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

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ABSTRACT. The grafting of the tools of communication studies on the economics of knowledge helps to investigate the mechanisms of knowledge governance. The actual economic benefits stemming from knowledge externalities depend on the characteristics of a) their sources, b) the context in which spillovers take place, c) the possible recipients. In the Italian experience between 1950-1992, state owned enterprises (SOE) have been one of the most effective mechanisms of knowledge governance. Italian SOE were very effective emissaries of knowledge externalities as they imitated the US corporate model of intramuros R&D laboratories and yet were characterized by an objective function based upon output maximization under the constraint of average profitability. Their support to the growth of the system was crucial not only with respect to the creation of basic infrastructure but also as active players in implementing effective mechanisms of knowledge governance. 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. Moreover the specific objective function of SOE favoured higher levels of knowledge generation than exploitation. These characteristics helped disseminate relevant knowledge externalities that played a strong and positive role on total factor productivity in the second part of the XX century in Italy. Their role was stronger than the knowledge externalities stemming from research activities carried out by private firms.

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KEY-WORDS: KNOWLEDGE EXTERNALITIES; TECHNOLOGICAL COMMUNICATION; INNOVATION; TFP; SOE.

1.INTRODUCTION

The peculiar characteristics of knowledge as an economic good, and specifically its limited appropriability, non-exhaustibility, limited excludability, indivisibility and hence cumulability and complementarity account for a significant and increasing part of total factor productivity growth. Technological knowledge is not only the output of a dedicated activity but also and mainly an input that can and must be repeatedly 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 can be accessed at costs that are below those of its intra-muros reproduction (Arrow, 1962 and 1969). The tacit component of knowkledge has a crucial role in the selection 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 total factor productivity growth is well known (Griliches, 1979 and 1992; Romer, 1986, 1990 and 1994). Knowledge externalities are a cornerstone of the new growth theory (Aghion and Howitt, 1998). The grafting of the tools of communication studies on the economics of knowledge suggests that knowledge spillovers are not all alike: a large number of complementary conditions are necessary for signals to actually perform communication. The actual economic benefits stemming from knowledge externalities depend on the complex web of institutional characteristics that qualify the mechanisms by means of which knowledge generated by an agent can affect the amount and quality of knowledge generated by another agent (Antonelli, 2008).

Specifically the grafting of recent advances of communication studies onto the new economics of knowledge makes it possible to analyze how knowledge governance works and assess how knowledge externalities work with the tools of communication processes and hence to identify three distinct factors, i.e. the characteristics of a) emissaries, b) the recipients and c) the context in their successful use. Within this framework, the spillovers, that carry knowledge externalities, can be thought of as signals that reach their destination according to the characteristics of their sources, the context in which they take place, and the features of the possible recipients.

This framework makes it possible to articulate the view that the actual levels of effective knowledge externalities and their actual effects on the generation of new technological knowledge and the eventual introduction of technological innovations with its positive effects in terms of the increase of total factor productivity depend on the characteristics of a) the emissaries of knowledge spillovers, b) the recipients and perspective users and c) the context in which the use of external knowledge carried by spillovers takes place.

The analysis of the characteristics of the emissaries of knowledge externalities seems a promising avenue of research. Knowledge externalities are likely to be stronger when the characteristics of the emissaries favour not only the emission of knowledge signals, but also their actual reception by perspective users. State owned corporations 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 may have qualified them as 'excellent emissaries'. State owned corporations were able to feed the fast rates of total factor productivity growth of the system with the provision of strong and far-reaching spillovers carrying high quality knowledge externalities.

This paper contributes to the knowledge externalities enquiry in two ways. First, in section 2, it elaborates an analytical framework to investigate the mechanisms of knowledge governance, assess the differences among knowledge externalities in terms of the characteristics of the emissaries and identifies the types of knowledge externalities. Second, it explores the characteristics of state-owned corporations 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 emissaries of knowledge externalities to private firms. Section 3 implements a simple model that frames the distinctive role of knowledge externalities according to their emissaries. In section 4 the paper presents the empirical evidence testing the hypothesis that because of their characteristics as knowledge emissaries, knowledge externalities spilling from the research and development activities carried out by state owned corporations played a much stronger role than the knowledge externalities spilling from the research and development activities carried out by private firms. The conclusions stress the advances made possible by the application of the tools of communication studies to the economics of knowledge, summarize the results of the empirical analysis and try to generalize the economic policy implications of the positive role of state owned corporations as effective emissaries of knowledge externalities.

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

2.1. THE ANALYTICAL FRAME

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 processes of research and development, and external knowledge, that is the access to the stock and flows of technological knowledge generated by third parties (David, 1993).

The generation of technological knowledge is a specific activity that is based on recombination processes that identify the elements of the existing knowledge and reorganize it. Existing knowledge both internal and external to each firm is an essential component of the recombinatory process together with the tacit knowledge acquired by means of learning processes and formal research and development activities. Much attention has been paid to the latter two and much less attention has been paid to the role of external knowledge in the generation of new knowledge (Nelson, 1982; Cassiman and Veugelers, 2006; Arthur, 2009).

External knowledge can be acquired by third parties with formal transactions and interactions. Interactions between knowledge possessors and knowledge users play a central role in the actual transmission of knowledge. 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 (Marshall, 1920; Metcalfe, 2007).

Knowledge externalities are not all alike. Their actual effects on economic growth and total factor productivity depend on a variety of factors. Knowledge externalities are mostly pecuniary externalities rather than pure ones. The difference is crucial. Pure externalities apply when no interactions and transactions among producers and recipients 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 has 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 screening, search, assessment, decodification of the multiple sources of knowledge externalities and the wide variety of possible forms of interaction and transactions that make the acquisition and use of knowledge as an input into the generation of new knowledge possible. The appreciation of the amount of dedicated activities and costs that make the absorption of external knowledge possible has led to substitute the notion of pecuniary knowledge externalities to the notion of pure knowledge externalities (Cohen and Levinthal, 1989 and 1990).

At each point in time, for given characteristics of the structure of the knowledge embedded within a system – in terms of knowledge coherence, complementarity and cumulability – the actual levels of access to external knowledge depend upon the knowledge connectivity and ultimately the knowledge governance mechanisms that are at work among firms, households and institutions, within industries, regions and countries. A variety of institutional and economic factors shape the levels of knowledge connectivity: secrets and intellectual property right regimes limit the dissipation of new and old technological knowledge. Dispersion and fragmentation limit the access to used knowledge. Additionally, also institutional mechanisms may be inadequate in offering an efficiently working system of knowledge transmission. Knowledge governance plays a key role in the organization of the systemic interactions that make the access and use of existing knowledge within an economic system possible.

Knowledge governance consists in the set of rules, procedures, modes and protocols that organize the use of knowledge in an economic system. It includes a variety of institutional factors that qualify the architecture of relations, ranging from the extremes of pure transactions to pure interactions, including hierarchical coordination within firms, and, most importantly transactions-cum-interactions. In the field of knowledge, transactions-cum-interactions play a crucial role because of the strong tacit component of knowledge. The tacit attribute in fact makes impossible to transfer knowledge through impersonal transactions. The tacit component calls for true interactions between parties so as to complete transactions and to integrate external into internal knowledge. The quality of knowledge governance mechanisms at work, at each point in time, within each economic system, can be seen as the endogeneous result of a systemic process of polycentric governance. A variety of localized paths to organizing and managing at the system level the use of the existing technological knowledge as an input into the recombinant generation of new technological knowledge and the consequent introduction of total factor productivity enhancing technological change can emerge and consolidate, according to the institutional setting of each system and its path dependent characteristics (Ostrom, 2010).

