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Abstract

The aim of the paper is to discuss and to provide evidence for the existence of pecuniary knowledge externalities, considered here as the main cause of positive disequilibrium experience by downstream producers. This last effect, confirmed by the empirical analysis here performed, contrasts the postulates of the model of growth through creative destruction due to Aghion & Howitt (1992), where downstream producers remain very much passive in front of new technological knowledge externally generated.

Keywords: pecuniary knowledge externalities, endogenous growth, creative destruction, Input-Output

1. Introduction

A high uncertainty accompanying innovative activities has been extensively recognized in the incumbent economic literature so far. The low probability of success of the research activity, relatively long time periods over which the innovative results are to be expected, the uncertainty triggering the implementation of inventions, and their transformation into innovations, as well as the manifold risks coming from the competitors operating in the innovative environment - all these elements contribute to a nontrivial nature of innovative activity. Moreover, the unpredictability of the results of innovations makes it difficult to accept the study of the process in a standard framework of maximization. The argument has been recently treated by Antonelli and Scellato (2008). They develop the concept of creative reaction as a set of conditions including incentives and opportunities necessary to provide an appropriate environment for intentional decision-making. The last element, instead, is the generating power of new knowledge, and consequently, of new technologies. Most importantly, the aforementioned necessary conditions for the creation of novelty appear on the out-of-equilibrium path.

Extending further the complexity argument, a more general view of the innovation process leads to consider spillovers accompanying the exchange of knowledge between producers. A general distinction between pecuniary and technological externalities has been widely accepted in the incumbent theoretical discussion. In particular, in the field of the new growth theory and in the theory of location of innovative activities across space, the existence of external effects in an innovative context has been illustrated as a free of charge benefit deriving from the generation of new knowledge. These technological externalities derive from a direct interaction between producers, as opposed to pecuniary externalities which require the price system in order to exert their indirect, i.e. market mediated influence.

Nevertheless, these two kinds of well-known and extensively discussed externalities do not fully exhaust the whole spectrum of effects occurring when new knowledge is generated and made available to the market. Often undervalued here is the fact that new technological knowledge obtained from external sources by downstream producers is implemented in the further generation of knowledge and eventually in the production of goods by means of dedicated activities. In that process of knowledge implementation downstream users experience an externality permitting them to exploit externally generated knowledge at favorable cost conditions. This effect, labeled as pecuniary knowledge externalities, is put on the focus of the present theoretical discussion and its evidence is studied in an empirical exercise regarding the European economy.

More precisely, the concept is confronted with the main results of the model of growth by Aghion and Howitt (1992) and in that way it introduces an important element into the analysis of the existence of equilibrium conditions postulated in the model. The occurrence of pecuniary knowledge externalities implies that downstream producers - inherently passive in the model by Aghion and Howitt - thanks to the new productive possibilities created with the implementation of external knowledge, generate further innovations. As a result, the perceived positive TFP dynamics destabilizes equilibrium conditions and the steady state growth postulated by Aghion and Howitt.

The analysis conducted here is organized as follows. Section 2 reviews the assumptions, the main results and the empirical treatment offered so far to the model of growth through creative destruction by Aghion and Howitt (1992). Moreover, the definition of pecuniary externalities is recalled from the seminal work of Scitovsky (1954). Finally, the concept of pecuniary externalities will be adequately restricted to the case in which these effects provoke repercussions in the decision to give rise to the new internal technological knowledge generated downstream with the implementation of the external sources of knowledge. For this reason the concept of pecuniary knowledge externalities will be introduced. Section 3, dedicated to the empirical analysis, describes the methodology, presents the data and comments on the results. The last section summarizes the results of the empirical model in the view of the theoretical motivation.

2. Theory and motivation

The evolution of the growth theory starting from the second half of the XX century brought a considerable passage from exogenous growth models, in which an economy is supposed to grow only in the short run according to parameters changing outside of the model, to models of growth based on mechanisms of long run growth endogenously determined.

The main reason why neoclassical models were not able to endogenize the growth process is the assumption of constant returns to scale and decreasing returns to each factor.

This assumption was gradually removed by means of a wider definition of capital, including human components, to which diminishing returns weren´t applied any more. However, the pure redefinition of capital was still an insufficient improvement in this sense, as technological change continued to be assumed fixed and given exogenously. Only subsequently, the possibility to generate new ideas inside the research sector permitted for a satisfactory endogenization of the state and progress of technology into the growth process. This appeared as a more powerful method of escaping from diminishing returns to scale than it was in the case of a pure re-definition of capital. Nevertheless, some conceptual problems, regarding in particular nonrival nature of new knowledge, were still hampering this new line of treatment. Finally, the contribution of Romer (1990) and Aghion & Howitt (1992) introduced some elements of imperfect competition, permitting in that way to construct a satisfactory model of growth with endogenous technological change.

The model of growth through creative destruction by Aghion & Howitt (1992) is based on vertical interactions between producers. In that way upstream producers benefit from new ideas generated in the research sector and use them to produce innovative intermediate goods which are subsequently supposed to replace the old inputs in the production of final goods. Finally, as these intermediate goods are employed in the process of production of the final goods, technological progress is transferred in the way to influence the economy at large. The introduction of novelties, their transformation into a productive result upstream and the implementation of innovative inputs in the production process downstream is, ultimately, considered as the exclusive source and explanation of economic growth at the system level. This functioning of the filiéré, where successful innovations push the old solutions out of the market, has been based on the process of creative destruction, first introduced and described by Schumpeter (1942).

In their book on the economics of growth published in 1998 Aghion & Howitt discuss several shortcomings of the model, regarding in particular the assumption on the scaled-up structure of the economy, the description of knowledge as the parameter *A*, the disregard towards institutions and transaction costs, the way of representing the research sector. The general structure and the dynamics of the model remain very much the same with no further consideration over the possibility that some external effects may hamper the stability of the model.

As it has been mentioned before, as an important consequence of the generation of knowledge implies in the model by Aghion and Howitt innovative producers absorb new technologies at no cost and so benefit from technological externalities. Moreover, as argued by Antonelli (2008) the model comprises also the occurrence of pecuniary externalities, where innovative intermediates are offered to the final good producers at a price lower than in equilibrium. Nevertheless, in such a context downstream producers remain passive players and do not experience further consequences on their innovativeness. If, instead, we assume that downstream producers implement this externally generated technological knowledge in an internal process of knowledge generation, this offers a space for a further category of externalities, namely, pecuniary knowledge externalities (PKE). Consequently, through the influence on the growth rate of TFP downstream, the appearance of PKE may considerably change the main steady state results of the model.

