Measuring Intersectoral Knowledge Spillovers: an Application of Sensitivity Analysis to Italy

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ABSTRACT. R&D spillovers are unanimously considered as one of the main driving forces of technical change, innovation and economic growth. This paper aims at measuring inter-industrial R&D spillovers, as a useful information for policy-makers. We apply an "uncertainty-sensitivity analysis" to the Italian input-output table of intermediate goods split into 31 economic sectors for the year 2000. The value added of using this methodology is the opportunity of distinguishing (separately) between spillover effects induced by productive linkages (the *Leontiev forward multipliers*) and those activated by R&D investments, capturing also the uncertain and non-linear nature of the relations between spillovers and factors affecting them.

KEYWORDS: R&D spillovers, Input-output models, Sensitivity analysis, Monte Carlo simulations

JEL CODES: O32, C67, C15

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INTRODUCTION

The alternative of measuring the embodied inter-industrial R&D[1] spillovers through technology-based (patents or innovation flows) instead of transaction-based matrices (the so-called "indirect method") looks like less relevant today than in the past: as Verspagen (1997) remarked, in fact, both the methods are at the end centred on transaction, with the technology-based ones adding also the limits on data availability and construction on the one-to-one relation between supplier and main user.

Also Scherer (2003), in revisiting the two different applications, suggests that the R&D spillover measured by patent matrices can be tolerably well replaced by a combination of intermediate goods and capital flows matrices, especially if the first order I-O matrix is replaced by the Leontief inverse matrix, where the productive system is disaggregated into vertically integrated productive subsystems. The vertical chain of production is a key carrier of embodied and disembodied technological knowledge; there, as Lundvall (1988) remarked, the user-producer information exchanges, where fully information disclosure (as well as cooperation) is not always the rule, enhance the innovation processes and the effective and aware use of goods. This transfer of information, parallel to the production transactions, is not measured by the Leontief coefficients.

Notwithstanding these limits, we assume that it could be still useful to improve the application of the embodied R&D spillovers approach since, for example, in all the contributions we have examined, it is not possible to distinguish between the role of the "inducement" effect, due to the importance of an industrial product as input (linkage coefficient), resulting from a country's specific industrial development (as Drejer, 2000), and its innovation diffuser role given by the R&D component. The consequence of ruling out this aspect can be an over-evaluation of the role of some industries compared to others. This is, for instance, what results from some studies on R&D inter-industrial spillovers in Italy, where the innovation diffuser role of the high-tech sectors seem to be severely over-estimated.

Two branches of the economic literature have dealt with knowledge spillovers: the new growth theory has stressed that economic growth is the endogenous outcome of an economic system where R&D processes involve dynamic increasing returns, arising from the special property of knowledge to generate externalities. The national innovation systems approach, on its side, adopted the idea that externalities and spillovers positively affect firm/industry productivity and underlined the relevance of firms' interactions supporting the creation of externalities. In this literature "technology transfer" is the core activity of an innovation system where some technologies are transferred unintentionally through spillovers and others are deliberated transfers occurring via market and non-market links.

The paper deals with spillover effects via the inter-industry market transfers in productive subsystems and specifically with the structure of technological interdependencies in a national system of innovation, as expressed by "embodied" R&D flows. This is a key channel of knowledge diffusion for both embodied and disembodied[2] knowledge flows (Lundvall, 1985). The paper performs an "uncertainty-sensitivity analysis" for the sectoral spillovers using an input-output table of intermediate goods for Italy split into 31 economic sectors for the year 2000. We apply a non-linear variance decomposition to detect the main factors affecting intersectoral spillovers.

Compared to other approaches our work seems to mark an advance on two directions: (1) on the possibility of distinguishing between spillover effects induced by the linkages at productive subsystem level (the Leontief *forward multipliers)* and that induced by the producer R&D effort; (2) on the opportunity of capturing the uncertain and non-linear nature of the relations between spillovers and factors affecting them.

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[1] R&D is the main input in the process of knowledge production and it is currently used as a proxy of the output (knowledge).

[2] The importance of looking at the national productive linkages lays in the fact that the presence of domestic innovative and competent producers gives the users an advantage (in relation to foreign competitors): geographical and cultural proximity might give them more direct and easy access to information from domestic producers (Lundvall, 1985).

The paper is organised as follows: we start by discussing in brief the state-of-the art on intersectoral R&D spillovers measurement, to go on by presenting the methodology used. Then, we expose our main findings to end up with a concise discussion and conclusion.

1. THE STATE OF THE ART AND ITS LIMITS

Measuring intersectoral spillovers is a hard and complex issue. Indeed, while different elements participate to shape this complexity, at least four aspects seem to be the most important to be taken into account: first of all, the problem of a rigorous definition of the concept of R&D spillovers, of their origin and propagation within and among industries; second, the high complexity in describing the interdependencies and interactions among firms and industrial sectors; third, the type of models to be employed in the analysis; fourth, finally, problems arising from data availability and measurement errors in variables construction.

There is a large literature on the subject, which we should roughly organize as in the following with the aim of correctly positioning our contribution.

First of all there is a distinction between "rent" and "knowledge" spillovers, firstly introduced by Griliches (1979). The "rent" type is related to economic transactions and originate from the fact that many goods and services incorporating R&D expenditures are sold at prices that do not generally cover their entire "full quality price". This phenomenon is due to the competitive pressure on market prices, so that only a perfect discriminating monopolist could sell at the good's full quality price by completely internalising the rent. Measuring the "pure rent" spillover is a necessary step to take into account the quality or efficiency improvement in goods provision when hedonic prices (i.e. prices corrected for quality) are not available (see van Meijl, 1997)[3].

Knowledge spillovers, which do not need to be related to input purchases, exist because knowledge created in some industries can be used (at least partly for free) in other industries (public aspect or externalities of knowledge). In the literature it has often been assumed (Verspagen, 1997) that knowledge spillovers are more directly related to the knowledge embodied in innovations than in economic transactions. The typical references in measuring technological (knowledge) spillovers have been two kinds of matrices: 1) Scherer (1982) and the Yale matrixes (Evenson and Putman, 1994), built respectively on US and on Canadian patents, and 2) innovation flows matrices built by De Bresson *et al*. (1994)[4].

