The mechanisms of knowledge governance: State owned enterprises and Italian economic growth, 1950–1994

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THE MECHANISMS OF KNOWLEDGE GOVERNANCE:
STATE OWNED ENTERPRISES AND ITALIAN ECONOMIC GROWTH, 1950-1994[*]

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Abstract

We investigate the mechanisms of knowledge governance and show that the actual economic benefits stemming from knowledge externalities depend on the characteristics of a) the sources of such externalities, b) the context in which spillovers take place, c) the potential users of the externalities. In the Italian experience of 1950-1994, state owned enterprises (SOE) have been one of the most effective mechanisms of knowledge governance. Italian SOE were effective sources of knowledge externalities as they imitated the US corporate model of intra-muros R&D laboratories. Research activities carried out by SOE were mainly based in upstream industries, with multiple user-producer interactions with firms active in downstream industries, and aimed at implementing a knowledge base characterized by high levels of generic content and a wide scope of application. These characteristics helped disseminate relevant knowledge externalities that played a positive role on total factor productivity in the second part of the XX century in Italy.

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1. INTRODUCTION

The peculiar characteristics of knowledge as an economic good, including its generation process, its limited appropriability, non-exhaustibility, limited excludability, indivisibility and hence cumulability and complementarity, account for a significant and increasing part of total factor productivity (TFP) growth. Technological knowledge is not only the output of a dedicated activity but also and mainly an input that can and must be used, again and again to generate new technological knowledge. The stock and flows of existing knowledge feed the generation of new knowledge both from inside the firms and outside: external knowledge plays a central role in the generation of new knowledge. Knowledge externalities are found if, when and where external knowledge spilling from agents that carry on their own R&D activities can be accessed by third parties at costs that are below those of its intra-muros reproduction (Arrow, 1969). The tacit component of knowledge has a crucial role in the process as its transfer asks for specific conditions favouring well-defined contexts (Antonelli, 2008 e 2011).

The role of knowledge externalities in supporting economic growth and explaining TFP growth is well known (Griliches, 1979 and 1992; Romer, 1994). Knowledge externalities are a cornerstone of the new growth theory (Aghion and Howitt, 1998). According to our hypothesis, however, knowledge spillovers are not all alike: a large number of complementary conditions are necessary for their occurrence. The actual economic benefits stemming from knowledge externalities depend on the knowledge governance mechanisms by means of which the knowledge generated by an agent can affect the amount and quality of knowledge generated by another agent (Freeman 1987; Antonelli, 2014).

Specifically we stress the fact that in order to analyze how knowledge governance works and the extent to which knowledge externalities take place three distinct factors must be analyzed: the characteristics of a) the sources of knowledge externalities, b) the perspective users and c) the context in which knowledge externalities occur.

Knowledge externalities are likely to be stronger when the characteristics of the sources favour not only the emission of knowledge outputs, but also their actual reception by perspective users. State owned corporations (SOE) characterized the second wave of Italian industrialization in the second part of the XX century. The peculiar and idiosyncratic features of their research activities and specifically the type of knowledge generation activities and of their knowledge base qualified them as 'good sources' of knowledge spillovers. SOE were able to feed the fast rates of TFP growth of the system with the provision of strong and far-reaching spillovers carrying high quality knowledge externalities.

This paper contributes to understanding technological change as an emergent system property where the introduction of productivity increasing innovations depends upon the characteristics of the system in terms of knowledge governance. It does it in two ways. First, in section 2, it elaborates an analytical framework to investigate the mechanisms of knowledge governance, assesses the differences among knowledge externalities in terms of the characteristics of their sources and identifies the types of knowledge externalities. Second, in section 3, it explores, within the Italian national innovation system, the characteristics of SOE from an institutional viewpoint and through novel empirical evidence as performers of R&D activities and importers of foreign technological knowledge, so as to qualify their role as producers of knowledge externalities to private firms. Section 4 implements a simple model that frames the distinctive role of knowledge externalities according to their source. In sections 5 and 6 the paper presents the empirical evidence testing the hypothesis that because of their characteristics as producers of knowledge, knowledge externalities spilling from the R&D activities carried out by SOE played a much stronger role than the knowledge externalities spilling from the R&D activities carried out by private firms. The conclusions stress the advances made possible by the distinction made between different types of firms as sources of knowledge externalities, summarize the results of the empirical analysis and try to generalize the economic policy implications of the positive role of SOE as effective suppliers of knowledge externalities.

2. THE GENERATION OF TECHNOLOGICAL KNOWLEDGE AND THE CHARACTERISTICS OF KNOWLEDGE SOURCES

Technological knowledge is at the same time the output of a dedicated process of knowledge generation and an input into the generation of further technological knowledge. The indispensable inputs of the generation of new technological knowledge include learning processes that enable the building of competence and the stocks of tacit knowledge, formal R&D and external knowledge, that is the access to the stock and flows of technological knowledge generated by third parties (David, 1993).

External knowledge can be acquired by third parties by means of both formal transactions and interactions, including the broad array of transactions-cum-interactions. Because of limited knowledge appropriability, knowledge producers cannot appropriate the full stream of economic benefits stemming from the generation of new technological knowledge. Part of these benefits may be used and appropriated by third parties that benefit of them as a form of externality (Arrow, 1969).

Technological spillovers, however, are not all alike: their actual effects –in terms of knowledge externalities- on output and TFP growth depend on a variety of factors. Knowledge externalities are mostly pecuniary externalities rather than pure technological ones: the actual use of spillovers entails specific absorption costs. Hence knowledge externalities do not enter the production function of other firms as unpaid factors, but rather their cost function (Scitovsky, 1954). The difference is crucial: technological or pure externalities apply when no interactions and transactions among producers and users are necessary for the effects to take place. Knowledge externalities would be pure ones when and if knowledge spillovers were freely available to everybody irrespective of the characteristics of the institutional context. The appreciation of the strong differences across regions, industries, countries and historic times in the actual effects of knowledge externalities led to appreciate the specific conditions that make the use of external knowledge -as an input into the generation of new knowledge- actually possible. The acquisition of external knowledge is the ultimate step of a process of absorption consisting of a variety of activities including the screening, search, assessment, decodification of the multiple sources of knowledge spillovers. The appreciation of the amount of dedicated activities and costs that make the absorption of external knowledge possible led to substitute the notion of pure knowledge externalities with the notion of pecuniary knowledge externalities (Cohen and Levinthal, 1989; Antonelli, 2013).

As the literature on the National Systems of Innovation has shown (Freeman, 1987; Lundvall, 1992; Nelson, 1993), the actual levels of access to external knowledge in an economic system depend upon the knowledge governance mechanisms that are at work among a large variety of economic agents, such as firms, households and institutions, within industries, regions and countries. A variety of institutional and economic factors shape the levels of knowledge governance. Knowledge governance consists in the set of rules, procedures, modes and protocols that organize the generation, dissemination and use of knowledge in an economic system. The sources of knowledge spillovers, their scope of application and the architecture of knowledge flows within the system play a major role in assessing the quality of knowledge governance. The former in turn influences the way in which existing technological knowledge leads to TFP growth enhancing technological change (Ostrom, 2010; Antonelli, 2014).

A number of specific factors affect the quality of knowledge governance mechanisms and consequently the existence of relevant pecuniary externalities. The institutional context in which knowledge interactions and transactions take place affects the levels of transaction and communication costs that define the levels of pecuniary knowledge externalities. The industrial sector of activity of the producers of knowledge externalities has important implications, whether it is upstream or downstream. In the former case technological knowledge has a wider scope of possible application. The characteristics of the knowledge spilling, once generated, and its actual effects on the generation of new technological knowledge and eventually its impulse on productivity growth are influenced by the strategies and the organization of the production process. Firms characterized by tight vertical integration are less likely to favour the emission of spillovers ready to use by new perspective users. On the contrary firms that rely on a variety of other firms at different levels of the production process for specialized tasks and use platform types of industrial organization are more likely to spill technological knowledge that can be readily used by third parties. Systematic user-producer interactions qualify their production organization. Research strategies of large corporations typically have a long-term horizon and larger shares of pure research. For this reason, large firms are more likely to be the sources of effective knowledge externalities with high levels of fungibility and hence to affect the generation of new technological knowledge by third parties.

The fungibility of research activities conducted by large firms is larger also because of their –more-systematic interactions with the academic system and the large public research centers (Howells, Ramlogan and Cheng, 2012). Research centers of large corporations have high levels of institutional and cultural proximity with academic research. Academic scientists are likely to work for such organizations. Their academic career often started from research activities carried out in the large research laboratories of such corporations. Professional interactions based on repeated short-term consultancies characterize their academic life. Knowledge spilling from such firms has a much wider scope of application than knowledge spilling from focused research activities carried out by specialized firms with a narrow technological field of activity and high levels of specialization in applied and development research.

In sum, the access conditions to existing knowledge are crucial for the effective generation of new technological knowledge and for the increase of the efficiency of all other production activities. Dedicated activities are necessary to screen, identify, acquire, purchase, decode, absorb and integrate it in the knowledge base of each firm. Pecuniary knowledge externalities are found when the costs of such activities are below the costs of intra-muros reproduction of external knowledge. Firms that benefit of actual pecuniary knowledge externalities can generate technological knowledge at costs that are below equilibrium levels and experience the increase of TFP levels. The levels of pecuniary knowledge externalities are not alike across regions, industries, countries and historic times. The dissemination of technological knowledge is not the spontaneous and automatic result of limited appropriability, but the result of knowledge governance mechanisms based upon an organized system of knowledge transactions-cum-interactions where key actors play the role of hubs.

When knowledge governance is effective, pecuniary knowledge externalities will positively affect TFP growth. Here the notion of innovation as an emerging system property applies. The introduction of productivity-increasing innovations is possible only when the quality of knowledge governance mechanisms at the system level supports and qualifies the creative reaction of firms (Antonelli, 2011).

The historic evidence of the role played by SOE in the implementation of an effective national innovation system in Italy in the second part of the XX century provides important clues to grasp the working of an organized complexity based upon the positive effects of a structured system of knowledge transactions-cum-interactions on the growth of TFP at the system level.

3. STATE OWNED CORPORATIONS AS MECHANISMS OF KNOWLEDGE GOVERNANCE AND EMISSARIES OF KNOWLEDGE SPILLOVERS: THE ITALIAN EVIDENCE 1950-1994.

The deflation of the late 1920s and the international financial crisis of 1929-1931 almost brought to the collapse of the Italian banking system and to the prospective failure of the largest Italian corporations that had emerged through the first wave of industrialization at the beginning of the XX century. The extent of the crisis required to recasting the bank-industry relationship through a banking and financial reform implemented in various steps between 1931 and 1938. The solution implied replacing the mixed banks with the State at the core of the economic system, producing one of the most important institutional innovations in the history of the Italian economy (Toniolo 1980, 2013): the establishment of the Istituto per la Ricostruzione Industriale (IRI).[1] As a result of a gigantic bailout operation of the banking and industrial system, IRI – a SOE – took over controlling participations of most of the largest companies – nearly bankrupt and good firms too – from the banks, cleaned the banking sector's balance sheet of non-performing loans, became a controlling shareholder of former universal banks (D'Antone, 2012).[2]

As a consequence, in 1933, IRI came to control a substantial part of the Italian economy: around 20% of total capital of Italian joint-stock companies, over 40% taking into account indirect chain-shareholding (Cianci 1977; Toniolo 1980; Amatori and Toninelli 2011). To get an idea of its sphere of influence, IRI came to hold in the 1930's: 100 per cent of the iron and steel war industry, of the artillery industry and of the coal-extraction industry (e.g. Terni, Ansaldo, Cogne); 90 per cent of shipyard; 80 per cent of railways production; 40 per cent of the non-military iron and steel industry; plus minor but significant shares in the textile (rayon and cotton) and engineering industries.[3] It also

[1] Law 23 January 1933, N. 5.

[2] In early 1930s the perverse relationship between bank and industry came to a breaking point (Amatori and Toninelli 2011): the three main banks lost the character of mixed banks and turned into holding companies in the course of the 1920s immobilizing a significant share of their resources in long-term loans and corporate equity stakes in connected leading Italian firms, which in turn depended completely on them for finance (Rodano 1983). The withdrawal of foreign lines of credit made banks ever more dependent on credit from the Bank of Italy (Italian central bank). By the beginning of 1931, the two main mixed banks Comit and Credito Italiano had no alternative but to turn to the government which secretly mandated loans to them, via the Liquidation Institute, ultimately financed by the Bank of Italy (Convenzione of 20 February 1931, in ACS, ASIRI, serie nera, cart.1 and Convenzione of 31 October 1931, in ASBCI, Sofindit, cart. 374, fasc. 1; the latter is also published in Guarino and Toniolo, 1993). Italy's banking crisis was finally settled in March 1934 by three deals (Convenzioni) between the State and each of the main mixed banks (Comit, Credit, Banco di Roma). The latter committed themselves to maintaining the nature of commercial credit banks, devoid of shares and credit stakes in industrial firms. In return, they were freed both from their excessive debt burden towards the Bank of Italy and from their excessive credit exposure towards firms. All industrial securities in the banks were transferred to the Sezione Smobilizzi of IRI (which absorbed the Liquidation Institute), while IRI's Financing Section aimed at making loans to businesses for a twenty-year period. To finance its activities, IRI issued long-term State-guaranteed bonds. The 1934 Convenzioni, definitively delivering a clear-cut separation between the three ex-mixed banks and industry and re-organizing the financial sector as it had emerged from the crisis, also contained regulatory prescriptions which inspired the 1936 banking legislation and which were, under this new guise, extended to all deposit-taking institutions. For a comprehensive analysis of banking and financial crisis and reform in 1920s-30s Italy see Barbiellini Amidei and Giordano (2014).

