into account.

Fig. 1. Italian Public R&D expenditures and GDP - Log-Level and growth rates (1963-2013)



Note: Log-level R&D 'pure' public expenditures upper LHS and growth rates upper RHS. GDP log-level and growth rates, bottom LHS and RHS respectively. Sources: Own elaboration based on data provided in Appendix A.

While private R&D expenditures have developed a positive trend for the period 1963-2013, public expenditures suffered a structural break in 1991, and remained stagnant, or even with a steadily negative trend and concentrated - most public activities and funds were targeted at the largest firms in the high technology sectors (Pianta and Sirilli, 1997). Given the constraints imposed by the convergence towards the single currency, coupled with the Maastricht Treaty, it is clear that public expenditures in these components suffered the most from the fiscal adjustments implemented by different Italian governments. The dramatic cutback in R&D expenditures since 1991 has had serious implications for Italian GDP and also for Europe (Archibugi and Mariella, 2021).

There is a consensus that the technology gap between Italy and the European average has widened. Italy, a country with a trajectory of growth characterised by low R&D[2] activities and a modest presence in high technology industries (Nascia and Pianta, 2018, p. 1). The Italian economy has largely failed to converge towards Europe's economic performances because of 'external factors included the rules set for the Monetary Union, the liberalisation of international capital flows, the rise of finance; on the domestic side, problems came from the lack of investment, the persisting small size of firms, the burden of a high public debt, the short-termism of domestic political process ... Such a weakening of the supply structure has gone hand in hand with the slow dynamics of demand ... the reduction of public expenditure has significantly contributed to Italy's long recession' (Nascia and Pianta, 2018, p. 2-4). Italy has undergone a process of structural change since 1991, and this can be seen at a glance in Figure 1. The structural break in 'pure' public R&D expenditure coincides with a change in the GDP trend, which, although positive, has slowed down dramatically. It is a process from which Italy has not yet emerged (Lucchese, Nascia and Pianta, 2016) and which has been deepened by the economic and financial of 2008/2009 (Pianta and Zanfei, 2016) and, lately, Covid-19.

For the case of Italy, there is a great amount of work on innovation developed at the firm or institutional level (Antonelli, 1989; Audretsch and Vivarelli, 1996; Pianta and Sirilli, 1997; Coccia, 2001, 2004, 2008a; Rodríguez-Pose and Refolo, 2003; Antonelli et al., 2007; Crespi and Pianta, 2007; Coccia et al., 2015; Bogliacino et al., 2017; Reale, 2018; Barbieri et al., 2020; Divella and Sterlacchini, 2020; Robbiano, 2020; Aldieri et al., 2021; De Matteis et al.,

[2]See Nascia and Pianta (2018) for an excellent descriptive analysis of R&D in Italy.

2021). However, the truth is that there is very little work analysing public expenditure on research and development for Italy at the aggregate level, with an analysis of the effects on output or productivity. Most of the papers analyse the US/European case (see Sirilli, 1999; Coccia, 2008b, 2010; Ugur et al., 2016; Aristei et al., 2017; Guarascio et al., 2017; Minniti and Venturini, 2017; Crespi and Guarascio, 2019; Archibugi et al., 2020; Ugur et al., 2020; Rehman et al., 2020; Celli et al., 2021; Deleidi and Mazzucato, 2019; Deleidi and Mazzucato, 2021) or worlwide (Castellacci and Natera, 2013), but not Italy in particular. Changing this trend a little, a recent paper by Centro Economia Digitale (CED, 2019) analyses the impact of changes in the technological composition of output on productivity, the authors find that an increase in the share of value added in high-tech sectors has a greater impact on productivity than an increase in the share of non-high tech sectors. Another branch of the literature focuses more on the impacts of public expenditures on output (multipliers) but these papers generally describe the impacts of aggregate expenditures such as consumption or public investment (Pistoresi et al., 2015; Deleidi, 2021) and do not go into very specific categories like R&D.

