Knowledge as an economic good: Exhaustibility versus appropriability?

Published version:

DOI:10.1007/s10961-018-9665-5

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KNOWLEDGE AS AN ECONOMIC GOOD: EXHAUSTIBILITY VS APPROPRIABILITY?[1]

CRISTIANO ANTONELLI
Dipartimento di Economia e Statistica "Cognetti de Martiis", Università di Torino & (BRICK) Collegio Carlo Alberto

ABSTRACT. The analysis of knowledge as an economic good has paid much attention to its limited appropriability. Lesser attention has been paid to its limited exhaustibility. The effects of the limited exhaustibility of knowledge may compensate the effects of its limited appropriability. The Arrovian knowledge market failure takes place only when and if the downward shift of the intertemporal derived demand for non-exhaustible knowledge engendered by the limited appropriability of knowledge and the consequent decline of the price of innovated goods is larger than the downward shift of the intertemporal derived demand of standard capital goods engendered by their obsolescence. The distinction between imitation and knowledge externalities is relevant to assess the appropriability trade-off. Imitation externalities stemming from intra-industrial spillovers favor the entry of new competitors that benefit of knowledge ready-to-use with negative effects that are far stronger than the positive ones. Knowledge externalities stemming from inter-industrial spillovers take place when knowledge spilling from one party can be used as an input in the knowledge generation function with positive effects that are far larger than the negative ones. The appreciation of the joint effects of the limited exhaustibility of knowledge and of the knowledge appropriability trade-off calls for the design of a new knowledge policy framework based upon the differentiation of both public subsidies with respect to their actual additionality and intellectual property rights with respect to terms and levels of exclusivity.

KEY WORDS: KNOWLEDGE EXHAUSTIBILITY; APPROPRIABILITY TRADE-OFF; INTERTEMPORAL KNOWLEDGE DERIVED DEMAND; KNOWLEDGE MARKET FAILURES;

[1] The support of the research funds of the Dipartimento di economia e statistica Cognetti de Martiis of the University of Torino and of the Collegio Carlo Alberto is gratefully acknowledged.

IMITATION VERSUS KNOWLEDGE EXTERNALITIES; SUBSIDIES WITH ADDITIONALITY REQUIREMENTS; DIFFERENTIATED INTELLECTUAL PROPERTY RIGHTS; KNOWLEDGE-SPECIFIC PATENTS.

JEL CODE: O33

1. INTRODUCTION

Arrow (1962) has paved the way to the economics of knowledge introducing the comparative analysis of knowledge as a public good. The Arrovian approach enabled to highlight the crucial differences between knowledge and standard economic goods, to implement an articulated analysis of their effects and to design public policy interventions aimed to contrasting their shortcomings.

The attention of the literature has focused the limited appropriability of knowledge and has stressed its implications in terms of the market failure stemming from the lack of appropriate incentives to allocate the correct amount of resources in its generation. The broadening of the analysis of knowledge as an economic good enables to unveil, next to its limited appropriability, other idiosyncratic characteristics that may have countervailing effects.

As a matter of fact, and quite surprisingly, much less attention has been paid to another key characteristics of knowledge: its limited exhaustibility. The analysis of its implications, beyond the focus on its effects in terms of increasing returns and monopolistic power, has not received the necessary attention. The role of the limited exhaustibility of knowledge as a countervailing factor of its limited appropriability deserves careful investigation.

The rest of this essay is organized as it follows. Section 2 explores the actual conditions of the exhaustibility of knowledge as an economic good. Section 3 applies the tools of the derived demand to explore in isolation the effects of the limited exhaustibility of knowledge on its demand and supply. Section 4 extends the framework to assess jointly the effects of its limited appropriability and exhaustibility Section 5 introduces the distinction between imitation and knowledge externalities. Section 6 explores the implications of the identification of the effects of the limited exhaustibility of knowledge on the design of new research and science policies with respect to the heterogeneity of knowledge and proposes the differentiation of intellectual property rights in terms to terms of levels of exclusivity and of research subsidies in terms of additionality requirements. The conclusions summarize the implications of the analysis for economics and economic policy.

2. THE EXHAUSTIBILITY OF KNOWLEDGE

So far the economic literature has identified the limited exhaustibility of knowledge only as an intermediary input in the generation of new knowledge. A large consensus has been encapsulated in the well-know Newton's quote: "if I have seen further it is by standing on the shoulders [sic] of Giants". The extended duration of knowledge as an input in the generation of further knowledge has been implemented with the notion of knowledge cumulability. The literature has appreciated its positive effects in terms of economic growth at the system level and creation of barriers to entry and market power at the firm level.

The new growth theory has acknowledged the positive role of the accumulation of knowledge on growth stressing the increasing returns at the system level that stem from the cumulability of knowledge. Romer (1990) and Grossman and Helpman (1994) assume that, at the system level, the past experience of R&D accumulates in pools of quasi-public knowledge so that the unit costs of further R&D decline. Aghion and Howitt (1992) assume that long run growth depends upon the technological competence acquired in past research activities and made available at the system level by knowledge spillovers.

The resource based theory of the firm identifies in the accumulation of knowledge the basic element of the bundle of resources that defines a firm (Penrose, 1959; Kogut and Zander, 1992). Along the same lines, the evolutionary literature has highlighted the intrinsic cumulativity of knowledge as a key factor of the long-term competitive advantage of innovators in product markets stressing the role of knowledge cumulatibity as a major source of barriers to entry and asymmetric profitability (Dosi, 1988).

The technology management literature has identified the cumulativity of knowledge as the key element that accounts for the persistence of innovativity: firms that have been able to build up a knowledge base are more likely to remain innovators in the long term, especially if the strength of their internal knowledge base is complemented by the effective access to pools of external knowledge cumulated by means of knowledge spillovers. As Teece (2000: 37) notes: “Technology developments, particularly inside a particular paradigm, proceeds cumulatively along a path defined by the paradigm. The fact that technological progress builds on what went before, and that much of it is tacit and proprietary, means that it usually has significant organization-specific dimensions. Moreover, an organization's technical capabilities are likely to be 'close to the previous technological accomplishments (Teece 1988; Teece et al., 1994)”.

Cefis and Orsenigo (2001) provide strong empirical evidence on the cumulability of knowledge within firms and its role in accounting for the persistence in the rates of introduction of innovations.

Recent advances in the economics of knowledge have stressed the role of the stock of existing knowledge as a necessary input in the recombinant generation of new knowledge. As Arthur notes: “I realized that new technologies were not ‘inventions’ that came from nowhere. All the examples I was looking at were created-constructed, put together, assembled-from previously existing technologies. Technologies in other words consisted of other technologies, they arose as combinations of other technologies” (Arthur, 2009:2).

In this literature the emphasis on the role of the internal accumulation of knowledge is more and more complemented by appreciation of the central role of the accumulation of external stocks of quasi-public knowledge (Antonelli, Crespi, Scellato, 2015; Antonelli and Crespi, 2013).

The relevant duration of patent terms -20 years in the European Union and in the United States- can be considered a reliable clue of the current consensus about the limited exhaustibility of knowledge and the extended duration of its economic value.

The economic literature has little investigated the broader economic effects of the lower exhaustibility of knowledge as an economic good with respect to standard goods. Attention has been focused on non-excludability, the first key characteristic of public goods. Yet its application to knowledge implies necessarily the identification and appreciation of the role, not only of its limited appropriability, but also of its limited exhaustibility

As a matter of fact the limited exhaustibility of knowledge lies at the heart of its non rivalry in use, another – much better known- property. Non rivalry in use applies to public economic goods characterized by indivisibility of benefits: " A good is nonrival or indivisible when a unit of the good can be consumed by one individual without detracting, in the slightest, from the consumption opportunities still available to others from that same unit. Sunsets are nonrival or indivisible when views are unobstructed." (Coornes and Sandler, 1986: 6). The definition of non rivalry in use has been progressively stretched and applied to a variety of impure public goods including knowledge (Stiglitz, 1999). Its application to knowledge has not appreciated an important implication: non rivalry in use of knowledge takes place not only because of its non-excludability, but also because of its limited exhaustibility. The possibility to sharing knowledge, and yet retaining the possibility to keep using it, is possible only because of its non-exhaustibility. It seems quite obvious that the use by an agent of a standard excludable economic good characterized by standard exhaustibility excludes the possibility that a second agent can keep using it at the very same conditions. The limited exhaustibility of knowledge and its non excludability, stemming from its limited appropriability, are intertwined since the very first steps of the economics of knowledge. It is necessary to disentangle their separate effects.