The use of this kind of matrices for measuring technological knowledge spillovers, has been criticized by Verspagen (1997) since they are built on a user-producer structure, where only the main economic industry in which patents or innovations are used have been identified, underestimating larger spillover effects. These methods (patents and innovation flows matrixes) refer still to transaction-based linkages. Larger technological knowledge spillovers, on the contrary, have been measured through technological or geographical "proximity" indices introduced for the first time by Jaffe (1986) and applied in an original way by other scholars such as Verspagen (1997) and Los and Verspagen (2000). In this case each firm/industry can receive a part of a total external pool of knowledge as function of its technological (or geographical) distance from the others. Table 1 presents a concise classification of embodied and disembodied approaches to spillovers measurement.

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[3] Griliches and Lichtenberg (1984), for example, modify the traditional Solow residual with a spillover component to correct sectoral TFP (total factor productivity) growth in the case of non-quality-adjusted inputs measurement.

[4] Other ways for measuring pure knowledge spillovers are R&D classified by product fields instead of patents (Goto and Suzuki (1989), for example, determine in this way the position of the Japanese industry in a technology space) and data on the disciplinary composition of R&D staffs (Adams, 1990). See also Los (1997).

Table 1. Classification of spillover measurements according to the embodied and disembodied approach

Embodied spillovers				**Disembodied spillovers**	
Technology-based (*direct method*)		Transaction-based (*indirect method*)		Proximity-based (*pure knowledge*)	
Patents matrix	Innovative flows matrix	Intermediate I-O matrix + R&D flows	Investment I-O matrix + R&D flows	Geographical distance	Technological distance

What are the relations between these different typologies of spillover measurement and where do we position our contribution? Different scholars have tried to study the relations among these different R&D spillovers through correlation coefficients or by studying the relation between productivity growth and different types of indirect R&D through regression analysis. Do the different matrices measure different things or are they just different methods for measuring the same thing? Following Verspagen (1997) the patent-based matrices measure knowledge spillovers related to economic transactions more than technological linkages among sectors, and he finds that the correlations among the different matrices are rather low. Therefore, he concludes that the user-producer patent-based matrix and the technological proximity matrix can be taken as complements.

As to van Mejil (1997), who looks at the total R&D intensity by sector, by adding up to the own R&D intensity the various input related (investments and intermediate inputs purchases) and non input related knowledge spillovers (patent-based matrix), there appears important differences among sectors. In high-tech sectors internal R&D and patent-based R&D spillovers represent more than 90% of all used R&D for nine out of ten industries, while for medium and low-tech sectors R&D spillovers embodied in intermediate goods are relatively more important. Finally, R&D spillovers embodied in investment goods are relatively more important in the service sectors. In sum, sectors where internal R&D is low, mostly use inputs that embody R&D.

Since the degree to which intra-industry technology knowledge generate externalities depends on the level of economic and technological interdependence among industries, where technological interdependencies are based on the transfer of “special commodities” such as patents or technical services, some authors find that it could be useful to adopt a mixed approach gathering two kinds of spillovers: “technological based” and “transaction based” measures (Sterlacchini 1987; Cincera, 2005). Other scholar (van Pottelsberghe de la Potterie, 1997) found out that patent-related transactions profile might be approximated by input-ouput matrices even if they assume that patent-based matrices catch more knowledge spillovers than I-O matrices.

Finally, Scherer (2003) suggests that the embodied technology measured by patent matrices could be tolerably well replaced by a combination of transactions and capital flows matrices. He reaches this result both by using simple correlations with his original (but more time-consuming-to-build) matrix and by performing comparative effects on productivity.

Our contribution looks at the spillovers related to intermediate goods transactions, therefore only to a component of the total (direct and indirect) carrier of knowledge diffusion. What is important to underline is that the I-O matrix of intermediate goods cover all intersectoral transactions (differently from the user-producer patent or innovation flows matrix) and that the application of the *Leontief multipliers* as weights of the other sectors’ R&D allows to take into account the bundle of linkages related to the production activities. As De Bresson wrote (1999, p. 4): *“the supplier-user approach had to be subsumed within a wider encompassing framework: networks of innovation”*, which are the dominant patterns in innovation. We look at the vertical linkages within a value chain in a multiplicity of industries. The problem, following the result of De Bresson *et al*. (1994), is that only a smaller part of the economic transaction in a I-O matrix concerns innovative goods: the density of innovative activities was around 43% of the intermediate productive exchanges[5] for 1985 in Italy. We believe, however, that our possibility of distinguishing between productive linkages effects and R&D effects could really improve the standard use of an I-O intermediate goods matrix.

2. THE SCOPE OF THE PAPER

In despite of the different approaches discussed we face in the literature a similar formula for the measure of the j-th sectoral spillover. This formula assumes the following form:

$$S_j = \sum_{i=1}^{N} w_{ij} K_i$$

where K_i is the knowledge stock of the i-th sector (or its R&D expenditure) and w_{ij} is a suitable system of weights, whose form depends on the chosen approach (technology, transaction and proximity-based). Although their differences, all these approaches share some common drawbacks:

1. a first shortcoming derives from the failure to identify the "importance" of factors affecting spillovers, especially when strong non-linearities are at work. In particular, standard techniques fail to recognize the separate effect of "transaction weights" and "R&D expenditures level" on knowledge diffusion and final production. Indeed, this distinction seems to be of great usefulness since, while transaction based weights represent the "inherited"[6] state of technology with its complementarities and strength of linkages, the level of R&D should be viewed as the essential carrier of the "improved quality" or "innovation". While transactions could be viewed as a largely diffused carrier of technical complementary knowledge, R&D has a less frequent presence and impact on the final production;
2. a second limitation comes from the type of formula adopted. In fact, as shown by some authors (Sterlacchini, 1987; Marengo and Sterlacchini, 1990; Leoncini and Montresor, 2001; Dietzenbacher and Los, 2002) within a I-O environment, the spillover formula should take into account not only the direct effects ("expenditure coefficients"), but also the indirect effects, that can be obtained by exploiting greater information contained in a I-O table. This can be done through the application of the Leontief inverse I-O matrix;
3. a third limit can be found in a static analysis of the spillover effect, as in the case of weights built on the input-output tables. Many of these coefficients, in fact, are not stable on time, but can vary as a consequence of "technical change";
4. a fourth drawback seems to be due to the lack of dealing with "uncertainty" within the variables chosen as inputs of spillover formulas. These variables, in fact, are usually taken as "deterministic coefficients", whereas they could be random. Uncertainty can be due both to theoretical assumptions (for example, are R&D expenditures exhaustive measures of "knowledge"?), or to errors in variables measurement.