Due to the gap in the literature, it was decided to analyse the long-run relationship between pure public R&D expenditures and Italian output, controlling for various factors.

4. Data, Methods, Identification Strategy and Results

4.1. Dataset, Methods and Identification Strategy

The dataset used is constructed with annual data for the period 1963-2013. Istat provides information on research and development expenditures by institution, as well as how these expenditures were financed. This is how I constructed a variable to analyse research and development expenditure by public institutions and financed exclusively by public institutions (*lrd_pub*), excluding universities and public enterprises. On the other hand, the level of output (*ly*) was taken from from the historical data series constructed by the Central Bank of Italy, which exist since 1861. The data was adjusted to be compatible, since ISTAT also provides information on R&D expenditure as a percentage of output, and this allowed for harmonisation. Other information was taken as a control for the model, so as not to suffer from omitted variables. Thus, the control variables are: public consumption (*lpc*) and total investment (*li*), both from the Central Bank of Italy database, and also expenditure and development research made by universities (public and private) (*lrd_uni*), as well as the remaining research and development expenditure (*lrd_other*) (mainly private, but including private and public expenditure with different sources of financing). I also control for the Italian nominal discount interest rate for the period 1964-1977 and Treasury Bills for Italy for the period 1978-2013. The sources of the database can be found in Appendix A. All variables were deflated by the historical consumer price index (base 2015=100), except nominal interest rates, and then expressed in logarithms.

Once the database was constructed, the first thing I did was to test the order of integration of the variables in order to impose the best possible methodology on time series analysis. For each variable I test the order integration through 6 different methodologies (Augmented Dickey-Fuller, Dickey-Fuller GLS, Phillips-Perron, Kwiatkowski-Phillips-Schmidt-Shin[3], Elliot-Rothenberg-Stock Point-Optimal and Ng-Perron). Detailed results are presented in Appendix B. For some variables, but especially for the main variable - public R&D expenditure - results are mixed, so the order of integration remains open. Given this information, ARDL models are the standard to apply when the order of integration of the variables is mixed or when doubts exist.

[3]It must be clarified that the null hypothesis of KPSS is stationarity.

I consider that the 'pure' public R&D expenditure variable can be a determinant of output, I thus estimate a dynamic model in which output is the dependent variable and 'pure' public R&D expenditures is the independent variable. It is important to clarify here that the imposition of exogeneity in the ARDL model is previously formulated by the underlying economic theory. This is why I do not deal here with questions concerning the endogeneity of public R&D expenditures, financed only by public institutions. There is a growing literature that considers this type of expenditure, as well as military expenditure (see Ramey, 2011; Girardi, 2020), as the most autonomous - i.e. not the result of current income - and thus can be considered exogenous. Even if there are political pressures to reduce spending, the government can always ultimately decide what spending to reduce, and the composition will be the result of the clash of different political groups defending different interests. This is why those expenditures are considered as being really autonomous. As already stated above, the model is controlled by several fixed regressors such as: total investment (li), public consumption (lpc), the nominal discount rate of interest for the Italian economy (lr), R&D expenditure made by private firms (lrd_priv), R&D expenditure made by public and private universities (lrd_uni) and, finally, other R&D expenditures that were not taken into account in the previous variables (lrd_other).

To avoid autocorrelation problems that were present with 2 lags, as these are annual variables, 3 lags are taken as the rule to follow. Twelve different models are estimated, the most adequate being the ARDL (3,3) according to AIC, BIC, HQ and Adj. R-Sq. criteria. These results are presented in Appendix C. The model therefore consists of an ARDL(3,3) model with multiple controls. The equation to be estimated is as follows:

$$LGDP_t = C + \alpha_1 LGDP_{t-1} + \cdots + \alpha_n LGDP_{t-n} + \beta_1 LRD\_pub_t + \cdots + \beta_n LRD\_pub_{t-n}$$
$$+\gamma_1 LI_t + \gamma_2 LPC + \gamma_3 LR + \gamma_4 LRD\_PRIV + \gamma_5 LRD\_UNI + \gamma_6 LRD\_OTHER + \epsilon_t \tag{1}$$

where C is the constant and ϵ_t is a random disturbance term.