In particular, it has been often argued that the growth rates of TFP are interdependent between sectors[1]. Here, we argue that these dependences go through intermediate goods transactions, registered in Input-Output tables. These intermediate transactions enable downstream producers to acquire innovative inputs and thus incorporated in them externally generated knowledge. Downstream producers enjoy not only a better quality of production inputs, but they react creatively in front of this external source of knowledge, but implement it internally by means of dedicated activities of learning and of interacting with upstream innovators. In this process of implementation, downstream knowledge users experience an externality, namely, pecuniary knowledge externality, as the costs necessary to adapt new knowledge from external sources are lower than the equilibrium conditions would imply in case knowledge would possess characteristics of a normal economic good. In that way, downstream professional users become innovators themselves. This appears as a new element in the context of the modern growth models: the operating of PKE brings a radical change of downstream producers innovativeness and this new source of dynamics is likely to provoke instability in the steady state equilibrium postulated in the growth models so far.

[1] For a survey of the relevant literature, see Nadiri (1993).

2.1. Pecuniary versus technological externalities

The initial contribution of Meade (1952) has been recognized as a crucial and decisive point of departure for the further development of economic thinking in the area of external effects. His original analysis concerned the distinction between externalities that are generated by "unpaid factors" and those that instead raise due to "creating atmosphere". However, Meade himself justified only partly any further extension of the concept, by saying that "external economies or diseconomies may not fall into either of these precise divisions and may contain features of both of them." Nevertheless, the discussion that followed his original contribution pointed out the importance of the distinction between technological and pecuniary externalities. Following this line of theoretical discussion, the main definitions due to Scitovsky (1954) concerning both technological and pecuniary externalities will be recalled. The crucial need in this sense will be to depict a clear conceptual distinction between the two. This is essential in order to introduce in a second step a new concept of externalities, namely, pecuniary knowledge externalities. It will be stressed that their influence might have important consequences on the results postulated in the model of growth through creative destruction.

In general terms, external effects, positive or negative, will occur in all these instances, in which the activity of one firm[2] is influenced, directly or through market mechanisms, by another firm or a group of firms. This formulation is applicable, both to technological and pecuniary external economies, as both are related to all these effects that a firm does not experience exclusively due to its individual activity.

In technical terms, following the definition given by Meade (1952), external economies occur when circumstances external to the firm operate in the way that the productive result of a firm, say (y_1), depends not exclusively on the factors employed in the process of production and proper to that firm (x_1), but also on the output generated (y_{-1}) and factors used (x_{-1}) by the other firms. Analytically, this can be written

$$y_1 = F(x_1; y_{-1}, x_{-1}) \tag{1}$$

[2] The discussion is related to firms. However, without loss of generality, the definition of external effects may be applied to any other group of economic actors, consumers and governmental institutions as well.

where F is the production function. According to Scitovsky, the definition just recalled is strictly related to the concept of direct interdependences among producers, which in the convincement of Scitovsky are the only ones compatible with the theory of general equilibrium. Indeed, the main feature of direct interdependences, analogously to the definition of Meade, is that the productive result of individual producer, except for the dependency from his own inputs, may be influenced by the activity of other firms. Going further, because the effects of the influence are to be observed on the production function, Scitovsky attribute them the label of "technological external economies".

Originally, the concept of technological externalities - and the parental concept of knowledge spillovers - builds on the Marshallian description of dynamic interactions occurring in industrial districts where technological knowledge is a production input spilling freely in the atmosphere. Communication, transaction and implementation costs arise neither in the acquisition nor in the use of knowledge and no market mechanism is required in order to make it available to the users. Moreover, once new knowledge is generated, it circulates in the production system without implying interactions between knowledge producers and knowledge users. Such a view of knowledge as a public or quasi-public good has been applied in the methodological work by Griliches (1979, 1992) and adopted in the most influential models of the new growth theory (Romer, 1990; Aghion and Howitt, 1992; Grossmann and Helpman, 1995; Jones, 1995).

Opposing this notion of externalities, Scitovsky defines another category of external effects, the so called pecuniary externalities. He starts by observing that, generally, external effects have been often invoked in the theory of industrialization of underdeveloped countries as a complementary part to the equilibrium assumptions. In other words, externalities has been treated as a residual collection of all these cases in which the applicability of the conditions for an optimum allocation of investment funds in a wider context of imperfect competition has been difficult to maintain. The lack of a formal treatment in this context has been repaired by Scitovsky who managed to infer from available examples and discussions a rigorous definition of externalities, in which the category of pecuniary externalities is conceptually included.

According to Scitovsky, externalities are met whenever the profits of a producer result not only from his individual activity, but are also affected by actions of other producers. In analytical terms, this can be written in the following way

$$P_1 = B(y_1, x_1; y_{-1}, x_{-1}) \quad (2)$$

where P_1 expresses profits of a firm that are influenced not only by its own output (y_1) and inputs (x_1), but also by the output (y_{-1}) and inputs (x_{-1}) of other firms.

This definition of externalities is an even broader version of the definition due to Meade, as it includes both direct and indirect interdependences between firms. The relevant difference lays in the nature of the mechanisms driving these effects. While in the first case, interdependences directly affect production functions via technological spillovers between firms, on the contrary, the indirect interdependences are supposed to occur through mechanisms external (and so indirect) to the productive activities of the firm, and in particular these mechanisms that are driven by the market. This last type of indirect interdependences, giving raise to changing profitability results of the producer, is commonly recognized to be the cause of pecuniary externalities. The most common market mechanism that we can think about in this context is the price system.