[3] See "Information concerning IRI, October 1949" in ASIRI, s2.4-fl.2-p.18; "Institute for Industrial Reconstruction – IRI," Review of Economic Conditions in Italy, Vol. 4, No. 1, January 1950.

controlled 80 per cent of telephone services and of shipping lines, about 40 per cent of the banking and financial sector, as well as about 30 per cent of the electrical industry.

Originally conceived as a temporary solution, IRI was supposed to reorganise technically and financially these enterprises, initially offloading the industrial participations whenever feasible.[4] While a few large firms (among them Edison) were sold back to private shareholders, the main part remained under IRI wing for decades to come, as IRI (aided by autarchy and war preparation) was transformed in a permanent institution ("perennialised") in 1937.[5] After WWII the Italian government, instead of divesting public properties as in other countries, implemented an original institutional set-up that allowed IRI to operate in a market economy and gradually enlarge its reach within the system.[6] IRI became one of the major tools in supporting reconstruction and growth after the war (Castronovo 2012). [7]

Starting from an agricultural-based economy in the XIX century, Italy undertook a distinctive industrialization process and registered unprecedented output and TFP growth in the second half of the twentieth century, which made it one of the richest countries in the world, to be then hard-hit by a stagnation and long negative productivity growth phase in the last two decades (for an overview of the Italian economy growth process and the role played by innovation and SOEs, see: Graziani 1972; Zamagni 1993; Crafts and Toniolo 1996; Barca 1997; Ciocca and Toniolo 1998-2004; Giannetti 1998; Amatori and Colli 1999; Antonelli and Barbiellini 2011; Toniolo 2013).

At the beginning of the 1950s, Italy stood out because of the high percentage of workers employed in agriculture. Furthermore, Italy had an elastic supply of labour and the relations prevailing in the labour market favoured the establishment of a long virtuous phase – destined to have a traumatic end in the late 1960s – in which wages grew more slowly than labour productivity, facilitating high profits that encouraged investment. The process of structural change that accompanied technological change, had a crucial influence on Italian economic and innovative performance in the post- World War II era: the opportunities of employing under-used labour in agriculture in more productive manufacturing industries made an important contribution to economic and productivity growth, more and for longer than in the rest of Europe. Italy had the opportunity to 'exploit' the technological gap accumulated during the long Fascist dictatorship by taking part in Europe's unequalled process of catching up on the United States, this process was linked to the ability to adopt Fordist methods. On the basis of this opportunity, the growth of internal demand – higher per capita income, spreading of modern consumption patterns – was an important factor leading to intense technological diffusion in manufacturing, with investments increasing production capacity, resulting in a significant technological modernization of capital. A crucial process in the Italian structural change was the growth and development of a strong investment goods industry (Antonelli and Barbiellini 2011).

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[4] "Passed under State control, it was possible to examine them [i.e the industrial firms] in depth and to make decisions regarding solely the interests of the production and the defence of the Nation, as well as the economic interests of the State" ("IRI annual report to shareholders of 1934", ACS, ASIRI, serie nera, cart. 18).

[5] "IRI Report" of 6 May 1937, reported fully in Cianci (1977: 362-371).

[6] After WWII the state owned enterprises system expanded in the production of energy with two other groups, namely ENI (1953) that entered the oil industry, and ENEL (1962) for production of electricity; EGAM (1958) was created to operate public mining companies and EFIM (1962) was established to operate in the mechanical industry, following rescue operations of private firms. In 1956 a dedicated Ministry (Ministero delle Partecipazioni Statali) was created to assure a political steering on the SOEs system. We shall concentrate the analysis on the IRI group as the role of the other SOEs in R&D activities was far less relevant.

[7] If the role of Government altering the country's financial structure in the 1930s was not specific to Italy – "this became especially apparent after the First World War, particularly in Europe, where government institutions became involved in financing industrial reconstruction on a fairly broad scale, and where government resources in general grew relative to those of the banking sector" (Tilly 1992: 87) – at the eve of World War II, as an entrepreneurial State, Italy "was second only to the Soviet Union in the extent of its state property ownership" (Romeo, 1998:135).

Mass production technologies fitted well in a country with an abundant supply of labour with adequate basic education and a number of small but well-trained engineers; a quite large national market allowed the exploitation of economies of scale, especially in the production of durable consumer goods, which in turn generated a competitive advantage in export markets (Toniolo 2013). The pervasive impact of international technology transfer, including foreign direct investment, was mainly due to the ability of the Italian firms to acquire and disseminate technical knowledge through imitation and adaptation (Barbiellini, Cantwell and Spadavecchia 2013). However the post-war institutional environment adequate for a process of rapid catch-up for a "backward" economy was not necessarily appropriate once convergence on the technological frontier had been largely achieved at the end of 1980s (Eichengreen 2007; Crafts and Magnani 2013).

In the post-WWII period, in particular during the years of Italian "economic miracle", SOE were given high managerial autonomy, and under a good management resulted a tool for acceleration of investment and technical progress; IRI firms had a crucial role in giving a boost to discontinuity and modernization of the Italian economy, leading to the success of Italian catch-up, in terms of contribution to fixed capital accumulation, infrastructure creation, investment in human capital and research and development activities (Amatori 2013). In a first long phase, IRI acted as a company with public goals and a State majority ownership (as witnessed also by the continuity between the men building the private Italian industry in the years of the Great War and those leading until the '50s and '60s the firms under IRI). Later on, being more and more often hijacked for political purposes, IRI became the "armed wing" of the State employer, the instrument of a harmful pervasive government intervention in the economy (Barca and Trento 1997; Amatori, Millward and Toninelli 2011; Crafts and Magnani 2013).[8]

IRI grouped similar concerns under the control of sub-holding companies: STET (1933) for telephone services, Finmare (1936) for shipping companies, Finsider (1937) for steel, Finmeccanica (1948) in the mechanical sector, Finelettrica (1952) in the electrical sector, Fincantieri (1959) for shipyards. IRI further enlarged its reach in the 1950s and in subsequent decades, obtaining an absolute majority of shares of RAI (the national broadcasting company) in 1952 and taking control over Alitalia (the national airline) in 1957. IRI's employment grew steadily in 1950s and 1960s, dramatically in the 1970s (from 202.000 in 1938 to 257.000 in 1960, 357.000 in 1970, to reach 557.000 in 1980); in 1982 IRI reached a peak of 3.6% of total national product (Pellegrini 2014).[9] IRI continued to operate until the 1990s, when a wave of privatizations began.[10]

Organized as a super-holding on top of the sectorial holdings, owing a sound capital base, entitled to issue long-term State-guaranteed bonds, IRI for a long phase – as a corporation wholly owned by the State but quite autonomous financially and in running business – was able to offer much needed fresh capital, to reorganize and run a large block of SOE – maintained joint-stock companies under

[8] The main limitations of the IRI model were: chronic underfunding of SOEs and undue burdens imposed by politics; excessive sectoral diversification of the activities of the group; problems of communication with private business; political and ideological impositions on the Group strategic choices, with progressive commitment as an agency for development; role of short-term partisan political interests on business; excessive "sharing" by IRI management of the inappropriate tasks imposed by politics. See Amatori (2013); Artoni (2013); Silva (2013).

[9] In the present study we refer to IRI Group and sub-holding boundaries as defined by official IRI balance sheets (consolidated and not) and IRI's Historical Archive documents. For a recent precise definition and analytical re-construction of the Italian SOE system boundaries see Toninelli and Vasta (2010); thanks to this study we do know that the three main state holdings (IRI, ENI and EFIM) controlled up to 2500 firms and 40.2% of total share capital of Italian corporations in 1983, almost doubling since early 1950s.

[10] The few firms that had not been sold to private agents (Finmeccanica, Fincantieri, Fintecna, Alitalia e RAI) were transferred to the Treasury. On 27th June 2000 liquidation of IRI began and was completed in 2002.

private law – active in a variety of upstream industries ranging from the production of steel, ships, machinery and capital goods, motorcars, trains and airplanes (Saraceno 1981: 78-9).

From an institutional viewpoint the "IRI formula" was quite specific: "the matching of State property with the style of private entrepreneurship and management" (Amatori and Toninelli 2011).[11] While IRI, as a holding company, was actually a SOE as the Treasury possessed 100% of its capital, the operating companies were (often) public companies as their shares were traded in the Stock Exchange. The majority of their shares were retained by IRI. This institutional mix of property rights had the important implication that operating companies, and hence IRI, were constrained to make profits (and be competitive) so as to be able to pay dividends (coupons) to shareholders (bondholders). The levels of profitability for the shareholders were important to sustain the value of shares in the stock markets not in order to avoid the risks of hostile take-overs – since IRI held the majority of shares – but in order to allow them to raise capital in the financial markets through the emission of new shares and bonds. The viability of the access to the financial markets was regarded as an important resource for the group because of the huge flows of investments in basic infrastructure and in capital goods that were necessary to support the growth of the country.

The institutional setup of IRI led to the sequential implementation of quite a peculiar incentive mechanism based on an objective function typically characterized by output maximization but applied under the constraint of average levels of profitability that – with high pay-out ratios – could support the distribution of attractive dividends to shareholders. This peculiar constrained objective function played a major role in shaping the growth strategies and specifically the research strategies of the IRI corporations, reducing risk aversion and encouraging long-term R&D investment projects (Ravazzi 2013, pp. 171 and 246).

The basic aim of Italian SOEs in fact was to actively support the growth of the system providing it with investments in basic infrastructure, including the generation of knowledge, that could stir additional flows of investments by private companies, increasing their profitability and productivity. The mismatch between the 'large-r' generation of technological knowledge and its 'small-er' exploitation made room for the dissemination of effective knowledge spillovers providing the Italian national innovation system with a large supply of high quality knowledge externalities that could be easily and effectively accessed by other firms in the system and used in the recombinant generation of new technological knowledge and in the introduction of technological innovations.

In the four decades following WWII, IRI became one of the main protagonists of the fast growth of the Italian economy with important investments in infrastructure and related upstream manufacturing activities playing a central role in the second wave of industrialization (Amatori 2013).

[11] An important active interpreter of IRI's experience claimed that the appropriate choice for the SOE was to pursue "economicità" (Saraceno 1975) – i.e. economic health – while targeting economic goals established within the framework of social and political constraints (Toninelli 2000; Amatori and Toninelli 2011). The blending of state property and market conduct, the idea of giving strategic industrial companies to the "right hands" worked quite well especially in the 1950-60s golden age (Osti 1993). However this framework implied a "controversial relationship" between political power and managerial forces, which increasingly exposed the SOEs system to inappropriate political pressures, the risk of the prevalence of electoral goals, up to the risk of corruption and illegal practices' infection; even if the law stated that social and political constraints were to be considered "improper financial burdens" in SOEs balance sheet, supposed to be offset by special State endowment funds, a bias towards debt accumulation prevailed (Balconi, Orsenigo and Toninelli 1995). See also Woods (1998); Barca et al. (2001); Amatori (2013).

While IRI's weight on the Italian economy was particularly relevant in the steel and in the transport equipment industries, its presence was very significant also in the machinery and equipment industry (almost 50% of all Italian corporations' assets in this industry in 1936, 20% in early 1950s still 8% in 1981) and in the electrical equipment industry (10% in 1952, over 20% in 1980; Toninelli and Vasta 2010; Pellegrini 2014; see also Giannetti and Vasta 2009; Colli 2013; Doria and Tolaini 2013).

The IRI group, because of its size, the breadth and diversity of its firms, was a crucial component of the input-output relationships of the Italian economic system, feeding with sophisticated and innovative products businesses in all industries (Pellegrini 2014). The industrial specialization of IRI in the provision of advanced intermediary inputs and capital goods and generally in upstream industries played an important role in magnifying the actual amount of external technological knowledge, often of foreign origin, that could benefit the recombinant generation of technological knowledge by firms active in downstream industries (Aghion and Howitt, 1992; Gehringer, 2011).

IRI played a central role in building and implementing the Italian research system with the systematic build-up of a chain of advanced research laboratories ranging from telecommunications, to informatics and electronics (including microprocessors), machinery and specifically numeric control machine tools, textile machinery, nuclear power and advanced machinery for power and electricity generation, airplanes and military equipment.