The grafting of the tools of communication studies helps to investigate the mechanisms of knowledge governance. Four basic issues can be identified. First, it is clear that the quality of communication channels and the context in which user-producer interactions take place exert a key role. The institutional context in which knowledge interactions take place can be characterized by high levels of transaction and communication costs that add on to knowledge absorption costs and reduce the levels of pecuniary knowledge externalities. Other contexts may ease the access to external knowledge for the high quality/low cost of knowledge interactions and transactions, perhaps thank to high levels of trust and low levels of information asymmetries (Arrow, 1969).

Second, the characteristics of the users of external knowledge spilling in the context play a key role. Some recipients are more apt than others to take advantage of some types of technological knowledge. Some recipients may be more able than others to interact with the emissaries of knowledge spillovers and/or to take advantage of the characteristics of the institutional context in which the emission and eventual absorption of knowledge take place (Graf, 2011).

Thirdly the characteristics of knowledge need to be taken into account. Knowledge is not all alike. Knowledge items differ in terms of appropriability, excludability, cumulability and fungibility. Knowledge items also differ in terms of the content of tacitness. Some knowledge items are more codified than others and as such increase the viability of the actual transmission and secondary use by new recipients for the generation of new technological knowledge. The characteristics of the knowledge generation process matter. Some kinds of technological knowledge have a strong content of generic knowledge acquired through pure research and are based upon deductive processes of generalization. The variety of knowledge items that contributes to the generation of new knowledge also differs: in some cases new knowledge uses a limited knowledge base, in others recombination includes a wide variety of knowledge items. The larger the variety is and the more relevant the quality of the context and the heterogeneity of actors participating into the process are (Saviotti, 2007).

Finally, the characteristics of emissaries are crucial. 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 of the firms in terms of intellectual property right regimes. The industrial sector of activity of the emissaries has important implications whether it is upstream or downstream. In the former case technological knowledge has a wider scope of possible application.

The organization of the production process of the emissaries plays a central role. Firms characterized by tight vertical integration are less likely to favour the emission of spillovers ready to use by new recipients. 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 as such their research projects are characterized by higher shares of pure research. For this reason, large firms are more likely to be the emissaries of technological knowledge with high levels of fungibility and hence to affect the generation of new technological knowledge by third parties more directly also because of the high levels of diversification. The intrinsic serendipity of the knowledge generation process of large corporations leads to niche innovations that are less likely to be directly developed and may instead actually be introduced by smaller firms that are part of the platform.

Finally and most important, emissaries differ substantially in terms of sheer fungibility of the knowledge generated. Large firms fund and perform large research projects that rely on systematic interactions with the academic system and the large public research centers (Howells, Ramlogan and Cheng, 2012). Large 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.

As much as communication takes place when the emission of signals is strong and clear, the context through which it is disseminated does not obstacle it and the recipients are equipped to actually receive it, knowledge spillovers do take place and benefit the generation of new technological knowledge and hence pecuniary knowledge externalities are found and make total factor productivity growth stronger, when the combination of characteristics of technological knowledge spilling and the features of emissaries of technological spillovers are favourable.

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

The financial crisis of the Thirties had brought to the collapse of the Italian banking system and the prospective failure of the largest Italian corporations that had emerged through the first wave of industrialization. The State nationalized the failing banks and became the owner of a large block of corporations active in a variety of upstream industries ranging from the production of steel, ships, machinery and capital goods, motorcars, trains and airplanes, electricity and telecommunications. [1] The Istituto per la ricostruzione industriale (IRI), with its “perennization” in 1937, became a holding to manage a large group of State Owned Enterprises (SOEs) in a closed autarkic economy.[2] After WWII and the Fascism defeat, the Italian government, instead of

[1] On 23 January 1933, Law No 5 created IRI to provide an effective institutional setting for the restructuring of the Italian banking system. IRI took over the industrial participations held by the big commercial banks and cleaned the banking sector’s balance sheet of non-performing loans. IRI worked to reorganise technically and financially these enterprises, initially offloading the shares whenever feasible. 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; 90 per cent of the naval industry; 80 per cent of naval companies and of the locomotive industry; 40 per cent of the iron and steel industry; 30 per cent of the electricity industry; 20 per cent of the rayon industry; 13 per cent of the cotton industry (Toniolo 1980: 250). It also controlled the mechanical and armaments’ industries, telephone services, as well as the three ex-mixed banks. In all, IRI owned over 40 per cent of Italian shareholders’ capital, hence resulting the greatest holding company in Italy. 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.

[2] With IRI’s “perennization” in 1937, the weight of the government sector in the Italian economy was reinforced. IRI grouped similar concerns under the control of sub-holding companies: STET (1933) in telephony, Finmare (1936) in shipping companies, Finsider (1937) in steel, Finmeccanica (1947) in the mechanical sector, and Finelettrica (1952) in

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 on the economy[3].

From an institutional viewpoint the IRI formula was quite specific. 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 so as to be able to pay dividends to shareholders. The levels of profitability for the shareholders were important to sustain the value of shares in the stock markets not to avoid the risks of hostile take-overs – since IRI held the majority of shares – but to allow them to raise capital in the financial markets increasing the viability of the frequent 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 intermediary and 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.

The basic aim of Italian SOEs in fact was to provide an active support to 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.

Figure 1 highlights the objective function of the Italian state owned enterprises. Traditional state owned firms maximize output and produce Q1. Traditional private firms maximize profits and produce Q2. Italian state owned enterprises following their objective function of output maximization under the constraint of an average

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the electrical sector. In 1955 IRI accounted for 44% of Italian steel output, 80% of national capacity in shipbuilding, and 26% of total banking deposits. IRI further enlarged its reach in the 1950s, obtaining an absolute majority of RAI (the national broadcasting company) in 1952 and taking control of Alitalia (the national airline) in 1957. See "Daily Report on Italian Home and Foreign Affairs", n. 167, 27 July 1954, Agenzia Est-Ovest Italiana, Roma, in ASIRI, s2.4-fl.2, p. 32.

[3] Actually after WWII the group of state owned enteprises expanded in the production of energy with two other groups, namely ENI that entered the production of oil, and ENEL for electricity. We shall concentrate the analysis on the IRI group as the role of these other SOEs in R&D activities was far less relevant.

profitability produce in the area between Q1 and Q2, probably in the neighbours of Q3.

The specific objective function of SOEs based on output maximization constrained by average profitability lead to an increase in the amount of resources invested in the generation of technological knowledge beyond the capability to exploit it.

The mismatch between the ‘large-r’ generation of technological knowledge and its ‘small-er’ exploitation made room for the dissemination of 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.

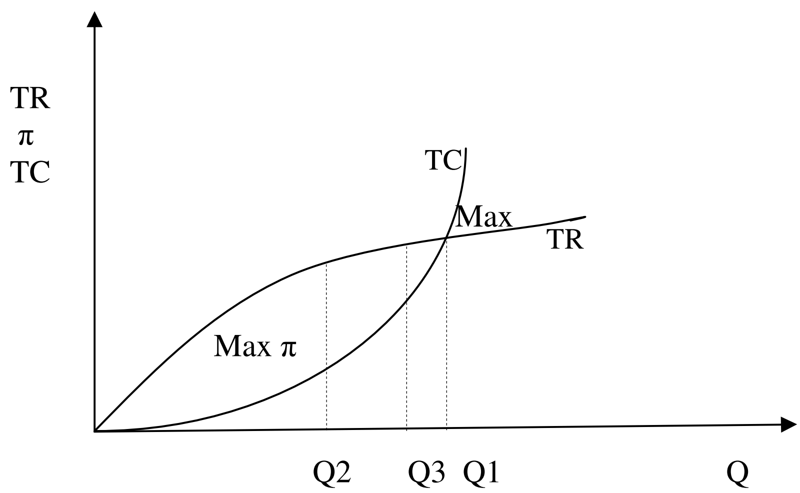

Figure 1. The objective function of Italian state owned enterprises

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.