In more practical terms, if an investment in an industry - or in a single firm - constitutes a source of improvement of its productive capacities and through the usual market mechanisms this new technological improvement implicitly or explicitly is integrated as a part of transactions, this will likely cause pecuniary effects. In the first place, the opportunity created by a convenient acquisition of innovative intermediate inputs will have obvious effects of reduction in production costs of the producer. Consequently, this improvement of the productive capacity will ultimately lead to lower output prices and thus will result in benefits for industries using the output as an intermediate input in their production as well as for the final consumers. Here the list of potential chain effects and actors influenced by pecuniary effects is not exhausted: an improvement of the productive capacities of an industry may have further positive vertical or horizontal effects, i.e. effects experienced by an industry producing complementary goods, or by an industry producing a substitute good with respect to the innovating industry. The list may be further adequately completed with not rare cases of pecuniary external diseconomies that occur each time a producer, due to imperfect appropriability of technological knowledge, suffers from not remunerated parts of his activity or some aspects of the activity of other producers provoke a harm on his economic results. Liebowitz and Margolis (1994), for instance, provide an example of negative pecuniary effects in which a firm producing an additional unit of output and, thus, marginally lowering price of its product provokes harm on competitive firms. However, this negative effect regards competitors producing substitutive goods, while those supplying a complementary goods, due to demand-driven effects, experience a positive impact. Moreover, the strength and persistence of these spillovers do not need to follow any standardized pattern and will potentially differ according to particular characteristics of each industry. The main point here, however, is not to discuss all possible cases and their extensions, but rather to make it clear that the determinant element classifying an externality as pecuniary is its positive or negative impact on profits (or income) occurring through some market mechanism. In this sense, pecuniary externalities are considered as occurring indirectly, mediated through some mechanism that is external to the production activity and not through interactions that directly concern technical conditions in the production of involved firms.

2.2. Pecuniary knowledge externalities

Having put light on the important differences characterizing both concepts of externalities, pecuniary and technological ones, the central argument in the present theoretical discussion can be introduced. As it has been already mentioned, the phenomenon of pecuniary externalities accompanying the transactions of intermediate goods is by no means incompatible with the model by Aghion and Howitt. Pecuniary effects operate fully in their model each time a successive innovation is incorporated in intermediate production which results in intermediate inputs available at lower costs for the final good producers. Moreover, this effect does not need to provoke any further repercussion on the equilibrium conditions of the entire economy as it is fully internalized before the system reaches equilibrium. Also technological externalities can be observed whenever intermediate producers benefit from newly generated knowledge at no cost.

Nevertheless, in an environment where downstream producers are potentially innovative and maintain vertical linkages based on the exchange of innovative intermediates, one can expect the occurrence of a particular category of pecuniary external effects. These externalities offer a cost opportunity in the internal process of transformation of externally generated knowledge and contribute to a positive TFP dynamics in the downstream sector. For that reason, this particular category of externalities has been accurately labeled with the term of pecuniary knowledge externalities (PKE)[3].

[3] For seminal contributions on PKE, see Antonelli (2007, 2008).

An essential requirement for PKE to occur is thus the availability of externally generated knowledge that can be offered to downstream innovative producers. Generally, there exist several channels, tacit or explicit, through which downstream producers may access new technological knowledge. Patents and licenses are the most popular explicit mechanism of interactions between innovative producers. Moreover, new knowledge can be acquired as a part of intermediate good. Finally, to a certain extent it is also plausible to assume that technological knowledge spills over between producers, disconnected from any market transaction. However, external knowledge, in order to become an input in the downstream generation of further knowledge, has to be assimilated internally by means of dedicated activities of internal learning, external training and other generic or specific interactions with the innovative upstream producer. This means that external knowledge never is a costless input and requires dedicated resources in the process of its implementation and transformation. Nevertheless, thanks to its indivisibility, intrinsic nonexhaustibility and partial appropriability, the actual costs necessary to make use of external knowledge are lower than the market conditions would establish for a normal good transaction. This offers an essential cost opportunity that can be used by the downstream producer in the adaptation of the external knowledge and in the further generation of new knowledge, as well as in the standard production of goods. Consequently, thanks to PKE, the downstream producer becomes an innovator himself and experiences a positive TFP dynamics. This is a new element with respect to what the model of growth by Aghion and Howitt actually predicts. In fact, not only upstream producers are able to generate new technologies, but also the downstream knowledge users deliver their own positive contribution to the growth process.

A simple graphical illustration may further clarify the concept of PKE and non negligible consequences that they work out. Following Antonelli (2007) in the considerations over the production function of knowledge, Figure 2.1 shows that producers affected by positive pecuniary knowledge external effects perceive a smaller inclination of their isocost curve. This would imply that they choose to implement more knowledge from external than from internal sources, in addition to the fact that more internal knowledge would be possible to obtain with the same level of budget resources. This last effect is represented by the fact that the tangency point of the cost curve is achieved in correspondence to a higher isoquant curve. The situation here illustrated refers to the alternative use of external and internal knowledge and as such describes an equilibrated choice of downstream producer between alternative inputs in the knowledge generation process. Nevertheless, such a PKE-motivated choice provokes positive dynamics of the producer's TFP and, if considered inside the model by Aghion and Howitt, would have further implications in terms of positive disequilibrium in the production of final good.

From the above argumentation it becomes intuitive that the presence of pecuniary knowledge externalities fits better in a context of the path dependent disequilibrium, in which a continuous emergence of technological changes under the form of new products, new processes, new organizational solutions, finally, new or changed market mechanisms, replaces the old ones in a process of creative destruction. Each firm, conditioned by pushing competitive impulses, will be forced to promote adjustments, in order either to maneuver the environment in a desired direction or to catch up with occurring changes. In this sense, indisputable seems the fact that "disequilibrium, rather than equilibrium, is the main characteristic of an evolutionary economic system"[4], of which pecuniary knowledge externalities constitute inseparable part.

