Center for European, Governance and Economic Development Research

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Discussion Papers

Number 102 – June 2010

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ISSN: 1439-2305

Pecuniary Knowledge Externalities in a New Taxonomy: Knowledge Interactions in a Vertically Integrated System

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Abstract

The paper presents a new sectoral taxonomy that focuses on the existence of non negligible external effects, deriving from user-producer knowledge interactions, the latter in turn coupled with intermediate goods transactions, in a system of vertically integrated manufacturing and services sectors. These externalities, the so called pecuniary knowledge externalities, are the main source of changing technological conditions experienced by downstream producers. A distinguishing feature of the taxonomy consists, thus, in being derived from a particularly dynamic contexts of changing production functions. The taxonomy is obtained from an empirical exercise, examining effects generated by idiosyncratic knowledge in a system of input-output intermediate transactions between sectors in the European economy. The results permit to classify sectors in five groups, confirming the previous evidence of relevant differences in technological characteristics among sectors.

Key words: Pecuniary knowledge externalities, Sectoral patterns, Vertical linkages

1. Introduction

The appearance and transformation of technological trajectories in a system of vertically integrated sectors have been discussed in a wide range of the recent literature (Nelson and Winter, 1977; Dosi, 1982; Freeman et al., 1982; Pavitt, 1984). Considering these changing trajectories, numerous contributions were aimed at determining sectoral patterns of innovation and at offering innovation-based classifications mainly of manufacturing activities (Freeman et al., 1982; Pavitt, 1984; Soete, 1999). Only recently, with the recognition of a growing importance of service sectors as a source of innovations and consequently of growth potential, some authors advocated the need to reconsider the framework in the way to provide a unified treatment of the economic system, with manufacturing and service sectors interacting with one another and playing equally important roles (Gallouj and Weinstein, 1997; Evangelista, 2000; Miozzo and Soete, 2001; Guerrieri and Meliciani, 2005; Castellacci, 2008).

Among sectoral classifications, the taxonomy originated by Pavitt (1984) has received a proper recognition and has been extensively explored in empirical studies of industrial structure in modern economies. Pavitt offered a classification of firms on the ground of their technological competences possessed and exercised in a vertically integrated productive system. The taxonomy, although it represents a record of a historical formation of groups of firms in a capitalistic order, is conceptually nested in a static representation of an observed set of technological regimes.

The present study aims to extent the aforementioned strand of the literature by proposing an intrinsically dynamic sectoral classification of both manufacturing and service activities based on the concept of pecuniary knowledge externalities (PKE), extensively discussed in Antonelli (2007, 2008a). The originality of the taxonomy here presented lays in the fact that it classifies vertically interrelated sectors according to their reciprocal influence coming from user-producer interactions of technological knowledge that accompany transactions of intermediates. Consequently, upstream-generated external knowledge acquired at a cost by downstream producers in the course of intermediate transactions, becomes an input both in the production of new goods and of further knowledge, provoking considerable repercussions on the system dynamics of total factor productivity. This active presence of downstream innovative users, and the fact that technological knowledge do not spread freely in the air, distinguishes the approach here presented from previous contributions, both in the new growth theory and in evolutionary strand of the literature, where downstream users remain very much passive, their production functions do not change and technological knowledge circulates at no cost.

The taxonomy has been derived from an empirical exercise based on a panel of 25 sectors in 13 countries between 1995 and 2005. The data come prevalently from OECD STAN database. The empirical evidence confirms results of past studies highlighting the existence of non negligible differences between sectors in their technological characteristics. The results permit to discriminate five groups of sectors according to their participation in the transmission of technological knowledge and upstream-downstream knowledge interactions.

The paper is organized as follows. Section 2 lays a theoretical background, by reviewing existing contributions in the field of sectoral patterns of innovation. A particular attention is dedicated to the Pavitt's taxonomy. Section 3 presents the new taxonomy with a short discussion of its theoretical implications in terms of the growth dynamics. Section 4 describes the model, the data used, the methodology and the main results obtained. The last section concludes.

2. Patterns of sectoral innovation and their taxonomies in a vertically integrated production system

The development of the modern evolutionary economics, with its birth that can be traced back to the beginning of the 1980s, benefited greatly from contributions of Dosi (1982), Freeman et al. (1982), and Nelson and Winter (1982). These studies opened up a new perspective in the analysis of innovation process. Dissatisfied with a fragmented treatment of the subject and inspired by the Schumpeterian approach, these authors defined conceptual borders and offered a comprehensive view of analysis of the growth dynamics, where technological change occurring in a complex environment plays a central role.[1]

The recognition of a great variety characterizing technological regimes observed in each sector accompanied this strand of the economic literature from the beginning. Already Nelson and Winter (1977), anticipating the new ideological direction, pointed out on the vast interindustry differences in rates of technological progress. As a predictable consequence, these

[1] The same inspiration motivated the developers of the new growth theory (Romer, 1990; Aghion and Howitt, 1992) to incorporate technological knowledge as an endogenous force in the growth process. However, the way to consider its influence in the interaction between producers differs considerably with the conceptualization followed in the modern evolutionary economics (for an extended discussion on the subject, see Castellacci, 2007).

differences in technological performance lead to the establishment of sectoral patterns that have the chance to persist for a period of time, depending on idiosyncratic characteristics governing sectoral structures and activities. Each sector is distinguishable by a particular set of capacities to generate new knowledge, to create innovation and of opportunities to arrive at more efficient productive, organizational and business solutions. The generation of knowledge, in particular, arises as an outcome of an intentional and composed activity of internal learning, research, development and of decision to implement knowledge from external sources (Antonelli, 2008b). The acquisition of external knowledge requires the establishment of qualified intersectoral relations and of knowledge government mechanism (Antonelli, 2008b) able to mediate knowledge interactions. The interplay between technological capacities internal to each sector and the functioning of knowledge government mechanism determines the ultimate success of knowledge interactions. Consequently, a specific dynamics of changes in each single sector is ultimately determined.