To determine the existence (or not) of a long-run relationship between the variables, use is made of a Long Run Form and Bounds test (Pesaran and Shin, 1995; Pesaran et al., 2001). Furthermore, a Granger causality test is run for the main variables - 'pure' public R&D and GDP. Finally, to check for robustness, I run post-estimation tests such as residuals normality test, specifically, the Jarque-Bera test. For auto-correlation, I run the Breusch Godfrey test and ARCH test and, lastly, to check for the correct specification, I run the Ramsey RESET test. As for dynamic stability of the model, the CUSUM and CUSUM of Squares tests are run. Granger causality test and post-estimation tests are shown directly in the Appendix D.

4.2. Results

Having chosen 3 lags, the model has 48 observations after adjustments. Table 1 shows the results for the short-run ARDL (3,3) model in which the dependent variable is the rate of growth of GDP - D(GDP), therefore one can observe the dynamics of the rate of growth of output.

In this case, the constant is significant as well as the 'pure' public expenditures on R&D. The level of R&D expenditures exerts a positive short-term effect on the growth rate of output. The coefficient accompanying the variable LRD_PUB is 0.056 which means that a 1% increase in R&D spending by public institutions and financed exclusively by public institutions increases, on average, the output growth rate by 0.056%. On the other hand, an impact on

Table 2: Short-run results

Variable	Coefficient
C	2.857***
LGDP(-1)	-0.544***
LRD_PUB	0.056**
D(LY(-1))	-0.158
D(LY(-2))	-0.223**
D(LRD_PUB)	0.010
D(LRD_PUB(-1))	-0.037
D(LRD_PUB(-2))	-0.067***
LI	0.190***
LPC	0.143*
LR	0.004
LRD_PRIV	0.073**
LRD_UNI	0.017
LRD_OTHER	-0.042***

Note: *=pval<0.1, **=pval<0.05, ***=pval<0.01.

Source: Own computations based on data provided.

the growth rate of R&D spending by public institutions and financed exclusively by public institutions has a negative and significant effect (in the second lag) on the growth rate of output. These results, which at first sight seem to be contradictory, are usual in ARDL models where short-run factors with lags are generally incorporated to avoid autocorrelation problems and could absorb part of the business cycle phenomenon. Control variables, on the other hand, are significant and with the expected sign, except for total R&D (which excludes pure public, university and pure private sector research and development). It should be reminded that these are controls to avoid omitted variable problems, analysing the short-run impact is less relevant to the long-run objective of this paper.

Table 3: Long-run results

Variable	Coefficient
LRD_PUB	0.102**
CointEq(-1)	-0.544***
EC = LGDP - (0.1029*LRD_PUB)	

Note: *=pval<0.1, **=pval<0.05, ***=pval<0.01.

Source: Own computations based on data provided in Appendix A.

In Table 3, the long-run results are presented. Here the level of output is the explanatory variable and a 1% increase in pure public spending on R&D generates a 0.10% increase in the level of output. The F-Bounds test - available upon request - provides an F-statistic of 32.13, largely exceeding the upper limit marked by Pesaran et al. (2001, p. 301) and the t-Bounds Test shows a value of -7.57, exceeding the lower limit marked by Pesaran et al. (2001, p. 304). This suggests that there is evidence of a long-run relationship between the time-series presented in the model, hence preventing the possibility of a spurious relationship. As the error correction equation shows in Table 3, the long-run adjustment happens at 0.54 each year, meaning that it takes on average 2 years to complete the adjustment in domestic production. One might claim that this result supports the idea that in the long-run 'pure' public expenditures in R&D has a positive effect on the level of output.

Finally, a Granger causality-test following Toda & Yamamoto (1995) is performed and it can be rejected that 'pure' public expenditures in R&D do not affect the level of output. These results and post-estimation tests are shown in Appendix D.