As a matter of fact, the comparative analysis of standard economic goods and knowledge as an economic good shows that the exhaustibility of knowledge is much lower than the exhaustibility of standard economic goods.

Standard economic goods are characterized by high levels of exhaustibility. Consumer goods, such as food or personal services are fully exhausted by their consumption. Durable consumer goods have lower levels of exhaustibility: yet their duration is limited. Intermediary goods are fully exhausted by their transformation into output. Capital goods have a longer duration. Economic obsolescence is usually faster then their physical exhaustion. The introduction of superior capital goods makes existing capital goods that are not yet exhausted by physical wear and tear, obsolete.

The exhaustibility of knowledge is limited. Consumption of knowledge as a final good does not imply its exhaustion. The use of knowledge as an intermediary input does not entail exhaustion. The same piece of knowledge can be used repeatedly as an intermediary input without any effect on its duration. Finally, the use of knowledge as a capital good does not entail any physical wear and tear. The duration of knowledge as a capital good may be exposed to economic, rather than physical obsolescence. The introduction of superior knowledge may reduce the economic life of existing knowledge.

The understanding of the multiple role of knowledge that acts twice as an input and once as an output unveils another limit to its exhaustibility.

Knowledge in fact is an essential input in the technology production function, i.e. the production of all kind of goods (Griliches, 1979, 1984, 1986, 1992; Griliches and Pakes, 1984) as well as the output of the knowledge generation as a dedicated activity (Jaffe, 1986). The generation of knowledge as an output, moreover, is the result of the recombination of existing knowledge: knowledge enters the knowledge generation function as an indispensable input (Weitzman, 1996). Even after that existing knowledge experiences economic obsolescence as a capital good used in the production of other goods, it remains an indispensable intermediary input in the generation of new knowledge.

The analysis of the multiple role of knowledge as: i) an input in the technology production function; ii) an output of the knowledge generation function; iii) an input in the knowledge generation function enables to grasp the radical difference in terms of exhaustibility of knowledge as a capital good with respect to standard capital goods. The economic obsolescence of standard capital goods entails their economic exhaustion. This is not the case of knowledge. Its economic obsolescence may entail its exhaustion as an effective capital good in the technology production function, but not in the knowledge generation function, where it remains an indispensable intermediary input.

The limited exhaustibility of knowledge has important implications for economic analysis and policy.

3. THE INTERTEMPORAL DERIVED DEMAND OF KNOWLEDGE

The analysis of the derived demand is a powerful tool that enables to identify the effects of the limited exhaustibility of knowledge compared to the standard exhaustibility of economic goods that enter a technology production function as capital (and intermediary) inputs (Antonelli, 2017a).

The formal analysis of the derived demand for technological knowledge enables to follow and yet stretch the application of the Arrovian approach from the analysis of knowledge as an output to the analysis of knowledge as an input. We can proceed with the same comparative approach confronting the outcomes of knowledge as a standard good with substantial exhaustibility to the outcomes of knowledge as a non-standard good characterized by limited exhaustibility[2].

The analysis of the derived demand of a capital good with an economic life that lasts more than a single unit of time requires to take into account the distribution of the yearly economic benefits distributed over the stretch of time along which the capital good remains into operation taking into account the erosion effects of its obsolescence. When the economic life of a capital good exceeds the single unit of time it is necessary to move from the instantaneous derived demand to the intertemporal derived demand.

The intertemporal position of the derived demand of any intermediary and capital good (K) is determined by the horizontal sum of the instantaneous derived demand schedules,that is the yearly schedules of its ($P_Y P'_K$) the product of the price (P_Y) of the output (Y) and marginal product in physical quantities (P'_K) taking into account the rates of obsolescence that reduce the portion of the capital good in use each year.

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[2] The comparison between knowledge as an economic good and standard economic goods explores here exclusively the effects of the limited exhaustibility of knowledge and does not –yet- integrate the effects of its limited appropriability. The integration of the effects of both the limited exhaustibility of knowledge and its limited appropriability will be implemented in Section 4.

For the same token, the intertemporal derived demand of knowledge as an input in the technology production function is determined by the horizontal sum of the instantaneous derived demands measured at each point in time by its marginal product in value ($P_Y P'_T$) that is the marginal product in physical quantities of knowledge (T) as an input in the technology production function- times the price of output Y, taking into account the rates of obsolescence that reduce the portion of the capital good in use each year (Antonelli, 2017a).

The rates of obsolescence play a major role to identify the position of the intertemporal derived demand as they have a strong effect on the time distribution of the sequence of marginal products of the portions of input that remain in the production process. At each point in time the position of the intertemporal derived demand is determined by the sum of the instantaneous schedules of derived demand over the stretch of time through which the knowledge input exerts its productive effects taking into account the non-exhausted portion still effective.

The starting point is the Cobb-Douglas specification of the knowledge production function:

(1) $Y = K^{\alpha} L^{\beta} T^{\gamma}$

where Y stands for the output, K for the capital stock, L for the labor input and T for the knowledge stock

In the case of standard intermediary and capital goods the economic and physical obsolescence entails the yearly reduction of their marginal product in value ($P_Y P'_K$). Assuming standard economic parameters, the ($P_Y P'_K$) of the first year is 100%, the ($P_Y P'_K$) of the second year is reduced to 80%, the ($P_Y P'_K$) of the third year is reduced to 60% and so on until the capital good is fully exhausted[3].

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[3] The rates of tax depreciation provide a reliable clue about the actual obsolescence of tangible capital goods. Although they exhibit a relevant variance - the heights of 30-40 % for petrochemical and digital capital goods, to 25% for machinery- they confirm that the average duration of the economic life of tangible capital goods rarely exceeds 4 years.

According to the analysis conducted above it seems possible to claim that the exhaustion of knowledge in its dual role of capital good in the technology production function and intermediary good in the knowledge generation function takes place at slow rates. Much slower than any standard economic good.

In the case of knowledge the economic and physical obsolescence entails a far lower yearly reduction of its marginal product in value ($P_Y P'_T$). Assuming a possible parameter, the ($P_Y P'_T$) of the first year is 100%, the ($P_Y P'_T$) of the second year is reduced to 95%, the ($P_Y P'_T$) of the third year is reduced to 90% and so on until knowledge is actually exhausted.

Because the analysis implemented so far does not take into account the effects of the limited appropriability of knowledge that will be considered at a later stage, it seems clear that the position of the intertemporal derived demand of knowledge, calculated as the horizontal sum of the yearly schedules of the marginal products in value of the non-exhausted portions of knowledge, is far higher than the position of the intertemporal derived demand of any other capital good.

The intertemporal derived demand of standard capital goods assuming that the current period were t_1 and the initial year t_0 and taking into account depreciation/obsolescence (d), is:

$$(2) \quad D = \sum_{t=t_0}^{t_1} (1-d)^{t_1 - t} P_Y P_{K_t}$$

The instantaneous derived demand of knowledge (where the depreciation/obsolescence rate is □□□equals the instantaneous derived demand of any other capital good:

$$(3) \quad \sum_{t=t_0}^{t_1} (1-d)^{t_1 - t} P_Y P_{K_t} = \sum_{t=t_0}^{t_1} (1-\delta)^{t_1 - t} P_Y P_T$$

when:

$$(4) \quad d = \delta$$

The intertemportal derived demand for knowledge is larger than the intertemporal demand for capital when the effects of the duration of capital goods and knowledge over a stretch of time that is larger than the unit are taken into account:

$$(5) \quad d > \delta$$

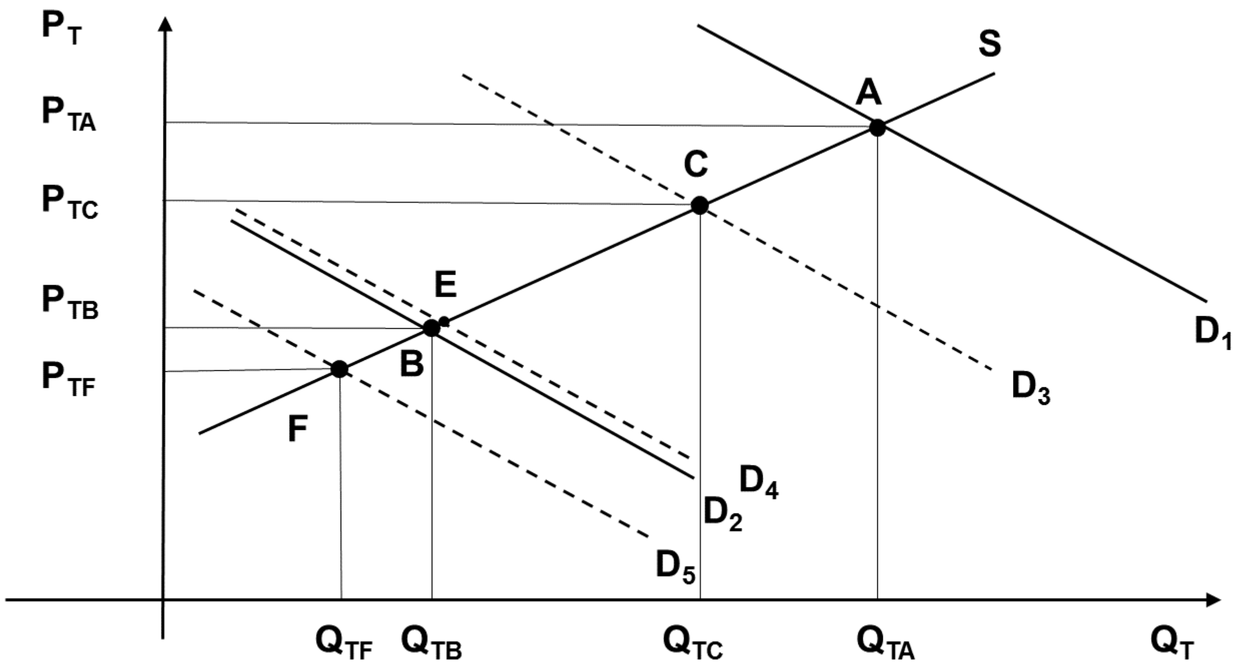
Equation (5) holds because the exhaustibility of knowledge is lower than the exhaustibility of standard capital goods and consequently larger portions of knowledge capital remain in service with respect to contemporary capital goods. As a consequence the intertemporal derived demand for knowledge lies far above the derived demand for any standard capital good:

$$(6) \quad \sum_{t=t_0}^{t_1} (1-d)^{t_1-t} P_Y P_{K_t} > \sum_{t=t_0}^{t_1} (1-\delta)^{t_1-t} P_Y P_T$$

Figure 1 shows the implications. The higher position of the intertemporal derived demand for knowledge (D_1) stemming from its limited exhaustibility contrasts the lower position of the intertemporal derived demand for standard economic goods (D_2) stemming from their higher levels of exhaustibility that reduce the efficiency time window of a given capital good. The position of (D_2) can be regarded as the benchmark. Out-of-equilibrium conditions take place when the position of the derived demand for knowledge does not coincide with the benchmark and lies either above or below it.

Assuming a standard supply curve (S) with a positive slope, it is clear that, not only the equilibrium demand for knowledge (Q_{TA}) is larger than the equilibrium demand for any standard economic good, (Q_{TB}) but also the price of knowledge (P_{TA}) is larger than the benchmark equilibrium price of any standard capital good (P_{TB}).

FIGURE 1. THE DERIVED DEMAND FOR KNOWLEDGE AND STANDARD ECONOMIC GOODS WITH DIFFERENT LEVELS OF EXHAUSTIBILITY AND APPROPRIABILITY



Because of the crucial role of the limited exhaustibility of knowledge - without taking into account the effects of its limited appropriability- the incentives to allocate resources to generate knowledge are not lower but actually larger than the incentives to allocate resources to standard economic goods. The analysis of the effects of the limited exhaustibility of knowledge suggests, in fact, that markets may oversupply knowledge rather than undersupply it. The Arrovian market failure would work the other way around: too much knowledge is generated and too little standard capital goods are demanded by the system. Too much investment in knowledge takes place and too little investments take place in standard tangible goods. Because of excess duration of its economic life there is an excess-supply of knowledge.

4. THE LIMITED EXHAUSTIBILITY AND APPROPRIABILITY OF KNOWLEDGE

The Arrovian analysis of knowledge as an economic good concentrated its attention of the limited appropriability of knowledge. It is now time to bring it back into the frame. The limited appropriability entails the spillover of proprietary knowledge: “inventors” cannot retain the full stream of benefits stemming from the generation of new technological knowledge and the related introduction of innovations. Imitators can take advantage of the knowledge generated by inventors. Imitation enables the entry of new competitors and the generalized use of process innovations with the consequent downward shift of the supply curve and the fall of the price of products that have been produced by means of new knowledge (P_Y)[4].

The uncontrolled leakage of knowledge and its spillover, however, arenot instantaneous. The large evidence provided by the literature confirms that imitation and absorption are not free but entail consistent resources and

[4] The analysis implemented in this Section considers only the ‘negative’ effects of the limited appropriability of knowledge on the price of innovated goods and hence on the revenue of innovators and consequently on the position of the derived demand for knowledge. It does not integrate the analysis with the appreciation of the ‘positive’ effects of the limited appropriability of knowledge in terms of the knowledge spillovers that help reducing the cost of innovators with the consequent downward shift of the supply of innovated goods and not only of the derived demand of knowledge (See Antonelli 2017b).

dedicated activities that need time to display their effects (Mansfield, 1981 and 1986). Spillovers are not instantaneous, but diachronic. As a consequence their effects are distributed aver time: the entry of new competitors exerts its effects through time. Innovators can fully appropriate the economic benefits of their innovation only in the first unit of time (year). In the second, fast imitators and incremental innovators -that rely on proprietary knowledge leaking from inventors- enter the market place and bring about a reduction of the prices. The price of the innovated products declines progressively:

(7) $(P_Y)_{t=1} > (P_Y)_{t=2} > (P_Y)_{t=3}$

The effects of the limited appropriability of knowledge on its derived demand consist in the reduction of the value of the marginal product of knowledge. The limited appropriability of knowledge entails a backward shift of the position of its derived demand. The fall of prices takes place at augmented rates in the third and following years. Now the position of the intertemporal derived demand for knowledge determined by the horizontal sum of the different time schedules of the instantaneous derived demands is affected by the progressive reduction of P_Y

The derived demand schedules D_3 , D_4 and D_5 of Figure 1 exhibit the outcome. The position of the intertemporal derived demands of knowledge shifts according to the different assumptions about the rates of decline of the prices of the output (P_Y).

The amount of the actual backward shift is of course a matter of empirical evidence. It is clear that the position of the intertemporal derived demand for knowledge will coincide with the position of the demand for standard capital goods when the rate of economic and physical obsolescence of standard capital goods equals the rate of decline of the prices of innovated goods stemming from the limited appropriability of knowledge:

(8) $\sum_{t=t_0}^{t_1} (1-d)^{t_1-t} P_Y P_{K_t} = \sum_{t=t_0}^{t_1} (1-\delta)^{t_1-t} P_Y P_T$

In Figure 1 this is the case of the coincidence between equilibrium points B and E where B is found on D_2 that represents the intertemporal derived demand of standard economic goods with standard exhaustion and E belongs to the intertemporal derived demand curve of knowledge with diachronic spillovers that engender a sequence of lower prices of the output Y. In this case the rate of depreciation of standard economic goods and the rate of decline of the price of the output Y coincide. This is the case where the limited exhaustibility of knowledge engender positive effects on the derived demand that are exactly compensated by the negative effects that stem from the uncontrolled leakage of proprietary knowledge that in turn causes the entry of new competitors and the limited appropriability of the knowledge generated by 'innovators'. In this case the limited exhaustibility of knowledge acts as an effective countervailing property that can balance the negative effect of the limited appropriability of knowledge. The positive effects of the limited exhaustibility of knowledge balance the negative effects of its limited appropriability.

If the rates of decline of the price of innovated goods are lower than the rates of obsolescence, the market place will suffer from excess supply of knowledge. The position of the intertemporal demand for knowledge remains above the position of the intertemporal derived demand of standard economic goods:

$$(9) \quad \sum_{t=t_0}^{t_1} (1-d)^{t_1-t} P_Y P_{K_t} < \sum_{t=t_0}^{t_1} (1-\delta)^{t_1-t} P_Y P_T$$

In this case the market place is likely that produce too much knowledge at prices that are larger than it would take place if knowledge were a 'perfect' economic good. The market failure takes place but the effects are opposite to the Arrovian market failure.