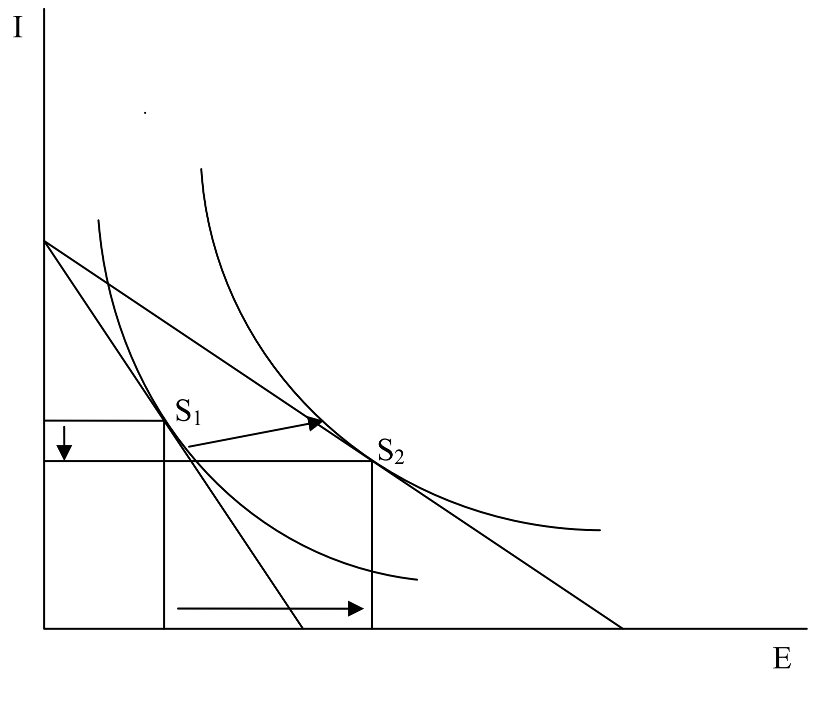

Figure 2.1. *Implications of pecuniary knowledge externalities in terms of the use of internal and external knowledge.*

[4] Chandra and Sandilands (2006).

It should be stressed that all important pecuniary mechanisms discussed so far are supposed to occur and be the stronger the more intensive are the transaction linkages between industries. For that reason, the input-output context seems to be adequate and the most reliable in assessing the impact of pecuniary knowledge externalities. There is no clear direction of causality. From the one side, more intensive intermediate transactions involving innovative inputs motivate downstream users to take advantage of pecuniary external effects in the process of implementation of externally generated new knowledge with the final effect of a positive TFP dynamics. On the other side, the occurrence of pecuniary knowledge externalities, by offering better conditions in the acquisition and exploitation of new knowledge, should provoke more intensive transactions between sectors with a final positive effect on the growth rate of TFP of the downstream producer.

Originally, the attribution of a particular importance to input-output linkages in determining the speed and the direction of economic development has been made in the pioneering contribution by Leontief (1936), later confirmed also by Hirschman (1958). In the recent years, the contribution by Ciccone (2002) was aimed to affirm that the process of industrialization is strongly depending on the adoption of intermediate-input intensive technologies, as in such a situation a small increase in returns at the firm level can translate into a significant result on the aggregate income. Finally, Voigtländer (2008) adopts an input-output approach in order to investigate the role of intersectoral linkages in the process of skill upgrading. His main argument goes through the innovation-skill complementarity *within* sectors, combined with the fact that innovations are transmitted *across* sectors by means of input-output linkages.

3. The empirical model

The empirical exercise here presented is based on a panel estimation that applies the fixed effect method. The aim of the estimation is to affirm the existence of pecuniary knowledge externalities and to assess their role played in influencing the direction of dynamic changes occurring in 25 sectors observed in 14 European economies over two time periods selected from the time interval 1995-2004. The analysis and the results obtained focus on the evidence confirming a significant influence that the growth of TFP registered in upstream innovative sectors exercises on the capacity to innovate experienced by downstream producers. The mechanism driving this influence is mediated by the operating of pecuniary knowledge externalities. In this perspective, the process of intersectoral knowledge transmission is not disconnected from the market relations, as in the case of technological externalities, but is supposed to go through intermediate transactions of innovative inputs.

The next section will present the model. Section 3.2 describes the data used in the estimation, while section 3.3 presents the results and the methodology followed in the estimation procedure.

3.1. The basic set up

The aim of the model is to investigate the existence and the strength of the external effects, having on their basis transfers and implementation of externally generated technological knowledge. These transfers are driven by the intermediate market transactions through which new knowledge from external sources is perceived by the downstream producers who implement it in the process of further generation of knowledge. As a consequence, TFP shows positive dynamics not only upstream, as in the growth models, but also downstream. This mechanism can be represented by the following functional form referring to each downstream sector *i*:

$$\begin{aligned} d(TFP)_{i,k,t} = \beta_1 a_{i1,k,t} d(TFP)_{1,k,t} + \beta_2 a_{i2,k,t} d(TFP)_{2,k,t} + \ldots + \beta_{25} a_{i25,k,t} d(TFP)_{25,k,t} + \\ \gamma d(w)_{i,k,t} + \delta R\&D_{i,k,t} + e_{i,k,t} \end{aligned} \tag{3}$$

or in a compacted form

$$d(TFP)_{i,k,t} = [B]\left[\mathbf{a}_{\mathbf{i,k,t}}\mathbf{d}(\mathbf{TFP})_{\mathbf{j,k,t}}\right]' + \gamma d(w)_{i,k,t} + \delta R\&D_{i,k,t} + e_{i,k,t} \tag{4}$$

where [*B*] is the vector of coefficients and $\left[\mathbf{a}_{\mathbf{i,k,t}}\mathbf{d}(\mathbf{TFP})_{\mathbf{j,k,t}}\right]'$ is the transposed vector of explanatory variables, each given by the product between the expenditure coefficient and the growth rate of total factor productivity for each upstream sector *j*, in country *k*, at time *t*. The expenditure coefficient family, $\mathbf{a}_{\mathbf{i,k,t}}$, with its single expression, $a_{ij,k,t}$, measures the relative importance of acquired intermediate input coming from an upstream sector *j* and directed to a downstream sector *i*, over the total value of the downstream production obtained by the sector *i*. Expenditure coefficients are contemporary to the growth rate of TFP, $d(TFP)_{j,k,t}$, in the sense that for the year, say, 1995 is taken the coefficient from that year, together with the TFP growth rate over the period 1994 – 1995. In this way, it is assumed that innovative inputs are immediately available on the market and can be acquired by downstream users. Two control variables are included, namely, the rate of change of wages in sector *i*, as well as the level of expenditures in research and development[5] in that same sector. These two variables are supposed to control for possible influences on the growth rate of TFP driven by effect that are not considered in the method of calculation of the TFP growth rate, but that may play some role on the TFP dynamics. Indeed, the growth rate of total factor productivity has been obtained from the Thörnquist-Theil Divisia index:

$$\log\left(\frac{A_i(t+1)}{A_i(t)}\right)=\log\left(\frac{Y_i(t+1)}{Y_i(t)}\right)-\left(1-\overline{\alpha}_1(t)\right)\log\left(\frac{K_i(t+1)}{K_i(t)}\right)-\left(\overline{\alpha}_1(t)\right)\log\left(\frac{L_i(t+1)}{L_i(t)}\right) \qquad (5)$$

where $\overline{\alpha}_1(t)=[\alpha_i(t)+\alpha_i(t+1)]/2$. Being constructed as a residual from a constant returns production function, the index does not skip all kinds of influences, other than these coming from upgraded productivity of labor and capital and, thus, influences that do not enter any of the two subtracting terms related to the usual production factors. Among these influences, changing compensation conditions of employees and sectoral expenditure in R&D activity are considered as the most relevant elements potentially influencing the rate of change of TFP.