In order to tackle these important issues we perform an "uncertainty-sensitivity analysis" for sectoral spillovers using an input-output table of intermediate goods and services for Italy split into 31 economic sectors for the year 2000. The aim of our work is to provide an advance compared to previous literature along the four lines traced above.

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[5] De Bresson *et al*. (1994; 1999) compared the matrix for innovative flows of 1981-85 with a similarly sized matrix of intermediate goods and found out that if the matrices are more aggregated (12x23) the density of innovative goods are higher (43%); differently, when the matrices are more disaggregated (43x66) the density of innovative activities is lower. Some authors (Cioffi and Potì, 1997) calculated the density of the total innovative exchanges compared with intermediate goods exchanges for 22x40 matrix for 1990-92 and found out a higher density: innovative activities clustered in 56% of the total cells.

[6] As Drejer (2000) the structural analysis of R&D interdependencies is in relation with the past industrial development.

3. OUR METHODOLOGY

Our methodology, trying to overcome some of the limitations faced by previous efforts on measuring inter-sectoral spillovers, is drawn on an uncertainty-sensitivity analysis, fairly new in economic applications while widely used in chemicals and physics. Our procedure pursues the following steps:

1. we start by using as spillover formula the one proposed by Dietzenbacher and Los (2002) based on "I-O forward multipliers"[7]. This formula takes the following form for the *j*-th spillover:

   $$SPILL_j = \sum_{i=1}^{N} g_{ij} R_i$$

   where the various g_{ij} are the Leontiev *multipliers* taking into account "direct and indirect" productive effects of various sectors *i* on sector *j*, and where R_i are R&D expenditures;
2. we go on by holding the g_{ij} and R&D sectoral expenditures to be both uncertain inputs, assuming for them specific probability distribution functions (pdf). In particular we take, according to previous experiments, a lognormal pdf for the g_{ij} and a normal one for the R_i (see Bullard and Sebald, 1988);
3. the third step consists of a Monte Carlo sampling simulation, through which we perform an uncertainty analysis of the results. In particular we obtain a specific pdf for each sectoral spillover along with its distributional properties (mean, coefficient of variation, skewness and so on);
4. our fourth step focuses on a more policy-oriented direction. This is the core of our paper. We apply to data the method of "sensitivity analysis" developed by Saltelli et al. (2004) to identify which of the uncertain factors considered in our spillover formula are the "most important" in explaining the overall variability (total unconditional variance) of our outputs (the 31 spillovers). This is a "variance based" method using ANOVA decomposition, but adapted to the case of a non-linear relation. Indeed, when both the g_{ij} and the R_i are random variables, $SPILL_j$ is a "non-linear" function of those inputs. Standard ANOVA decomposition is based on linearity assumption so that, in our case, a more sophisticated method of variance decomposition has to be implemented (the Sobol's method);
5. finally, using this variance decomposition method we obtain, for each sectoral spillover, a rank for the 62 inputs (31 g_{ij} and 31 R_i) considered. Once the main factors have been identified, we can then describe the relation between them and the spillovers.

3.1 The spillover formula using the I-O table

Measurement of I-O based spillovers follows essentially two different methods. In the conventional method, the first order input-output transactions matrix (see Terleckyj, 1980) closer to the Scherer's original approach, the weights representing the extent to which the R&D undertaken by other industries may be taken as part of the industry *j*'s technology stock, are equal to the I-O expenditure coefficients. The idea is that the benefit that the industry *j* obtains through R&D embodied in intermediate goods is directly proportional to the parts of the output that the sector *j* buys form other sectors.

The other method adopts the "total requirements" (Leontief inverse) matrix, by taking into account inputs used both directly and indirectly to produce a vector of outputs. It has been largely applied by different scholars (such as, for Italy: Sterlacchini 1987; Marengo e Sterlacchini, 1990; Leoncini and Montresor, 2001). In this case an operator B is derived from the I-O table, which allows the translation of the measures (R&D expenditures) from a sectoral to a subsystem environment. Each column in the B matrix represents a subsystem, i.e. a vector of the quotas of sectors' output that directly (those on the diagonal) and indirectly (all the others) enter in each component of the final demand[8]. Rows represent the distribution of the output

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[7] The Leontiev inverse matrix has been applied in all indirect method spillover measure by Italian scholars, but always with a "backward" approach. We apply the "forward" approach, but in a different way from Dietzenbacher and Los (2002).

[8] Cells in the matrix B are quotas of the sectoral output unit distributed by subsystems.

unit of each sector by subsystem and consequently the amount of the R&D expenditure of sector *i* embodied in *i*'s output demanded by other sectors or re-used by the same *i* (elements on the main diagonal). This same formula has been used by Dietzenbacher and Los (2002) who add an explicit distinction between *backward* and *forward* linkages. The two kinds of spillovers represent the same phenomenon, but from alternative perspectives. Backward multipliers explain the R&D effort directly and indirectly associated with a unitary increase in the industry *j* final demand (for consumption or investment or export); forward multipliers explain by what proportion the output value of an industry *j* should increase as a consequence of a unitary increase of the industry *i* primary costs (here R&D expenditures). In our application we adopt the forward multiplier measure.