In Figure 1 this is the case of equilibrium point C that belongs to D_3 that represents the intertemporal derived demand curve of knowledge with diachronic spillovers that engender a sequence of lower prices of the output Y that have negative effects on the position of the derived demand far lower than the effects of the standard exhaustibility of capital goods represented by the benchmark derived demand D_2. This is the case of knowledge characterized by high levels of cumulativity that enables 'inventors' to exploit it through time and to use it in the recombinant generation of new knowledge so as to stretch the duration of monopolistic power and the height of barriers to entry and to mobility. In this case both the price and quantity of knowledge are far larger than it would take place if knowledge had standard economic characteristics. The prices of innovated goods decline at a rate that is far lower that the decline of the efficiency time window of standard economic goods. The limited exhaustibility of knowledge has ‘positive’ effects that overcompensate the ‘negative’ effects of its limited appropriability.

The well known Arrovian case of knowledge market failure will take place when and if the rates of decline of the prices of innovated goods, engendered by the diachronic effects of the limited appropriability of knowledge, yield negative effects than the positive ones stemming from the slow rates of exhaustion rates of obsolescence and as a consequence the position of the intertemporal derive demand for knowledge is lower that that of any standard capital good:

$$(10) \quad \sum_{t=t_0}^{t_1} (1-d)^{t_1-t} P_Y P_{K_t} > \sum_{t=t_0}^{t_1} (1-\delta)^{t_1-t} P_Y P_T$$

This is the case of equilibrium point F in Figure 1. Point F belongs to D_5 that represents the intertemporal derived demand curve of knowledge with diachronic spillovers that engender a sequence of lower prices of the output Y. In this case the reduction of the price of innovated goods has negative effects on the position of the derived demand far larger than the effects of the standard exhaustibility of capital goods represented by the benchmark intertemporal derived demand D_2. This is the case of knowledge items that have low levels of natural appropriability and that consequently can be easily imitated and absorbed by free-raiders. In these special cases the market place is unable to allocate the correct amount of resources to the generation of knowledge that produces knowledge at costs that are below equilibrium levels.

The Arrovian market failure takes place –only- in this latter case. The system is unable to allocate the appropriate amount of resources to the generation of knowledge and its use in the introduction of innovations when the negative effects of its limited appropriability on the incentives to invest in R&D outweigh the positive effects of its limited exhaustibility. The Arrovian knowledge market failure is no longer a general case that applies in all circumstances: it is a possibility that takes place in circumstances that need to be specified and investigated.

The identification of the substantial heterogeneity of knowledge enables to use the analytical framework implemented so far as not only as a didactic device but an actual and effective tool able to discriminate across knowledge items. A large literature provides evidence on the heterogeneity of knowledge: Adams and Clemmons (2013) calibrates diffusion lags among fields and sectors for science, finding that while the mean lag is about six years in standard data, there is a clear evidence across fields. Knowledge is a bundle of heterogeneous items that are differentiated by varying levels of exhaustibility and appropriability[5]. Their different combinations enable to classify knowledge into different classes of "economic imperfections" and consequently different types of market failures:

i) knowledge items with low exhaustibility and high appropriability lead to an inverse market failure the excess supply of knowledge;

ii) knowledge items with high exhaustibility and low appropriability lead to the classic market failure characterized by undersupply;

iii) knowledge items for which high levels of exhaustibility compensate low levels of appropriability are not expected to engender any market failure.

5. IMITATION VERSUS KNOWLEDGE EXTERNALITIES

[5] Patent statistics provide important clues to gauge the levels of knowledge exhasutibility and appropriability: i) the levels of knowledge exhaustibility can be approximayed by the rates of advance of knowledge as measured by the rates of patents applications of technological classes. The larger are the rates of increase of applications in a class and the faster can be thought to be the rates of obsolescence of the papternts that belong to that technological class; ii) the dates of backward citations provide additional information about the levels of knowledge exhaustibility. The longer the time span between backward citations and dates of application and the lower the exhaustibility; iii) the levels of knowledge appropriability can be approximated by the amount of current backward citations: the larger the number of current backward citations and the larger are expected to be the effort to inventing around.

5.1 THE FRAME

This section expands the analysis of the appropriability trade-off with the identification of two types of externalities stemming from knowledge spillovers: imitation externalities and knowledge externalities, and the working of two distinct mechanisms, by means of which the stock of quasi-public knowledge affects the economic system. The stock of quasi-public knowledge, in fact, engenders respectively knowledge externalities when spillovers are inter-industrial and imitation externalities when spillovers are intra-industrial.

Imitation externalities are at the core of the Schumpeterian arguments according to which: i) the monopolistic market power of innovators is intrinsically transient because of the inevitable entry of new competitors that can imitate the innovation first introduced by third parties, and ii) engenders a positive sum game because the short term negative effects of monopolistic rents are more than balanced by their long terms positive effects in terms of incentives to the introduction of innovations that eventually drive the cost and the price of innovated goods well below the original level (Schumpeter, 1942). The Arrovian analysis of the limits of competitive markets for knowledge also applies mainly if not exclusively to imitation externalities (Arrow, 1962).

Imitation externalities take place when proprietary knowledge spills within the industry. Imitators can use knowledge ready-to-be-used to compete with 'inventors' (Lhuillery, 2011). Imitation externalities provide the technology production function with the supply of knowledge as an input at costs that are below equilibrium level. The amount of goods that can be produced with a given budget increases. The price of innovated products, as a consequence, in the product market of inventors falls (Bloom, Schankerman, Van Reenen, 2013). Inventors can appropriate only a small fraction of the benefits of their knowledge. Incentives to the generation of new knowledge are consequently reduced and the standard Arrovian postulate applies fully.

Spillovers, however, are not only intraindustrial, but also interindustrial: in this case they yield knowledge externalities. The advances of the economics of knowledge have, in fact, progressively made clear that knowledge is at the same time an input and an output. The knowledge used as an input in the production of all the other goods is itself the output of a dedicated activity and an indispensable, not only for the introduction of an innovation, but also for the generation of further knowledge (David, 1993). Weitzman (1996 and 1998) enriched the analysis of the knowledge generation function highlighting its recombinant character: new technological knowledge is generated using existing knowledge items. Its generation consists in the recombination of knowledge items that enter the process as inputs. Fleming and Sorenson (2001) suggest that the generation of technological knowledge follows a branching process where the new modules stand upon the old ones. The generation of knowledge acquires the typical traits of a non-ergodic process where the present is influenced, at each point in time, by the past. This approach has important implication: i) the selective availability of existing knowledge shapes the direction and the rate of the generation of new knowledge; ii) the larger is the portfolio of existing and accessible knowledge modules and the larger is the productivity of the knowledge generation process.

The analysis of the actual role of knowledge spillovers shifts away from the technology production function and privileges the new analytical framework of the recombinant knowledge generation function. The new context is quite different. The output is no longer the goods produced using knowledge, both internal and external, as an input, but knowledge itself. Different layers of knowledge are now considered on the inputs side. Next to research and development activities and the stock of internal knowledge, the stock of external knowledge is now considered as an input. The stock of external knowledge that entered the technology production function, now enters the knowledge generation function: in both cases it is a relevant input (Fleming, 2001).

Knowledge externalities take place when proprietary knowledge spills outside the industry and is not ready-to-be-used as such, but is used by recipients as an input for the recombinant generation of new knowledge. Knowledge externalities augment the amount of knowledge that can be produced by the knowledge generation function with a given budget. Knowledge externalities take place when and if the cost of external knowledge, spilling from third parties and cumulated in the stock of quasi-public knowledge that characterizes economic systems, is lower than the costs its regeneration. Knowledge externalities exert three distinct effects: i) direct positive effects in the knowledge generation function as they enable to increase the amount of knowledge that can be produced with a given budget; ii) indirect positive effects as the cheaper knowledge generated upstream in the knowledge generation function enters the downstream technology production function and enables to produce a larger amount of output with a given budget; iii) negligible negative effects on the price of goods produced and sold in the product market of the inventor.