5. Conclusion

There is a consensus in the literature that public policy is needed. Some argue that the state should direct and promote it, while others think that interventions should be used only to address 'market failures'. However, one thing is undeniable: all the literature agrees that there are particular expenditures, those on public R&D, that can generate persistent effects on output.

From this point of view, and partly taking up the notion of autonomous components of aggregate demand, in this paper I analyse the impact of public R&D spending on Italian output for the period 1963-2013. My results indicate that the effect is positive and significant in the long run.

Given that an increase in public R&D expenditure has a persistent effect on output, my results call for a reconsideration of the science and technology policy developed in Italy since 1991. The structural adjustment in R&D expenditure has had a direct (and irreversible) impact on output, and in order to return to a long-term growth path, the course needs to be changed.

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Appendix A. Data Sources and Web References

- *LRD_PUB* Research and Development ependitures by public institutions funded by public institutions without Universities. 1964 and 1966 estimated with simple average. Source: Istat `http://seriestoriche.istat.it/fileadmin/documenti/Tavola_20.1.xls` and `http://seriestoriche.istat.it/fileadmin/documenti/Tavola_20.2.xls`. Variable in logarithms.

- *LRD_UNI* Research and Development ependitures by public and private Universities funded by all sectors. 1964 and 1966 estimated with simple average. Source: Istat `http://seriestoriche.istat.it/fileadmin/documenti/Tavola_20.1.xls` and `http://seriestoriche.istat.it/fileadmin/documenti/Tavola_20.2.xls`. Variable in logarithms.

- *LRD_PRIV* Research and Development expenditures by private firms funded by all sectors, mainly by private firms. From 1995 to 2013 estimated with the assumption that the percentage of R&D of private enterprises is equal to its historical average of 86% of total R&D of total firms (public and private). 1964 and 1966 estimated with simple average. Source: Istat `http://seriestoriche.istat.it/fileadmin/documenti/Tavola_20.1.xlsandTavola20.2.` and `http://seriestoriche.istat.it/fileadmin/documenti/Tavola_20.2.xls`. Variable in logarithms.

- *LRD_OTHER* Total Research and Development expenditures less previous R&D expenditures. 1964 and 1966 estimated with simple average. Source: Istat `http://seriestoriche.istat.it/fileadmin/documenti/Tavola_20.1.xls` and `http://seriestoriche.istat.it/fileadmin/documenti/Tavola_20.2.xls`. Variable in logarithms.

- *LPC* Government Consumption. 1964 and 1966 estimated with simple average. Source: Archivio Storico Istat 1861-2017. http://seriestoriche.istat.it/fileadmin/documenti/Serie%20Storiche%20della%20Contabilit\unhbox\voidb@x\bgroup\let\unhbox\voidb@x\setbox\@tempboxa\hbox{a\global\mathchardef\accent@spacefactor\spacefactor}\let\begingroup\endgroup\relax\let\ignorespaces\relax\accent18a\egroup\spacefactor accent@spacefactor%20nazionale%201861-2017.zip. Variable in logarithms.

- *LI* Total Investment. 1964 and 1966 estimated with simple average. Source: Archivio Storico Istat 1861-2017. http://seriestoriche.istat.it/fileadmin/documenti/Serie%20Storiche%20della%20Contabilit\unhbox\voidb@x\bgroup\let\unhbox\voidb@x\setbox\@tempboxa\hbox{a\global\mathchardef\accent@spacefactor\spacefactor}\ let \begingroup\endgroup\relax\let\ignorespaces\relax\accent18a\egroup\spacefactor accent@spacefactor%20nazionale%201861-2017.zip. Variable in logarithms.