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) (see Toninelli and Vasta, 2010).

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 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 from the technology of steel to telecommunications, 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. These research laboratories imitated explicitly the model of American large corporations (Chandler, 1962, 1977 and 1990). [4]

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 1980's. In 1986 IRI reached a maximum of 15% of all national investment in R&D, while SOE reached a maximum of 22% of all national R&D and 38% of total Business enterprise sector R&D (BERD).).[5]

Until 1980 IRI's R&D expenditures covered on average over 70% of all SOEs R&D (around 55% until early 1990s). Since mid 1980's instead SOE's R&D weight decreased, and especially IRI's R&D retrenched markedly in the early 1990s with the privatization process (see Figures 2 and 3). As a share of value added in fact, IRI's investment in R&D stopped its remarkable and long growth and started to scale down after 1986 (see Figure 4).

[4] In the field of telecommunication technologies perhaps, CSELT (Centro Studi e Laboratori Comunicazioni) was established in 1964 to conduct and supervise R&D activities of the STET sub-holding Group, with the aim of following the Bell Laboratories example.

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

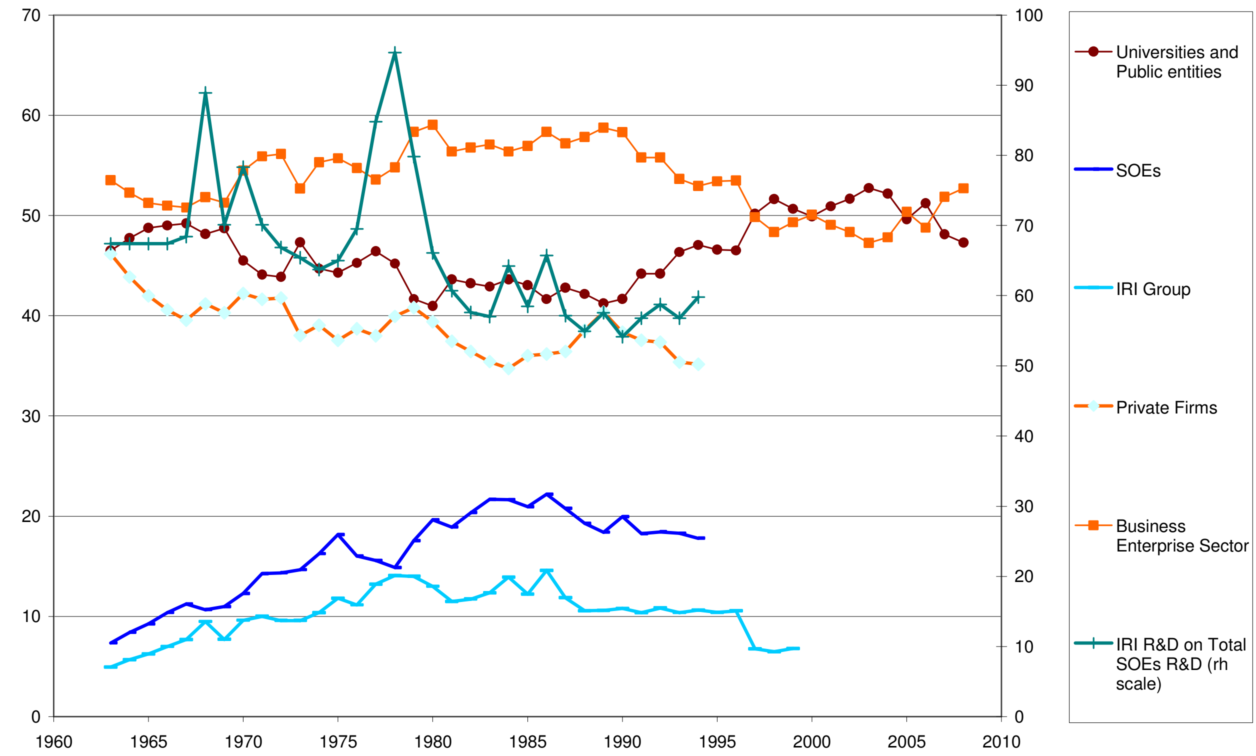

Figure 2. R&D expenditures by sector (%) – Italy

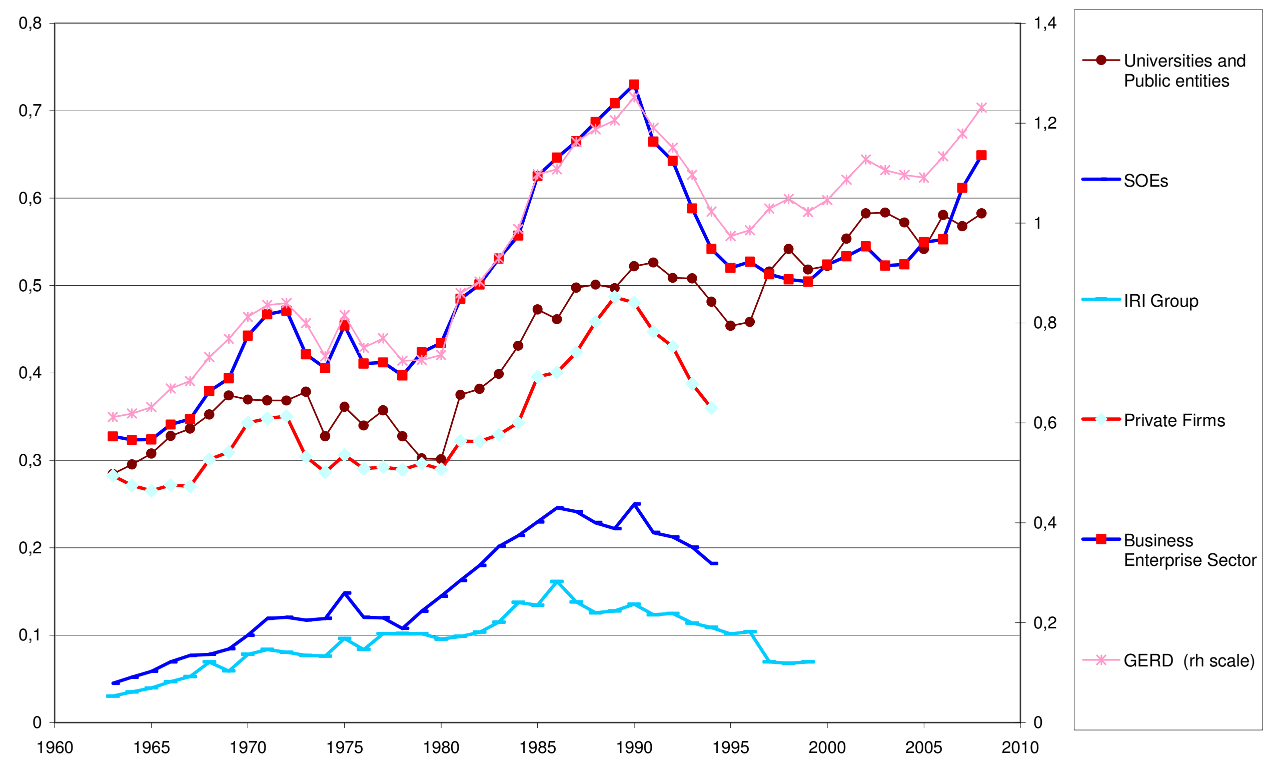

Figure 3. R&D expenditures by sector on GDP (%) – Italy

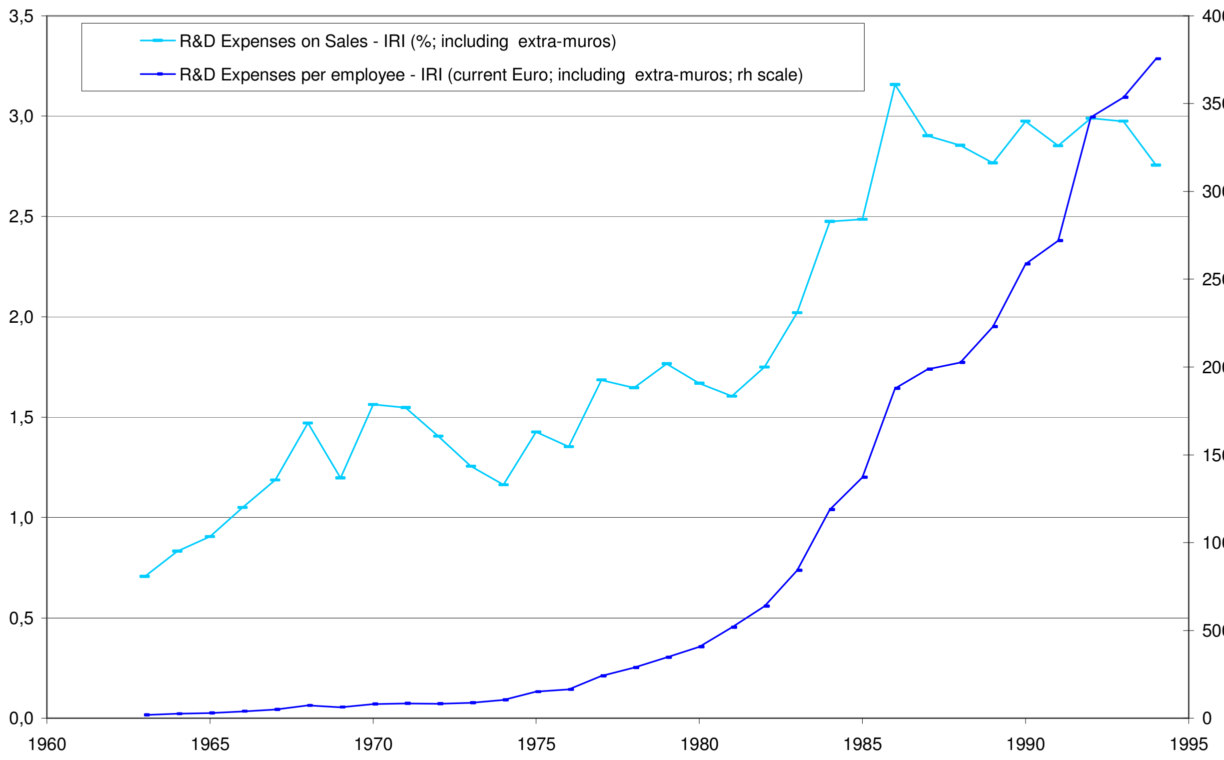

Figure 4. R&D expenditures – IRI Group (A)

Figure 5. R&D expenditures – IRI Group (B)

IRI was an increasingly open R&D system, as witnessed by the increasing share of R&D commissioned from outside IRI's enterprises and by the increasing share of extramuros R&D (see Figure 5).

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 e Lamborghini, 1978; Aghion e Tirole, 1994; Zeitlin e 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 private corporations 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. Statistical evidence combined with the results of a rich literature of case studies on IRI's Group firms confirm 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.