3.1.1 The spillover formula using *Leontiev forward multipliers*

In the conventional input-output formula, the spillover weights are the relative expenditure coefficients x_{ij} / X_j, that is, the fraction of the *j*'s purchase of intermediate (or capital) goods produced by sector *i* (i.e., x_{ij}) on total sector *j* production (i.e., X_j).

It is, however, a really raw and approximate formula for the overall spillover captured by sector *j*, at least for two reasons:

1. since it considers only "direct effects";
2. since it is not related to any economic meaning.

In order to overcome these shortcomings Dietzenbacher and Los (2002), among other scholars, suggested to use a formula based on Leontiev input-output *forward/backward* multipliers instead of expenditure coefficients. In these multiplier applications, the approach takes into account both direct and indirect effects and the level of "*j*'s production increase" in order to define, in that way, a proper and more effective notion of "R&D externality". The model is quite simple. It starts from the *j*'s costs equation:

$$[1] \qquad \sum_{i=1}^{n} x_{ij} + Z_j = X_j$$

where Z_j is the *j*'s primary costs. By defining $b_{ij} = x_{ij} / X_i$, we obtain by substitution:

$$[2] \qquad \sum_{i=1}^{n} b_{ij} X_i + Z_j = X_j$$

that in matrix form becomes:

$$[3] \qquad \mathbf{BX} + \mathbf{Z} = \mathbf{X}$$

where **B** is the n-dimensional matrix of various b_{ij}. By simple matrix algebra we get that:

$$[4] \qquad \mathbf{X} = [\mathbf{I} - \mathbf{B}]^{-1} \mathbf{Z}$$

where $\mathbf{G} = [\mathbf{I} - \mathbf{B}]^{-1}$ is the well-known Leontiev matrix of *forward multipliers*. The generic element of this matrix, g_{ij}, indicates the increase of the *j*'s production value "directly and indirectly" generated by one euro of primary expenditure in sector *i*. By supposing (a) fixed prices (short-run setting), and (b) R&D expenditure (*R*) working as primary costs, we have that $R_i g_{ij}$ represents the increase of sector *j*'s production due to an amount of R_i euros of R&D expenditure in sector *i*. The total amount of *j*'s production increase due to the overall sectoral R&D expenditure is therefore given by:

$$[5] \qquad SPILL_j = \sum_{i=1}^{N} R_i g_{ij} \, ,$$

that is the *j-th* column sum of the matrix $\mathbf{G} \cdot \hat{\mathbf{R}}$, where $\hat{\mathbf{R}}$ is the diagonal matrix of the various R_i.

3.2 *The setting of our Monte Carlo experiment*

According to the 2-digit NACE classification of Italian manufacturing, we consider the previous formula ([5]) for 31 industrial sectors (see annex A) as the basis of our Monte Carlo experiment. In order to calculate the matrix **G** we use the I-O table of Italian intermediate goods and services provided by ISTAT (the Italian national institute of statistics) for the year 2000. Once obtained **G,** we consider the R&D expenditures as published by ISTAT (2006) for the year 2003[9].

The formula [5] contains, for each sector considered, 62 factors representing: the state of technology and productive complementarities (the 31 g_{ij}) and the state of knowledge flows creation (the 31 R_i). Our Monte Carlo experiment involves the following steps:

1. we assign to each factor a specific probability distribution function (pdf). In particular we take a normal distribution for the R&D expenditure (R_i) and a log-normal one for the forward multipliers (g_{ij}). For each random variable the construction of the pdf follows the following procedure:
   a) the expected value (the mean of the pdf) is taken equal to the published value;
   b) for the calculus of the variance (σ), we fix a 25% of error ($\delta=0.25$) around the mean taking a 99.7% of confidence in this interval, so that:

      for normal: $\Pr(\mu - \delta\mu \le R \le \mu - \delta\mu) = 0.997$

      for log-normal: $\Pr(g_0 / D \le g \le g_0 D) = 0.997$ [10].

   For the normal distributions, by looking at the tabulated values, we obtain that $\sigma = \delta\mu/3$, while for the log-normal ones, we can apply the same procedure by remembering that, if *g* follows a log-normal distribution, then *ln(g)* follows a normal one. Finally, we decide to truncate the R&D expenditures' distributions at values less or equal than the mean (leaving out, hence, their right part)[11].
2. Once assigned a specific distribution to each factor, we generate *randomly* (and for each of the 31 sectors), *N* combinations of *independent* input factors (i.e., *N* samples).
3. Using the formula [5] we obtain (again, for each sector *j*) the output ($SPILL_j$) corresponding to each sample generated until we receive, at the end of this procedure, the entire distribution of $SPILL_j$.
4. Once performed this simulation, we apply the *sensitivity analysis* using the FAST procedure[12] to find out which, among the factors considered, explains the greatest part of total unconditional output variance. We finally rank these factors according to the fraction of the overall variance explained.

3.3 *Sensitivity analysis using variance-based methods: main and total importance indexes*[13]

The aim of this paragraph is to provide the basic algebra to build the sensitivity indicators for the spillover formula used in our simulation. Let's start by considering a general formula of the type:

$$Y = f(X_1,...,X_k,...,X_K)$$

where *Y* is a generic output and $X_1,...,X_K$ are *K* generic independent stochastic input factors. Assume *V(Y)* to be the unconditional variance of *Y* and suppose to fix the input X_k at the level X^*_k. The conditional variance of *Y* can be written as:

$$V_{\mathbf{X}_{-k}}(Y \mid X_k^*)$$

where the variance is taken over the vector $\mathbf{X}_{-k}$ of dimension *(K-1)*. We can compute this conditional variance for each factor. It is clear that, by definition, the lower the level of this variance,

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[9] We consider R&D expenditures of 2003 instead of 2000 since they appear to be more consistent with the I-O sectoral disaggregation, expressing them at prices of 2000 using suitable sectoral deflators.