The Arrovian postulate does not apply to inter-industrial spillovers and knowledge externalities because there is not the risk of market failure stemming from the fall of price of products within the industry of inventors, with the well-known consequences in terms of missing incentives and undersupply of knowledge. The positive effects of inter-industrial spillovers, instead, are very strong in terms of reduced knowledge costs.

The distinction between imitation and knowledge externalities is important to define the scope of application of the Arrovian analysis and to identify a map of the different mixes of positive and negative effects of spillover that are at the core of the appropriability trade-off. The distinction is most important for its implications on the intellectual property right regime. It paves the way, in fact, to articulate the current intellectual property right regime, based on homogeneous and exclusive patents, with the introduction of knowledge specific patents with differentiated levels of exclusivity, according to the use of spillovers whether intra-industrial or inter-industrial.

5. 2 THE ANALYSIS

Following Arrow (1962) we compare the actual market place with the equilibrium market place that would take place if technological knowledge were a standard economic good with the standard levels of appropriability and excludability. Following Griliches (1979 and 1992) we rely upon: i) a technology production function where technological knowledge enters the production process next to capital and labor and ii) a knowledge generation function where the output is technological knowledge and R&D activities and the internal and external stocks of technological knowledge are the inputs.

We proceed to analyzing the effects on the appropriability trade-off, first of imitation externalities and next of knowledge externalities.

5.2.1 IMITATION EXTERNALITIES

Knowledge spilling from "inventors" is ready to be used as such by competitors in the very same product market. The access to imitation externalities affects the technology production function with the introduction of the stock of external knowledge ready-to-be-used that spills from competitors (ETC):

(11) Y = K□□ L□□LT□□□□□T□□

With a given budget the access to external knowledge spilling from competitors enable to produce output Y at low(er) costs. The costs of external knowledge, in terms of absorption and imitation costs, is >0 but lower than the costs of knowledge if it were a standard good.

The entry of imitators in the product market of the innovated good has the direct effect to increase rivalry and competition and reduce the price-cost-margins of innovators:

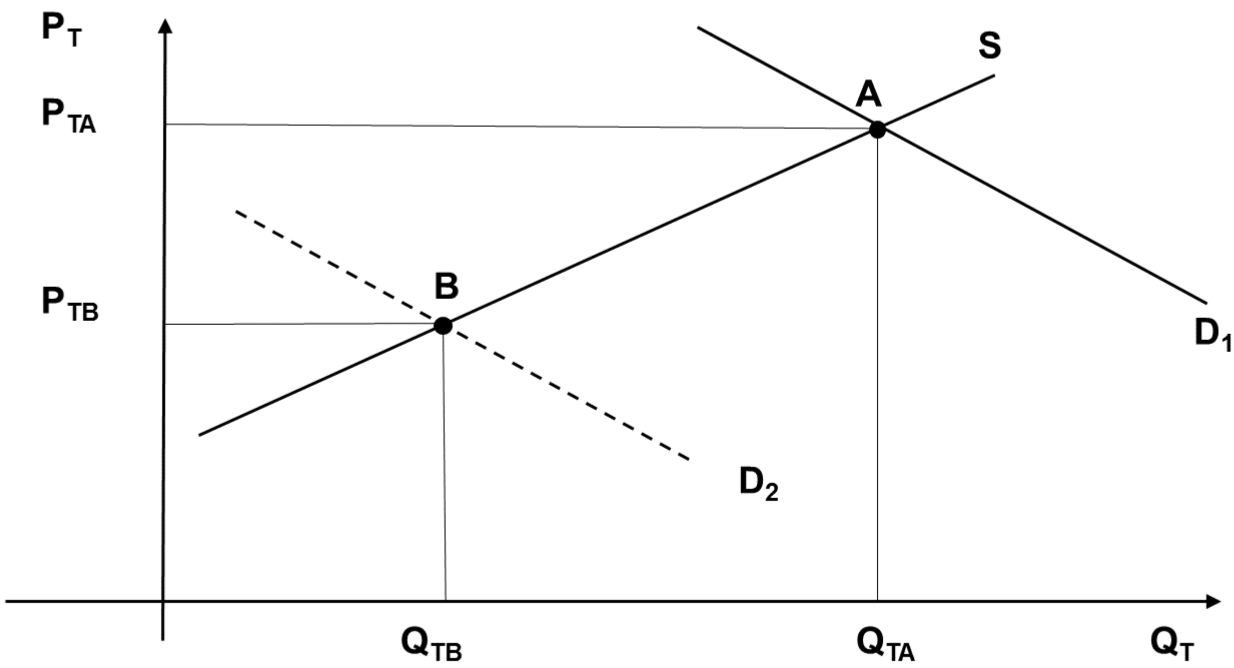
(12) $(P_Y)_{t=1} > (P_Y)_{t=2} > (P_Y)_{t=3}$

The fall of the price of the innovated goods has the direct consequence to lowering not only the price-cost margins of innovators so as to undermine their incentives to innovate, but also the position of the derived demand for knowledge.

In the market for knowledge imitation externalities engender the downward shift of the demand for knowledge, well below the equilibrium levels that would take place if knowledge were a standard economic good, and no changes in the knowledge supply. The combined effect is the well-known Arrovian market failure with knowledge quantity and price far below equilibrium levels.

Figure 2 provides a graphic exposition of the analysis.

FIGURE 2. THE APPROPRIABILITY TRADE-OFF WITH IMITATION EXTERNALITIES



Intra-industrial spillovers engender the reduction of the market price of innovated goods and hence the downward shift of the intertemporal derived demand for knowledge (D) from D_1 to D_2. D_1 and S_1 represent the Arrovian benchmark of the intertemporal derived demand of knowledge if it were a standard economic good. The effects of imitation externalities on knowledge costs are negligible and are not taken into account for the sake of clarity: the supply schedule does not shift. The consequences are clear. The equilibrium quantity of knowledge supplied by the competitive market place shrinks from Q_{TA} to Q_{TB}. The equilibrium price of knowledge also shrinks from P_{TA} to P_{TB}. The Arrovian postulate clearly holds: the system is unable to produce the correct amount of knowledge.

The economic obsolescence of knowledge “ready to be used as such” is quite high. New vintages of knowledge are generated and reduce the possibility of taking advantage of knowledge spillovers. Imitation externalities are fully consistent with the Arrovian analysis.

5.2.2 KNOWLEDGE EXTERNALITIES

Let us now consider the case of knowledge externalities. External knowledge spilling from third parties is not “ready-to-be-used-as-such”. Knowledge spills from firms active in other industries and can be used only as an input in the generation of new technological knowledge. It does not enter the technology production function but the knowledge generation function. The recombinant generation of knowledge relies on the access to the full stock of existing knowledge. Thee conomic obsolesescnce of "knowledge as an input" is limited.

Let us now include, next to the technology production function (1), the knowledge generation function, where T is the flow of technological knowledge, R&D are research and development activity and a is its output elasticity, L accounts for learning and b is its output elasticity,□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□c□□□□□□□ □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ir□□□□□□□ □□□□□□□□□□□□□□□□□□□□□□□

(13) T = R&D□□ L□□ □□□c□□□T□

External knowledge has a cost of absorption >0, that is, however, far below the levels of the cost of a knowledge input with all the characteristics of a standard economic good. The access to external knowledge enables to produce a larger amount of output T with a given budget.

Technological knowledge generated, at low costs, upstream in the knowledge generation function, enters in the downstream technology production function (1).

The cheaper knowledge, available at costs that are below equilibrium levels, enables to increase the levels of total factor productivity in the production of all the other goods (Y).