- *LGDP* GDP. 1964 and 1966 estimated with simple average. Source: Archivio Storico Istat 1861-2017. http://seriestoriche.istat.it/fileadmin/documenti/Serie%20Storiche%20della%20Contabilit\unhbox\voidb@x\bgroup\let\unhbox\voidb@x\setbox\@tempboxa\hbox{a\global\mathchardef\accent@spacefactor\spacefactor}\let\begingroup\endgroup\relax\let\ignorespaces\relax\accent18a\egroup\spacefactor accent@spacefactor%20nazionale%201861-2017.zip. Variable in logarithms.

- Deflator: Consumer Price Index of All Items in Italy (ITACPIALLMINMEI). Index 2015=100. Organization for Economic Co-operation and Development, Consumer Price Index of All Items in Italy [ITACPIALLMINMEI], retrieved from FRED, Federal Reserve Bank of St. Louis; https://fred.stlouisfed.org/series/ITACPIALLMINMEI, June 1, 2021.

- *LR* Nominal Interest rate. INTDSRITM193N 1964-1977 (Interest Rates, Discount Rate for Italy, Percent per Annum, Annual, Not Seasonally Adjusted) and INTGSTITM193N 1978-2013 (Interest Rates, Government Securities, Treasury Bills for Italy, Percent per Annum, Annual, Not Seasonally Adjusted). 1963 assumed 64-66 average. retrieved from FRED, Federal Reserve Bank of St. Louis; `https://fred.stlouisfed.org/series/ITACPIALLMINMEI`, June 1, 2021.

- Note: Public Consumption, Investment and GDP adjusted to ratios of R&D from Table 20.1 and 20.2 of ISTAT for harmonization.

Appendix B. Unit Root Tests

Table 4: Unit Root Tests

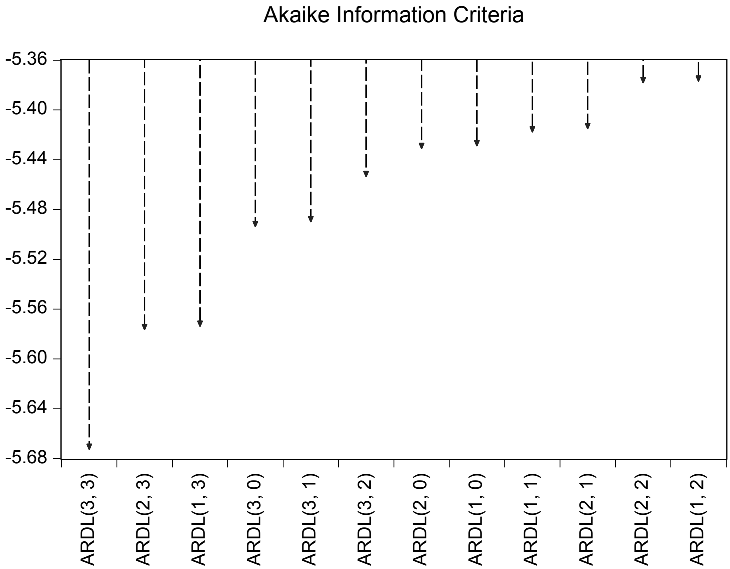
Variable	ADF	ADF-GLS	PP	KPSS	ERS-PO	NG
R&D Public Expenditures	-2.784*	-0.304	-2.964**	0.718**	137	66.3
GDP Italy	-6.570***	-0.866	-6.12***	0.900***	1682	11.078
University R&D Public Expenditures	-3.044**	0.25	-2.94**	0.930***	207	86.81
Private R&D Expenditures	-1.926	0.26	-1.77	0.930***	348	51.37
Other R&D Expenditures	-3.627***	-0.29	-3.364**	0.624**	117	47.59
Government Consumption	-3.083**	0.095	-5.053***	0.903***	614	43.63
Total Investment	-2.918*	-0.817	-2.921**	0.826***	95	23.91
Nominal interest rate	0.021	-0.314	-0.620	0.365*	22	22.10

Note: *=pval<0.1, **=pval<0.05, ***=pval<0.01.

Source: own computations based on data provided.

Appendix C. Model Selection Criteria

Fig. 2. Model Selection Criteria



Sources: Own elaboration based on data provided in Appendix A.