Partly sharing IRI's general drive towards Americanization of 1950s-60s (Chandler, 1962, 1977 and 1990; Osti 1993; McGlade 1996; Chandler, Amatori and Hikino 1999; Zeitlin and Herrigel 1999; Amatori 2013), IRI's research laboratories imitated explicitly (adapting it to the Group specific nature) the model of American large multidivisional corporations' labs, also thanks to American consultants and study visits of IRI's teams to the US (Ricciardi 2003; Lavista and Ricciardi 2013).[12] In particular in the field of telecommunication and electronics technologies in 1961 CSELT (Telecommunication Centre studies and laboratories) was established, an autonomous research centre to conduct and supervise R&D activities of the STET sub-holding Group, with the explicit aim of following the Bell Laboratories experience (Mariotti 2014).[13] In the field of marine engineering, IRI, Fincantieri, Finmare, Ansaldo of Finmeccanica and other IRI's companies founded in 1962 CETENA (Marine engineering Center studies). Finsider in 1963, together with IRI, Finmeccanica, Fincantieri, in joint-venture with private firms such as Fiat and Falck, founded CSM (Metallurgical Research Centre) for research in the field of iron and steel. Through the 1960s many IRI's corporations strengthened or founded their R&D laboratories, among them the main investors Selenia (electronics) and Alfa Romeo (automotive), but also Nuova San Giorgio (servo control system), Telespazio (satellite telecommunication), Italsider, Dalmine and Terni (iron and steel).

[12] The meeting "Ricerca e Sviluppo nel gruppo IRI", organized by IRI headquarter in 1964 to refocus the group strategic orientation on technological innovation and R&D activities, was opened by two reports on the "highly advanced American experience" by the dean of the MIT School of Science and by the executive vice-president of Stanford Research Institute (Lavista and Ricciardi 2013).

[13] The project of STET industrial expansion and technological development involved, along with the establishment of Cselt (previously Centro Studi e laboratori Stet, renamed Centro studi e laboratori telecomunicazioni since 1964), the acquisition of control of SIRTI in 1965-66, the creation in 1967 of STS (Consortium for Telecommunications Systems via satellites) in joint venture with Sit-Siemens and the American company Gte, the acquisition in 1969 of Raytheon Elsi (producer of electronic components), the passage of Selenia and Elettronica San Giorgio – Elsag to the group in 1970, the establishment of SGS-Ates in 1972 (later on STMicroelectronics); steps mostly envisaged by the "Piano elettonico", defined by IRI at the end of 1960s to plan the establishment of an "Italian electronic pole". See Bottiglieri (1987); Malerba, Bussolati and Torrisi (1996); Comei (2013); Mariotti (2014). Helped to undermine the "electronic pole" development, the poor integration of activities between the R&D labs and centers, between manufacturing and telecommunication service companies of the group, and the resulting inability to develop and capture technological synergies and complementarities (Mariotti 2014, p. 11).

In the post WWII era IRI's and SOE's contribution to the national effort in R&D investment was highly significant and increasing until mid-1980s (Antonelli and Barbiellini Amidei 2007; Giannetti and Pastorelli 2007). In order to analyse quantitatively the R&D effort of IRI Group and its sub-holdings over the period, we reconstructed for this study the time series data on R&D expenses covering the period 1963-1998.[14] Our new data show that in 1986 IRI reached a maximum of 15% of all national investment in R&D, while SOE reached a maximum of 22% of Italian Gross domestic expenditures in R&D (GERD) and 38% of total Business enterprise sector R&D (BERD). IRI's R&D intensity, as measured by R&D expenses on total sales, reached the levels similar to the other international counterparts. This was due in particular to R&D investment expansion by Finmeccanica and STET companies, inter-company CSM steel research centre, naval engineering Cetena and Centro ricerche SME for the agri-food industry, as well as a result of the creation of new corporate labs, reaching the number of 90 in mid 1980s (Doria and Tolaini 2013, p. 456).

Until 1980 IRI's R&D expenditures on average accounted for over 70% of all SOEs R&D (around 55% until early 1990s). Since mid 1980s instead SOE's R&D weight decreased, and especially IRI's R&D retrenched markedly in the early 1990s with the privatization process (see Figure 1). As a share of value added in fact, IRI's expenses for R&D stopped its remarkable and long growth and started to scale down after 1986 (see Figure 2).

FIGURES 1 AND 2 ABOUT HERE

Looking at IRI's sub-holding stands the leading role played by Finmeccanica and STET companies in the Group R&D activity. Finmeccanica alone covered 41% of the total IRI R&D on average over the period 1963-1990, more than 50% in the Sixties.[15] STET followed closely as a crucial R&D pole with 39% of the total IRI spending on R&D on average over the period 1963-1990, but with a primary role (over 50%) during the most dynamic phase of SOEs investment in R&D in 1968-1976. This was the phase of a redefinition of IRI's development trajectories - as it emerges from the analysis of fixed investment sectoral destination – with a strong focus on the expansion of the electronics and telecommunications industry (at the expenses of basic, capital-intensive industries, Pastorelli 2006, p. 18; see also Colli 2013; Comei 2013; Doria and Tolaini 2013; Mariotti 2014), with a leading role of STET high-tech companies.[16] All these companies were endowed with their own research laboratories. Finmeccanica was actually the sub-holding with the highest R&D on

[14] The data on the expenses for in-house R&D performed by IRI Group companies and for commissioned by IRI and performed externally R&D have been reconstructed for this study using archival IRI's sources of information: IRI, "Ricerca, sviluppo e innovazione nel gruppo Iri" (marzo 1992); IRI, "Ricerca e sviluppo Serie storica 1984-1991. Dati aziendali" (maggio 1992); IRI, "Ricerca e sviluppo Serie storica 1966-1990. Dati consolidati"(giugno 1992). In our elaborations we also used Antonelli and Barbiellini Amidei (2007, 2011), Istat. (1963–2010), and Istat (2011), which are also the sources for our data concerning the expenditures in Research and Development activities classified by typology of economic actors: Universities and Public entities, Private Firms and SOEs.

[15] Among main Finmeccanica's R&D investing companies were: Alfa Romeo, in the automotive industry; Ansaldo San Giorgio and Elettrodomestici San Giorgio in the electromechanical sector; Sant'Eustacchio, Fabbrica Macchine Utensili and Mecfond in large machine tools, steel and packaging machinery (companies later on passed under Finsider); Selenia in electronics, Nuova San Giorgio in electronics and textile machinery (companies later on passed under STET); OTO Melara in weaponry.

[16] Among main STET's R&D investing companies were: Ates (in participation with the American multinational RCA), then SGS (former Olivetti group, founded in partnership, other than with Telettra of the Fiat group, with the U.S. company Fairchild) - ATES in semiconductors (later on ST- Microelectronics); Selenia (before 1970 part of Finmeccanica) in electronics and military industry; Elettronica San Giorgio-Elsag, in numerical control systems for machinery and other electronic systems; Sit- Siemens (before the end of WWII part of the German group Siemens & Halske) then Italtel, in telecommunications equipments.

Total Assets ratio, around 15%, increasing over the period 1963-1990; STET followed at a distance, with an R&D on Total Assets ratio between 5 and 10%; much lower values were recorded by the other sub-holdings.

IRI was an increasingly open R&D system, as witnessed by both the increasing share of R&D performed in-house by IRI companies but commissioned from outside IRI Group and the increasing share of R&D commissioned by IRI and performed externally (extra-muros) (see Figure 2). In particular, Finmeccanica and STET worked as research platforms both for the entire IRI Group and the entire Italian industrial system: the share of Finmeccanica research commissioned from outside was indeed very large, almost 40% of the total, equal to about 60% of the total IRI research externally commissioned over the period 1963-90. A similar role was played by STET, with externally commissioned R&D reaching 83% of the total IRI and 34% of total STET R&D between the mid-sixties to the mid-seventies.[17]

The management of the innovation process within the IRI group was very much influenced by the American top-down approach and aimed at the control of the full process of exploitation of new scientific ideas into technological knowledge (Antonelli and Lamborghini, 1978; Aghion and Tirole, 1994; Zeitlin and Herrigel, 1999). A large portion of the research budget was devoted to development and applied research, yet at the beginning of 1990s the share of pure research of SOE's, and among them that of the IRI group, was larger than the share of the large corporations of the private sector 2,3% vs 1,9% (Antonelli and Barbiellini Amidei, 2007). The relations with the academic system were strong and systematic with significant interactions and career exchanges with the main schools of engineering. The researchers of IRI's Group firms worked at par with academics and several careers developed through phases in both corporate and university laboratories. Empirical evidence analysed by a rich literature of case studies on IRI's Group firms confirms that the US corporation model was systematically followed, especially for what concerns the attention to the scientific content of the research and the proximity to academic research. In the Group's internal survey on research collaborations performed in 1967 about half of the companies involved reported the existence of several formalized contacts with universities and research institutions.[18] At the end of the 1980s the IRI survey on the collaborations of the Group R&D laboratories with external structures, listed 108 initiatives for cooperation with universities and 94 with research institutes (National Research Council-CNR and National Committee for Research and Development of Nuclear Energy and Alternative Energies-ENEA) out of a total of 746 partnerships in the period 1988-90.[19] In 1986 IRI promoted the creation of a network of 9 consortia research centres ("Città-Ricerche")in order to strengthen the links between scientific capabilities in the universities and the innovation needs of enterprises and to favor the exchange of skills and experience, between the two sectors, in agreement with the CNR (National Research Council), local business associations (Unioncamere), Universities and other institutions, .[20]

The detailed analysis of the IRI research system documents its intentional role as the interface between scientific research performed by the academic system for the sake of scientific progress and its use as an input into the generation of technological knowledge. The empirical evidence

[17] In particular stood out Alenia (returned in the Finmeccanica group, as result of the merger of Selenia and Aeritalia) for relations with universities, Ansaldo and Fincantieri with CNR and ENEA The remaining sub-holdings were generally less open and definitely more buyers than suppliers of R&D services.
[18] IRI, Sintesi dei programmi quadriennali 1968/1971, p. 15.
[19] IRI, "Ricerca, sviluppo e innovazione nel gruppo Iri", marzo 1992.
[20] Particularly significant was the consortium research centre of Pisa, in association with Finmeccanica, Avio Spa and Piaggio, and Catania in association with STMicroelectronics. Research centres were also established in Genoa, Maccarese, Milan, Naples, Padua, Rome and Venice (Senato della Repubblica, X Legislatura, 10a Commissione Permanente - Industria, commercio, turismo, "Indagine conoscitiva sulla competitività tecnologica dell'industria italiana, 3 December 1991)

shows that the share of research performed extra-muros but funded by SOE's, as well as by the IRI group was almost double than the corresponding share of the research funded by the private firms.[21]

IRI group also had a crucial role as importer and distributor of foreign technologies throughout the national industrial system, also thanks to the use of recombination processes to generate new technological knowledge. IRI's firms made, in fact, a considerable effort of creative adoption and often intermediated the access of Italian private business to new technologies developed abroad. SOEs acquired foreign technological knowledge – both (mainly up to early 1970s) codified knowledge through the import of foreign disembodied technology (patents, blue prints) and know-how, skills and competences (especially in the 1980s) through technology agreements, joint research programs and joint ventures with foreign multinationals active in advanced industries. This technological knowledge was used in processes of technology recombination, which allowed adoption, adaptation and valorization of the specific knowledge resulting from localized learning in and outside the SOEs system (Antonelli and Barbiellini 2011; Barbiellini, Cantwell and Spadavecchia 2013).

The evidence on IRI's import of technological knowledge suggests that the purchases by the firms of the IRI Group of disembodied foreign technology, in the form of royalties for patents, blueprints and technical assistance, were highly significant and increasing since early 1950s until mid 1960s, perhaps even more than for the Italian economy as a whole. [22] In this period the IRI Group fulfils the modernization of productive structures and products portfolios thanks to a massive recourse to the external acquisition of licences (Finmeccanica and STET companies in particular) and technical assistance (Finsider companies in particular), in connection with the design of new plants, the purchase of foreign machinery, the modernization of existing plants.[23]

In order to analyse quantitatively the import of disembodied technology by IRI Group, we reconstructed for this study the time series data for the technology balance of payments for IRI and its sub-holdings over the period 1963-1990. [24] Our new data show that in 1966 the IRI ratio of expenses for the acquisition of foreign technology on the Group total sales (see Figure 3) reached a value equal to 0,4%, higher than the ratio of Italian expenses of the Technology Balance of Payments over GDP (TBP; equal to 0,25% in the same year); a really significant one also when we consider that the equivalent IRI's R&D/Sales ratio was equal to 1 per cent. IRI's purchases of foreign disembodied technology were equal to 7% of all Italian purchases in 1966. Since the end of the 1960s and especially in the 1970s IRI's purchases of foreign disembodied technology as a ratio

[21] In 1979 R&D expenditures performed extra-muros were 21% of total SOE's R&D and only only 13% of private firms, in 1991 the shares were respectively 14% and 9%. Our elaborations on: Tav 11, p. 39, in Istat, Indagine statistica sulla ricerca scientifica, in «Bollettino mensile di statistica. Supplemento», n. 19, 1982; Tav. 333, p. 324, in Istat, Annuario Statistico Italiano, 1982; Antonelli and Barbiellini Amidei (2007).

[22] See "La dipendenza tecnica del gruppo IRI dall'estero" in ASIRI, SD 1585, Servizio R.I., 6. Temi SRI, 6.2.4/4 – Convegno sulla componente estera del Gruppo IRI – Gruppo di lavoro "Coordinamento Attività Commerciale", 1965.