[10] This form of the confidence interval derives from the fact that the log-normal is an asymmetric distribution. Furthermore, observe that we use a log-normal distribution for the various g_{ij} (instead of a normal one) since they are non-negative and really close to zero, so that a normal pdf hypothesis couldn't prevent possible negative values in our simulations.

[11] The basis of this choice is theoretical. We believe, in fact, that the published values of R&D expenditures are to be taken as an upper bound of the potential "knowledge creation" deriving from each sector.

[12] In the FAST (Fourier Amplitude Sensitivity Test) procedure the variance of a generic output Y (in a space of dimension k) is re-written as a 1-dimensional integral with respect to a scalar variable s (see Saltelli *et al*., 1999). In our Monte Carlo we perform 15,000 sample replications to obtain results using the software Simlab 2.2 developed by Saltelli *et al*. (2004).

[13] This paragraph draws on Saltelli (2006) whose is a concise exposition.

the greater the importance of the factor X_k in explaining the overall variance of Y. The problem with this measure of "sensitivity", nevertheless, is that (a) it is a point estimate, and (b) in non-linear models it can be greater than $V(Y)$.

In order to overcome these two problems instead of a "point estimate" we can use an "average estimate" of this kind:

$$E_{X_k}\left\lfloor V_{\mathbf{X}_{-k}}(Y \mid X_k)\right\rfloor.$$

This last index is really useful since, by standard ANOVA decomposition, we know that:

$$V(Y) = E_{X_k}\left\lfloor V_{\mathrm{X}_{-k}}(Y \mid X_k)\right\rfloor + V_{X_k}\left\lfloor E_{\mathrm{X}_{-k}}(Y \mid X_k)\right\rfloor.$$

It means that X_k is influential when $V_{X_k}\left\lfloor E_{\mathbf{X}_{-k}}(Y \mid X_k)\right\rfloor$ is high (and $E_{X_k}\left\lfloor V_{\mathbf{X}_{-k}}(Y \mid X_k)\right\rfloor$ low). Therefore, we can define as the *main effect* of X_k on Y (or *first order sensitivity index*) the following (relative) measure (ranging between 0 and 1):

$$[6] \qquad S_k = \frac{V_{X_k}\left\lfloor E_{\mathrm{X}_{-k}}(Y \mid X_k)\right\rfloor}{V(Y)}.$$

It can be proved that for a generic algebraic formula:

$$\sum_{k=1}^{K} S_k \le 1$$

where equality holds only for linear or additive models[14]. For non-linear (or non-additive) models it has been showed that, in case of independent stochastic factors, the unconditional variance of Y can be written as:

$$[7] \quad \sum_k S_k + \sum_k \sum_{j>k} S_{kj} + \sum_k \sum_{j>k} \sum_{l>j} S_{kjl} + \ldots + S_{1,2,\ldots,K} = 1$$

where the various S that are not main effects are said to be "interactions" (of second, third, fourth, … order). For the second order, for example, we have that:

$$S_{kj} = \frac{V_{kj}}{V(y)} = \frac{1}{V(y)}\left\{\begin{array}{l} V_{X_k X_j}\left\lfloor E_{\mathrm{X}_{-kj}}(Y \mid X_k, X_j)\right\rfloor - \\ - V_{X_k}\left[E_{\mathrm{X}_{-k}}(Y \mid X_k)\right] - V_{X_j}\left[E_{\mathrm{X}_{-j}}(Y \mid X_j)\right] \end{array}\right\}$$

and so on for greater orders. Expression [7] contains ($2^K - 1$) elements that are computationally difficult to estimate jointly. In applications, nevertheless, it is interesting to calculate for each factor only *main* and *total effects*. The latter, indeed, is defined as:

$$[8] \qquad \begin{aligned} S_k{}^T &= 1 - \frac{V_{\mathrm{X}_{-k}}\left\lfloor E_{X_k}(Y \mid \mathrm{X}_{-k})\right\rfloor}{V(Y)} = \\ &= \frac{E_{\mathrm{X}_{-k}}\left\lfloor V_{X_k}(Y \mid \mathrm{X}_{-k})\right\rfloor}{V(Y)}. \end{aligned}$$

and it represents the sum of all the terms including the factor X_k (both singularly or with interactions). For example, if $K=3$ we have, by definition, that:

$$\begin{aligned} S_1{}^T &= S_1 + S_{12} + S_{13} + S_{123} \\ S_2{}^T &= S_2 + S_{12} + S_{23} + S_{123} \\ S_3{}^T &= S_3 + S_{13} + S_{23} + S_{123} \end{aligned}$$

so that the difference between the total effect and the main effect defines a measure of the strength of the interactions between factor 1 and the other factors:

$$[9] \qquad \Delta_1 = S_1{}^T - S_1 = S_{12} + S_{13} + S_{123}\,.$$

At the same time, since for linear (or additive) models interactions are zero, this difference can also be interpreted as a measure of the factor's degree of non-linearity (or non-additivity), whereas for the overall formula a measure of the non-linearity (or non-additivity) is give by:

$$1 - \sum_{k=1}^{K} S_k$$

Observe, finally, that:

$$\sum_{k=1}^{K} S_k{}^T \ge 1$$

where equality holds just for linear or additive models (no interactions).

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[14] An additive model is a model where each addend is function of only one factor. For instance, $Y = \sum_k X_k{}^2$ is an additive formula.

4. CHARACTERIZING THE ITALIAN INPUT-OUTPUT TABLE FOR INTERMEDIATE GOODS AND SERVICES

The degree to which technological knowledge and innovation spread through the economy depends on the level of economic and technological interdependence among sectors. The structure of the productive linkages is the result of the country's past industrial development and can be used as a point of departure before analysing the R&D spillover indices.

The aim of the paragraph is to offer a simplified reading of the main characteristics of the Italian I-O table of intermediate goods and services for the year 2000. In particular we are interested in providing a compact description of the "diffusive capacity" of sectors according to the coefficients **G** of the Leontief matrix. First of all we introduce the methodology (par. 4.1) and thereafter the results of its application (par. 4.2).