Appendix D. Granger-causality and post-estimation tests

Granger (1969) proposes a method to test for causality in a statistical manner between two variables and their feedback mechanism or, in other words, by measuring temporal precedence. It is not a substitute for causality in a theoretical sense. In this case, as series are nonstationary, in order to apply a Granger causality test, I applied the Toda and Yamamoto

(1995) procedure, hence with 4 lags.

Table 5: Granger Causality Test

Granger Causality Test	ADF
LRD_PUB does not Granger Cause LGDP	2.202*
LGDP does not Granger Cause LRD_PUB	1.579

Note: *=pval<0.1, **=pval<0.05, ***=pval<0.01.
Source: own computations based on data provided in Appendix A.

Table 5 shows causation in a Granger sense. According to these results, I can reject - with a 10% confidence level - that 'pure' public R&D expenditures does not cause - in a temporal sense - GDP while I cannot reject that GDP does not cause R&D expenditures.

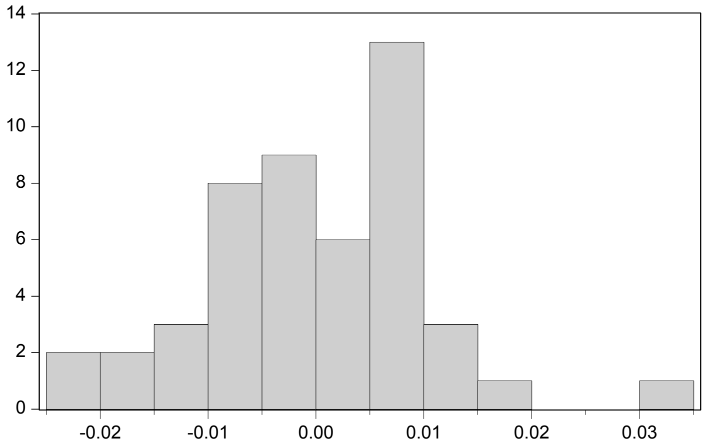
Table 6: Post-estimation tests

Post-estimation tests	
Durbin-Watson statistic	1.649
Breusch-Godley LM	0.382
Breusch-Pagan-Godfrey	0.160
ARCH Heterocedasticity Test	0.998
Ramsey Specification test	0.351
Jarque-Bera test	1.952

Note: *=pval<0.1, **=pval<0.05, ***=pval<0.01.
Source: own computations based on data provided in Appendix A.

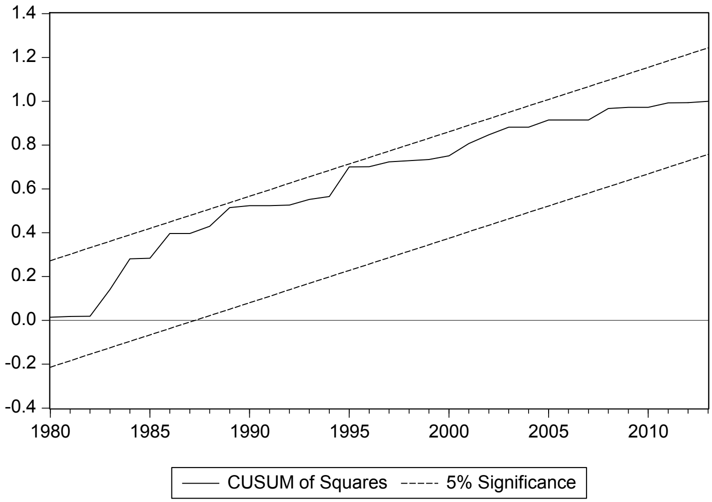
Following Savin & White (1977, p. 1992) at a 1% significance level, the Durbin-Watson statistic should be, at least, over 1.573 in order not to reject the null hypothesis of non-serial correlation. The calculated DW (48,3) is 1.649. Breusch-Godley LM can't reject the null hypothesis of non-serial correlation. The Breusch-Pagan-Godfrey test shows a low p-value, hence it rejects the null hypothesis that there is a presence of heteroskedasticity. From the ARCH test's results I can conclude that this series of residuals exhibits no conditional heteroscedasticity. The Ramsey Specification test does not reject the null hypothesis of correct specification. As for normality, the Jarque-Bera test is not statistically significant, meaning that the residuals are distributed normally (see Figure 3). The latter allows me to go on with a forecasting procedure, given that the estimators might be efficient (Gabrisch, 2019, pp. 13, 22–23).