[23] Terni, Cornigliano-Italsider (from American Rolling Mill Corporation and US Steel) and C.M.F. (in the process of building a new big metal carpentry plant in joint venture with US Steel) accounted for over 70 per cent of total Finsider technology balance of payment expenses in early 1960s. Italsider was by far the main buyer of technical assistance in early 1970s, from US Steel and Yawata Iron & Steel; in early 1980s the consultancy of Nippon Steel was a crucial ingredient of Finsider's "Taranto Rationalising Plan" to improve productivity, involving both engineering and organization aspects (with 70 Japanese engineers, managers, technicians and foremen stationing in Italy for two years; the head of the Japanese team becoming in early 1990s Ilva's CEO). See Pastorelli (2006); Ranieri and Romeo (2014).

[24] The data on technology balance of payments for IRI and its sub-holdings have been reconstructed for this study using archival IRI's sources of information: IRI, "Ricerca, sviluppo e innovazione nel gruppo Iri" (marzo 1992); IRI, "Ricerca e sviluppo Serie storica 1966-1990. Dati consolidati" (giugno 1992). In our elaborations we also used Antonelli and Barbiellini Amidei (2007, 2011), which are also the source for our data concerning the Italian Technology Balance of Payments.

of total sales decreased sharply (a partial recovery of the ratio in the first half of the 1980s was partly the result of a sharp devaluation of the coeval Italian national currency Lira). IRI's purchases resulted in 1990 (last year of data availability) equal to a much lower 0,6% of all Italian purchases of foreign disembodied technology.

Looking at IRI's sub-holdings stands out the leading role of the import of foreign technology by Finsider (41% of total IRI purchases), followed by Finmeccanica and STET companies, covering altogether on average over 90% of both sides of IRI Group technology balance of payments over the period 1963-1990.. In particular Finsider stood out for the relevance of technology purchases up to the early seventies. Anyway Finmeccanica was the most intensely involved in the purchase of foreign technology, in relation to the size of its budget, with disbursements amounting to 1.3% of its total assets on average in the period 1963-1990, more than Finsider (0.8%) and STET (0.4%). For all three sub-holding, as for IRI as a whole, TBP disbursements clearly outweighed the revenues.

Advanced foreign technologies were increasingly accessed also thanks to joint ventures with foreign multinationals active in high-tech industries and foreign direct investment through acquisitions or brownfield entry in developed markets, Finmeccanica and STET companies in particular.[25]

FIGURES 3 ANB 4 ABOUT HERE

This evidence in any event confirms that IRI played an absolutely relevant role in intermediating the access to new technologies developed abroad, thanks to both (mainly up to early 1970s) the acquisition of foreign disembodied technology, and (especially in the 1980s) to technology agreements, joint research programs and joint ventures with foreign multinationals active in advanced industries.

The structure of the research activity of the IRI group was very much influenced by the effort to imitate the 'American' corporate model and indeed it succeeded from the viewpoint of the generation (often thanks to import and recombination processes) of technological knowledge. The IRI firms were pushed (also by American consultancy firms and co-operation and assistance programs) towards the American model characterized by large corporations that rely upon internal markets and hierarchical interactions in the generation of new technological knowledge (Osti 1993; Amatori 2013; Lavista and Ricciardi 2013). The American model strength lay in the capability to accumulate and valorize stocks of existing knowledge internally. Diversification provided the opportunities to increase at the same time the scope of application and the breadth and diversity of knowledge units that could enter the recombination process. Corporations could limit the spilling of knowledge externalities and appropriate the economic benefits of the applications of technological

[25] Notable examples of joint ventures of Finmeccanica and STET companies with foreign multinationals were: in electromechanical and power generation, Ansaldo (after exit nuclear industry) starting a joint ventures with the Swiss company ABB to develop transformers and with Siemens to develop gas turbo technology in late 1980s; in industrial automation, the Seiaf joint venture of Elsag with Ibm, and the technological cooperation (through Esacontrol) of Elsag and Ansaldo with the American company Bailey Controls in mid 1980s, then acquired in 1989 to become, as Elsag Bailey, a leading multinational in the industrial automation technology; in telecommunication equipment, Italtel with the American telephone company GTE in the first half of 1980s, involving two way flows of technicians and know how exchanges between corporate labs, with a crucial contribution of the IRI's research center CSELT, and at the end of 1980s the (last attempt of the) strategic alliance with AT&T to access frontier technologies and develop internationally; in microelectronic, the SGS-Ates merge with the French Thomson semiconducteurs to become in 1987 SGS-Thomson and one of the main player of the semiconductors industry. See Acocella 1983; Malerba, Bussolati and Torrisi (1996); Pastorelli (2006); Zamagni (2009); Doria and Tolaini (2013; pp. 392-3, 444-454).

externalities. In the 'American' model the academic system was the main source of external technological knowledge. In the IRI's adaptation of the corporate model the acquisition from abroad of foreign technology was crucial.

The IRI corporations did not succeed in the implementation of the 'American' corporate model from the viewpoint of the exploitation of technological knowledge generated. The reduced appropriation of the benefits of the applications of technological knowledge internally generated and the limited application of the technological knowledge generated from the research system of the IRI corporations was due to an array of factors: the complex, non (fully) profit seeking system of incentives, including their porous borders with respect to the creative interactions with downstream users and customers and participants in the "public" industrial platforms.

However the IRI group indeed succeeded from the view point of the dissemination of technological knowledge: boosting the drive of the Italian system towards American technology through the emission of knowledge pecuniary externalities. This was true both for the (few) large private corporations involved in some formal R&D and in significant import of embodied and disembodied American technology, and for medium and small firms relying on internal learning and external user-producers technological interactions. The specialization in upstream industries together with the heavy role of pure and long-term research favoured the dissemination of technological spillovers to a large array of downstream firms.

The organization of the IRI group plays an important role in this context. The structure was really decentralized before the end of the Sixties, with the basis of the pyramid (the firms level) largely independent from the top. Endowed with good managers (often technicians, engineers) and high managerial autonomy, SOE were able to pursue a great deal of investments in new industries, mostly free from political constraints. Their action was speeded up by the idea that IRI had to pursue a policy of investment and development of strategic networks, achieving economic efficiency ad remaining competitive with private business: investments in the generation and dissemination of new technologies were perceived as functional to this policy.

From this viewpoint, the IRI corporations have been actually for quite a long period a major mechanism of knowledge governance and a central component of the Italian distributed model of recombinant generation of technological knowledge (Antonelli and Barbiellini 2011). This model has been successfully experienced in Italy in the years 1950-1990. Networks of firms characterized by high quality user-producer interactions relied upon vertical relationships in building their technological knowledge. Direct relations among users and producers of capital goods and parts were at the heart of this model. Direct knowledge interactions were the result of a long-term process of market exchanges based on tangible goods. Relations between users and producers of capital goods, in particular, gradually evolved into knowledge interactions. A novel mode of transactions-cum-interactions developed as an important outcome. The transactions of capital goods gradually were enriched by systematic knowledge interactions where both users and producers could take advantage of tacit knowledge generated in learning by doing and by using.

The descriptive evidence provided so far enables to put forward the hypothesis that the Italian SOEs played a strategic role in the growth of productivity as key elements of the organized complexity of the Italian National System of Innovation, providing crucial knowledge externalities to the rest of a national system characterized by the substantial weakness of an advanced scientific infrastructure and the lack of an appropriate fabric of private big corporations. While the contribution of SOEs to the growth of the national economy has been appreciated with respect to other aspects, their role as main source of knowledge spillovers and hence productivity growth has been little appreciated so far. From this viewpoint it can be argued that the discovery of this specific positive role of the SOEs in the Italian National System of Innovation, as key factors of the introduction of productivity-increasing innovations adds new elements to appreciate the renewed implementation of the Italian SOEs in the late 1940s. As a matter of fact this argument received little attention among the analyses that supported the active role of the State in the economy (Shonfield, 1965 and Cottino, 1978). From this viewpoint the privatization implemented in the late 1990 as a consequence of the radical changes in the balance between public and private power that were taking place in advanced countries, deprived the national innovation system of one of its main pillars as the central source of knowledge externalities.

4. THE HYPOTHESES AND THE MODEL

4.1. THE HYPOTHESES

The matching between the analytical frame and the empirical evidence of the specific institutional set-up provided by the case of IRI, highlighted so far, enables us to spell out the basic hypothesis. Innovation is the emergent property of the organized complexity of an economic system that takes place when the actual amount of knowledge externalities available at low costs to firms is able to support their reaction and make it creative as opposed to adaptive (Antonelli, 2011). Knowledge spillovers do not work automatically in all conditions: technological spillovers are not all alike. A complex web of contextual conditions are necessary to make spillovers actually able to support the generation of new technological knowledge, the introduction of technological innovations and hence the eventual increase of TFP. Knowledge spillovers require a specific institutional context to be actually useful and effective. Their actual impact varies according to the types of knowledge being disseminated, the characteristics of the recipients and, most importantly here, the characteristics of the emissaries.

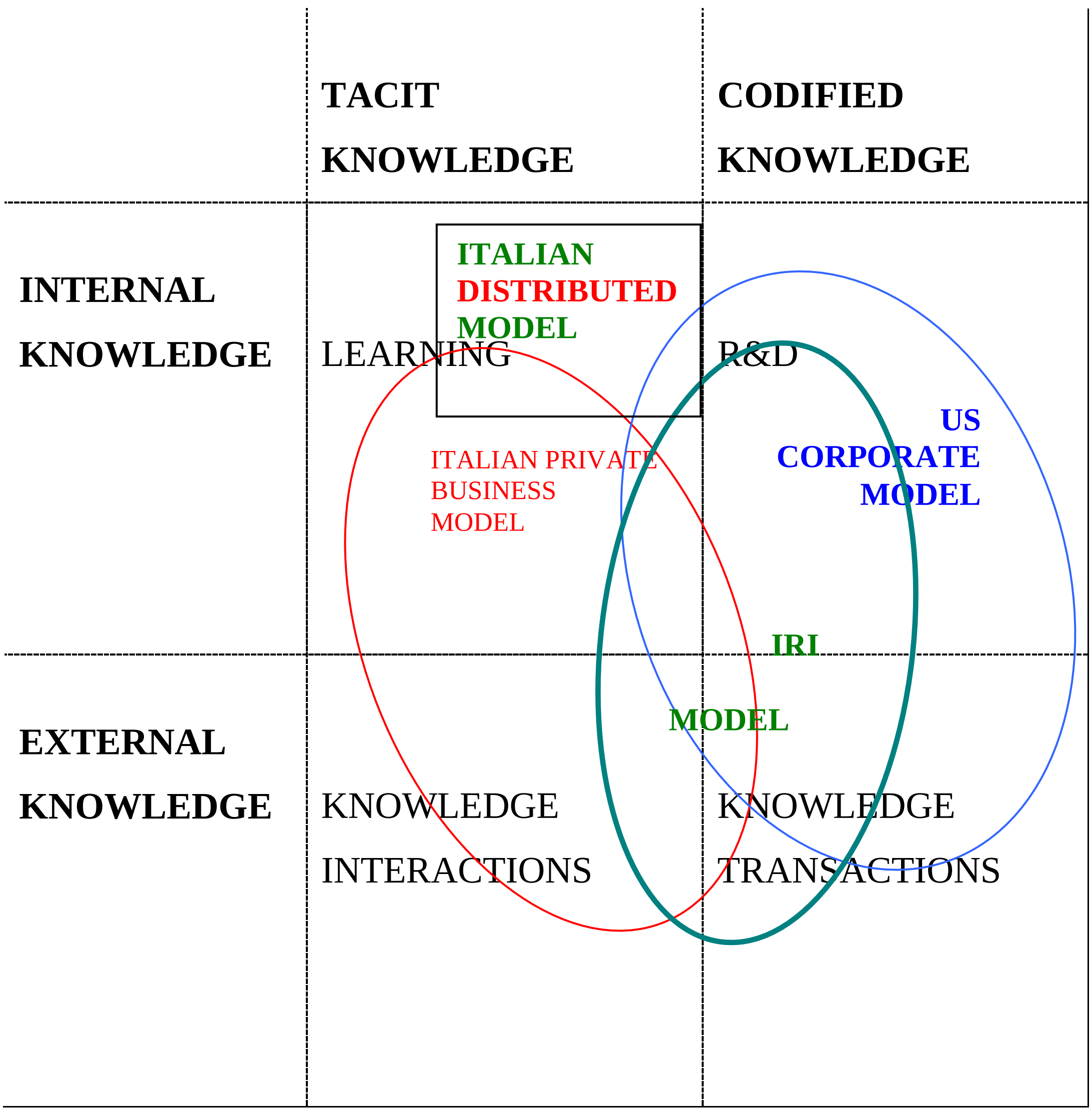
Knowledge externalities spilling from the IRI research system were especially apt to support the Italian second wave of industrialization, for the characteristics of the technologies being generated and implemented, typically associated with upstream activities, with a strong content of generic knowledge based upon scientific knowledge and a strong base of pure research conducted in close collaboration with the academic system. The top-down approach to the generation of technological knowledge applied by the IRI corporations enhanced the content of scientific inputs and intensity of interactions with the academic system so as to increase the amount of knowledge spillovers and the opportunities for third parties to benefit from intra-muros research projects carried out by the IRI corporations. The intrinsic variety of the fields of activity of the IRI corporations also favoured the downstream recombinant generation of new technological knowledge by firms active in related sectors that could specialize in the integration of diverse knowledge inputs into new synthetic knowledge (see Table 1).