Technological features of a single sector and of the system as a whole can be observed moving along a particular technological trajectory determining the path of progressive exploitation of innovative capacities put into motion in the "problem solving activity" (Dosi, 1982). Over time the observed dynamics of changes in the best technical practices demonstrates rather regular paths leading to the establishment of a set of technological opportunities gained from available radical innovations. In any historical era, thus, it is plausible to search for a technological paradigm, defined as a state of technical and economic production conditions that provide the system with a sector-specific growth potential.[2] Technological paradigm will persist till new dynamics determines its passage to a different one, with sectors experiencing rather profound transformation. The direction and the magnitude of the outcome of changes occurring in each sector depend on the type of forces dominating the process. In particular, two kind of forces are commonly recognized, namely, technological competition (or selection) and innovation (Castellacci, 2007). Both are a part of the creative destruction first defined by Schumpeter (1942) as a process in which in a highly competitive environment obsolete solutions are constantly replaced with new ones.

All these ideas put a fundament for the analysis of sectoral patterns of innovation, with their subsequent reapplication and further extension. By individuating differences among

[2] The concept of technological paradigm has been first defined by Dosi (1982) where he focused on the specificity of each paradigm created as a response to a "*selected* technological problem".

sectors, these studies try to provide classifications of productive activities according to some specific features, most of the times related to innovative capacities at the sectoral level.

In his well-known contribution, Pavitt (1984) aimed at developing a firm-level taxonomy derived from common technological characteristics of firms.[3] Pavitt explained the classification in terms of source of technology, requirements of users and possibilities for appropriations. On the basis of these variables Pavitt classified firms into four groups: supplier dominated, production intensive, specialized suppliers and science based.

Supplier dominated firms are technologically dependent on innovative suppliers of equipment and material. They are generally small and operate in traditional manufacturing as well as in some non-manufacturing sectors. *Scale-intensive producers* are firms operating in bulk materials and assembly. Innovative firms dedicate essential part of their resources to improvements in their process technology. *Specialized suppliers* focus on introduction of product innovation addressed mainly to other sectors. They supply principally production equipment. *Science-based firms* dedicate essential resources in R&D activities with the scientific support coming from universities and research centers. They operate mainly in chemical, and electronic sector.

This original and, by no means, influential taxonomy, despite its undisputable contribution to the understanding of forces driving technology-based interactions, suffers, however, from some shortcomings, partly recognized by the author himself. The data used in Pavitt's analysis survey significant innovations introduced into the UK. Apart their limited geographical dimension, the data are constrained to consider only innovative firms and, as a consequence, they automatically exclude firms that rarely introduce innovations, or do not perform them at all. The taxonomy, thus, covers only a part, without doubt relevant, of the economy. Moreover, while the taxonomy has been constructed by observing firm-level innovations, for the purpose

[3] Tidd et al. (1997), Evangelista (1999), Marsili and Verspagen (2002), Castellacci (2005, 2006) proposed refinements of the original taxonomy that, nevertheless, maintains its crucial position in any analysis on differences in innovative capacities between sectors.

Using the same statistical source as Pavitt, i.e. the data collected at the SPRU by Townsend et al. (1981), Freeman (1982) offers a taxonomy of innovations. Observing technological characteristics of innovations, Freeman distinguished three major categories, namely, *incremental*, *radical* and *pervasive*. Aiming at finding common features relating both the sectoral taxonomy by Pavitt and the technological taxonomy by Freeman, Soete (1986) classifies sectors into six groups according to their characteristics as suppliers and/or users of innovations. Most importantly, he stresses on a great role played by pervasive innovative sectors and on a crucial influence that vertical interactions between users and suppliers of innovations exercises in designing technological trajectories.

of its further use, the categories have been referred to industries, and in that way treated in theoretical discussions and used in later empirical applications.[4] A missing point is the consideration, whether the classification still holds if one recognizes a non negligible presence of non innovative firms inside industries classified as innovative according to the taxonomy. This argument follows the one raised by Archibugi (2000). He observes, in fact, the discrepancy firm-industry applied in the original study by Pavitt. However, the suggestion that he makes invites to develop taxonomies that would classify firms and not industries. In the present context, as it will be applied in the empirical exercise, it is suggested to maintain the sectoral dimension, that for many reasons is more useful and understandable than the one at the firm level, and to use, for the coherence reasons, the data at the sectoral level.

But there still remains one important limitation, mentioned already by Pavitt. The limitation is also connected with the statistical source of information used for the analysis and consists in a certain incongruence of the data that being static, cross-sectional are meant to study a theory that is intrinsically dynamic. Archibugi (2000), in reality, identifies some elements fitting an inter-temporal dimension, by saying that the taxonomy reveals the capitalistic history of classes of firms distinguishable by the way in which they introduced innovations. Nevertheless, the meaning of dynamic context in the present study is much stronger. Most importantly, the empirical analysis has been based on a panel estimation, permitting to observe intertemporal effects of intersectoral input-output relations. Moreover, the concept of pecuniary knowledge externalities applied to construct the taxonomy is intrinsically dynamic.

Here, namely, stays the originality of the new taxonomy and of the approach advocated in its development. The dynamic effects coming from the operating of pecuniary knowledge externalities (PKE) have been extensively described in the pioneering contributions by Antonelli (2007, 2008a). Anticipating briefly the analysis that follows, PKE are meant to significantly influence the system dynamics of technological capacities of single sectors and of the economic system at large.

The mechanism of the transmission of technological knowledge regards without limitations both manufacturing and service sectors, connected in a system of vertical interdependences. Pasinetti (1973) who defined the concept of vertically integrated sectors, managed to model it synthetically as a vector of intermediate uses required to obtain a certain output. Sectors, thus, are connected by means of vertical linkages that involve exchange of physical goods as well as

[4] As an example, see Laursen and Meliciani (1999).

of intangible items, cooperation initiatives and interaction between firms located at different levels in the vertical chain of production.