In the markets for knowledge the effects of knowledge externalities consists in:

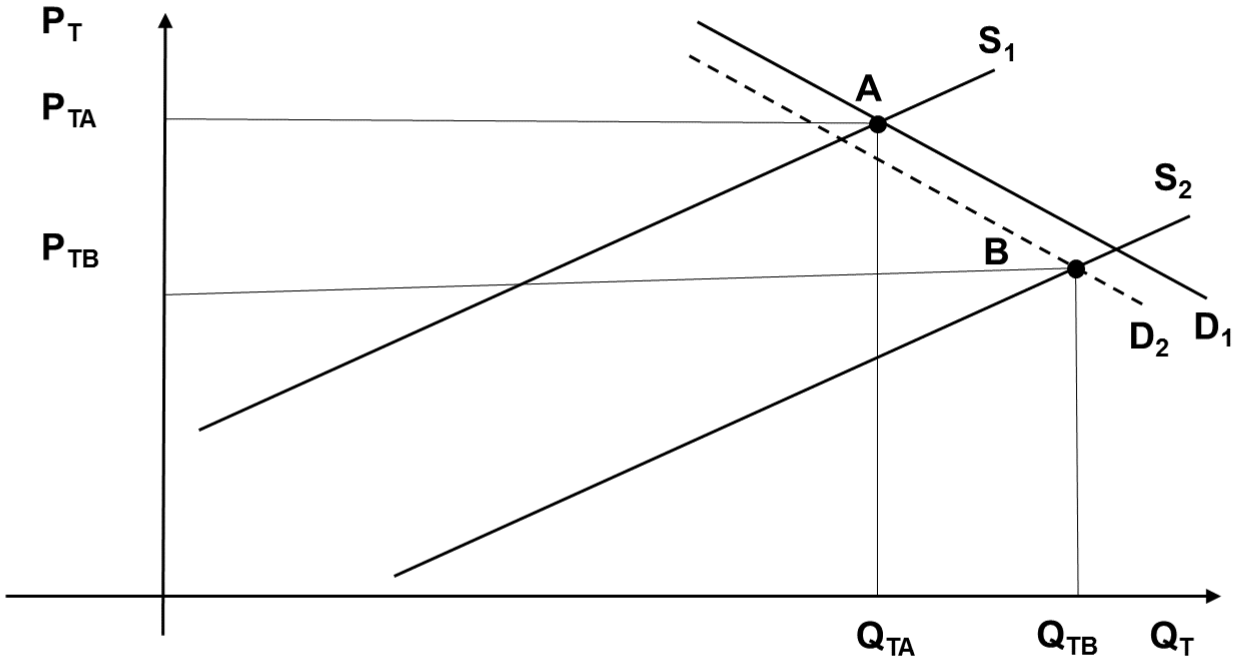
i) the reduction of knowledge costs and consequently the downward shift of the knowledge supply schedule.

ii) a small downward shift of the schedule of the derived demand for knowledge that would be lower than it would had taken place if knowledge were a standard economic good. Knowledge externalities engender in fact a small reduction of the price of goods produced with the cheaper internal knowledge.

The combined effect is an increase of the quantity of knowledge far larger than it would take place if knowledge were a standard economic good. The price of knowledge is lower than in equilibrium. The low price of knowledge has in turn positive effects in terms of total factor productivity: the costs of a key input such as knowledge are lower than in equilibrium.

Figure 3 provides a graphic exposition of the analysis.

FIGURE 3. THE APPROPRIABILITY TRADE-OFF WITH KNOWLEDGE EXTERNALITIES



As in Figure 1, S_1 and D_1 represent the Arrovian benchmark of respectively the supply and the intertemporal derived demand of knowledge if it were a standard economic good. Inter-industrial spillovers engender only a minor reduction of the market price of innovated goods so that the downward shift of the intertemporal derived demand for knowledge from D_1 to D_2 is negligible. The effects of imitation externalities on knowledge costs are strong: the supply schedule shifts from S_1 to S_2. The consequences are clear. The equilibrium quantity of knowledge, supplied by the competitive market place, increases from Q_{TA} to Q_{TB}. The equilibrium price of knowledge also shrinks from P_{TA} to P_{TB}. The Arrovian postulate clearly does not hold: the system is actually able to produce a large amount of knowledge at low prices, larger than it would take place if it were a standard economic good. Knowledge is “better” not “worst”, than standard goods.

The distinction between imitation and knowledge externalities is quite relevant as it enables to articulate the analysis of the implications of both the (limited) appropriability and exhaustibility of knowledge. Imitation externalities, stemming from knowledge ready-to-be-used and hence characterized by high levels of economic obsolescence, tilt the appropriability trade-off in favor of the Arrovian postulate. Knowledge externalities, stemming from knowledge as a necessary input in the recombinant generation of knowledge and hence with low levels not only of physical but also economic obsolescence, tilt the appropriability trade-off against the Arrovian postulate. The net level of imitation externalities is negative as their positive effects in terms of reduced knowledge costs are not able to balance the negative effects in terms of missing incentives to the generation of knowledge. Knowledge externalities, on the opposite, engender large net positive externalities. Their positive effects in terms of reduced knowledge costs are larger than their negative effects in terms of downward shift of the derived demand for knowledge.

The implications for knowledge policy are important.6. IMPLICATIONS FOR KNOWLEDGE POLICY

Knowledge policies have been heavily influenced by the large consensus about the Arrovian knowledge market failure. The analysis of the negative economic consequences of the limits of knowledge as an economic good has been implemented for several decades and provided the base for an articulated set of economic policies aimed increasing the incentives to the generation of knowledge deemed to be insufficient.

The cornerstones of the knowledge policy that stems from the hypothesis of a generalized knowledge market failure due to the limited appropriability of knowledge, are: i) the public support to the generation of knowledge by means of the supply of scientific and technological knowledge with the creation of a public infrastructure including academia and specialized public research centers and the provision of public subsidies designed to reducing the costs of knowledge generating activities so as to balance the negative effects of the persistent limited appropriability of proprietary knowledge even after the protection provided by patents; ii) the public support to knowledge exploitation with the implementation of the intellectual property rights regime designed to increase the natural appropriability of knowledge Let us analyze them in turn.

5.1 THE PUBLIC SUPPORT TO THE KNOWLEDGE GENERATION.

The evidence shows that automatic public subsidies granted to R&D activities performed by private firms yield only a limited increase of the R&D actually carried out. A large literature confirms that the additionality of public R&D subsidies -measured by the ratio of additional R&D activities actually carried out the public subsidy - is below 100%. When additionality is <1 public subsidies reduce the cost of research performed by firms but increase the actual size of the stock of quasi-public knowledge that yields spillovers to a limited extent. An important share of public subsidies substitutes internal funds with a crowding out effect (David, Hall, Toole, 2000). When instead additionality is >1, public subsidies perform two crucial functions: i) do help reducing the costs of private research, and ii) do help increasing the actual flow of knowledge spillovers.

The results of the analysis carried on so far question the generalized application of the standard Arrovian framework and its strong implications in terms of knowledge policies. The limited exhaustibility of knowledge yields positive effects that may compensate and occasionally overcompensate the negative effects of its limited appropriability. The consideration of the dual role of knowledge spillovers as the cause of the reduction of the benefits that the 'inventor' can appropriate and yet an essential facility indispensable for the recombinant generation of new knowledge (Antonelli, 2007) and a cause of the knowledge externalities that help reducing the costs of new knowledge so as to compensate for the negative effects of the limited appropriability confirms the need of a new knowledge policy framework (Antonelli, 2017a and b).

The actual increase of the amount of R&D expenditures carried out by firms matters as soon as the effects of the limited exhaustibility of knowledge in terms of the long term accumulation of a stock of knowledge with beneficial effects on knowledge costs. This dynamics is all the more relevant when the positive effects of the limited appropriability of knowledge are considered. The knowledge externalities stemming from knowledge spillovers benefit all the system. Hence the larger are the flows of R&D activities at each point in time and the faster the accumulation of the quasi-public stock of knowledge, and the larger the amount of knowledge externalities that become available.

This calls for a new policy framework able to take into account the joint effects of both the limited appropriability and exhaustibility of knowledge. The provision of public subsidies to R&D activities and the intellectual property right regime should be differentiated so as to take into account the intrinsic heterogeneity of knowledge and the full array of outcomes of the varying levels of appropriability and exhaustibility.

The additionality of public subsidies to R&D activities of the firms that receive the subsidy becomes relevant as soon as the appropriability trade-off, augmented by the limited exhaustibility of knowledge with its long terms positive effects on the knowledge generation function and hence on knowledge cost, in terms of knowledge externalities, are taken into account. R&D subsidies, in fact, benefit not only the recipient firm that is compensated of the negative effects of the limited appropriability of knowledge, but the whole system provided that the subsidies yield positive effects in terms of additional volumes of R&D activities and hence additional flows of spillovers and consequent increased levels of knowledge externalities.

The level of additionality can be defined in terms of the ratio of the increase in absolute levels of the R&D expenditures of the recipient firm i to the amount of public subsidies (SUB) received by the same firm.