4.1 The redistributive effect index

In the literature various indexes for measuring sectoral diffusive capacity in an I-O environment have been proposed[15]. We choose to adopt the indexes of "redistributive effects" proposed by Roland-Holst and Sancho (1992), since they seem particularly suitable to our specific context[16].

Consider the previous formula:

$$[10] \qquad \mathbf{X} = \mathbf{G}\mathbf{Z}$$

where **G** is the Leontiev matrix. By differencing both members we obtain:

$$d\mathbf{X} = \mathbf{G}d\mathbf{Z} .$$

Consider now the following normalized expression for **X:**

$$\mathbf{x} = \frac{\mathbf{X}}{\mathbf{e'X}}$$

where **e = (1, 1, …, 1)**. The time derivative of **x** takes the following form:

$$d\mathbf{x} = \frac{d\mathbf{X}\cdot(\mathbf{e'X}) - \mathbf{X}\cdot(\mathbf{e'}d\mathbf{X})}{(\mathbf{e'X})^2}$$

or:

$$d\mathbf{x} = \frac{1}{(\mathbf{e'X})}\left[\mathbf{I} - \frac{\mathbf{X}\cdot\mathbf{e'}}{(\mathbf{e'X})}\right]\cdot\mathbf{G}d\mathbf{Y} = \mathbf{T}d\mathbf{Y} .$$

The matrix **T** is known as the "redistributive matrix". Its generic element, t_{ij}, is given by:

$$t_{ij} = \frac{1}{\mathbf{e'X}}\left[g_{ij} - \frac{X_j}{\mathbf{e'X}}\cdot\mathbf{e'g_{i.}}\right]$$

where $\mathbf{g_{i.}}$ represents the vector formed by the *i*-th row of **G**. It is easy to see that:

$$t_{ij} \geq< 0 \quad \Leftrightarrow \quad \frac{g_{ij}}{\mathbf{e'g_{i.}}} \geq< \frac{X_j}{\mathbf{e'X}} ,$$

that is, t_{ij} is positive if the share of *j*'s increase of production due to an exogenous injection from sector *i* is greater than its initial share on overall production. In this case *j* takes advantage of *i*'s injection (and vice versa when t_{ij} is negative).

An interesting property of t_{ij} is that its sum on *j* is equal to zero. In fact:

$$\sum_j t_{ij} = \frac{1}{\mathrm{e'X}}\left[\sum_j g_{ij} - \frac{\sum_j X_j}{\mathrm{e'X}}\cdot\mathrm{e'g_{i.}}\right] = \frac{1}{\mathrm{e'X}}\left[\sum_j g_{ij} - \mathrm{e'g_{i.}}\right] = 0$$

since:

$$\mathbf{e'X} = \sum_j X_j , \qquad \text{and} \qquad \sum_j g_{ij} = \mathbf{e'g_{i.}}$$

---

[15] Among the most popular indicators it is of worth to remind the "Rasmussen dispersion indices", and in particular the "power of dispersion" and the "sensitivity of dispersion" index (Rasmussen, 1957). See Drejer (2003) for a recent discussion on this subject.

[16] This index was at first developed in a Social Accounting Matrix (SAM) framework for analysing redistributive effects of exogenous policies on sectors, factors and institutions' income. We apply it in a I-O model where only sectors are considered. Compared to traditional measures of sectoral diffusion capacity this index is more appropriate to map graphically (as it will be clearer afterward) the state of these kind of sectoral interdependences.

In our application, nevertheless, we get rid of $1/\mathbf{e'X}$ and we consider a normalized index obtained by dividing t_{ij} by the sum of positive terms contained in the vector $\mathbf{t_{i.}}$ and that we indicate as $\mathbf{e't_{i.}}^{(+)}$. Our index, hence, takes the following form:

$$m_{ij} = \mathbf{e'X} \cdot \left[\frac{t_{ij}}{\mathbf{e't_{i.}}^{(+)}} \right].$$

Also the sum of m_{ij} on j is zero, but this index represents percentage (rather then level) measures of advantages (if positive) or disadvantages (if negative). Furthermore, this index seems to be particularly explicative of the diffusive capacity of each exogenous sector i. In fact, a simple index of this capacity ranging between zero and one is provided by:

$$f_i = 1 - m_{ii} .$$

It is quite intuitive to recognize that the greater the level of f_i, the greater the diffusive capacity of sector i. For instance, when f_i is exactly equal to 1, the overall advantage generated by sector i spreads within i itself (and totally out of i when f_i is exactly equal to 0).

4.2 The Italian matrix of the redistribution effects

Working on the matrix of the redistributive effect (matrix **M**) we can put into evidence the diffusive capacity of sectors due to the structure of the productive linkages, to be taken into account when we operate with the R&D expenditure and spillovers indices.

The redistribution matrix is presented in table 2. It shows how the expenditure of one euro in an exogenous sector i impacts on the output of the other sectors j (with a positive or negative sign) and which sector benefits more. The most diffusive industries are identified by a combination of a relative lower intra-sector impact and a higher number of positive values in other sectors. We chose a threshold for the number of positive values and for the share of intra-industry benefit (see table 3).

For all industries it can be easily observed that the major impact remains into the industry itself. This is probably also due to the aggregation level, the two digit analysis, necessary for using the sectoral classification of R&D expenditure.

Major diffusive capacity is found in two industries: “basic metals” (12)[17] and “fabricated metal products” (13), due to the fact that the I-O table concerns only intermediate products exchanges. Medium-high diffusive capacity towards user sectors is found in “energy sectors” (1) (mining, coke, petroleum, nuclear and so on), in “wood and wood products” (6), in “other non-metallic mineral products” (11) and in “office, accounting and computing machinery” (15).

A medium-low capacity of diffusion concerns sectors such as “rubber and plastics” (10), “electrical machinery” (16), “radio, tv and communication equipment” (17), “energy (electricity, gas, steam, water) supply and distribution” (22).