These spillovers could effectively support the generation of technological knowledge by the rest of the system mainly, if not exclusively, characterized by small and medium sized companies. Research activities performed by the private firms had a much stronger applied content and often focused on the development of the new technologies disseminated through the Italian economy by the IRI research system. Research activities performed by the private firms were mainly based on low levels of codified knowledge and impinged upon a strong component of tacit knowledge based on processes of learning by doing and learning by using. As a consequence the technological knowledge spilling from the research performed by private firms had a much lower impact in terms of knowledge externalities and eventually TFP growth on the rest of the system.

Summing up, we put forward the hypothesis that the IRI group and more generally the Italian SOEs played a central role in the generation and dissemination of advanced technologies and technological knowledge to the rest of the economy so as to be a central component of the Italian innovation system. The IRI group also acted as a crucial interface between the generation of new advanced technologies, both in academia and abroad, and the rest of the national economic system.

Table 1 provides the knowledge quadrant that identifies the ingredients of the knowledge generation activity that stem from the combinations of internal and external, tacit and codified knowledge and synthesizes the different possible mixes of ingredients that have been experienced respectively in the American corporate model and in the Italian distributed model to generate new technological knowledge (Antonelli and Barbiellini Amidei, 2011). With respect to the Italian model, SOEs played the crucial role of main performers of codified knowledge and providers of external knowledge – often with a primal foreign provenance – to the rest of the system, concentrating their activity in the upper right cell of the knowledge quadrant and providing the Italian innovation system with crucial inputs into the bottom cells via both knowledge interactions and knowledge transactions. The understanding of the systemic interdependencies of innovation systems enables to grasp the central role of SOEs in the Italian distributed model as the main providers of knowledge externalities to the rest of the system (Metcalfe, 1995).

Table 1. The knowledge quadrant



Because technological knowledge is at the same time the output of a dedicated activity and an input for the generation of further technological knowledge -as well as for the production of all other goods- its dissemination plays a crucial role. The dissemination of technological knowledge is not the spontaneous and automatic result of spillovers, but the result of knowledge governance mechanisms based upon an organized system of knowledge transactions-cum-interactions where key actors play the role of hubs. Because of their centrality in the user-producer relations and their active role of interface with the advances of the scientific and technological frontiers abroad IRI corporations played a key role not only in the generation of technological knowledge but also in its dissemination. Knowledge externalities stemming from research activities performed by the IRI corporations were very effective, more than research activities performed by the private firms, in terms of their contribution to the third parties' generation of additional technological knowledge and hence introduction of technological innovations with the ultimate effect of providing a strong(er) support to the increase of TFP at the system level.

4.2. THE MODEL

A knowledge generation function nested with a technology production function are the key components. The knowledge generation function provides the knowledge that is necessary in the technology production function to produce all the other goods. In the generation of new technological knowledge, internal and external knowledge are complementary inputs (Nelson, 1982; Weitzman, 1996). Next to internal knowledge obtained by means of R&D activities and the valorization of learning processes, external knowledge is indispensable for nobody can command all the knowledge available at any point in time (Antonelli, 2013). External knowledge is the output of generation activities performed by other firms in the system. We distinguish between the external knowledge generated by the private firms and the external knowledge generated by IRI.

In our case, the knowledge generation function and the cost equation can be written as follows:

(1) $T = (IK^{a} \, EKP^{b} \, EKIRI^{c})$ with $a+b+c =1$
(2) $C = pIK + uEKP + vEKIRI$

where T represents new technological knowledge generated with constant returns to scale by means of internal knowledge (IK) and external knowledge spilling from private firms (EKP) and IRI (EKIRI). Here (p), (u) and (v) represent their respective unit costs. The unit cost of internal knowledge p consists of the market price of the resources – primarily skilled labor – that are necessary to perform R&D activities and to learn. The unit costs of external knowledge (u) and (v) spilling respectively from private firms and from IRI, consist in the cost of the resources that are necessary to access and to use the knowledge possessed by other agents in the system, into the recombinant generation of new technological knowledge.

Pecuniary knowledge externalities are found where and when the costs of external knowledge (u) and (v) are below a general equilibrium level for the cost of external knowledge (x*). If, where and when knowledge were a standard economic good, x would be found where its marginal and average costs meet its marginal product. If the actual costs of external knowledge (u) and (v) are lower than equilibrium levels the amount of knowledge generated T will be larger than the equilibrium level T*. The firm will produce more and cheaper technological knowledge than in a system where external knowledge have higher – equilibrium – costs (Antonelli, 2013).

Following Griliches (1979), technological knowledge directly enters the standard Cobb-Douglas production function of all the other goods with constant returns to scale of each firm. Hence:

$(3)\ Y = A\ (I^g\ T^d)$ with $g+d = 1$
$(4)\ C = cI + sT$

where for the sake of simplicity I is a bundle of tangible inputs, c are their costs, T is technological knowledge, s its cost and A measures TFP levels.

Firms can actually benefit of positive pecuniary knowledge externalities to access external knowledge and hence take advantage of the upstream localized generation of larger amounts of ‘cheaper’ technological knowledge, with cost below equilibrium level, when $s < s^*$. In these circumstances they will produce an output Y that is larger and cheaper than in equilibrium conditions. Following Abramovitz (1956) the level of TFP is measured by the ratio between the real historic levels of output Y’, and the theoretical ones calculated as the equilibrium use of production factors:

$(5)\ A = Y' / I^*\ T^*$

Where I^* and T^* are the equilibrium quantities of production factors and A measures TFP.

The case for a positive value of the TFP takes place when the access to technological knowledge as an input into the generation of new technological knowledge is affected by localized out-of-equilibrium conditions and is cheaper than in equilibrium conditions. Hence the output of all the other goods produced downstream in localized equilibrium conditions characterized by pecuniary knowledge externalities will be larger than in equilibrium conditions.

The results can be summarized as it follows: firms produce more than expected and hence experience an ‘un-explained’ residual in the actual levels of output that are larger than the expected ones ($Y' > Y^*$), if and when:
1) the costs of external knowledge spilling respectively from private firms and state owned IRI corporations and used in the upstream knowledge generation function are lower than in general equilibrium ($u < x^*$) and ($v < x^*$);
2) the localized output in terms of technological knowledge is larger than in general equilibrium conditions, i.e. the actual levels of T (T’) are larger than the general equilibrium levels (T^*) ($T' > T^*$);
3) the costs of the technological knowledge that enters the Cobb-Douglas production function for all the other goods are also lower ($s < s^*$).

These elementary passages enable us to support the basic proposition that TFP levels and rates of growth depend on the levels and the rates of change of the discrepancy between the general equilibrium costs of external knowledge and the actual localized ones according to their respective sources. Hence we can put forward the basic proposition that TFP levels stem from pecuniary knowledge externalities:

(6) $A = f\ (T'/T^*)$
(7) $T'/T^* = g\ (u / x^*, v/x^*)$
(8) $A = h\ (g(u/x^*, v/x^*))$

The hypotheses of the model can be tested with a simple econometric specification, where TFP (A) is the dependent variable of the R&D activities of private firms and SOEs:

(9) $A = a + b\ R\&DP + c\ R\&DIRI + e$.

The assumption is that the parameter of the R&D expenditures of IRI (R&DIRI) is significantly larger than the parameter of R&D expenditures conducted by private firms (R&DP): thus the expectation is that: c>b.

5. THE DATA AND THE ECONOMETRIC STRATEGY

In order to measure the contribution of the R&D performed by the SOE and the private firms in Italy in the second half of the XX century we use the time-series of the R&D expenditures performed by IRI, the time-series of the R&D performed by private Italian companies and the levels of TFP for the whole Italian economy during the second half of the XX century. The data on R&D expenses funded by IRI have been reconstructed for this study using mainly archival IRI's sources of information for the period 1963-1994.[26] We deflated the expenditures in current prices, in order to obtain the real flows of investments, by the deflator of Italian GDP (in 2010 constant prices) recently elaborated by the Bank of Italy in a recent in-depth analysis on the overall growth of the Italian economy in the last century (Broadberry, Giordano, Zollino, 2013; Baffigi 2013).

The flows of R&D investments performed by the private business sector proceed from the expenditures in R&D activities classified by typology of economic actor provided by ISTAT. [27] Also in this case the data refer to the flows of in-house expenditures in R&D. Again the data in current prices have been deflated by the GDP deflator developed by Broadberry et al (2011). The data of Broadberry et al. (2011) were also used for the time series of TFP growth at the country level for our chosen period of observation (1963-1994).[28]

The simple OLS test of equation (9) to assess whether the impact of IRI's and private R&D on TFP differs, using the logs of each of the variables, raises several problems. First of all the variables under observation may contain a unit-root process, so as to affect our estimates. The plots of the time series of TFP and of the investments in R&D funded by respectively IRI and private firms (expressed in logs) in Figure 5, indeed, show a quite sustained rate of growth for all of the variables (with a considerable slow-down after 1990) which suggests that they are not stationary processes, and confirms on the unreliability of normal OLS estimators on the levels of the variables. In order to statistically confirm such evidence we compute an augmented Dickey-Fuller test on the three variables, allowing for the existence of a trend. The results shown in Table 2 confirm our concerns: the test cannot exclude the null hypothesis of the presence of a unit-root in each of the three variables in levels. The same test tells us instead that the first differences of the logged variables are stationary processes on which standard estimation would not suffer from spurious correlations.

INCLUDE FIGURE 5 AND TABLE 2 ABOUT HERE

[26] The archival IRI's sources of information used for the reconstruction of IRI's R&D expenses are: IRI, "Ricerca, sviluppo e innovazione nel gruppo Iri" (marzo 1992); IRI, "Ricerca e sviluppo Serie storica 1984-1991. Dati aziendali" (maggio 1992); IRI, "Ricerca e sviluppo Serie storica 1966-1990. Dati consolidati" (giugno 1992). In our elaborations we also used Antonelli and Barbiellini Amidei (2007, 2011), Istat. (1963–2010), and Istat (2011),

[27] Our elaborations on Istat (1963–2010) and Istat (2011); see Antonelli and Barbiellini Amidei (2007).

[28] Since in our model we will use the level (and not the growth rates) of TFP, following Solow (1957), we used the following formula in order to obtain an index number of TFP: $A_t=A_{t-1}(1+r_t)$ where r_t is the Broadberry et al. (2011) annual growth rate of TFP and A_{1963}, i.e. the first period of A, is arbitrarily set to 100. In the estimation of equation (9) we then took the natural logarithm of the newly created time-series of TFP.

We then transform equation (9) into an auto-regressive distributed lag model with all the variables expressed in first differences, including also lag values of the dependent variable in order to increase the reliability of the estimates:

$$\Delta_1 \ln(A_t) = a + \sum_i^p b_i \Delta_1 \ln(R\&DP_{t-i}) + \sum_i^p c_i \Delta_1 \ln(R\&DIRI_{t-i}) + \\ + \sum_i^p g_i \Delta_1 \ln(A_{t-i}) + u_t \qquad (10)$$

where Δ_1 is the difference operator, p is the number of lags, and u_t is the serially uncorrelated error term.