The key role of IRI corporations in the provision of advanced intermediary inputs and capital goods to the rest of the system provided large opportunities for systematic networking with downstream users building up intense user-producer interactions that facilitated the adoption of new advanced technologies by downstream users. The IRI research system actually helped both the diffusion of new technologies and the generation of new technologies by downstream users providing access to a wide knowledge base with high levels of fungibility and variety.

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 shows that the share of research performed extra-muros but funded by SOE's (not consolidated for industrial groups), as well as by the IRI group – with 21% of total SOEs R&D expenses in 1979 and 14% in 1991 – was almost double than the corresponding share of the research funded by the private firms (13 and 9% in the same years).[6]

If we look at IRI's import of technological knowledge, we also see 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) was highly significant and

[6] Our elaborations on Tav 11, p. 39, in Istat, Indagine statistica sulla ricerca scientifica, in «Bollettino mensile di statistica. Supplemento», no. 19, 1982; Tav. 333, p. 324, in Istat, Annuario Statistico Italiano, 1982; Antonelli and Barbiellini Amidei (2007).

increasing since early 1950s until mid 1960s, as and perhaps even more than for the Italian economy as a whole.[7] 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 and technical assistance (Pastorelli, 2006).

In 1966 the IRI ratio of expenses for foreign technology on the Group total sales (see Figures 6 and 7) reached a value equal to 0.4%, even higher than the ratio on GDP of Italian expenses of the Technology Balance of Payments (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 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 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.