We can also add that the industries which benefit more (positive values) from an exogenous expenditure are regrouped around the centre of table 2 from sector 10 to sector 20 including sector 23: they represent manufacturing sectors and construction.

If we read table 2 by column, we find out which sectors i are more diffusive for each sector j: for instance, the “machinery industry” (14) is positively influenced by expenditures in “rubber and plastics” (10), in “basic metals and fabricated metal products” (12 and 13), in the “electrical machinery and apparatus” (16) and has a strong intra-sector redistributive effect, while positive effects from IT industry are not present. This separation between machinery industry and IT industry characterised historically the development of these sectors in Italy and we still find out its presence in 2000.

We take table 2 as a benchmark for the reading of our results on sensitivity analysis.

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[17] The number in the brackets refers to the two-digit sector ID according to the annex A.

Table 2. The redistribution matrix of exogenous on endogenous sectors based on the Roland-Holst and Sancho (1992) approach. Emphasized cells present positive value

i \ j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1	0.73	-0.05	-0.02	-0.02	-0.01	-0.01	-0.00	-0.01	-0.02	-0.01	0.05	-0.01	-0.03	-0.05	-0.01	-0.01	-0.02	-0.01	-0.03	-0.01	-0.01	0.22	-0.00	-0.16	-0.02	-0.06	-0.11	-0.02	-0.01	-0.07	-0.20
2	-0.04	0.87	-0.02	-0.01	0.03	-0.01	-0.01	-0.01	-0.02	-0.01	-0.02	-0.03	-0.04	-0.05	-0.00	-0.02	-0.02	-0.01	-0.03	-0.01	-0.02	-0.03	-0.07	0.10	-0.09	-0.06	-0.09	-0.02	-0.01	-0.07	-0.17
3	-0.03	-0.05	0.83	0.16	0.01	-0.01	-0.00	-0.01	-0.03	-0.01	-0.02	-0.02	-0.03	-0.05	-0.00	-0.02	-0.01	-0.01	-0.02	-0.01	-0.01	-0.03	-0.06	-0.14	-0.08	-0.05	-0.07	-0.02	-0.00	-0.06	-0.14
4	-0.03	-0.05	0.01	0.98	0.00	-0.01	-0.01	-0.01	-0.04	-0.01	-0.02	-0.02	-0.03	-0.05	-0.00	-0.02	-0.01	-0.01	-0.03	-0.01	-0.02	-0.02	-0.06	-0.15	-0.08	-0.04	-0.06	-0.02	-0.00	-0.05	-0.13
5	-0.04	-0.05	-0.02	0.03	0.97	-0.01	-0.01	-0.01	-0.04	-0.01	-0.02	-0.02	-0.03	-0.05	-0.00	-0.02	-0.01	-0.01	-0.01	-0.01	0.01	-0.03	-0.06	-0.12	-0.08	-0.05	-0.07	-0.02	-0.00	-0.06	-0.15
6	-0.04	-0.04	-0.02	-0.02	-0.01	0.69	-0.01	-0.01	-0.04	-0.01	-0.00	-0.01	-0.01	-0.03	-0.00	-0.01	-0.02	-0.01	-0.02	-0.00	0.24	-0.03	0.06	-0.18	-0.09	-0.05	-0.08	-0.02	-0.01	-0.07	-0.16
7	-0.05	-0.01	-0.02	-0.01	-0.01	-0.01	0.84	0.16	-0.01	0.00	-0.01	-0.02	-0.03	-0.03	-0.00	-0.01	-0.02	-0.01	-0.03	-0.01	-0.01	-0.03	-0.06	-0.09	-0.06	-0.06	-0.12	-0.02	-0.00	-0.04	-0.20
8	-0.05	-0.05	-0.02	-0.01	-0.01	-0.01	0.02	0.98	-0.03	-0.01	-0.02	-0.03	-0.04	-0.05	-0.01	-0.02	-0.02	-0.01	-0.04	-0.01	-0.00	-0.03	-0.06	-0.06	-0.02	-0.05	-0.12	-0.01	0.00	-0.04	-0.18
9	-0.03	-0.04	0.02	-0.01	-0.00	-0.01	0.01	0.00	0.87	0.09	0.00	-0.01	-0.02	-0.03	-0.00	-0.00	-0.01	-0.00	-0.02	-0.01	-0.00	-0.02	-0.05	-0.20	-0.10	-0.07	-0.11	-0.02	-0.00	-0.08	-0.15
10	-0.05	-0.05	-0.02	-0.01	0.02	-0.01	-0.00	-0.01	0.01	0.90	-0.01	-0.02	-0.02	0.02	-0.00	0.02	-0.01	-0.01	0.03	0.00	0.00	-0.03	-0.01	-0.19	-0.05	-0.07	-0.12	-0.02	-0.01	-0.08	-0.22
11	0.03	-0.03	-0.02	-0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	0.76	0.00	-0.02	-0.03	-0.00	-0.01	-0.01	-0.01	-0.02	-0.01	-0.01	-0.02	0.24	-0.19	-0.09	-0.06	-0.09	-0.02	-0.01	-0.07	-0.18