Each coefficient in the vector [*B*] is supposed to measure in terms of growth rate the impact on total factor productivity that a downstream sector *i* may receive from upstream innovative producers, as a result of successful implementation of new technological knowledge created upstream and transferred to the downstream sector by means of intermediate market transactions. External knowledge is incorporated in the intermediate inputs and is supposed to be used, together with the internal sources of knowledge, in the process of downstream generation of technological knowledge. That process of knowledge implementation and further knowledge generation is expected to be considerably influenced by pecuniary knowledge effects. As it has been already described before, the main contribution of PKE consists in enabling downstream producers to implement externally

[5] Here the level of expenditure in R&D has been considered. However, would be also possible to consider the influence of the change in the level of the R&D expenditure as a factor having some impact on the dynamics of the TFP.

generated technological knowledge into their internal process of knowledge generation at costs lower than in equilibrium. As a consequence of this externality, the downstream sector i is able to generate an innovative output and experiences a positive dynamics of TFP.

This is the mechanism on which equation (3) has been built. It is aimed to grasp the dynamics provoked by relevant market interactions and, in particular, these resulting in technological influences between knowledge producers and knowledge professional users. More precisely, the dynamics of TFP of the sector i is a function not merely of direct influences connected with changes in TFP of upstream sectors, but more precisely of the indirect technological influence coming as a consequence of the acquisition of innovative intermediate inputs. For that reason, the rate of change of TFP of each upstream sector j has been accompanied by the corresponding expenditure coefficient from Input-Output tables.

The estimation of equation (3) without further robustness analysis runs the risk of being too general to prove the main argument. Indeed, as the main equation is constructed in the way to grasp the simultaneous effect of technological impact occurring through transactions, nothing permits us to exclude a priori that this effect is driven by one of the two elementary forces and thus the simultaneity that is crucial for the main argument to hold would run the risk of losing its relevance. To diminish that risk, the estimation framework is enriched by two additional equations.

The first of these additional equations is supposed to illustrate the functional relationship of the growth rate of total factor productivity of each downstream sector as a function of the growth rates of TFP of all the other sectors considered in the analysis. The estimation of such an equation should check for the fact that pure technological spillovers may be relevant. This first additional equation is also the crucial one in checking the robustness of the main hypothesis, as well as in arguing that the concept of technological spillovers, pervasively populated in the theoretical and empirical literature of the recent decades, may result insufficient rational to be examined on its own.

The second additional equation regresses again the growth rate of total factor productivity of sector i as a function of a series of expenditure coefficients of that industry towards all the other sectors. The rational motivating the estimation of this second equation consists in proving that the link between intermediate transactions and TFP growth is statistically too weak to explain the dependent variable.

In analytical terms the two additional equations may be represented in the following way:

#

$$d(TFP)_{i,k,t} = \beta_1 d(TFP)_{1,k,t} + \beta_2 d(TFP)_{2,k,t} + \ldots + \beta_{25} d(TFP)_{25,k,t} + e_{i,k,t} \quad (6)$$

$$d(TFP)_{i,k,t} = \beta_1 a_{i1,k,t} + \beta_2 a_{i2,k,t} + \ldots + \beta_{25} a_{i25,k,t} + e_{i,k,t} \quad (7)$$

with the variables as defined before.

3.2. Data

In constructing the panel some considerable difficulties rose. One of them consisted in coordinating numerous categories of data, subsequently used to calculate some variables or directly included in the estimating equation, in the way to maintain the number of sectors and of countries as high as possible. Moreover, because the Input-Output tables are elaborated with the 5-years intervals, this limited considerably the temporal dimension of the analysis. As the final result, the panel has been chosen to include 25 sectors in 14 countries, over two time periods, 1995 and 2000.

Among sectors, there are two of them belonging to the traditionally considered primary sectors, namely *agriculture, hunting, forestry and fishing* and *mining and quarrying*. Manufacture includes twelve industries. Finally, services are comprised among remaining eleven sectors[6].

The country selection brought the choice to include a number of European developed countries, mainly, but not all, members of the "old" European Union at twelve, in addition to the Czech Republic, Norway and the United States. The unavailability of the relevant data made it impossible to consider some other countries that, instead, would be worth to include in the current work, namely Canada, Korea and Japan.

The main data source for the present analysis is the OECD STAN database, from which the data on value added, labor compensation of employees, fixed capital stock and fixed capital formation have been retrieved. These data have been then used to compute the annual growth rate of TFP for the examined years, 1995 and 2000. More precisely, the growth rates

[6] The full list of industries as well as of countries is included in the Appendix A.1.

account for the yearly variability in TFP, so that for 1995 and for 2000, the rates measure the change in TFP level from 1994 to 1995 and from 1999 to 2000, respectively. For some countries, in particular, for Austria and the Netherlands, it was necessary to compute first the time series of fixed capital, as these data were missing in the STAN database. This computation has been based on the Perpetual Inventory Method, in which the data on average service life and depreciation rates at the sector level have been taken from the Bureau of Economic Analysis.

Secondly, Input-Output tables from the OECD 2006 edition have been used for the aforementioned countries in order to obtain expenditure coefficients for each sector in each country. These coefficients, derived from Input-Output tables and calculated as a fraction of expenditure coming from an intermediate sector *i* and dedicated to the acquisition of intermediate inputs of sector *j*, over the value of total output obtainable from the production performed in the sector *i*, measure the relative importance of the transaction of intermediate good coming from a supplying sector *j* and used in the production performed by an acquiring sector *i*. However, before the coefficients had been calculated, it was necessary to deflate Input-Output tables, which originally are expressed in the current prices. The intermediate goods and the final output deflators by sector available from the STAN database were used to convert the tables from current to constant values. For some countries, however, the data on deflators were missing and consequently it was necessary to take them from the corresponding national statistical offices.