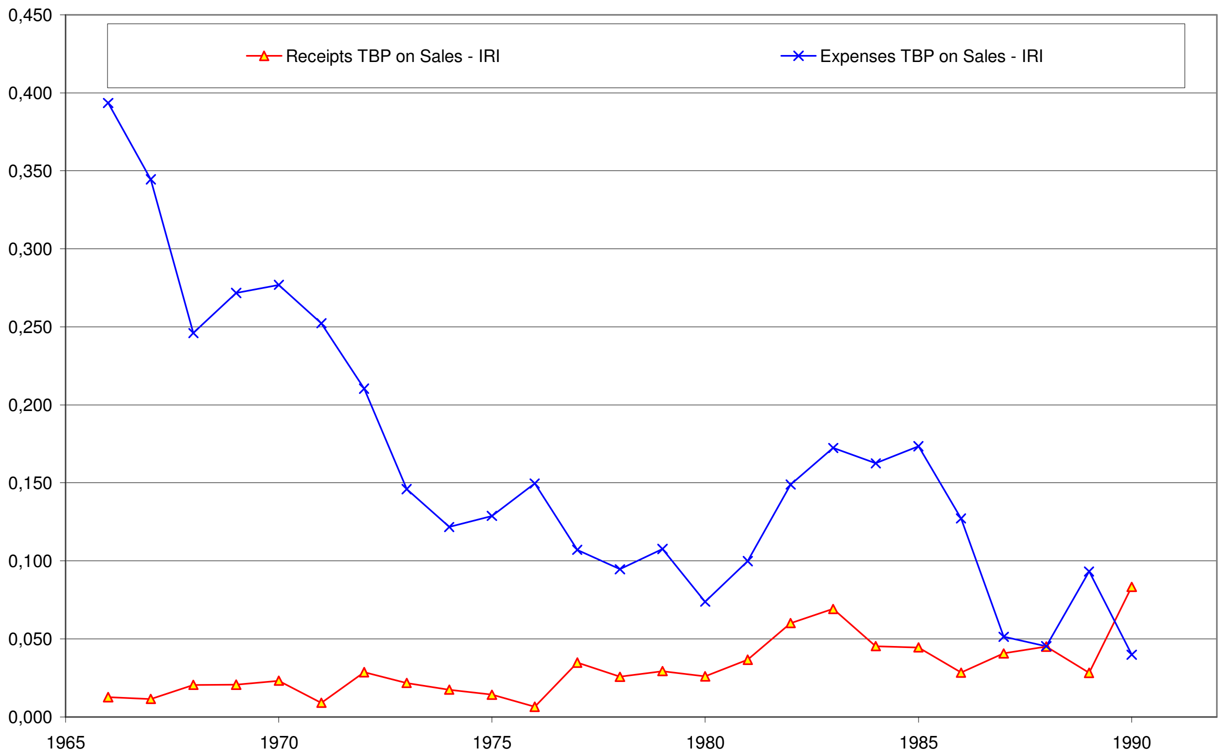

Figure 6. Technological Balance of Payments (%) – IRI Group (A)

[7] 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.

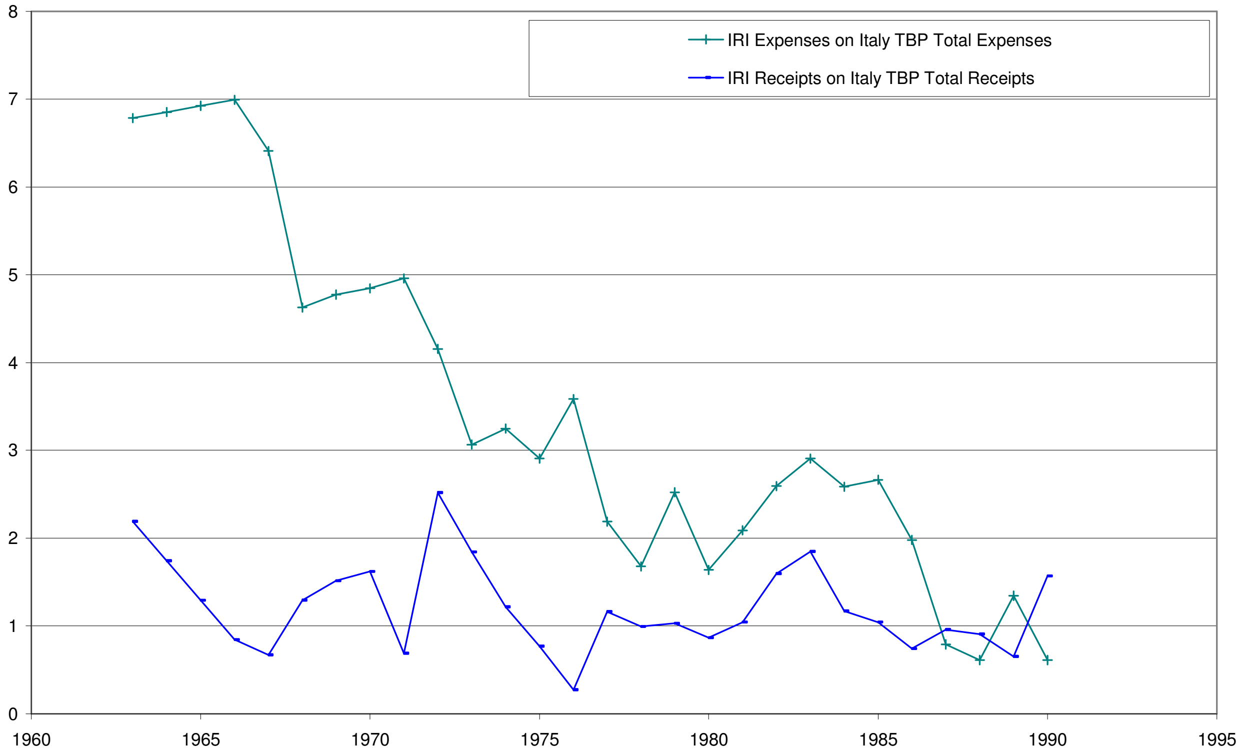

Figure 7. Technological Balance of Payments (%) – IRI Group (B)

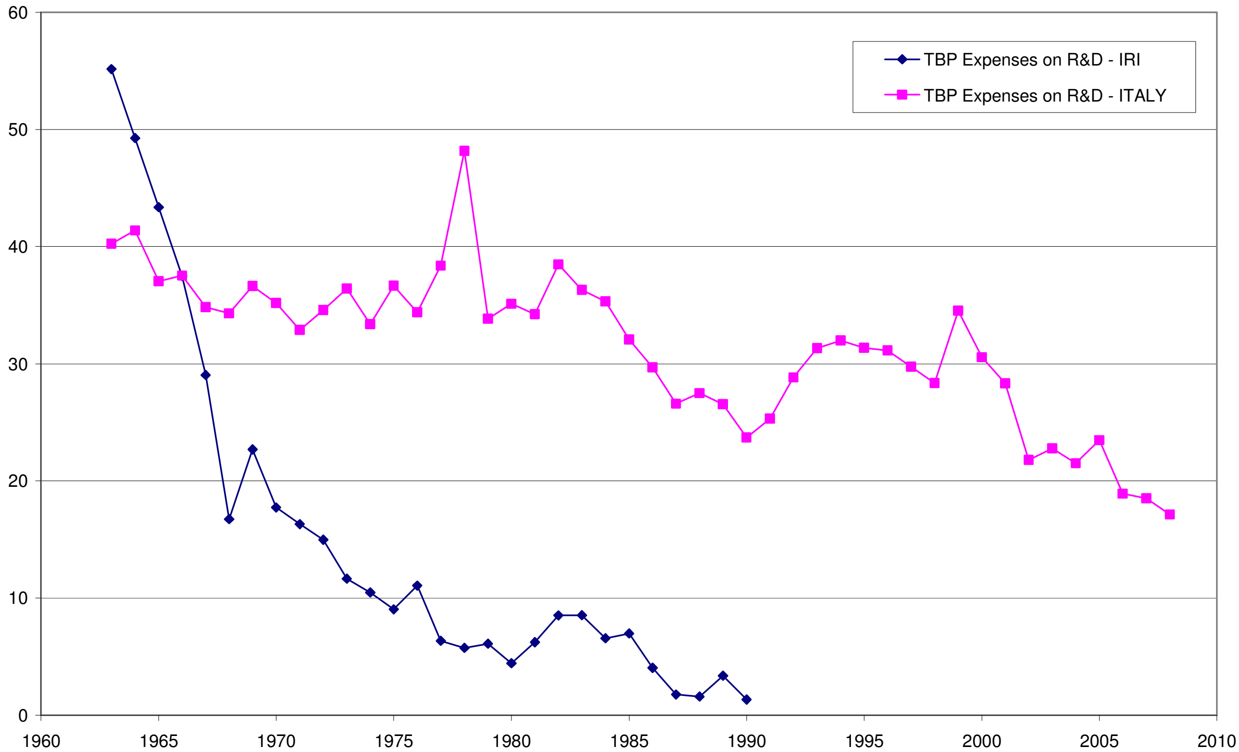

Figure 8. TBP Expenses on R&D expenditures (%)

If we look at the IRI's Group ratio of foreign disembodied technology purchases on R&D expenditures (see Figure 8) and we compare it with the equivalent Italian ratio (high in an international comparison), we see that a significant effort of 'technological emancipation' was made by the IRI's system since the end of the 1960s: while in 1966 IRI's foreign disembodied technology purchases were equal to 37.5% of R&D, as for Italy as a whole, they decreased to only 1.3% of IRI's R&D expenses in 1990, when the equivalent Italian figure was still equal to 24%.