Vertical interactions driven by innovations have been also extensively discussed by Lundvall (1985), who formalized them in a use-producer model. Recalling the ideas of Rosenberg and Arrow, Lundvall analyzed some specific characteristics underlying relationships between innovative producers and "professional users".[5] Linkages between operators are based on "the regular flow of tangible or intangible products from the producer to the user" (Lundvall, 1985, p. 7). Apart linkages, users and producers interact by means of information channels that regard signals not embodied in the flow of products. Information exchanged refers to technology involved.[6] The establishment of information channels is expensive. In a similar way, changing the channel is connected with prohibitively high cost, due to complexity and specificity of technological information involved. However, once the information channel exists, Lundvall doesn't predict any other cost connected with the exchange of technological information. Nor has the transmission of the new technology from the producer any further consequence in terms of innovativeness of the user. In the present framework, instead, effects of the exchange of technological knowledge going beyond the pure satisfaction of the downstream user, deriving from the availability of an innovative input, are a determinant element in understanding the dynamics of the whole system.

The framework of vertical linkages has been adopted also by Pavitt (1984) in the construction of his taxonomy that constituted a powerful conceptual basis for the study of intersectoral linkages in manufactures. This strength regards Pavitt's particular focus on the vertical nature of upstream-downstream interactions, where output generated downstream is obtained with the direct or indirect use of innovative intermediates.

Such a system of direct and indirect relations will be applied here as well, by implementing an input-output perspective in the analysis of external effects, that occur in the upstream-downstream transmission of technological knowledge associated with market-driven transactions of intermediate goods. Input-output transactions are considered as a weighting tool in measuring the relative strength of technological impact in vertical user-producer relations. What matters in this process of dynamic intersectoral repercussions is that, in contrast with

[5] The fact that the users are professional should distinguish them from consumers. While professional users are supposed to search actively and constantly for better solutions, adapting behaviors and skills to new technological conditions, consumers, in contrast, are not involved in a search for new goods and adopt innovations only if they do not require additional training and any change in behavior. For further details, see Lundvall (1985).

[6] The last element of user-producer interactions is constituted by cooperation in a common project.

Lundvall and Pavitt, downstream producers not only benefit from more efficient inputs, but they experience changes in their production functions as a consequence of a successful appropriation and transformation of technological knowledge originated upstream. The dynamics generated by means of PKE exercises, thus, far stronger impact than that described in the literature so far, where generally the production functions of the technology users were assumed as given.

2.1. PKE in an intersectoral perspective

The nature of the influence exercised by PKE differs from external effects hypothesized in the new growth theory and adopted from the seminal contribution of Griliches (1979). Generally, Griliches distinguishes two classes of spillovers occurring in an innovative environment, namely, rent spillovers and pure technological spillovers. While the former are transmitted through traded goods, the latter are mediated through other channels, like development of common research projects, conferences, workshops, specialized literature, exchange of experiences by workers and technological information embedded in instruments of property right protection. Moreover, the rent spillovers encompass the idea of pecuniary externality in the sense of Scitovsky (1954), occurring when an innovative input is acquired at a price lower than it would follow from the increase in its quality. A firm acquiring an innovative input, thus, receives a part of upstream generated innovation as externality. On the contrary, pure knowledge spillovers are characterized by an "atmospheric" nature of knowledge implemented as a production factor, as they do not involve any cost on charge of users receiving them.

The spirit of PKE differs from both concepts. Most importantly, mechanisms underlying their occurrence refer both to the exchange of intermediates and to channels of transmission typical for pure technological spillovers. Nevertheless, in contrast with rent spillovers, PKE focus on by no means negligible consequences that the implementation of technological knowledge incorporated in acquired innovative inputs has on technological capacities, and thus, on the production function of sector of destination.

Concerning pure technological spillovers, the main element distinguishing the framework of knowledge-based pecuniary effects from pure technology transfers is that in the case of PKE any flow of technological knowledge, being rooted in contractual relations, provokes a cost, however law it might be. The cost of external knowledge refers to effort made in order to search, screen, understand and purchase knowledge generated by other agents. Also communication and transformation of knowledge is costly, as it consists in dedicated activities of receiving, absorbing and assimilating it to a particular environment. External knowledge, thus, flows by no means freely within a network of interactions between innovative producers and qualified users. Nevertheless, overall costs associated with external knowledge are lower than the cost of internal early generation of knowledge and lower than equilibrium levels would normally imply. The latter refers to a hypothetical situation in which technological knowledge would have properties of a normal economic good. In such circumstances and as a consequence of vertical commercialization of technological knowledge between knowledge producers and knowledge users, PKE operate in the way to permit downstream producers to assume an active role, by combining internal and external sources of knowledge in the production process of goods and in the generation of new knowledge. As a result, total factor productivity (TFP), both upstream and downstream is expected to follow a dynamic path.

More precisely, PKE are to be observed whenever downstream producers experience positive impact on their technological capabilities – measured in terms of growing TFP – as a consequence of knowledge interactions with upstream innovative producers. Thanks to the access to external knowledge, accompanied by the internal activity of learning by using and by research and development, as well as by other dedicated activities involving outside relations, downstream users become active players and providers of new knowledge. Nevertheless, the operating of PKE is by no means automatic. If the access to external knowledge is neglected by its excessively high costs, or some inefficiencies hamper the right functioning of knowledge governance mechanism (Antonelli, 2008b), potentially possible PKE will not occur. Consequently, a fruitful knowledge environment can remain unexploited, if otherwise innovative users face prohibitively high barriers in the exploitation of new external knowledge. In addition to these mainly institutionally rooted issues, the occurrence of PKE will differ according to intrinsic characteristics of sectors determining the ability, on the one side to transfer knowledge efficiently to the market, and on the other side to exploit the powerful potential experienced with the acquisition of external knowledge.