Even if the specification in equation (10) is more robust with respect to equation (9), it provides us only with the short-term dynamics of the two R&D variables on the growth of TFP. Furthermore, even if we included the lagged value of the growth rate of TFP as a further control, we suspect that in the short run many other unobserved variables could possibly influence the relationship between the two types of R&D and the growth of TFP and eventually affect the sign of our estimated coefficients. Furthermore given our historical perspective and the quite long period of observation, what we are mainly interested in is the long run relationships between the variables. As a matter of fact we want to see whether a stable long-run equilibrium between the variables of our model exists and then study the adjustment process that drives the levels of TFP and of the expenditures in R&D of private and IRI back towards the equilibrium. In particular this will allow us to identify the relations of long-run causality between the three variables (Engle and Granger, 1987). The econometric methodology that allows to checking for this type of relationships relies on error correction models. Given the fact that we are checking for the existence of a long-run equilibrium between three different variables we will introduce a vector error-correction model (VECM) and transform equation (10) into an unrestricted vector auto regressive (VAR) model of the following kind:

$$\Delta_1 \ln(A_t) = a_1 + \sum_i^p \left[b_{1i} \Delta_1 \ln(\mathrm{R\ \&\ DP}_{t-i}) + c_{1i} \Delta_1 \ln(\mathrm{R\ \&\ DIRI}_{t-i}) + g_{1i} \Delta_1 \ln(A_{t-i}) \right]$$
$$+ \lambda_1 ECT_{t-1} + u_{1t}$$
$$\Delta_1 \ln(R\&DP_t) = a_2 + \sum_i^p \left[b_{2i} \Delta_1 \ln(\mathrm{R\ \&\ DP}_{t-i}) + c_{2i} \Delta_1 \ln(\mathrm{R\ \&\ DIRI}_{t-i}) + g_{2i} \Delta_1 \ln(A_{t-i}) \right]$$
$$+ \lambda_2 ECT_{t-1} + u_{2t}$$
$$\Delta_1 \ln(R\&DIRI_t) = a_3 + \sum_i^p \left[b_{3i} \Delta_1 \ln(\mathrm{R\ \&\ DP}_{t-i}) + c_{3i} \Delta_1 \ln(\mathrm{R\ \&\ DIRI}_{t-i}) + g_{3i} \Delta_1 \ln(A_{t-i}) \right]$$
$$+ \lambda_3 ECT_{t-1} + u_{3t}$$
(11)

In equation (11) ECT_{t-1} represents the error correction term and it allows to identify the directions of causality in our model, i.e. it tells us whether a causal ordering exists between the flows of the two types of R&D expenditures and the levels of TFP in the economy, or if they are to be considered as simultaneously determined. Eventually this procedure will allow us to understand what are the variables that drive the adjustment process back towards the equilibrium, when the system deviates from its long-run equilibrium. Specifically the significance of the λ_1 coefficient in the first equation of the VECM will determine a long-run Granger causality stemming from the combination of *R&DP* and *R&DIRI* towards *A*. If the λ_2 coefficient of the second equation is significant as well, this will mean the existence of a bi-directional long-run Granger causality between A and *R&DP*. If on the contrary the λ_2 coefficient of the second equation will not be significant, the causal relationship will be uni-directional from *R&DP* towards *A*. The same reasoning applies for the other possible combinations of dependent variables: for instance, a bi-directional causality will be found between *R&DP* and *R&DIRI* if both λ_2 and λ_3 are significant, while a uni-directional causality from *R&DP* to *R&DIRI* will result if only λ_3 is significant; a bi-directional causality will be found between *A* and *R&DIRI* if both λ_1 and λ_3 are significant, while a uni-directional causality from *R&DIRI* to *A* will result if only λ_1 is significant.

6. RESULTS

Column (1) of Table 3 presents the results of the simple OLS estimation of equation (9) i.e. of the levels of TFP on the contemporaneous real flows of expenditures in R&D by private firms and by IRI. The results show high R-squared and positive and significant coefficients for both the regressors: furthermore, as expected, the coefficient of R&DIRI is higher than that of R&DP. However, given the results of the augmented Dickey-Fuller test (Dickey, Fuller, 1981), these results might be affected by spurious relations due to the presence of unit-roots in each of the three variables involved.[29] We then check whether different specifications of this model change these initial results, giving more robustness to our analysis. Table 3 presents the results of the first-differences transformation of equation (9), i.e. the estimation of the autoregressive distributed lag model of equation (10).[30] As in the previous specification the results show positive and significant coefficients for the R&DIRI, while now R&DP displays negative but not significant coefficients. The results hold also when we include the lagged growth rate of TFP. Summing up both specifications, in levels and in differences, confirm our original hypothesis on the different size of the coefficients of IRI and private firms R&D expenditures: moreover the estimations confirm that the coefficient of the R&D expenditures performed by IRI is always positive and significant.

INCLUDE TABLE 3 AND FIGURE 5 ABOUT HERE

We then come back to the problem of cointegration and long-run causality. The plots displayed in Figure 5 suggest that the variables show a very similar positive growth-trend: we then want to test whether any long-run Granger causality exists between them (Engle and Granger, 1987). When we check for the existence of such a relationship for the period 1963-1994 we do not find evidence of long run equilibrium.[31] However by observing in Figure 6 the plot of the residuals of the OLS estimation of equation (9) and the fitted and real values of the time series of the log of TFP we find

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[29] A related problem arising in such estimation consists also in the high level of correlation between R&DIRI and R&DP, which is likely to cause serious problems of multicollinearity.

[30] Given the relatively small number of observation (30 when using first differences), we chose to include only two lags of the explanatory variables and of the dependent variable.

[31] The methodology used to check for a long run relationship consists in testing whether the following linear combination: $res_t = \ln(A_t) - b\ln(R\&DP_t) - c\ln(R\&DIRI_t)$ is stationary. If this is the case we could include the lagged residuals of the estimation of equation (9) (see Column (1) of Table 3) in equation (10) and check for their significance. The significance of the residuals would imply a long-run Granger-causality stemming from the investments in R&D by private and IRI-owned firms towards the growth of TFP. However the results of a Dickey-Fuller test on the residuals of the estimation of equation (9), (see the last column of Table 2), cannot reject the null hypothesis of the presence of a unit root. Furthermore the inclusion of the lagged residuals of equation (9) in equation (10), in Column (4) of Table 3, does not lead to any significant coefficient, and hence cannot confirm the existence of a long-run Granger causality between the expenses in R&D and the growth of TFP for the whole period considered (1963-1994).

evidence of a structural break after 1990, that is likely to affect the long-run relationship between our variables.[32]

We have hence decided to implement a more complete approach to identify lung run causality by limiting our sample to the period 1963-1990 (in order to exclude observations occurring after the structural break) and implementing the Johansen (1995) procedure for multivariate cointegration. The first step consists in checking whether one or more cointegrating relationships exist among the variables of interest. In order to do so we compute the trace statistic, which allows us to know the rank of our cointegration. Table 4 exhibits the results of the Johansen cointegration rank test for TFP, R&DP and R&DIRI (Johansen, 1988; Johansen and Juselius, 1990). The numbers in the last column are the corresponding critical values at 5% significance level. The trace statistics indicate that there is one (1) cointegration vector for the time series of the (logs of) TFP, R&DP and R&DIRI. This result means that in the long run there exists a unique equilibrium that involves the three variables of our model.

INCLUDE TABLE 4, 5 AND 6 ABOUT HERE

Table 6 displays the estimated coefficients of the cointegrated equation, with the normalization restriction imposed by the Johansen procedure: these results will provide us with an estimation of the coefficients of the long-run equilibrium relationship between the three variables. The results confirm substantial difference between the estimated coefficients of R&DIRI and R&DP: while remembering that the imposed Johansen's normalization restriction presents the coefficients of the cointegrating variables with the opposite signs, we notice that R&DIRI has a positive and significant coefficient, while R&DP's coefficient is positive but not significantly different from zero. Table 6 also reports the result of a further test on the long run exclusion of the parameter of R&DP in equation (11): a likelihood ratio test distributed as χ^2 on the hypothesis that the long-run coefficient of R&DP is equal to zero indeed fails to reject the null. The results on the long run equilibrium relationship between the three variables tell us that such an equilibrium crucially depends on the level of expenditures in R&D performed by firms belonging to IRI.

Table 5 instead presents the results of the estimation of the trivariate VECM, implemented through the Johansen procedure. Finally Table 7 synthesizes the results of the previous two tables (without reporting the size of the coefficients) by testing, through the usual χ^2 tests, the short and long-run Granger causality in equation (11) (Granger, 1986), that is checking whether the estimated coefficients of the variables and of the error correction components are significantly different from zero. Both tables show that, among the three equations of the VECM, only the error correction term in the equation of TFP turns out to be significant, while in the equation in which respectively R&DP and R&DIRI are the dependent variables the coefficient of the error correction term appears to be not significantly different from zero. According to these results we infer that in the period up to 1990 the growth in R&DIRI, combined with R&DP, did long-run Granger cause the growth in TFP. Conversely there is no evidence of long-run Granger causality from the growth of TFP (combined with one of the two types of R&D expenditures) towards R&DP or R&DIRI. These results confirm the existence of a long-run equilibrium between the variables, and tell us that as expected the direction of causality goes from the expenditures in R&D towards the increase of TFP: however, as shown in Table 6, these results are mainly driven by the IRI's R&D expenditures.

[32] As the graphs clearly show the goodness of fit of the estimated coefficients of R&D is high for the period 1963-1990, while at the beginning of the 90's the two paths, that of real TFP and that of the predicted values, start to diverge (and consequently also the residuals increase), This is probably due to the steep decline of expenditures in R&D both by the private and public sector.

When looking at the short-run Granger causality, Tables 5 and 7 show us that including the long run dynamics into the picture lowers the significance of the coefficients that were significant in the estimation of equation (10). In the equation in which TFP growth is the dependent variable none of the coefficient is significantly different from zero. The same is valid for the equation with R&DIRI as a dependent variable, in which none of the coefficients turns out to be significant. The only short-run Granger causality is found from R&DIRI (twice lagged) to R&DP, in the equation in which R&DP is the dependent variable.

INCLUDE TABLE 7 ABOUT HERE

Summing up, when we analyze the overall period of observation, going from 1963 until 1994 we find strong evidence of a positive relationship between the lagged increase of R&DIRI on the growth of TFP, while the coefficient of R&DP is not significantly different from zero. We don't find instead evidence of a stable cointegrating relation between the three variables in this same time-span. The analysis of the residuals of equation (9) suggests the existence of a significant change in the relationship among the variables after 1990. Consequently when we restrict our sample to the years up to 1990 we find evidence of a cointegrating relationship among the three variables: specifically we find evidence of a long-run Granger causality proceeding from R&DIRI and R&DP towards TFP. Furthermore the results of a multivariate cointegration analysis show that the coefficient of R&DIRI in the long-run equilibrium equation is larger than that of R&DP (which is not significantly different from zero), suggesting that the long run causality proceeds mainly from the R&DIRI. We also find evidence of a short-run Granger causality from R&DIRI towards R&DP. Through all the specifications implemented we find a satisfactory robust evidence of the important role of R&DIRI in the development of Italian aggregate TFP, which basically confirms the initial results displayed with the OLS estimation of equation (9).

7. CONCLUSIONS

This paper contributes the literature on innovation as an emergent system property that is possible only when effective knowledge governance mechanisms are in place at the system level. Knowledge externalities are not available at all times and in all places with any kind of institutional set-up. Quite on the opposite: specific institutions and contexts are more effective than others in the provision of effective pecuniary knowledge externalities. In turn, knowledge externalities play a key role to explain the increase of TFP (Antonelli, 2011 and 2013).

This approach provided important clues to elaborate a comprehensive assessment of the role of IRI to the Italian economic growth in the second part of the XX century as a key supporting factor of the continuuous introduction of productivity-increasing innovations at the system level. Because of its centrality in the user-producer relations and its active role of interface with the advances of the scientific and technological frontiers abroad, IRI played a key role not only in the generation of technological knowledge but also in its dissemination and further use as an input into the generation of new technological knowledge and introduction of technological innovations by the rest of the system. Knowledge externalities stemming from research activities performed by the IRI were very effective, more than research activities performed by private firms, in terms of their contribution to the third parties' generation of additional technological knowledge and hence introduction of technological innovations with the ultimate effect of providing a strong(er) support to the increase of TFP at the system level.

The strong role of IRI in providing effective pecuniary knowledge externalities to the rest of the system depends on many factors. First IRI was active in upstream sectors providing the rest of the economy with advanced intermediary inputs and capital goods. Its management style was based upon intense user-producer interactions with downstream users acting as the hubs of different industrial platforms where small and medium sized companies were participating in subcontracting activities and specialized tasks. R&D activity schemes typically imitated from US corporations were characterized by high intensity of (pure) research with a broad spectrum of applications and possible implementations in terms of incremental innovations and creative adoption by the members of the platform. The large corporate R&D laboratories performed an active role of interface between the academic pursuit of scientific knowledge and their possible technological and industrial applications with intense relations between academic and IRI researchers. The quality of the IRI's emission of spillovers was much stronger than the quality of the emission of the private firms, mainly small and medium sized companies, often directly owned by the families of the founders, that were more inclined to focus their research in the development of new prototypes and in the development of new applications and incremental innovations of new technologies originated and disseminated by the IRI corporations.

This evidence and the analytical framework that has enabled to identify and highlight this peculiar aspect of the Italian economic growth in the second part of the XX century warrant a generalization. As a matter of fact, possibly beyond the intentionality of the decision makers, the research system of IRI acted as a competent interface between the generation of scientific knowledge and its transformation in technological knowledge with great benefit for the Italian economy.

Its intentional and dedicated implementation may become an effective tool of an active economic policy to foster the rate of technological change and of increase of TFP especially when the characteristics of the context and of the recipients, in terms of size of the firms, industrial specialization, lack of interaction between the academic system and the business community may slow the pace of technological change. SOE played an effective role as central components of the knowledge governance mechanism that has been at the heart of a period of radical transformation of the Italian economy, favouring and complementing the interactions between the generation of scientific and technological knowledge and contributing to its distributed exploitation at the system level.

After their privatization the Italian innovation system moved from a combination of a distributed model based upon small firms clustering in industrial districts, supported by a strong corporate component based upon the IRI's model, to a standing alone private distributed model. While the former was rich in terms of knowledge externalities the latter was much weaker. This process has not been compensated by the active provision of knowledge externalities to the business sector by the public scientific system based upon universities and public research centres, as it happened in other advanced countries where the public scientific system became more and more involved in knowledge outsourcing in the knowledge intensive business service markets. Our hypothesis has the important implication that the privatization of Italian SOEs at the beginning of the 1990s had strong negative consequences on the viability of the Italian innovation system not only because it weakened the main performers of R&D activities but because it deprived the rest of the system of the provision of high quality knowledge externalities (Munari, Roberts, Sobrero, 2002; Mariotti, 2014).