The relatively high values of the royalties payments/R&D ratio for IRI Group until early 1970s, recall that the import of technological knowledge developed abroad was in post WWII era an integral and crucial part of IRI's innovative effort. Still in 1968 over 60% of IRI's total expenditures for foreign disembodied technology (and nearly half of contracts) involved US firms (Pastorelli, 2006). The subsequent rebalancing of foreign and internal sources of technological knowledge, suggests that IRI made a real attempt to develop a solid autonomous innovative capacity; at the same time the slightly increasing but definitely low levels reached by IRI's receipts of international technological transactions, a maximum of 2.5% of total Italian TBP receipts in 1972, point to the incompleteness of this attempt of technological capability build up as well as to the IRI's weak drive towards the market valorisation and exploitation of internally recombined technological knowledge.

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** 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. 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 externalities. In the 'American' model the academic system was the main source of external technological knowledge.

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 generated and actually, the limited application of the technological knowledge generated from the research system of the IRI corporations was due to an array of factors, apart from the complex, no (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 through the emission of knowledge pecuniary externalities the drive towards American technology of the Italian system, both of the (few) large private corporations involved in some formal R&D and in significant import of embodied and disembodied American technology, and of 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.

From this viewpoint, the IRI corporations have been actually for quite a long period a major mechanisms of knowledge governance and a central component of the Italian distributed model of recombinant generation of technological knowledge. This model has been successfully experienced in Italy in the years 1950-1990. Networks of firms characterized by high quality user-producer interactions rely 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.

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).

	TACIT KNOWLEDGE	**CODIFIED KNOWLEDGE**
INTERNAL KNOWLEDGE	LEARNING DISTRIBUTED MODEL	R&D CORPORATE MODEL
EXTERNAL KNOWLEDGE	KNOWLEDGE INTERACTIONS	KNOWLEDGE TRANSACTIONS

Table 1. The knowledge quadrant

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).

2.3 THE HYPOTHESIS

The matching between the analytical frame elaborated in section 2.1 and the empirical evidence of the specific institutional set-up provided by the case of IRI highlighted in section 2.2 enables us to spell out the basic hypothesis.

Knowledge spillovers do not work automatically in all conditions; technological spillovers are not all alike. A complex web of contextual conditions and idiosyncratic characteristics are necessary to make specific technological spillovers actually able to support the generation of new technological knowledge, the introduction of technological innovations and hence the eventual increase of total factor productivity. Technological spillovers require a specific institutional context to actually be useful and effective. The actual impact of technological spillovers varies according to the types of knowledge being disseminated, the characteristics of the recipients and, most importantly here, the characteristics of the emissaries.

The technological externalities spilling from the IRI research system were especially apt to support the Italian second wave of industrialization that took place in the four decades after WWII, 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 technological 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 trough 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 on the rest of the system.

Summing up, the IRI group and more generally the state owned enterprises 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 acted as a crucial interface between the generation of advanced technologies, both in academia and abroad, and the rest of the national economic system. Their privatization in the early 1990s deprived the national innovation system of a central emissary of knowledge externalities. Since then the Italian innovation system moved from a knowledge externalities rich combination of a private distributed model and an IRI's model, to a weaker standing alone private distributed model.

Hence our hypothesis: 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 total factor productivity at the system level.

3. THE MODEL AND THE RESEARCH STRATEGY

The knowledge generation function is an essential component of our analysis, together with the production function. The knowledge generation function provides the knowledge that is necessary in the production function to produce all other goods. In the generation of new technological knowledge, internal and external knowledge are complementary inputs that have to be combined in order to produce new technological knowledge (Nelson, 1982; Weitzman, 1996 and 1998). Next to internal knowledge obtained by means of research and development activities and the valorization of learning processes, external knowledge is indispensable for nobody can command all the knowledge available at any point in time. 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 the state owned IRI enterprises. External knowledge does not fall freely from heaven but can be acquired and used at a specific cost.

In our case, the knowledge generation function and the cost equation of technological knowledge of each firm 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 state owned IRI enterprises (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 research and development activities and to learn. The unit governance costs of external knowledge (u) and (v) spilling respectively from private firms and from state owned IRI corporations, 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 would have higher – equilibrium – costs.

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 the total factor productivity level.

Firms can actually benefit of positive pecuniary knowledge externalities in the access to 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 general equilibrium conditions.

Following Abramovitz (1956) we know that the level of total factor productivity 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 general equilibrium quantities of production factors and A measures total factor productivity.

The case for a positive total factor productivity 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 general 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 general 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 total factor productivity levels and its 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 emissaries. Hence we can put forward the basic proposition that total factor productivity levels stem from pecuniary knowledge externalities:

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

Total factor productivity levels can be explained by the excess amount of technological knowledge and output determined by costs of external knowledge that are below general equilibrium levels because of positive pecuniary knowledge externalities stemming respectively from private firms and state owned enterprises.

The hypotheses of the model can be tested with a simple econometric specification, where total factor productivity (A) is the dependent variable of the expenditures in research and development activities of private firms and state owned enterprises:

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

The assumption is that the parameter of the research and development expenditures of state owned IRI enterprises (R&DIRI) is significantly larger than the parameter of research and development expenditures conducted by private firms (R&DP); thus the expectation is that: $c>b$.

4. THE DATA AND THE ECONOMETRIC STRATEGY

In order to measure the contribution of the R&D performed by the public and the private sector in Italy in the second half of the XX century we used the data on R&D expenses funded by state owned enterprises, reconstructed for this study on the basis of IRI's archival sources, as well as the data provided by the Italian National Institute of Statistics (ISTAT), concerning the expenditures in Research and Development activities classified by typology of economic actor. Specifically we used the time series, for the years 1963-1994, of the aggregate real (2010 constant prices) flows of investments in R&D performed respectively by the enterprises belonging to the IRI-group and by the private sector. Our aim is to test the relationship of these two variables on the economic performances of the country, hence on the aggregate level of total factor productivity (A). For the measure of TFP, we used the data proceeding from a recent excellent in depth analysis on the overall growth of the Italian economic system in the last century, provided by the Bank of Italy (Broadberry, Giordano, Zollino, 2011).

As previously said our hypotheses concern the relationship expressed in equation (9): we want to check whether the impact of IRI's and private R&D on TFP differ between each other. The first specification of our analysis will then follow closely equation (9), using the logs of each of the variables and testing for their correlation with a simple OLS estimator. However we must take into account the possibility that the variables under observation may contain a unit-root process, which would strongly affect our estimates.

The plots of the time series of TFP and of the investments in R&D funded by IRI-owned enterprises and private firms, expressed in logs, in Figure 9, indeed, show a quite sustained rate of growth for all of the variables (with a considerable slow-down after the 1990) which does not allow to consider them as stationary processes, and confirms on the impossibility to use normal OLS estimators on the levels of the variables. We then 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.