The aforementioned knowledge interactions occur inseparably with market transactions of intermediate goods. Innovative producers, by offering a new input, transfer to users technological knowledge and at the same time engender in them a process of learning. Such a knowledge opportunity and the benefits deriving from its transformation result in upgrading TFP and ultimately in innovative output of creatively reacting users. In contrast with the view postulated in the new growth theory (Aghion and Howitt, 1992), the users affected by PKE do not remain passive, but respond to the technological stimulations provided by upstream specialized producers in the way to intentionally generate their technological knowledge and to modify their technology.

In such a dynamic perspective, the concept of PKE is applied in order to individuate intersectoral differences and to resume them in a new pattern of classification. The spirit of the taxonomy here developed follows the contribution of Castellacci (2008). He extends the literature on sectoral patterns of innovation by proposing a taxonomy constructed in a unified framework for both manufacturing and service sectors. For many years, indeed, based on the global development in the post-war era, authors concentrated on considering only manufacturing sectors in the study of sectoral patterns of innovation. Only recently, with a rapidly changing role of some service sectors, this has been considered as a non negligible limitation. Castellacci focuses on the need to overcome the limitation, by recognizing a growing importance of services in determining the growth dynamics of economic system in which innovations are continuously introduced. Moreover, the existence of vertical linkages between sectors both manufacturing and services requires the consideration of their reciprocal influence and manifold consequences being produced in the system as a whole. This is precisely the perspective adopted in the present study of PKE-based technological patterns.

3. A PKE-based taxonomy

Motivated by the seminal contribution of Pavitt (1984), the taxonomy here presented focuses on the role of PKE in influencing the dynamics of TFP, and consequently, the structure and the direction of changes in modern economies, occurring in a system of vertical linkages.

The taxonomy focuses on the existence of important technological effects leading to beneficial intersectoral knowledge interactions. Recalling briefly the discussion from the previous section, knowledge interactions accompanying transactions of intermediates generate pecuniary knowledge externalities that differ from pure knowledge spillovers by the fact that they are connected with a real cost on charge of downstream producers. However, due to the fact that the exploitation costs of external knowledge are lower than in equilibrium, downstream producers are motivated to take advantage from these favorable cost conditions and to exploit this knowledge-based pecuniary effect in the generation of new knowledge and in the production of goods. In this sense, the PKE-driven mechanism permits to investigate a new class of growth-fostering effects with technological knowledge assuming a central role in the system of intersectoral interactions.

The new taxonomy has been derived from an empirical exercise concerning manufacturing and service sectors in 13 European economies in the period 1995-2005. The taxonomy, illustrated in Figure (3.1.), distinguishes five groups of sectors. The horizontal axis represents sectors generating PKE, i.e. sectors that are a crucial source of knowledge interactions occurring thanks to internally generated technological knowledge, further transmitted to the rest of the economy together with market transactions of intermediate goods. On the vertical axis, in turn, are placed PKE receivers, i.e. sectors that benefit from opportunities created by external sources of knowledge. Such opportunities involve a process of learning by using and result ultimately in better productive conditions of goods and in the generation of new knowledge as well.

The five groups differ by the strength with which sectors belonging to each class appear as providers or receivers of PKE. Also the size of the figures representing groups assumes a role: the more numerous is a group, the bigger is the corresponding figure.