3.3. The estimation procedure and the main empirical results

The estimation method of equation (3) has been first based on the fixed effect model in the panel data framework. In this way the individual effect, the sector level effect, is excluded from the estimation by first averaging the explanatory variables and then subtracting the mean from the data. Furthermore, as the correlation coefficient obtained in the estimation with the fixed effect method appeared to be relatively low, the random effect has been estimated as well. In the next step, the Hausman test, permitting to choose a better estimation method between fixed and random effect, has been made. The two additional equations, (6) and (7), have been estimated with the fixed effect method.

Table (3.1.) presents summary statistics of the variables, where variables reported with the names of sectors refer to the product of TFP growth rate and the corresponding expenditure coefficient.

Table (3.2.) illustrates the results from the regression of equation (3). The fixed effect model appeared to be consistent. However, the Hausman test was unable to reject the null, so that the efficient random effect model prevailed over the fixed effect method. Country dummies were included in the analysis and appeared to be insignificant.

In general, the results show the evidence that in the case of some sectors the linkages through which they are related to the rest of the economy and numerous influences that they exercise on the TFP dynamics may play a relevant role. In particular, sectors for which the regression results according to random effect model offers a particularly strong support for this hypothesis include, among manufacturing sectors, the food, beverages and tobacco industry; textiles and textile products; wood and products of wood; chemical and fuel products; basic metals and fabricated metal products; machinery and equipment; electrical and optical equipment; transport equipment; manufacturing nec, and among services, electricity, gas and water supply; wholesale and retail trade as well as financial intermediation. Not surprisingly, the list of sectors just mentioned includes some that are of a particular importance in generating and providing the rest of the system with new technological knowledge. This is true both for the majority of European economies and for the United States. In fact - rather in the past, but still maintaining an important role - mechanical engineering, electricity and electrical devices, and in the recent decades especially information technologies are an example of these knowledge-intensive sectors that are crucial in determining national innovative capabilities and in transmitting positive influences on the production, imitation and most of all on the innovation processes in the economic system at large.

Also chemical industry, and in particular pharmaceutical production, is another broadly examined case study for which the recent literature found rather a strong evidence supporting its influential innovative character, fast growth of TFP and correlated positive repercussions on the rest of the economy. Many studies, among which the one by Arora and Gambarella (1990), underline the role of significant technological advances pioneered in genetic engineering that exert, in turn, a considerable influence on technological insight of the whole chemical industry and, in particular, on pharmaceutical producers. This provides an evidence of spillover effects inside the chemical industry. Analogously, the results of the regression here presented confirm that thanks to the production of new drugs, animal and plant agricultural products, as well as of new and better qualities of other chemical products, many other sectors, like agriculture, machinery or health services, benefit from the high innovative potential originated in the chemical industry.

Table 3.1. Summary statistics

variable	mean	SD
d(TFP)	.0099	.0531
agriculture	.0002	.0020
mining&quarrying	.0001	.0023
food,baverages,tobacco	.0002	.0016
textiles&textile prod.	.0002	.0023
wood&prod. of wood	.0002	.0017
paper&paper prod.	.0001	.0019
chemical&fuel prod.	.0002	.0037
rubber	.0001	.0014
nonmetal mineral prod.	.0002	.0006
basic met.&fabricated met.	.0017	.0175
machinery&equip.	.0003	.0018
electrical&optical equip.	.0009	.0038
transport equip.	.0001	.0029
manufacturing nec	.0001	.0010
electr., gas, water supp.	.0004	.0013
construction	.0001	.0014
wholesale&retail trade	.0005	.0012
hotels and restaurants	.00002	.0003
transport and communicat.	.0008	.0028
financial interm.	.0002	.0011
real estate	-.0003	.0018
public administration	.00002	.0001
education	.00002	.00003
health	.00002	.0004
community	-.0001	.0005
R&D	1262	4588
d(wage)	.0196	.0176

Table 3.2. Estimation results from the regression of the main equation (eq. 3) with fixed and random effect. Dependent variable is *d(TFP)_i*.

variable	fixed effect		random effect	
	coeff	SE	coeff	SE
R&D expenditure	.000	(.000)	.000	(.000)
wage growth r.	.041	(.115)	.077	(.084)
TFP growth r. by sector:				
agriculture	.399	(.879)	.111	(.737)
mining&quarrying	-.592	(.460)	-.630	(.413)
food,baverages,tobacco	.356**	(1.414)	4.579**	(1.094)
textiles&textile prod.	3.277**	(.998)	3.667	(.694)
wood&prod. of wood	4.301**	(1.674)	4.826**	(1.118)
paper&paper prod.	3.151	(1.580)	2.721	(1.264)
chemical&fuel prod.	2.134**	(.494)	1.726**	(.432)
rubber	8.726	(5.487)	5.730	(2.818)
nonmetal mineral prod.	2.227	(5.217)	5.912	(3.535)
basic met.&fabricated met.	2.204**	(.456)	2.079**	(.075)
machinery&equip.	5.780**	(.664)	4.839**	(.588)
electrical&optical equip.	2.767**	(.448)	2.444**	(.356)
transport equip.	6.413**	(.552)	6.361**	(.356)
manufacturing nec	1.751	(7.005)	-9.011**	(2.371)
electr., gas, water supp.	3.987	(2.394)	4.785**	(1.485)
construction	1.420	(5.827)	1.032	(3.658)
wholesale&retail trade	-11.521**	(4.865)	3.239	(2.608)
hotels and restaurants	14.343	(19.915)	.445	(14.044)
transport and communicat.	1.547	(1.551)	2.310	(1.183)
financial interm.	4.500**	(1.480)	3.924**	(1.132)
real estate	-3.028	(2.913)	-.132	(2.035)
public administration	-11.902	(94.083)	9.490	(43.180)
education	159.775	(315.798)	4.934	(205.123)
health	166.030	(128.549)	3.562	(83.851)
community	6.401	(9.797)	.700	(7.742)
cons	-.002	(.005)	-.012	(.003)
R^2 within; between; overall	0.9292; 0.7155; 0.7435		0.9109; 0.8173; 0.8260	

Notes: Standard errors (by sector) in parenthesis. ** accepted at 5%.