We then transform equation (9) into an auto-regressive distributed lag model with all the variables expressed in first differences, as it follows:

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

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

Since this analysis will provide us only with the short-term dynamics of the two R&D variables on the growth of total factor productivity, we will combine it with a vector error-correction model (VECM) in order to check also for the presence of a long-run relationship between the variables. We then transform equation (10) into an unrestricted vector auto regressive (VAR) model of the following kind:

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

In which ECT_{t-1} represents the error correction term. This procedure will allow us to say something about the long-run relationships of causality between the two R&D variables and the growth of total factor productivity. In particular 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 instead 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.

5. RESULTS

We start by showing in Column (1) of Table 3 the results of a simple OLS estimation of equation (9) of the levels of TFP on the contemporaneous real flows of expenditures in R&D by private firms and by state owned enterprises. The results show an extremely high R-squared and positive and significant coefficients for both the regressors: furthermore, as stated in our hypothesis, the coefficient of R&DIRI is higher than that of R&DP. However as we previously said, 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. A related problem arising in such an estimation consists also in the high level of correlation between R&DIRI and R&DP, which is likely to cause serious problems of multicollinearity. We then proceed, trying to check whether different specifications of this model will change these initial results, giving more robustness to our analysis.

Column (2) of 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). 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. In Column (2) we first introduce the lags of the R&DIRI and R&DP, without the lagged differences of TFP. As in the previous specification the results show positive and significant coefficients for the R&DIRI, while in this case R&DP displays negative but not significant coefficients. In Column (3) of Table 3 we then include the lagged differences of TFP growth, to check for the robustness of the previous results: however the coefficients of R&DIRI and R&DP are not affected at all by the inclusion of these lagged values of the dependent variable. Both specifications, in levels and in differences seem to confirm our original hypothesis on the different size of the coefficients of IRI enterprises and private firms R&D expenditures.

We then come back to the problem of cointegration that we previously introduced. By looking at the plots displayed in Figure 9, it seems clear 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). The first way to check for this 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 can include the lagged residuals of the estimation of equation (9) – as presented in 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 total factor productivity.

However the results of a Dickey-Fuller test on the residuals of the estimation of equation (9), as shown in 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).

In order to properly understand the failure of the error correction procedure we examine in Figure 10 both the plots 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. 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), probably because of the steep decline of expenditures in R&D both by the private and public sector. It seems quite evident that such a change in the relationship between R&D expenditures and TFP growth can be considered as a structural break that might have affected the long-run relationship between the variables.

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 cointegration 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.

Table 5 presents the results of the estimation of the trivariate VECM, implemented through the Johansen procedure. Table 6 displays the estimated coefficients of the cointegrated equation, with the normalization restriction imposed by the Johansen procedure. Table 7, instead, synthesizes the results of the previous two tables by testing, through the usual χ^2 tests, the short and long-run Granger causality in the 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.

Let's start by commenting the long-run causality tests in Table 6: first of all the results show a 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.

In Table 5, and consequently in Table 7 (in which the size of the coefficients are not reported), among the three equations of the VECM, only the error correction term in the equation of total factor productivity turns out to be significant, while in the equation in which respectively R&DP and R&DIRI are the dependent variables, this is not the case (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 total factor productivity. Conversely there is no evidence of long-run Granger causality from the growth of total factor productivity (combined with one of the two types of R&D expenditures) towards R&DP or R&DIRI.

When looking instead 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 total factor productivity 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.

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 growth 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. However the analysis of the residuals of equation (9) seem to suggest 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 total factor productivity. Furthermore the results of a multivariate cointegration analysis show that the coefficient of R&DIRI in the cointegrating 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. Finally we notice that, probably also due to the limited number of observations (reduced further by the identification of the structural break in 1990), including the long-run relationship into the analytical framework negatively affects the significance of the short-run causality from R&DIRI towards TFP growth. Through all the specifications implemented anyway 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).

6. CONCLUSIONS

The grafting of the tools of communication studies into the economics of knowledge provides important hints to investigate the mechanisms of knowledge governance that enable to better explore the working of knowledge externalities. Knowledge externalities play a key role in the new growth theory to explain the increase of total factor productivity. The excess increase of output, beyond the levels expected in equilibrium levels, can be explained by the peculiar characteristics of knowledge as an economic goods. Technological knowledge is a special economic good characterised by limited appropriability, non-exhaustibility, non-excludability, cumulability, complementarity and strong tacitness. Technological knowledge is not only an output but also an input, not only into the production of other goods, but also, perhaps especially, into the generation of new technological knowledge. An input that may be used many times without being exhausted. The access to existing knowledge both internal and external to each firm is necessary to generate new knowledge.

The access to existing knowledge external to each firm does not take place freely. The mechanisms of knowledge governance play a central role in making external knowledge actually available and accessible to perspective users for the generation of new technological knowledge. Dedicated activities are necessary to screen, identify, acquire, purchase, decode 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 total factor productivity levels. The levels of pecuniary knowledge externalities are not alike across regions, industries, countries and historic times. Pecuniary knowledge externalities are larger and hence total factor productivity increases are larger when the costs of external knowledge are lower. The application of the tools of communication studies enables to qualify the causes of the differentiated levels of pecuniary knowledge externalities. Pecuniary knowledge externalities levels depend upon not only the strength of the signals of the emissaries of knowledge spillovers, but also upon the characteristics of the context in which the emission takes place and the features of the perspective users.

These differences stem from different knowledge governance mechanisms. Such differences can be considered the result of alternative institutional solutions, or changing Coasian boundaries of the firm, that have emerged through historic time by means of recursive processes of interactions and structural changes to better organize the complexity of knowledge interactions and support the creation and exploitation of pecuniary knowledge externalities, according to the changing knowledge infrastructure of the system.

Knowledge spillovers emitted by state owned corporations of the IRI group were very strong, and combined with effective governance mechanisms, hence very low absorption costs. Consequently very high pecuniary knowledge externalities stemmed from IRI's firms R&D activities, as a result of their specific role in the generation and dissemination of technological knowledge in the second wave of Italian industrialization.

In the Italian experience the national innovation system was enriched by the active knowledge governance provided by state owned enterprises characterized by quite an original incentive mechanism stemming from an objective function based upon output maximization applied under the constraint of appropriate levels of profitability. This incentive mechanism played a major role in shaping the research strategies of the IRI corporations, implementing their active support to the growth of the system by providing it with investments in the generation of knowledge, that could stir additional flows of investments by private companies, increasing their profitability and productivity.

The IRI corporations were active in upstream sectors providing the rest of the economy with advanced intermediary inputs and capital goods. Their 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. Research and development 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 emission of knowledge spillovers by the state owned IRI corporations 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. The econometric tests confirm that the impact of knowledge externalities spilling from the research and development activities carried out by the IRI corporations, in the second part of the XX century has been much stronger than the impact, in terms of knowledge externalities, stemming from the private firms.

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 the IRI corporations acted as a competent interface between the generation of scientific knowledge and its transformation as 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 total factor productivity 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.

State owned corporations 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.