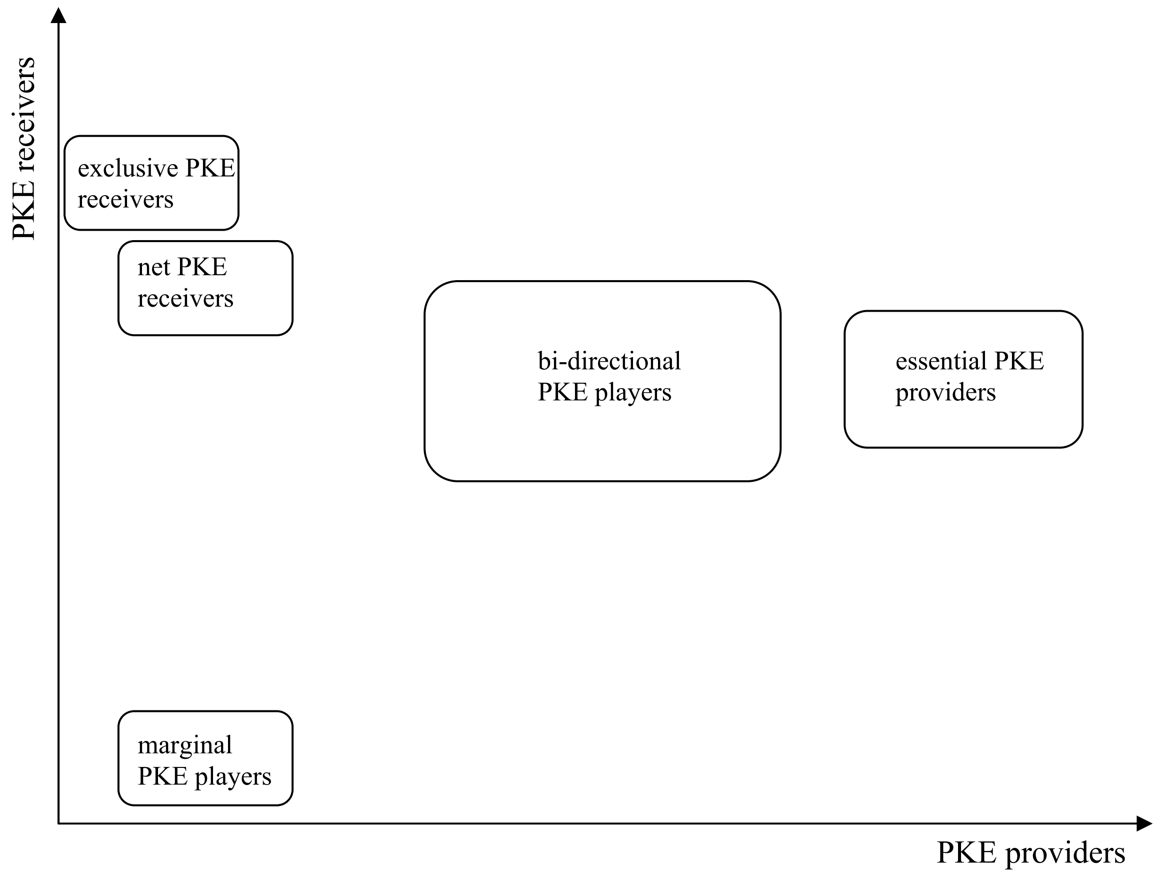

Figure 3.1. *The taxonomy based on PKE.*

The most numerous is the class of *bi-directional PKE players*. In terms of PKE providers/receivers, the group assumes a central position on the chart, with each sector appearing at the same time as a relatively strong provider and receiver of PKE, but either of the two features can be found as a prevalent characteristic of the group. Sectors belonging to the group are among important manufacturing producers (food, beverages and tobacco; chemicals and chemical products; machinery; electrical equipment; transport equipment), as well as service providers (electricity, gas and water supply; wholesale and retail trade; health and social work; other community, social and personal services).

Among *essential PKE providers* there are sectors possessing the ability to work out the most important influence in the system of technological knowledge interactions. Thanks to their innovativeness, its role played for the rest of the economy and a high degree of transferability of the technology incorporated into intermediate goods or services put on the disposition of downstream producers, these sectors generate technological knowledge that is effectively further transmitted downstream, and integrated there as a production input beside internal sources of knowledge. Technology transmitted by these sectors by means of intermediate transactions with the rest of the economy, initiates an important process of learning by using and becomes a crucial component in the production process of a number of downstream producers. Essential PKE providers, although to a limited extent, are also subject to external effects coming from the rest of the economy. Manufacturing sectors belonging to this group (pulp, paper and paper products, printing and publishing; rubber and plastic products; basic metals and fabricated metal products; construction) cannot be generally considered as particularly knowledge-intensive, or in the Pavitt's terminology, science-based producers. This suggest that what matters in the generation of a relevant PKE influence is not so much a high technological content, but rather transferability conditions offered by the technological regime governing the sector and the way in which technological knowledge is made available by upstream producers and incorporable in the production process downstream. Also competitiveness conditions of market transactions and generally the determinants of knowledge governance mechanism are supposed to influence the effectiveness of upstream-downstream technological influence. This means that what matters for a successful exploitation of new knowledge is a good working system of vertical interactions.

Innovative capacities of *net PKE receivers* are strongly influenced by technological impact from outside. Acquiring innovative inputs, these producers receive external technological knowledge and through a dedicated activity of learning they are able to successfully transform this new innovative insight and implement it in their production process. Towards a limited number of sectors they are also able to work out a positive influence, but on average they can be considered as net recipients of technological impact and can be placed rather on the left mid-high position of the chart. A certain analogy with the category of supplier-dominated firms in the Pavitt's taxonomy can be found here. In his view, innovations available for these firms are mostly generated outside. This is, in particular, the case of textile sector that belongs to the category of supplier-dominated firms in Pavitt's view and to net PKE receivers in the present taxonomy.[7] Nevertheless, it should be stressed that the focus here is not like in the Pavitt's work on the source of innovations, but rather on consequences that innovations coming from elsewhere provoke in terms of changing conditions of sectoral TFP. It can, indeed, well happen that some upstream innovations, even if playing a determinant role downstream, do not provoke there such further external effects. Consequently, this may be considered as a relevant source of differences in classifying sectors according to both taxonomies, the one originated by Pavitt and the one here presented.

The category of *exclusive PKE receivers* is composed by sectors characterized by an exclusive dominance of pecuniary effects arriving from other sectors. This means that their technological impact on other sectors is not relevant enough to activate sufficient pecuniary knowledge externalities. On the contrary, knowledge originated by upstream sectors causes positive disequilibrium in technological content of sectors here considered and becomes an important input in their activity. Mostly public services, in particular, public administration and defense - compulsory social security; and education, can be found in this class, in addition to sector of wood and products of wood and cork.

Finally, the notion *marginal PKE players* refers to sectors playing both as providers and as receivers very limited role in the system of pecuniary externalities based on technological knowledge interactions. To this category belong the primary sectors – agriculture and hunting, forestry and fishing; and mining and quarrying - and among services hotels and restaurants sector. Technological requirements of members of the class are not particularly high. In that sense, marginal PKE players cannot be classified among important purchasers of external knowledge and, consequently, are not involved in knowledge interactions. In that way, they are excluded from the majority of benefits connected with the use of external knowledge as a production input. If innovative inputs are acquired, they are implemented in the production

[7] Among other sectors classified as net PKE receivers there are other non metallic mineral products; and real estate, renting and other business activities.

process without further exploitation of their technological insight in order to generate new knowledge.

Being vertical intermediate transactions and the associated technological knowledge interactions between sectors the main focus of the present exercise, the intrasectoral technological influences and their consequences have been left outside. Knowledge interactions internal to each sector, may also be an important source of PKE for the sector itself. However, this would require a radical change of perspective from sectoral to firm level and, thus, could constitute a subject for a separate investigation.

4. Empirical analysis of sectoral patterns in technological knowledge interactions: the evidence from the European economy

This section presents the main results obtained from an empirical exercise, aimed to determine classes of sectors forming the new taxonomy. First, in Section 4.1 will be presented the model with its estimating equations. In Section 4.2 will be offered a short description of the data and their source. Section 4.3 illustrates the methodology used for the estimation, as well as the main results obtained.