Similarly, machinery production, as well as electrical and optical equipment - that last including among others the production of office, accounting and computing machinery - as well as medical, precision and optical instruments, all connected with an intensified use of ICT technologies and innovative softwares, are to be included in the group of these industries for which the results appear to be reasonably significant and, thus, in support of the basic intuition.

In this area, an important contribution is due to Jorgenson (2001) who sustains that robust results in high-tech industries accompanied by accelerated reduction of prices of information technology equipment has steadily upgraded the role of IT investment as a source of economic growth in America. Later this evidence has been confirmed also for the rest of the developed world. Jorgenson makes it clear that the rising importance of the productivity growth in industries producing IT equipment has paved the way for the further productivity revival in the rest of the American economy.

A particular attention deserves financial intermediation services. The results here obtained confirm the evidence from many past studies that better developed and more efficient financial services are an indisputable component influencing the growth performance of the economic system. They constitute an important source of improvements in the way of doing business and also through innovative financial instruments they reduce constraints faced by investors, innovators and generally by producers. The right efficiency dynamics in the financial intermediation is a condition for a positive influence, on the one hand, on the savings rates, and on the other hand, on the investment decisions, ultimately resulting in technological innovations occurring in the economy at large (Levin, 2004).

3.4. Robustness analysis

The estimation of equation (3) builds on the specification of dependent variables separately for each individual sector. Constructed in that way, equation (3) has an important role in analyzing the structure and impact of the linkages network *between* sectors, and in particular, of PKE that occur as a consequence of knowledge-based interactions between innovative producers. In fact, what is relevant in the present analysis is to assess, which sectors, considered individually, exercise the most significant impact on the TFP growth of the downstream sectors via PKE. Nevertheless, a legitimate objection is that the number of the dependent variables is high enough to run the risk of overestimation. For that reason, in order to mitigate that risk, an equation that considers as an explanatory variable an arithmetical average of influences coming from individual sectors has been estimated. In analytical terms, the equation under examination assumes the following from:

$$d(TFP)_{i,k,t} = \beta \cdot mean\sum a_{ij,k,t} \cdot d(TFP)_{j,k,t} + \gamma\, d(w)_{i,k,t} + \delta\, R\,\&\,D_{i,k,t} + e_{i,k,t} \qquad (8)$$

The results of this regression, shown in Table (3.3.), illustrate that also on average the joined effect of transactions and of the upstream-downstream technological influence is considerable and strongly supported by the data.

Table 3.3. Estimation results of equation (8), dependent variable *d(TFP)*

variable		estimation results	
		coefficient	SE
R&D expenditure		.000	(.000)
wage growth r.		-.036	(.099)
$mean\Sigma a_{ij,k,t} \cdot d(TFP)_{j,k,t}$		54.116**	(1.863)
_cons		-.007	(.003)
R^2 within	0.613		
between	0.778		
overall	0.720		

Note: ** accepted at 5%

Now, as it has been mentioned already earlier in this section, the analysis requires some additional and in a sense essential steps in order to strengthen and provide a rigorous proof of the main argument. Two additional estimations, presented in equations (6) and (7), are particularly helpful in interpreting the previous results consistently.

Table (3.4.) offers the summary results of the estimation from equation (6) previously introduced.

Both the F test on the overall performance of estimated coefficients and the R^2 statistics reveal that the explanatory variables have a rather poor explaining power over the sector level growth rate of TFP. In economic terms this would suggest that pure technological spillovers cannot be considered as the main force driving the process of upgrading of the productive capacities in the user sectors. Moreover, no sector, especially from the group of sectors that appeared to have a significant role in exercising influences on the economic system, as shown in the previous estimation, confirmed to be able to exercise any kind of influence by means of the pure sectoral TFP dynamics, disconnected from any market mechanism.

Table 3.4. Estimation results of the fixed effect model performed on equation (6).

variable: *d(TFP)* by sector	coeff	SE
agriculture	.011	(.153)
mining&quarrying	.102	(.210)
food,baverages,tobacco	-.020	(.306)
textiles&textile prod.	-.001	(.276)
wood&prod. of wood	-.029	(.288)
paper&paper prod.	.174	(.504)
chemical&fuel prod.	.041	(.136)
rubber	.062	(.365)
basic met.&fabricated met.	.017	(.058)
electrical&optical equip.	.091	(.146)
transport equip.	.034	(.078)
manufacturing nec	.113	(.231)
financial interm.	-.003	(.195)
R^2 .071		
R^2 (within) .022		
prob > F .886		

Notes: missing sectors have been dropped from the estimation

In order to offer a more rigorous treatment of the diverging results obtained from equation (3) and (6), Table (3.5.) puts together the results from both estimations for the sectors for which the linkages observed by means of equation (3) have been found to be significant. In brackets are reported relative standard errors, calculated as a fraction of the absolute standard error over the value of the coefficient. This provides a comparable measure of estimation results and enables a rigorous valuation of the robustness of the estimates[7]. A lower value of relative standard error is a sign of a better estimation results.

Table 3.5. Estimation results from equation (3) and from equation (6) – comparison

sector	equation (3), re		equation (6), fe	
	coeff	relative SE	coeff	relative SE
food,baverages,tobacco	4.579**	(.239)	-.020	(15.132)
wood&prod. of wood	4.826**	(.23)	-.029	(10.056)
chemical&fuel prod.	1.726**	(.250)	.041	(3.332)
basic met.&fabricated met.	2.079**	(.036)	.017	(3.334)
machinery&equip.	4.839**	(.122)	dropped	
electrical&optical equip.	2.444**	(.146)	.091	(1.612)
transport equip.	6.361**	(.074)	.034	(2.281)
manufacturing nec	-9.011**	(.263)	.113	(2.043)
electr., gas, water supp.	4.785**	(.310)	dropped	
financial interm.	3.924**	(.289)	-.003	(64.772)

Note: ** - accepted at 5%

In general, relative standard errors result to be much lower in the case of equation (3) than the corresponding values obtained from the regression of the pure TFP growth rates, appearing in support of equation (3). This, once again confirms that the latter estimation, on the contrary to the former one, cannot be considered as satisfactory and thus that the acceptable hypothesis is the one that recognizes the intersectoral technological influences coming from the market transactions.