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Figure 1. R&D expenditures of IRI firms, SOEs and other institutional sectors on GDP (%) – Italy

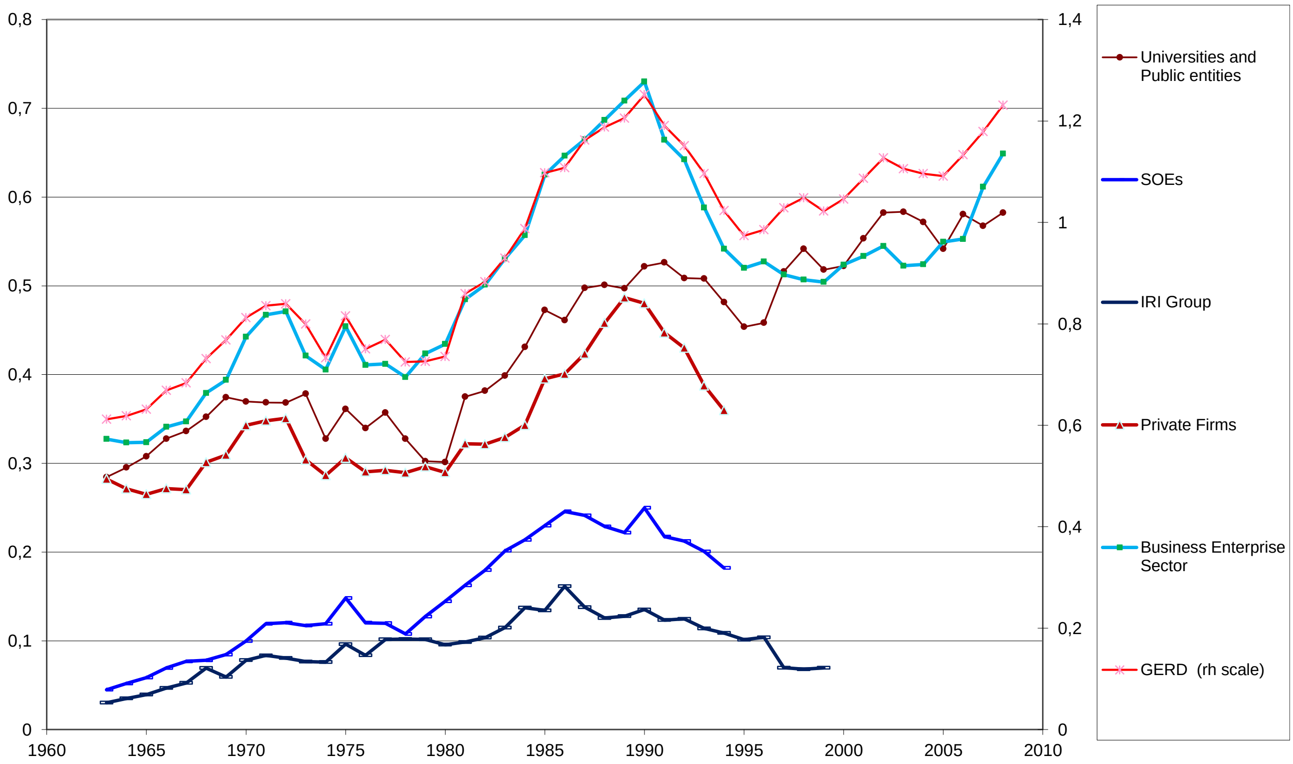


Figure 2. R&D expenditures – IRI Group

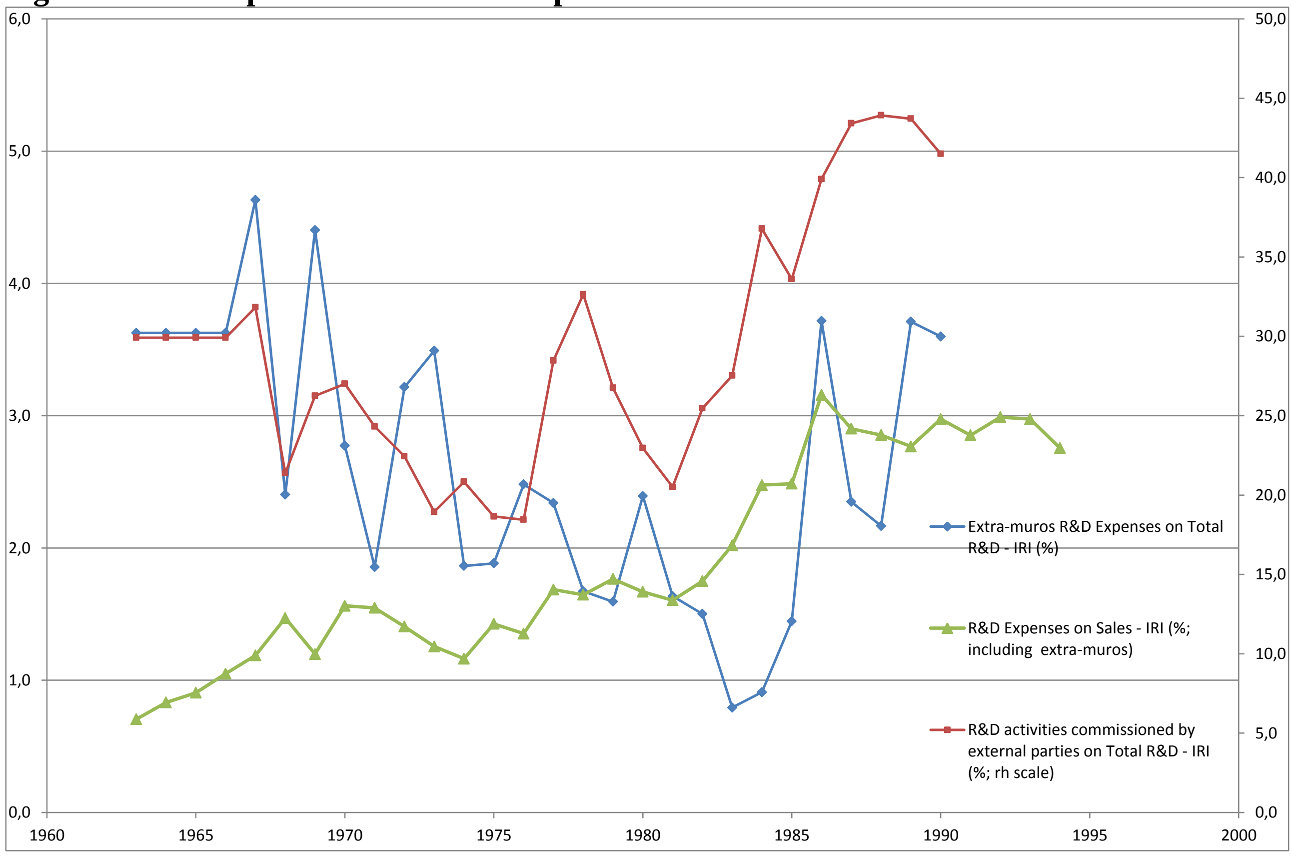


Figure 3. Technological Balance of Payments (%) – IRI Group

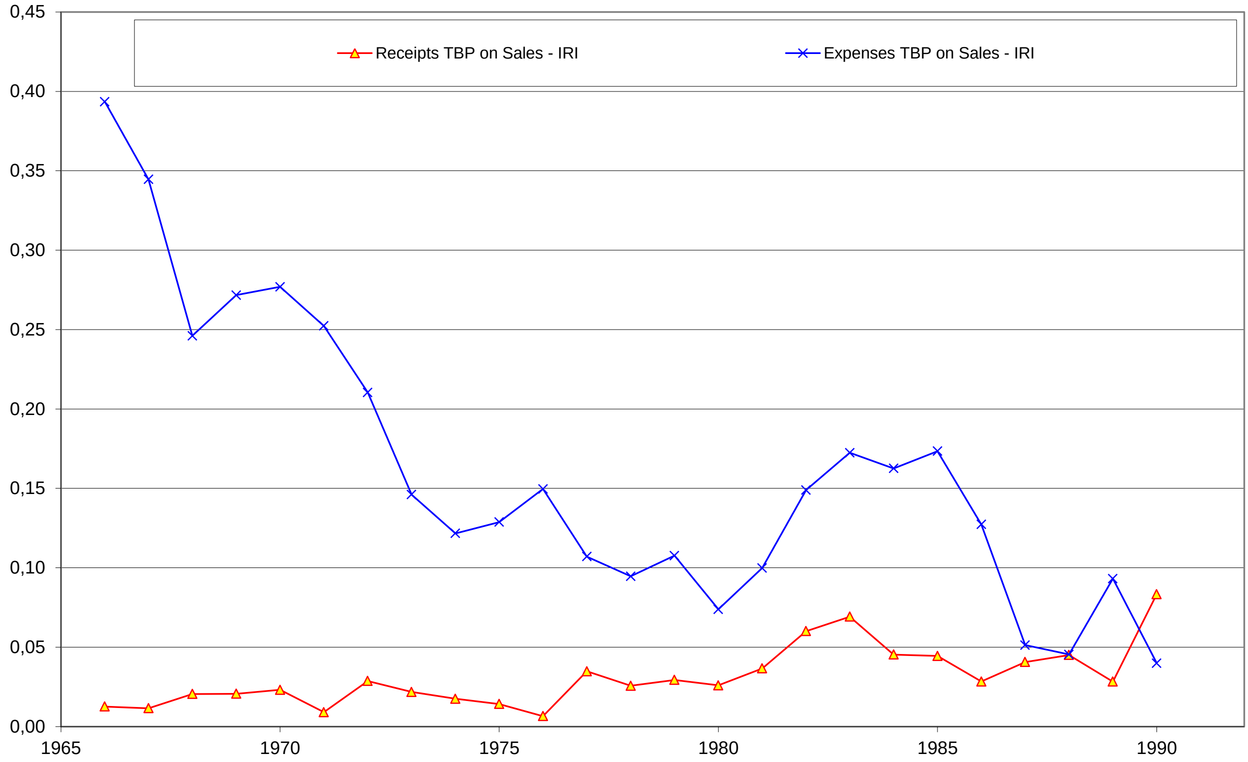


Figure 4. TBP Expenses on R&D expenditures (%)