4.1. The model

The structural form of the model assumes a sectoral dimension. The aim of the estimation in the present framework is to examine the occurrence of PKE in each single sector of the economy. For that reason, the model entails 25 estimating equations, each of which putting in a functional relationship the variation of downstream-sector TFP as a function of variables grasping the upstream technological influence, the latter defined as a product between the rate of change of sectoral TFP and the corresponding expenditure coefficient from the Input-Output tables.

The estimating equation related to sector *i* has been defined in the following way:

$$d(TFP)_{i,k,t} = \mathbf{b'}\left[\mathbf{a_{ij,k,t}} \cdot \mathbf{d}(\mathbf{TFP})_{\mathbf{j,k,t}}\right] + \delta \cdot R\,\&\,D_{i,k,t} + e_{i,k,t} \qquad (1)$$

where $\mathbf{b'}$ is a column vector of estimation coefficients that multiplies a row vector $\left[\mathbf{a_{ij,k,t}} \cdot \mathbf{d}(\mathbf{TFP})_{\mathbf{j,k,t}}\right]$, containing explanatory variables. The latter are defined for each time *t*, in country *k*, and for each relevant sector *j*, as a product between the rate of change of sectoral

TFP and the corresponding expenditure coefficient. As a control variable, R&D expenditure in sector *i* has been included. The last component in equation (1) is the error term.

The number of relevant sectors in each equation varies in function of a criterion commonly specified for all sectors. This criterion unifies two selection methods, one based on volumes of intermediate transactions and another one on dependence of intersectoral technological parameters. More precisely, the first method focuses on the relevance of volumes in intersectoral transactions registered in Input-Output tables. It identifies as relevant all these sectors for which the expenditure coefficient a_{ij} from Input-Output tables for 1995 at least in four countries appeared higher than 1%. Only one year, 1995, has been chosen, based on the observation that expenditure coefficients remain substantially stabile over time. Also the value of 1% and the number of countries (constituting almost 1/3 of all the 13 countries taken into analysis) have been established arbitrary.

The technological dependence method takes as a discriminating criterion the correlation between $d(TFP)_{i,k,t}$ and each element of the vector $\lfloor \mathbf{a}_{\mathbf{ij,k,t}} \cdot \mathbf{d}(\mathbf{TFP})_{\mathbf{j,k,t}} \rfloor$. In that way, as relevant are considered also sectors that, despite a limited volume of transactions with sector *i*, experience a significantly high correlation of their changing TFP with the rate of change of TFP in sector *i*.

The functional form represented in equation (1) aims to measure the impact that the technological knowledge generated by upstream sectors, measured in terms of the rate of change in TFP, is able to work out on TFP of the downstream sector *i*. Moreover, this influence, on the contrary with the idea of free of charge knowledge spillover, is supposed to come through PKE. They occur as a consequence of lower than in equilibrium costs of knowledge, transmitted through market transactions of intermediate goods. These transactions are measured in terms of the expenditure coefficients. For each sector *i*, the coefficients family a_{ij}, obtained as a fraction of expenditures made by sector *i* from the acquisition of intermediates generated by sector *j* over the total output of sector *i*, expresses a relative importance of sector *j* as a source of intermediate inputs implemented in the production process of sector *i*. The joint component, given by each element of the vector $\lfloor \mathbf{a}_{\mathbf{ij,k,t}} \cdot \mathbf{d}(\mathbf{TFP})_{\mathbf{j,k,t}} \rfloor$, is thus intended to measure the impact that each upstream sector *j*, relevant for downstream producer *i*, exerts on technological opportunities of the latter by means of knowledge externalities associated with transactions of intermediate inputs. This external influence is, in turn, possible thanks to knowledge opportunities created with transactions of innovative intermediates. Finally, each element of the vector of estimation coefficients, $\mathbf{b}'$, measures elasticity of the impact that each relevant sector *j* exercises on sector's *i* rate of change of TFP.

In some cases it is plausible to expect that the functional relation presented in equation (1) encompasses not only PKE, but also effects of other type that result in a negative sign of estimation coefficients. First, these effects may be assigned to the occurrence of a negative technological influence between vertically integrated sectors. This depressive effect can be explained in terms of an excessively strong competitive pressure coming from the introduction of an upstream innovation. Not being able to face dynamically changing market conditions in the way to adequate internal processes, downstream producers experience worsening of their market position. The existence of such a mechanism is a part of the Schumpeterian process of creative destruction, where innovative solutions work out a negative influence on the existing ones, that not being replaced on time by adequate innovative items, become obsolete and are pushed out of the market. Additionally, negative signs might express also changes of relative prices of goods and production factors between sectors.

4.2. The data

The OECD STAN database constitutes a principal statistical source, from where come the data taken for the calculation of sectoral TFP. The Input-Output tables, for the available years, and for the rest, the Use tables, were taken from the Eurostat database and in some few cases from national statistical offices.[8] The study regards 25 manufacturing and service sectors, analyzed in 13 European countries, during the period going from 1995 to 2005.[9]

For every sector a separated panel has been constructed, each containing 143 observations. Moreover, for every sector an annual TFP growth rate has been calculated using the Thörnquist-Theil Divisia index. In the functional form, the index assumes the following expression:

$$\log\left(\frac{A_i(t+1)}{A_i(t)}\right) = \log\left(\frac{Y_i(t+1)}{Y_i(t)}\right) - (1-\overline{\alpha}_1(t))\log\left(\frac{K_i(t+1)}{K_i(t)}\right) - (\overline{\alpha}_1(t))\log\left(\frac{L_i(t+1)}{L_i(t)}\right) \qquad (2)$$

[8] In some cases it was possible to obtain from national sources the tables not available from the Eurostat. This was the case of Austria (2005), the Czech Republic (2005), Norway (1995-2000 and 2005), Spain (2002, 2003 and 2005) and the UK (2004, 2005).