In an analogous manner, the fixed effect model has been applied to estimate the second subsidiary equation (eq. 7), which analyses the influence of the expenditure coefficients of each single sector *j* on the growth rate of TFP of sector *i* (Tab. 3.6). Here, the estimation results are slightly better than these obtained from equation (6), but still not satisfactory enough to be accepted as binding. Only in the case of electrical and optical equipment industry the coefficient appeared to be significant. However, for all the other sectors the estimation results are not favorable. In this manner it is also shown that transactions by

[7] Relative SE expresses the relative, as opposed to the absolute distance of the estimated coefficients to the true values of the coefficients.

themselves, without considering the underlying transfer of technological knowledge from upstream to downstream producers do not have any explanatory power.

Table 3.6. Estimation results of the fixed effect model performed on equation (7).

variable: *d(TFP)* by sector	coeff	SE
agriculture	.226	(.223)
mining&quarrying	-.558	(.244)
food,baverages,tobacco	-.031	(.234)
textiles&textile prod.	-.369	(.291)
wood&prod. of wood	.390	(.252)
paper&paper prod.	.335	(.325)
chemical&fuel prod.	-.163	(.159)
rubber	-.167	(.190)
nonmetallic mineral prod.	.007	(.457)
basic met.&fabricated met.	-.274	(.345)
machinery&equip.	.053	(.311)
electrical&optical equip.	-.880	(.247)
transport equip.	-.174	(.252)
manufacturing nec	.506	(.197)
electricity, gas&water supp.	.041	(.147)
construction	.276	(.204)
wholesale&retail trade	.398	(.257)
hotels&restaurants	.269	(.240)
transport&communication	.155	(.231)
financial interm.	.250	(.226)
real estate&retail trade	-.187	(.240)
public administer.	-.038	(.393)
education	.117	(.394)
health	-.054	(.372)
community	.232	(.321)
cons	.010	(.014)
R^2 .006		
R^2 (within) .112		
prob > F .031		

All this suggests that the first and the main estimating equation describes a phenomenon on its own. In fact, having estimated that equation, it has been proved that the dynamics of TFP at the sector level is driven by forces that express the combined operating of technological influences exercised by means of transactions. These market relations occur between sectors that transfer technological knowledge and downstream sectors that, after the necessary internal effort to adopt new knowledge, benefit from convenient external sources of knowledge. This is also to say that the satisfactory estimation results obtained from the main equation detect the operating of pecuniary knowledge externalities that are the driving force of the growth process at the system level. Moreover, the second and the third estimation from the robustness analysis, being not significant, have confirmed the intuition that the transfer of technological knowledge cannot be considered as a process disconnected from underlying interactions between upstream knowledge suppliers and downstream knowledge users. On the contrary, intermediate transactions of innovative components are followed by dedicated activities of support accompanying innovative users in the process of knowledge assimilation. Especially the poor results of the equation (6) contradict the importance of pure technological spillovers, emphasized strongly in the previous literature. All this confirms the relevance of pecuniary knowledge externalities that enter into the planning strategies regarding the production activity. In that way they are crucial component in determining the strength and the direction of technological impact resulting from particular choices[8].

4. Conclusions

The present analysis concerns important considerations on the external effects and the collateral effects accompanying the growth process in the modern economies. The occurrence of pecuniary knowledge externalities in the context in which technological knowledge arrives to the downstream sectors from external sources likely motivates further innovative initiatives with consequences in terms of a positive TFP dynamics. This last effect was not taken into account in the construction of the model of growth through creative destruction. In fact, the arrival of innovations from upstream sector is supposed to exercise the only influence on the downstream producers, by providing them with better qualities of intermediate goods and consequently permitting for a more efficient production of final goods. Nevertheless, no

[8] On the influence of pecuniary knowledge externalities on the emergence of innovation systems and the direction of technological change, see Antonelli (2008).

further innovative outcomes are supposed to be obtained downstream. Moreover, technological impact from upstream to downstream sector should not be considered as a separate phenomenon, but rather as a mechanism mediated by the structure of market linkages and corresponding commercial relations.

The estimation results offered a significant support for the above argumentation. Equation (3), based on the functional relationship between the sector level growth rate of TFP as dependent variable and, for all remaining sectors considered separately, a variable given by a product of the expenditure coefficient and again the growth rate of TFP, succeeded in discriminating sectors that appeared to have a particular intersectoral influence on the growth rate of TFP, exercised through the system of transactions, as measured in terms of Input-Output expenditure coefficients. Among these sectors there are some, like chemical industry; electrical and optical equipment, and most importantly financial intermediation, for which positive estimation results confirm previous empirical evidence, according to which these sectors can be considered as crucial components of intersectoral influences and consequently of dynamics driving development of modern economies. Indeed, their strongly innovative potential is broadly recognized as an important source of positive dynamics for the rest of the economic system.

Moreover, the robustness analysis provided also the proof that the growth of TFP at the sector level cannot be considered as driven separately, neither by transactions, nor by pure technological influences. Especially this last aspect appears to have an important insight for past empirical studies that, in many cases without success, tried to detect the existence of pure technological spillovers.

Appendix A.1. Sectors and countries included in the panel

List of sectors, compatible with the current STAN database classification:

1	Agriculture and hunting, forestry and fishing
2	Mining and quarrying
3	Food products, beverages and tobacco
4	Textiles, textile products, leather and footwear
5	Wood and products of wood and cork
6	Pulp, paper, paper products, printing and publishing
7	Chemical and fuel products
8	Rubber and plastic products
9	Other non-metallic mineral products
10	Basic metals and fabricated metal products
11	Machinery and equipment nec
12	Electrical and optical equipment
13	Transport equipment
14	Manufacturing nec; recycling
15	Electricity, gas and water supply
16	Construction
17	Wholesale and retail trade; repairs
18	Hotels and restaurants
19	Transport, storage and communication
20	Financial intermediation
21	Real estate, renting and business activities
22	Public administration and defense; compulsory social security
23	Education
24	Health and social work
25	Other community, social and personal services

Countries taken into analysis:

1	Austria
2	Belgium
3	Czech Republic
4	Denmark
5	Finland
6	France
7	Germany
8	Italy
9	Netherlands
10	Norway
11	Spain
12	Sweden
13	UK
14	USA

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