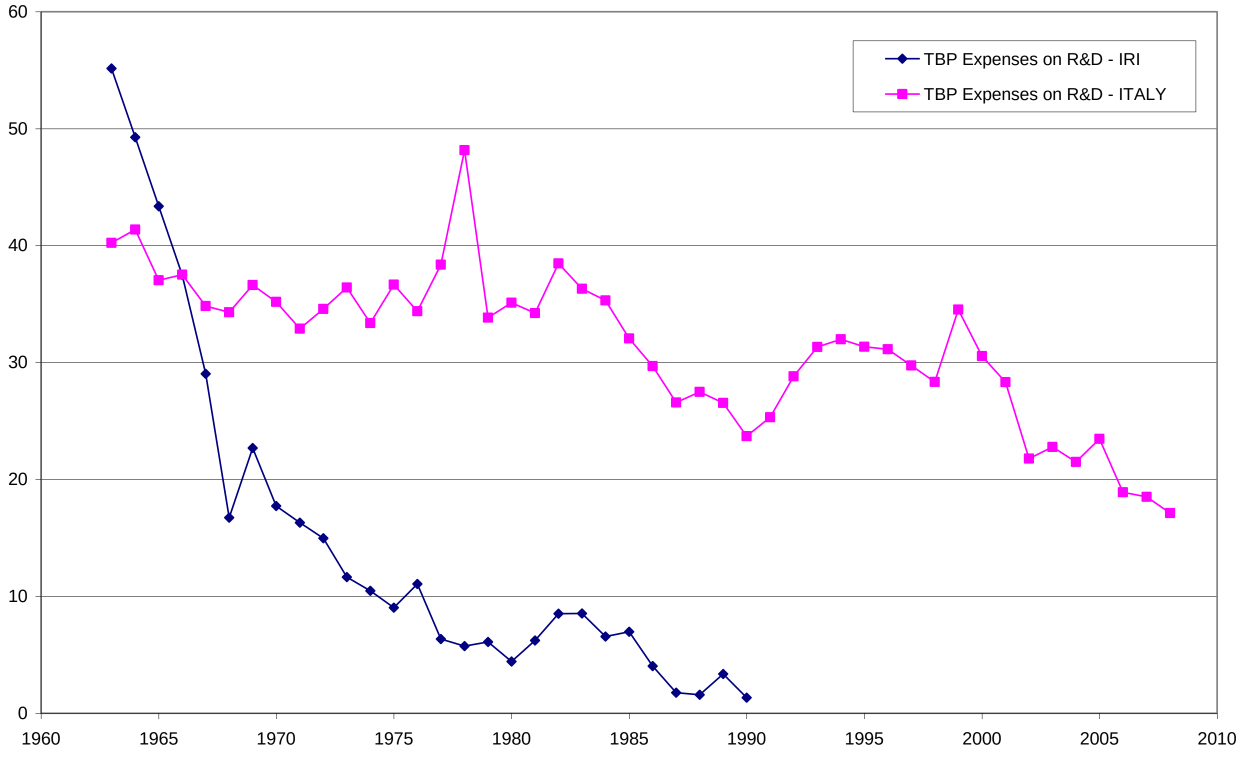
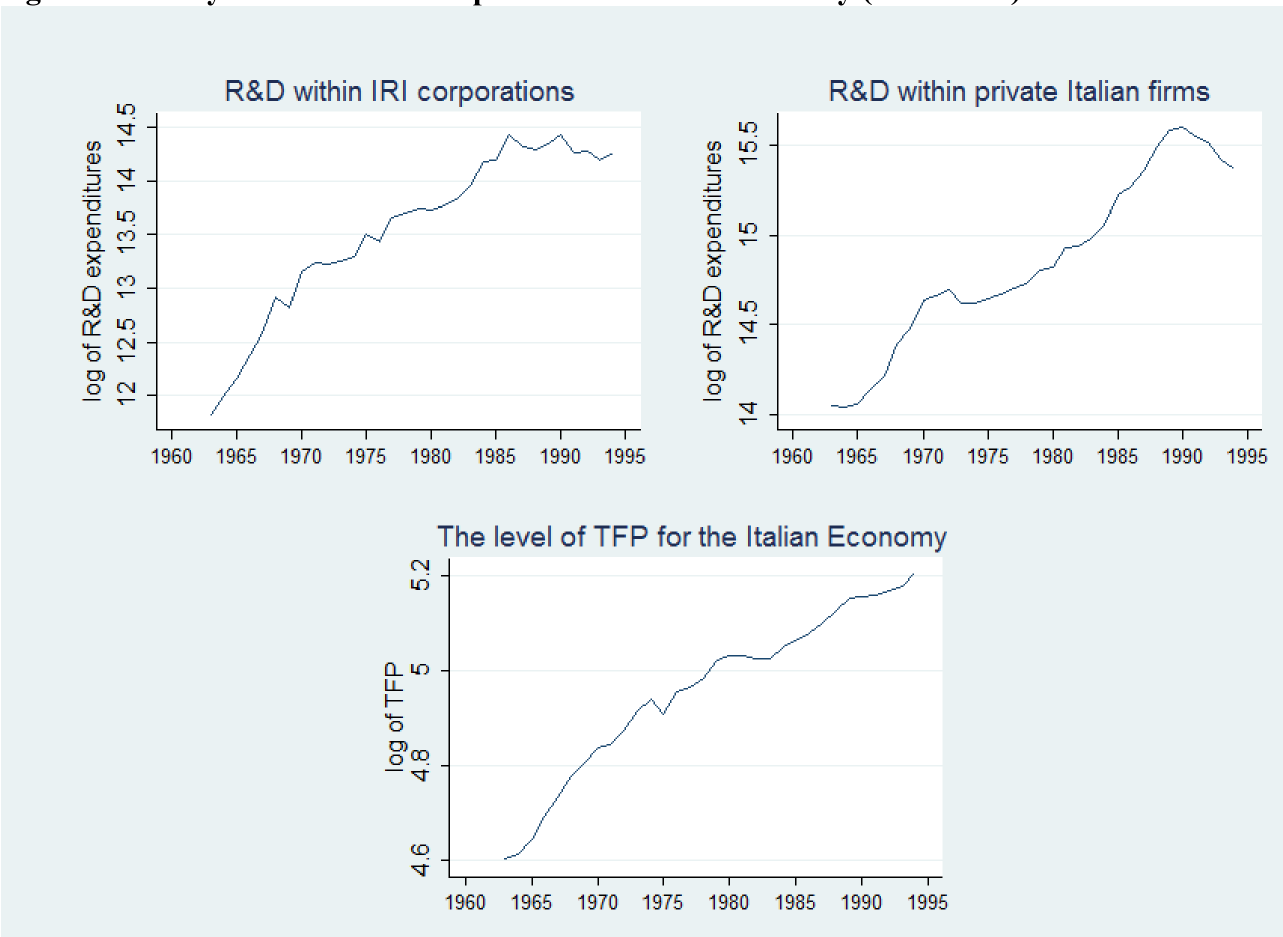


Figure 5. The dynamics of R&D expenditures and TFP in Italy (1963-1994)



Source: Istat (2011) and Broadberry et al. (2011). All variables are in logs. The level of TFP is arbitrarily set to 100 in 1963 and then the logarithm of the TFP time-series is plotted in the lower panel of Figure (6).

Table 2. Results of the Augmented Dickey Fuller unit-root tests

Variables	ln (A)	ln (R&DP)	ln (R&DIRI)	ECT
Z(t)	-1.045	-0.693	-1.236	-2.051
p.	0.9378	0.9736	0.9030	0.5737
Variables	Δ ln (A)	Δln (R&DP)	Δln (R&DIRI)	
Z(t)	-6.776***	-3.322*	-7.609***	
p.	0.0000	0.0627	0.0000	

Note: The null hypothesis being tested is that the variable contains a unit root. *** p<0.01, ** p<0.05, * p<0.1

Table 3. OLS estimates of equation (9) and (10)

Variables	(1) $\ln(A_t)$	(2) $\Delta_1 \ln(A_t)$	(3) $\Delta_1 \ln(A_t)$	(4) $\Delta_1 \ln(A_t)$
$\ln(R\&DIRI_t)$	0.164***			
	(0.026)			
$\ln(R\&DP_t)$	0.107**			
	(0.042)			
$\Delta_1 \ln(R\&DIRI_{t-1})$		0.049*	0.049*	0.026
		(0.026)	(0.029)	(0.031)
$\Delta_1 \ln(R\&DIRI_{t-2})$		0.069**	0.068**	0.058**
		(0.026)	(0.028)	(0.027)
$\Delta_1 \ln(R\&DP_{t-1})$		-0.056	-0.059	-0.095
		(0.055)	(0.059)	(0.062)
$\Delta_1 \ln(R\&DP_{t-2})$		-0.013	-0.0099	-0.067
		(0.054)	(0.059)	(0.067)
$\Delta_1 \ln(A_{t-1})$			0.040	0.141
			(0.190)	(0.193)
$\Delta_1 \ln(A_{t-2})$			-0.019	0.065
			(0.194)	(0.194)
ECT_{t-1}				-0.248
				(0.151)
Constant	-2.457***	0.013***	0.013**	0.016**
	(0.300)	(0.004)	(0.006)	(0.006)
Observations	32	30	30	30
R-squared	0.965	0.266	0.268	0.348
F	396.7	2.269	1.403	1.677

All models are estimated through OLS. Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Figure 6. Residuals and fitted values: OLS estimates of equation (9)

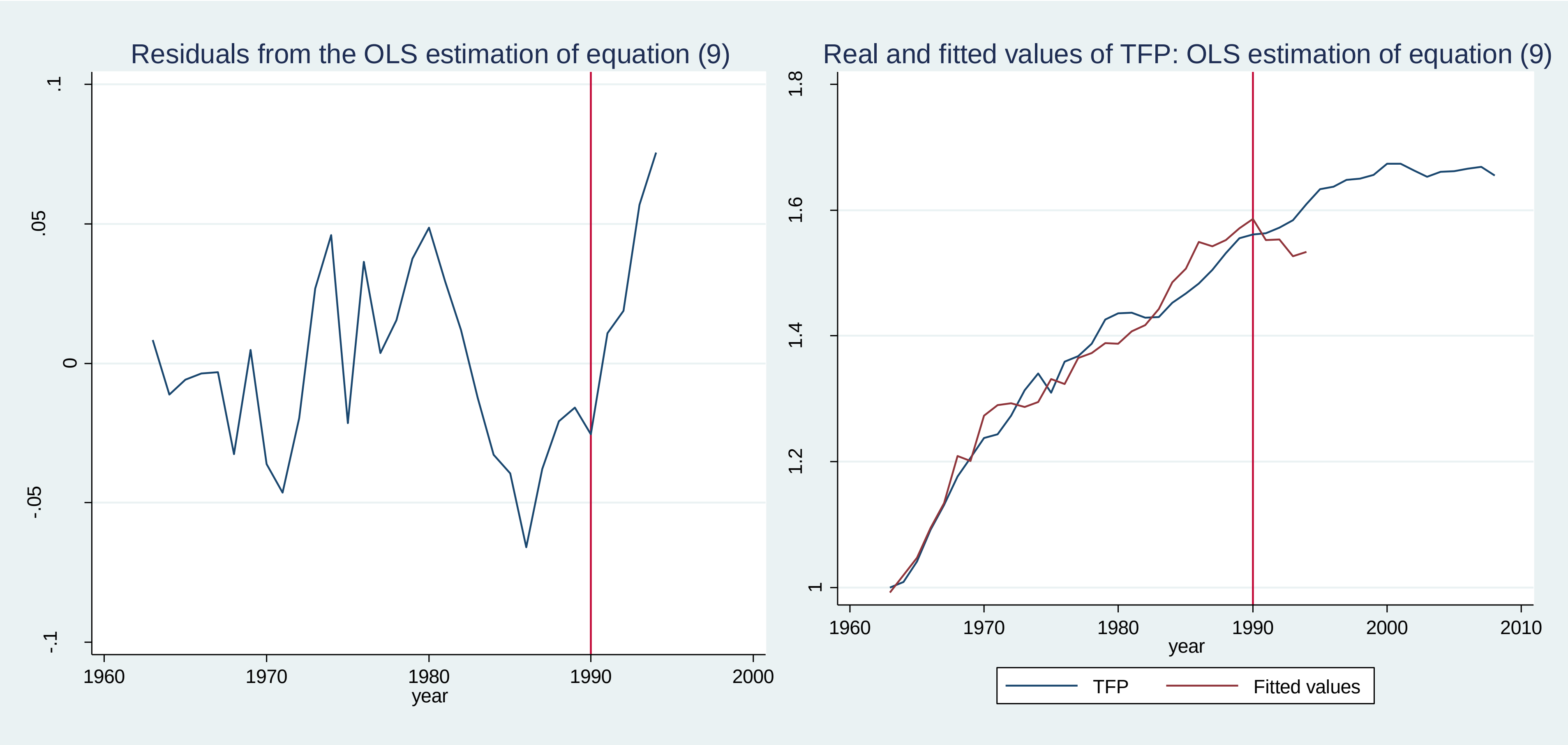


Table 4. Johansen tests for cointegration

Sample: 1963 - 1990 Number of obs. = 26 Lags = 2

maximum rank	parameters	trace statistic	5% critical value
0	12	33.2365	29.68
1	17	12.3300*	15.41
2	20	0.8473	3.76

Table 5. VECM estimates of equation (11) – Johansen procedure

	(1)	(2)	(3)
Variables	Δ_1 ln(A_t)	Δ_1 ln(R&DIRI$_t$)	Δ_1 ln(R&DP$_t$)
ECT$_{t-1}$	-0.297***	-0.826	0.540
	(0.115)	(0.922)	(0.399)
Δ_1 ln(A_{t-1})	-0.144	0.935	0.376
	(0.191)	(1.524)	(0.659)
Δ_1 ln(A_{t-2})	-0.125	0.277	0.447
	(0.188)	(1.501)	(0.649)
Δ_1 ln(R&DIRI$_{t-1}$)	-0.025	-0.423	0.194
	(0.041)	(0.331)	(0.143)
Δ_1 ln(R&DIRI$_{t-2}$)	0.0097	0.0897	0.310**
	(0.037)	(0.302)	(0.130)
Δ_1 ln(R&DP$_{t-1}$)	-0.020	0.117	0.057
	(0.063)	(0.502)	(0.217)
Δ_1 ln(R&DP$_{t-2}$)	0.025	-0.350	0.166
	(0.061)	(0.484)	(0.209)
Constant	-0.002	0.025	0.036
	(0.008)	(0.070)	(0.030)
Observations	25	25	25

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 6. Normalized cointegrating coefficients

1 Cointegrating equation

(Johansen normalization restriction imposed)

	ln (A)	ln (R&DIRI)	ln (R&DP)	constant
	1.000	-0.115**	-0.064	1.056
st. err.		(0.048)	(0.087)	
z		-2.39	-0.74	

Test that ln (R&DP) = 0

LR test of identifying restrictions: $\chi^2(1) = 0.656$ Prob > $\chi^2 = 0.418$

Table 7. Granger causality tests

	R&DP	R&DIRI	A	ECT
A	$b_{1i} = 0$ for each i	$c_{1i} = 0$ for each i	-	$\lambda_1 = 0$
	0.22	0.91	-	**6.65**
	0.894	0.633	-	**0.009**
R&DP	-	$c_{2i} = 0$ for each i	$g_{2i} = 0$ for each i	$\lambda_2 = 0$
	-	**5.64**	0.79	1.83
	-	**0.059**	0.672	0.1759
R&DIRI	$b_{3i} = 0$ for each i	-	$g_{3i} = 0$ for each i	$\lambda_3 = 0$
	0.52	-	0.41	0.80
	0.769	-	0.815	0.3700

The coefficients refer to equation (11).