Fig. 3. Histogram of Residuals



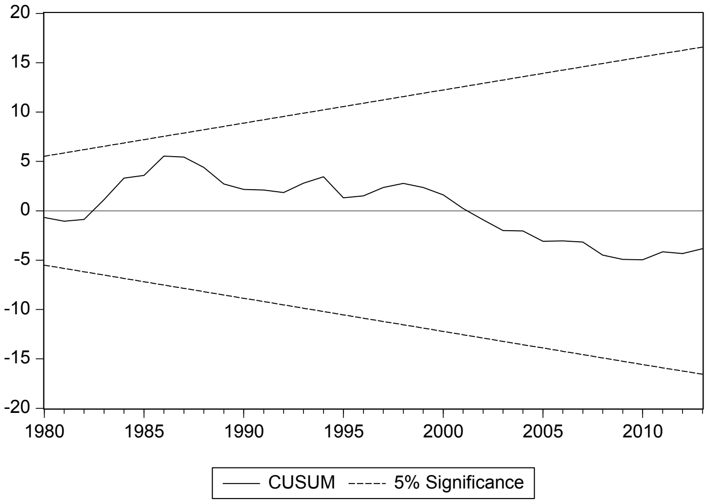
Source: Own elaboration.

Fig. 4. CUSUM of squares



Source: Own elaboration.

Fig. 5. CUSUM



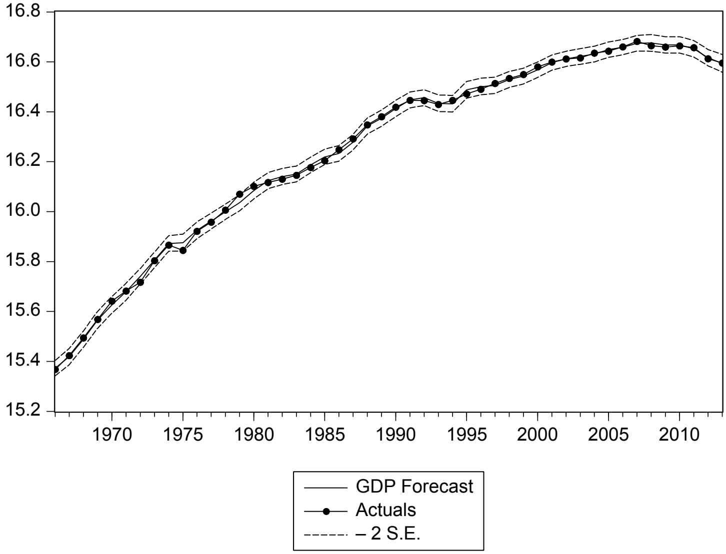
Sources: Own elaboration.

To check for the stability of the short-run dynamics and the long-run coefficients altogether, I apply the recursive estimation proposed by Brown, Durbin and Evans (1975), that is, the CUSUM of Squares and CUSUM tests. These show that, at a 5% significance level, the model is somewhat stable as it barely crosses the corridor.

Appendix E. Forecasting of Italian GDP

If public expenditures on R&D can be one of the determinants of output, then it may also be a good instrument for output forecasting. Having normal residuals, among other things, allows us to satisfy one of the conditions for efficient estimators. As can be seen in Figure 6, the model is able to predict the behaviour of the Italian GDP in a robust way.

Fig. 6. Forecasting of Italian GDP



Sources: Own elaboration.

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