According to the results of the analysis carried out so far the additionality requirement can be defined strong when the levels of additionality should be larger than 1:

(14) $\delta R\&D_i/SUB_i>1$

or weak, when lower than 1:

(15) $\delta R\&D_i/SUB_i<1$

According to the actual levels of appropriability -and related knowledge spillover with the consequent reduction of revenue for inventors as well as increase of knowledge externalities- and exhaustibility, a range of possible additionality requirements can be considered:

i) automatic R&D subsidies with strong additionality requirements should be granted to knowledge items with low levels of appropriability and exhaustibility[6]. The actual increase of R&D activities beyond the levels of public subsidies is an important target to knowledge policy because of the

[6] The granting of public R&D subsidies to the increase of R&D expenditures rather than to their level may reduce the crowding out effects.

long lasting positive effects of the additional knowledge on the increase of total factor productivity at the system level, in terms of additional spillovers.

ii) automatic R&D subsidies with low levels of additionality requirements can be granted to knowledge items with low levels of appropriability and high levels of exhaustibility. The classical Arrovian market failure applies and R&D subsidies do compensate for the missing incentives reducing the cost of private research.

Not only the levels of additionality requirements but also the mix of public interventions should reflect the actual levels of appropriability and exhaustibility. Crowding out, in fact, is less likely to take place when public subsidies target specific research programs. In this case, the State can use the provision of selective public subsidies to effectively influence the levels and the direction of the specific research activities identified according to the public relevance of the research projects that have been submitted by firms. Targeted research subsidies moreover help directing the research activities of a variety of firms so as to increase their compatibility and complementarity helping the dissemination of knowledge spillovers and related knowledge externalities at the system level.

The direct supply of knowledge by means of a public infrastructure consisting of dedicated research centers has indeed played a major role in increasing the supply of knowledge and its dissemination in the economic system especially when and if it has been coupled with dedicated and targeted public interventions especially on the demand side activating the competent demand pull mechanisms, the provision of targeted research incentives and most importantly the active role of state owned enterprises.

As Table 1 shows, the differentiation of public interventions according to the levels of knowledge appropriability and exhaustibility should include also the structure of intellectual property right regimes with the introduction of knowledge-specific rather than industry-specific patents.

5.2. THE PUBLIC SUPPORT TO KNOWLEDGE EXPLOITATION

The public support to knowledge exploitation is based upon intellectual property rights (IPR) and specifically on patents. Patents had been introduced first in the late XV century by the Republic of Venice to attract craftsmen from the Middle East to Venice. The economics of knowledge rationalized, ex-post, their role as an effective institutional remedy that is necessary to reduce the negative effects of the limited appropriability of knowledge. The current regime of IPR is based upon homogeneous patents characterized by absolute exclusivity.

There is no differentiation of patents across types of knowledge. The very same patent applies to the full spectrum of types of knowledge. Patent holders have the right to exclude third parties from the unauthorized use of their patents. Patent holders may decide to license their patents and receive a royalty from the users, but they are not obliged to license. They may retain the exclusive right to use the knowledge until the patent expires.

The exclusivity of the current IPR regime has been criticized for the high risks of anticommons (Heller and Eisenberg (1998). The barriers and delays to the use of proprietary knowledge stemming from exclusive IPR increase knowledge appropriability and hence the incentives to its generation, but reduce the general efficiency of the generation of knowledge. Exclusive IPR induce firms and inventors to duplicate research effort and to invent around. In the extreme cases, exclusive IPR impede the use of an essential facility that cannot be reproduced and stop the advance of technological knowledge. New technological knowledge, in fact, is the result of the recombination of existing knowledge (Antonelli, 2007).

The current intellectual property right regime together with high transaction costs in the markets for knowledge and excess expectations of patentees regarding the value of their knowledge assets produce a fragmented knowledge landscape where owners of small complementary bits of knowledge are unable to participate in the collective effort that is needed to generate new knowledge as an output while using existing knowledge an input (David and Hall, 2006).

At the same time it is clear that patents perform an essential role in the knowledge economy as they provide indispensable information about the progress in the frontiers of knowledge. The alternative to patents is secrecy: firms and inventors would try and keep their knowledge secret so as to reduce the risks of uncontrolled leakage. Secrecy has strong negative effects in terms of missing information about the advances of knowledge and may actually increase the amount of resources wasted in the duplication of research efforts.

The classical argument in favor of the introduction of differentiated patents rests upon the analysis of the types of market forms of the different industries (Gilbert and Shapiro, 1990). Patent terms should be industry-specific: shorter the more intense is competition, the higher the productivity of R&D activity and the more intricate the reverse engineering (Mosel, 2011). The appreciation of the intrinsic heterogeneity of knowledge enables to explore the introduction of knowledge-specific patents according to their levels of 'natural appropriability' and exhaustibility.

The literature that has concentrated its attention on the optimal breadth and length of patents, has not explored the possibility of different levels of exclusivity. The introduction of patents with both compulsory licensing and royalties enables to explore the possibility of varying levels of exclusivity as a second layer of differentiation of patents.

TABLE 1. TYPES OF KNOWLEDGE AND TYPES OF KNOWLEDGE POLICIES

	LOW EXHAUSTIBILITY	HIGH EXHAUSTIBILITY
HIGH APPROPRIABILITY	-SHORT TERM PATENTS WITH WEAK EXCLUSIVITY -AUTOMATIC R&D SUBSISDIES WITH STRONG ADDITIONALITY REQUIREMENTS -TARGETED R&D PROGRAMS	

	- DIRECT SUPPLY OF KNOWLEDGE	
LOW APPROPRIABILITY		-LONG TERM PATENTS WITH STRONG EXCLUSIVITY -WEAK ADDITIONALITY REQUIREMENTS

The design of a differentiated intellectual property right regime, based upon knowledge-specific patents, should take into account the actual levels of exhaustibility and natural appropriability of the knowledge items and affect not only the length of patents but also their exclusivity. It is necessary, in fact, to pay attention not only to the negative effects of spillovers in terms of reduced incentives, but also the positive effects of knowledge externalities and of the limited exhaustibility of knowledge. The exclusivity of intellectual property rights has negative effects in terms of reduction of knowledge externalities that stem from the delays to the access to knowledge. It is possible to modulate exclusivity according to the levels of royalties associated to compulsory licensing. In such an intellectual property regimes knowledge-specific patents are characterized by compulsory-licensing-cum-royalties. Intellectual property rights are no longer exclusive: licensing is compulsory, but not free (Antonelli, 2013). The levels of the royalties define the levels of de-facto exclusivity. High level royalties imply strong de-facto exclusivity. Low level royalties imply weak de-facto exclusivity. Intellectual property right regimes characterized by high exclusivity should not be granted to knowledge items characterized by low levels of exhaustibility for two strong reasons: i) low exhaustibility compensates already the negative effects of low appropriability, ii) exclusive property rights for knowledge items with low levels of exhaustibility have large opportunity costs at the system level as they limit and delay the knowledge spillovers and hence the access to knowledge externalities and the recombinant generation of new knowledge (Antonelli, 2017a and b).

The design of differentiated intellectual property rights in terms of both terms and exclusivity levels should be implemented according to the intrinsic heterogeneity of knowledge in terms of both natural appropriability and exhaustibility with the introduction of knowledge-specific patents:

i) Short-term patents with weak exclusivity that should be granted to knowledge items characterized by low exhaustibility and high natural appropriability; and

ii) Long-term patents with strong exclusivity that can be confirmed only to knowledge items with high levels of exhaustibility and very low levels of natural appropriability.

The differentiation of the IPR regime can be further implemented by the analysis of the distinction between intra-industrial spillovers and imitation externalities and inter-industrial externalities and knowledge externalities. The use of patents to remedy the negative effects of the limited appropriability of knowledge is an effective tool to increase the amount of knowledge generated in a system that is much more effective in the case of intra-industrial spillovers that engender imitation externalities, rather than in the case of inter-industrial spillovers that engender knowledge externalities.

The positive effect of patents, in fact, consists in the impediment to the entry of imitators in the very same industry. Patents help contrasting the Arrovian knowledge market failure as they create a legal monopoly that enables inventors to extract the expected quasi-rents from the exploitation of their knowledge and re-establish the appropriate levels of incentives to the generation of knowledge. As far as intra-industrial spillovers and hence imitation externalities are concerned, the negative consequences of patents, in terms of delayed use of an essential facility are compensated by the positive effects in terms of augmented knowledge appropriability and hence incentives to its generation.