[9] The list of countries includes Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Italy, the Netherlands, Norway, Spain, Sweden and the United Kingdom.

The index determines logarithmic growth rate of TFP as a difference between logarithmic growth rate of value added and logarithmic growth rates of labor compensation and of capital stock, the last two weighted by average values over two subsequent years of their respective parts in the value added, measured in terms of α coefficient from the standard Cobb-Douglas production function.

The expenditure coefficients multiplying *d(TFP)* in equation (1) have been obtained from deflated Input-Output or Use tables.[10] They were calculated as a fraction of expenditure of sector *i* made in intermediate inputs provided by sector *j* over the total value of output generated by sector *i*.

4.3. Methodology and results

The procedure consisted in estimating, sector by sector, 25 regressions, based on the mechanism designed in equation (1). These estimations were run according to the fixed effect model permitting in that way to average out the unobserved heterogeneity. Time dummies have been included.

For every sector *i*, relevant sectors *j*, included subsequently as explanatory variables, were determined according to the criterion described in Section 4.1. Table (4.1.) illustrates the complete list of sectors included in each estimation.

The results from the estimations, presented in Table (4.2.) below, indicate the network of vertical linkages based on knowledge interactions accompanying intermediate goods transactions between sectors. In every column, corresponding to each single regression, the numbers report the estimated values of the β coefficients that resulted to be statistically significant, i.e. coefficients relative to the upstream sectors that significantly explain the rate of change of TFP in sector *i*.

[10] Starting from 1995, the first observation of *d(TFP)* expresses the rate of change between 1994 and 1995. The corresponding expenditure coefficient that multiplies *d(TFP)* refers to 1995.

Table 4.1. Relevant sectors relative to the estimation equation of sector *i*. The full names of sectors is reported in Appendix A.1.

dep var	indep var
agr	food; wood; che; nmm; met; mach; el_eq; tr_eq; util; cons; whol; fin; health; tr&com; real
mng	food; che; nmm; met; mach; util; whol; tr&com; fin; real
food	agr; wood; pap; che; rubb; nmm; met; el_eq; tr_eq; manu; util; whol; tr&com; fin; real
text	agr; food; wood; pap; che; rubb; met; mach; util; whol; tr&com; fin; real
wood	agr; text; pap; che; rubb; nmm; met; mach; tr_eq; manu; util; cons; whol; tr&com; fin; real
pap	agr; text; wood; pap; che; rubb; nmm; mach; manu; util; cons; whol; tr&com; fin; real
che	mng; food; pap; rubb; met; mach; util; whol; tr&com; fin; real; health
rubb	text; pap; che; met; mach; el_eq; tr_eq; manu; util; cons; whol; tr&com; fin; real
nmm	mng; food; wood; pap; che; rubb; met; mach; el_eq; manu; util; cons; whol; htl; tr&com; fin; real; other
met	mng; che; rub; nmm; mach; el_eq; manu; util; whol; tr&com; fin; real
mach	pap; che; rubb; nmm; met; el_eq; tr_eq; util; whol; htl; tr&com; fin; real
el_eq	pap; che; rubb; nmm; met; mach; util; whol; htl; tr&com; fin; real
tr_eq	text; che; rubb; met; mach; el_eq; manu; util; whol; tr&com; fin; real; health
manu	text; wood; pap; che; rubb; nmm; met; mach; el_eq; tr_eq; util; whol; htl; tr&com; fin; real
util	mng; che; met; mach; el_eq; cons; whol; tr&com; fin; real
cons	mng; wood; che; rubb; nmm; met; mach; el_eq; tr_eq; whol; tr&com; fin; real
whol	agr; food; pap; che; rubb; met; el_eq; tr_eq; util; cons; htl; tr&com; fin; real; p_adm; other
htl	agr; food; pap; che; nmm; util; cons; whol; tr&com; fin; real; helath; other
tr_com	pap; che; el_eq; tr_eq; util; cons; whol; htl; fin; real; health
fin	pap; che; nmm; el_eq; tr_eq; manu; util; cons; whol; tr&com; real
real	pap; che; rubb; mach; el_eq; manu; util; cons; whol; htl; tr&com; fin; p_adm; other
p_adm	pap; mach; el_eq; tr_eq; util; cons; whol; tr&com; fin; real; other
edu	food; pap; manu; util; cons; whol; htl; tr&com; fin; real; p_adm; other
health	mng; food; pap; che; met; el_eq; manu; util; cons; whol; htl; tr&com; fin; real; other
other	pap; che; rubb; nmm; tr_eq; util; cons; whol; htl; tr&com; fin; real; p_adm; health

In the sense of columns sectors appear as receivers of PKE, while in the sense of rows they can be considered as providers of significant knowledge-based pecuniary effects. In the sense of rows, thus, one can read in how many cases each of upstream supplier exercised a relevant impact on the rate of change of TPF recorded by downstream producers.

Among the most influential sectors appeared to be sector of pulp, paper and paper products; basic metals and fabricated metal products; and construction. These sectors have been classified in the taxonomy as essential PKE providers. On the other extreme, agriculture and hunting, forestry and fishing; mining and quarrying; textiles, textile products, leather and footwear; public administration and defense – compulsory social security; and education services remain almost entirely outside of the system of intersectoral influences deriving from PKE, both as providers and as receivers. They do not work out any significant impact on other sectors in terms of PKE, and only in the case of the two service sectors there is some - prevalently negative - evidence of an influence that other sectors exercise on their TFP. The remaining sectors are placed in between, with a more or less strong position as providers or receivers of PKE.