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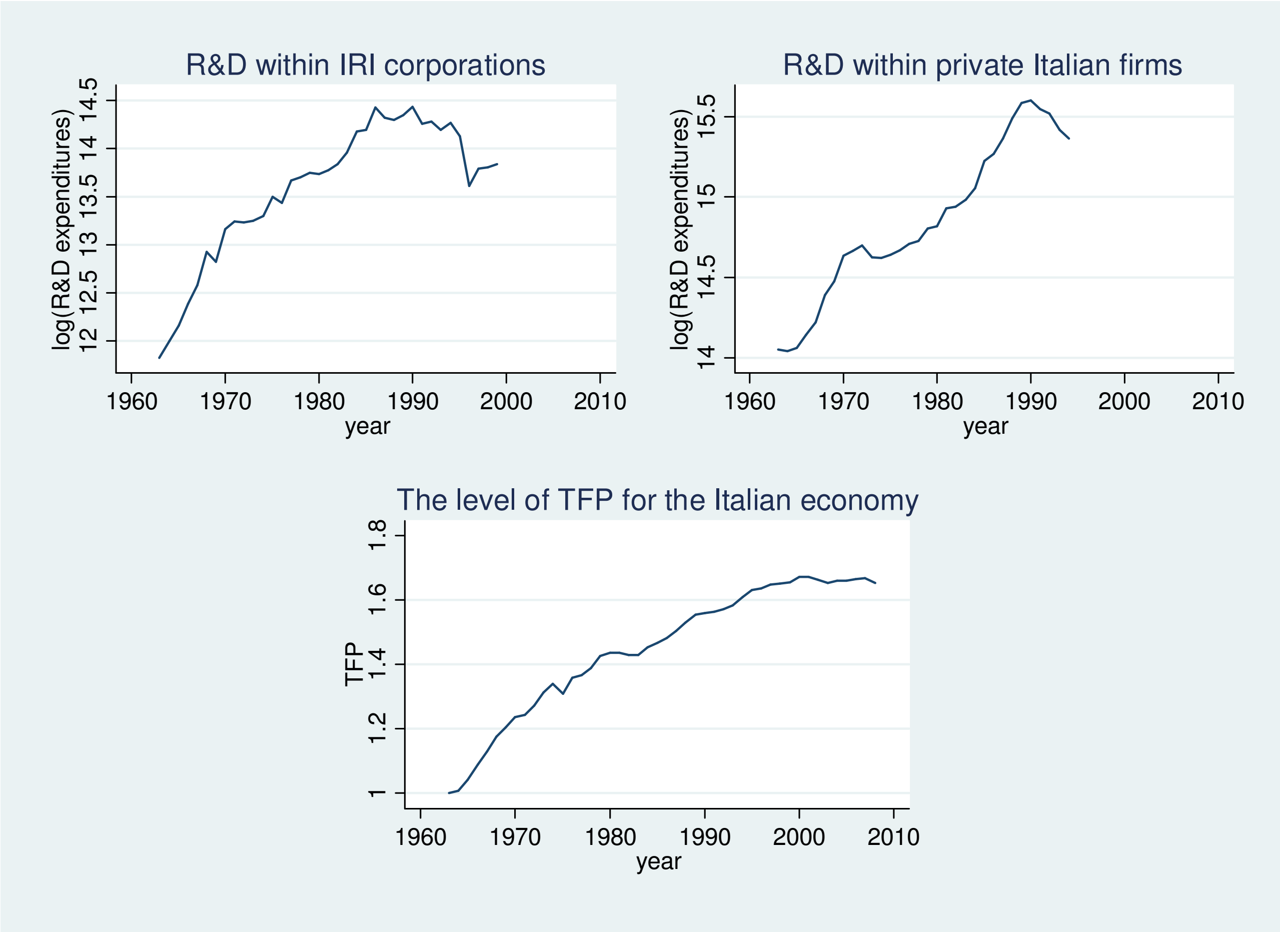
Table 2. Results of the Augmented Dickey Fuller unit-root tests

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

Figure 9. The dynamics of R&D expenditures and TFP in Italy (1963-2000)



Source: Istat (2011) and Broadberry et al. (2011).

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

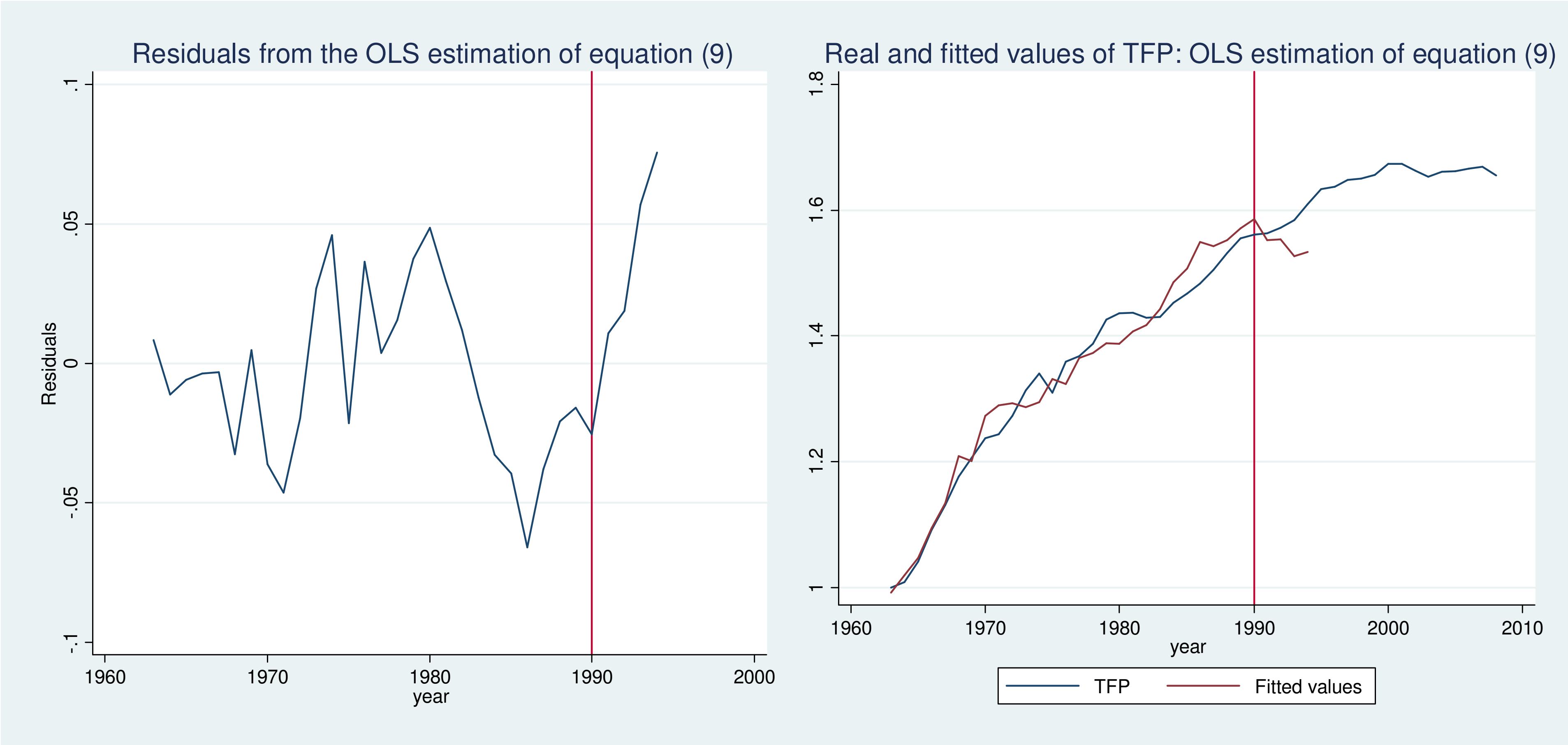


Table 4. Johansen tests for cointegration

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
	1.0000000	-0.1149232**	-.0641664	1.056714
st. err.		(0.0480031)	(0.0870157)	
z		-2.39	-0.74	

Test that ln (R&DP) = 0

LR test of identifying restrictions: $\chi^2(1) = 0.6562$ 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).