The negative consequences of exclusive IPR are much stronger for inter-industrial spillovers than for intra-industrial ones. The positive effects of patents are not sufficient to compensate the negative ones. Exclusive patents, in fact, limit the use of proprietary knowledge as an input in the generation of new knowledge that applies to other product markets and have no consequences in terms of augmented knowledge appropriability and hence incentives to its generation, but strong negative effects in terms of opportunity costs for the generation of new knowledge. Because of the exclusivity of patents, the recombinant generation of new knowledge cannot access existing knowledge as an essential facility.

The clear implication of this line of analysis consists in the suggestion to abandon homogeneous IPR and to differentiate the IPR regime with the introduction of knowledge specific patents. The new suggested IPR regime is based on knowledge specific patents where the use of knowledge acts as the discriminant factor. It is possible to distinguish two types of patents:

i) exclusive patents that apply to intra-industrial spillovers. Rivals and competitors in the same product market cannot use proprietary knowledge patented without the authorization of patent holders that retain exclusive intellectual property rights on their knowledge.

ii) non-exclusive patents characterized by compulsory licensing that apply to inter-industrial spillovers. Perspective users of proprietary knowledge as an input for the generation of new knowledge, that enables the introduction of innovations of other product markets, can access proprietary knowledge, provided they pay a royalty to patent holders. The identification of a fair level of royalties is clearly crucial[7].

Inventors can apply for the two types of patents for the very same type of knowledge. Inventors may apply for an exclusive patent so as to increase the appropriability of their proprietary knowledge and impede its imitative use in their product market and for a non-exclusive patent to participate into

[7] According to Antonelli (2013) this is possible with a Cobb-Douglas specification of the knowledge generation function where external knowledge enters as an input next to R&D activities and the stock of internal knowledge. Because knowledge is at the same time the output and an input, the level of royalties has the twin effect to affect both revenues and costs. The levels of royalties and hence the price of knowledge affects directly the revenue. The very same level of royalties affects the costs of knowledge as an input. In such a knowledge generation function standard substitution –albeit limited by substantial complementarity- between the three basic inputs implies that the changes in their cost affect total and average costs with non-linear effects. All changes in the price of knowledge have, instead, linear effects on the revenue. It is consequently possible to identify an optimum price of knowledge and use it to implement the working of compulsory-licensing-cum-royalties.

the benefits of its recombinatory use as an input to generate other knowledge, in terms of royalties.

6. CONCLUSIONS

The analysis of knowledge as an economic good is a fertile and promising field of investigation. Knowledge has several idiosyncratic properties that deserve all to be identified and explored in detail. Their implications and consequences are most important and need to be considered all together. The economic literature has paid much attention to a sub set of the broader bundle of knowledge idiosyncratic features. Attention has been attracted primarily if not exclusively by its limited appropriability, its non-rivalry in use, the sharp difference between generation and reproduction costs. The selection of these features has led to a substantial consensus about the limits of knowledge as an economic good and their consequences in terms of market failure.

The exploration of the full range of properties of knowledge as an economic good reveals other important features. Their assessment can complement the analyses based on the limited appropriability of knowledge alone. The identification of the limited exhaustibility as a key intrinsic property of knowledge enables to modify the standard frame according to which knowledge has many shortcomings and weaknesses as an economic good. Actually the ‘discovery’ of the limited exhaustibility of knowledge seems to uncover unexpected merits and strengths of knowledge as an economic good. Such unexpected merits and strengths yield positive effects in terms of dynamic increasing returns that are most likely to increasing -rather than decreasing- the incentives to the allocation of resources to its generation so as to engender extreme cases of augmented knowledge supply rather than undersupply.

The distinction between intra-industrial and inter-industrial spillovers enables to enrich the analysis of the appropriability trade-off. Intra-industrial spillovers engender imitation externalities that consist in the direct access of competitors and rivals, in the same product market, to proprietary knowledge ready-to-be-used as an input into their technology production function. Imitation engenders the entry of new suppliers and the consequent reduction of the prices of the innovated goods and the fall of the price-cost-margins of inventors. The traditional Schumpeterian argument according to which monopolistic market power for innovated goods is transient and yet positive in terms of welfare is based upon intra-industrial spillovers and applies to imitation externalities. Monopolisitc extra-profits are doomed to decline because of imitation and yet yield strong incentives to the generation of new knowledge. The Arrovian postulate, according to which the limited appropriability of knowledge is at the origin of a major failure of competitive markets for the lack of incentives to the generation of knowledge applies clearly to imitation externalities. The analysis of the approrpiability trade-off shows that the negative effects of imitation externalities are larger than the positive ones.

The Schumpeterian-Arrovian argument does not apply to knowledge externalities. Knowledge externalities have been identified only in a second step and they can be regarded as a major advance of the economics of knowledge. The identification of knowledge externalities stems from the analysis of the generation of knowledge. The generation of knowledge is an explicit economic activity where knowledge is at the same time an input and an output. The generation of knowledge in fact consists in the recombination of existing knowledge items. The access to knowledge generated by third parties plays a central role in the recombinant process. Existing knowledge is an essential facility. Knowledge spilling from third parties cumulates into a stock of quasi-public knowledge that firms try and use as an input. Knowledge externalities stem from the difference between reproduction and access costs. The positive effects of knowledge externalities consist in the reduction of knowledge costs and hence in the downward shift of the knowledge supply schedule. The negative effects in terms of reduction of the price of innovated goods in the original product market, and hence missing appropriation and fall of incentives, are negligible. The analysis of the appropriability trade-off shows that the positive effects of knowledge externalities in terms of above equilibrium supply of knowledge and below-equilibrium knowledge prices are far larger than their negative ones.

The appreciation of the sharp difference in the outcomes of the appropriability trade-off between intra-industrial and inter-industrial spillovers and consequently between imitation and knowledge externalities has important implications for the current regime of intellectual property rights. It seems necessary to overcome the limits of the homogeneous patent system based on the exclusivity of the knowledge property assigned by patents and to move towards a differentiated regime of intellectual property rights based upon knowledge specific patents.

It seems necessary to limit the application of current exclusive patents to intra-industrial spillovers. Patents holders retain the right to exclude competitors and rivals from the uncontrolled use of their proprietary knowledge ready-to-be used in their technology production functions.

The use of proprietary knowledge as an input in the recombinant generation of new knowledge should not be impeded. Compulsory licensing should apply for all uses of proprietary knowledge to generate new technological knowledge and introduce innovations in other industries and other product markets. The definition of fair royalties can be implemented with the provision of detailed information on R&D costs incurred by inventors. Users have the right to use proprietary knowledge as an input, provided they inform patent holders and pay them a fair royalty.

These results call for the implementation of a new framework for knowledge policy aimed at: i) increasing the additionality of R&D subsidies so as to foster the rates of accumulation of the stock of quasi-public knowledge and ii) limiting the exclusivity of intellectual property rights so as to fostering the dissemination of knowledge in the system and reducing its costs of access and use.

The systematic and generalized provision of exclusive intellectual property rights and automatic public subsidies to the generation of all kinds of knowledge, irrespective of their actual levels of exhaustibility and appropriability should be reconsidered. The heterogeneity of knowledge in terms of varying levels of exhaustibility and appropriability should be operationalized to design a differentiated set of knowledge policies.

The public support based on automatic subsidies to the generation of knowledge characterized by very low levels of appropriability and high exhaustibility seems appropriate because of the high risks of Arrovian market failure. The reduction of the cost of knowledge generation is necessary and the additionality requirements can be weaker. The public support to both the generation of knowledge characterized by low levels of exhaustibility and high levels of natural appropriability should be reconsidered. In this case the additionality requirements of public subsidies to R&D activities should be strong. Targeted subsidies should play a stronger role in the mix of public interventions. The selective rather than automatic support to the generation of knowledge characterized by very low levels of appropriability and high exhaustibility seems necessary in order to contrast pervasive crowding out effects.

The differentiation of intellectual property rights with the introduction of knowledge-specific patents with varying terms and levels of exclusivity should be implemented so as to take into account the intrinsic heterogeneity of knowledge in terms of levels of appropriability, with their twin positive and negative effects, and exhaustibility. Short-term patents with weak exclusivity should be granted to knowledge items with low levels of natural appropriability and high low exhaustibility. Standard patents with long terms strong exclusivity should be used for knowledge items with low levels of natural appropriability and high levels of exhaustibility.

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