Table 4.2. Estimation results: coefficients from the fixed effect regression of equation (1) for every sector *i* – only statistically significant results are reported. SE in brackets.

	dependent variable: d(TFP)												
	agr	mng	food	text	wood	pap	che	rubb	nmm	met	mach	el_eq	tr_eq
agr				.109* (.045)									
mng										-.015* (.008)			
food					.952*** (.258)		.346** (.104)						
text													
wood													
pap					.236* (.108)			.189** (.053)	.083* (.038)				
che								.004* (.002)					
rubb				-.167* (.068)	.195* (.096)		.331* (.140)						.082* (.035)
nmm													
met				.370*** (.089)	.063* (.030)				.057* (.028)		.018* (.009)		
mach								.104* (.051)					
el_eq													
tr_eq								.258* (.116)					
manu						.679* (.323)				.138** (.041)			
util											.106* (.045)	.227* (.113)	
cons					.191* (.094)			.528** (.165)	.294*** (.102)				
whol										.067* (.027)			
htl													
tr&com				-.101* (.047)			.110* (.063)						
fin					.183** (.057)	-.202** (.073)			.075* (.040)				-.241* (.104)
real													
p_adm													
edu													
health												-4.513** (1.571)	-7.276* (2.904)
other													
R&D			.072** (.024)			-.046** (.017)			.051*** (.016)				

significance level at 1 (***); 5(**) and 10% (*).

Table 4.2. continued.

	manu	util	cons	whol	htl	tr&com	fin	real	p_adm	edu	health	other
agr												
mng												
food										-.171* (.083)	.090** (.032)	
text	-.024** (.008)											
wood												
pap							-117* (.058)	.043* (.018)		-.076*** (.020)		
che				-.061* (.027)			-1.084*** (.211)					.049* (.022)
rubb								-.635*** (.077)				.417* (.208)
nmm							20.496* (8.029)					
met	.017* (.008)		-.035* (.017)	.184* (.079)							.495** (.149)	
mach		.133* (.050)										
el_eq							.365*** (.090)		-.024** (.008)			
tr_eq												.348* (.150)
manu												
util	-.075* (.036)											
cons		.190** (.060)					-.443** (.162)				.306*** (.068)	
whol		-.405** (.130)						.127*** (.026)				
htl	.083*** (.006)											
tr&com	.044* (.025)		.119* (.059)							-.076* (.033)	.159** (.054)	
fin										-.108*** (.025)		-.055* (.023)
real									.033** (.011)			
p_adm												
edu												
health						3.285* (1.565)						
other								.120* (.048)	-.072* (.034)	.155* (.075)		
R&D						.016* (.008)			.007* (.003)			

To some extent surprising appeared to be results concerning financial intermediation services. The most of the influence coming from and received by the sector has a negative sign. This would suggest that finance is principally involved in operating of a depressive effect, connected with the process of restructuring and modernization of the payment system. Also the change in relative prices might strongly influence estimation results, preventing from detecting the technological impact of financial intermediation on the rest of the economy.[11] Such an interpretation may be adopted also in the case of some other sectors, for instance chemicals and chemical products; wholesale and retail trade; transport and communication; and real estate, classified essentially in the group of bi-directional PKE players.

5. Conclusions

The aim of the paper has been to propose a new sectoral taxonomy, built upon the concept of PKE. Based on estimation results obtained from an empirical exercise, placed in an input-output context, the taxonomy groups manufacturing and service sectors into five classes, depending on their attitude as providers and/or receivers of PKE.

The concept of PKE focuses on the existence of knowledge-based pecuniary effects arising as an important by-product of intermediate goods transactions. The acquisition of innovative intermediates is accompanied by the transfer of relevant technological knowledge from innovative producer to active user. As a consequence, downstream users not only implement innovative intermediate inputs in their production process, but thanks to costs of acquisition of external knowledge lower than in equilibrium, they are given additionally the opportunity to receive and further transform upstream generated technological content into an innovative result internally created. In this sense, PKE are expected to influence the dynamics of changes of sectoral TFP and of the system as a whole.

The taxonomy has been derived from an empirical analysis aimed to investigate the occurrence of PKE in each of 25 manufacturing and service sectors in 13 European countries and over the period 1995-2005. The results of the estimation permitted to classify sectors into five groups, according to their involvement in originating or receiving external effects deriving from transmission of technological knowledge.

Sectors generating the most significant influence in terms of technological impact have been classified as essential PKE providers. Bi-directional PKE players are characterized by relatively important position both as providers – although their influence has appeared to be weaker than in the case of essential PKE providers – and as receivers of PKE. The next two classes, namely, exclusive PKE receivers and net PKE receivers refer to sectors that prevalently

[11] In many past studies it has been confirmed that finance plays an important role in the process of growth of the whole economic system and in transmitting the most relevant positive influence as provider of technological knowledge (Benhabib and Spiegel, 2000; Levine et al., 2000).

are addressed with external effects coming from the rest of the economy. Only in the latter group, and to a rather limited extent, sectors generate technological knowledge with further knowledge-based pecuniary external effects on sectors acquiring their innovative inputs. Finally, the group of marginal PKE players refers to sectors being neither providers nor receivers of PKE.

Considering the importance of the mechanism through which technological knowledge originated upstream, further transmitted downstream, and thanks to favorable cost conditions implemented in the production of goods and transformed into an innovative result, the taxonomy highlights the presence of sectors that are able to generate an important influence on the rest of the system. In this sense, both the group of essential PKE providers and bi-directional PKE players assume an essential role in determining the growth dynamics in a system of sectors vertically interlinked.

Appendix A.1. Sectors included in the panel

List of sectors, compatible with the current OECD 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 n.e.c.
12	Electrical and optical equipment
13	Transport equipment
14	Manufacturing n.e.c.; 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 other business activities
22	Public administration and defense; compulsory social security
23	Education
24	Health and social work
25	Other community, social and personal services

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