12	-0.04	-0.06	-0.02	-0.02	-0.02	-0.01	-0.01	-0.01	-0.01	-0.00	-0.01	0.57	0.18	0.12	-0.00	0.04	-0.01	-0.00	0.03	0.01	0.04	-0.02	0.01	-0.20	-0.09	-0.06	-0.10	-0.02	-0.01	-0.08	-0.19
13	-0.04	-0.06	-0.02	-0.02	-0.01	-0.00	-0.01	-0.01	-0.04	-0.01	-0.01	0.01	0.76	0.13	-0.00	0.01	-0.01	-0.00	0.04	0.01	0.01	-0.02	0.03	-0.20	-0.08	-0.06	-0.09	-0.02	-0.01	-0.07	-0.18
14	-0.03	-0.05	-0.02	-0.02	-0.01	-0.01	-0.01	-0.01	-0.04	-0.01	-0.01	-0.02	-0.02	1.00	-0.00	-0.01	-0.01	-0.01	-0.01	0.00	-0.01	-0.02	-0.04	-0.18	-0.07	-0.05	-0.08	-0.02	-0.00	-0.07	-0.16
15	-0.05	-0.06	-0.02	-0.02	-0.01	-0.01	-0.01	-0.01	-0.02	-0.00	-0.02	-0.03	-0.03	-0.04	0.85	-0.01	0.03	-0.00	-0.03	-0.01	-0.02	-0.03	-0.04	-0.13	0.05	-0.04	-0.11	0.08	-0.00	-0.05	-0.20
16	-0.04	-0.06	-0.03	-0.02	-0.02	-0.01	-0.01	-0.01	-0.05	-0.01	-0.02	-0.02	-0.01	0.05	0.01	0.87	0.03	-0.00	0.02	0.00	-0.02	-0.01	0.02	-0.19	-0.05	-0.06	-0.09	-0.02	-0.01	-0.07	-0.18
17	-0.04	-0.06	-0.03	-0.02	-0.01	-0.01	-0.01	-0.01	-0.04	-0.01	-0.02	-0.03	-0.03	-0.01	0.07	0.01	0.90	0.01	-0.02	0.01	-0.02	-0.03	-0.04	-0.18	-0.03	-0.05	-0.09	0.01	-0.00	-0.06	-0.16
18	-0.01	-0.06	-0.03	-0.02	-0.02	-0.01	-0.01	-0.01	-0.02	-0.01	-0.02	-0.03	-0.03	-0.03	0.00	-0.00	0.02	0.96	-0.01	0.02	-0.01	-0.02	-0.06	-0.19	-0.06	-0.06	-0.10	-0.02	-0.00	-0.07	-0.10
19	-0.04	-0.05	-0.02	-0.02	-0.01	-0.01	-0.01	-0.01	-0.04	-0.01	-0.02	-0.02	-0.03	-0.03	-0.00	-0.01	-0.02	-0.01	1.00	-0.00	-0.02	-0.03	-0.06	-0.11	-0.03	-0.05	-0.08	-0.02	-0.00	-0.06	-0.15
20	-0.04	-0.06	-0.02	-0.02	-0.01	-0.01	-0.01	-0.01	-0.05	-0.02	-0.02	-0.03	-0.03	-0.04	-0.00	-0.01	-0.02	-0.01	-0.03	0.94	-0.02	-0.03	-0.06	-0.16	0.06	-0.05	-0.09	-0.01	-0.00	-0.06	-0.09
21	-0.04	-0.05	-0.02	-0.02	-0.01	-0.01	-0.00	-0.01	-0.04	-0.01	-0.01	0.04	-0.00	-0.02	-0.00	-0.01	-0.01	-0.00	-0.02	-0.01	0.96	-0.02	-0.04	-0.17	-0.08	-0.05	-0.08	-0.02	-0.00	-0.07	-0.16
22	-0.04	-0.03	0.01	-0.01	-0.01	-0.01	0.01	-0.00	-0.00	0.01	0.02	0.00	-0.02	-0.03	-0.00	-0.01	-0.02	-0.01	-0.02	-0.01	-0.01	0.95	-0.05	-0.17	-0.09	-0.07	-0.11	-0.02	-0.01	-0.08	-0.18
23	-0.04	-0.05	-0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.05	-0.02	-0.02	-0.03	-0.03	-0.05	-0.00	-0.02	-0.01	-0.01	-0.03	-0.01	-0.02	-0.01	1.00	-0.16	-0.05	-0.04	-0.06	-0.01	-0.00	-0.05	-0.14
24	-0.05	-0.04	-0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.04	-0.01	-0.01	-0.02	-0.03	-0.04	-0.00	-0.01	-0.01	-0.01	-0.03	-0.01	-0.01	-0.03	-0.05	1.00	-0.07	-0.06	-0.11	-0.02	-0.01	-0.08	-0.20
25	-0.04	-0.04	-0.02	-0.01	-0.01	-0.00	-0.01	-0.01	-0.04	-0.01	-0.01	-0.02	-0.03	-0.05	-0.01	-0.01	-0.02	-0.01	-0.03	-0.01	-0.01	-0.03	-0.03	-0.11	1.00	-0.05	-0.12	-0.01	-0.00	-0.05	-0.20
26	-0.04	-0.06	-0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.05	-0.02	-0.02	-0.02	-0.02	-0.04	-0.01	-0.01	-0.02	-0.01	-0.03	-0.01	-0.01	-0.03	-0.04	-0.13	-0.05	1.00	-0.07	-0.01	-0.01	-0.05	-0.17
27	-0.04	-0.06	-0.02	-0.02	-0.01	-0.01	-0.01	-0.01	-0.05	-0.02	-0.02	-0.03	-0.04	-0.06	-0.01	-0.02	-0.02	-0.01	-0.04	-0.01	-0.02	-0.03	-0.06	-0.10	-0.07	-0.04	1.00	-0.01	-0.00	-0.05	-0.12
28	-0.04	-0.07	-0.03	-0.02	-0.02	-0.01	-0.01	-0.01	-0.05	-0.02	-0.02	-0.03	-0.03	-0.05	0.00	-0.01	-0.01	-0.01	-0.03	-0.01	-0.02	-0.03	-0.04	-0.14	0.02	0.04	-0.11	0.94	0.00	-0.01	-0.20
29	-0.05	-0.05	-0.02	-0.01	0.01	-0.01	-0.01	-0.01	-0.01	0.01	-0.01	-0.03	-0.03	-0.02	-0.00	0.00	-0.01	0.00	-0.02	-0.00	-0.01	-0.02	-0.03	-0.17	-0.04	-0.06	-0.11	0.01	0.97	-0.04	-0.20
30	-0.06	-0.06	-0.02	-0.01	-0.01	-0.01	-0.01	-0.00	-0.05	-0.01	-0.01	-0.03	-0.02	-0.03	-0.01	-0.01	-0.02	-0.01	-0.03	-0.01	-0.02	-0.04	-0.02	-0.03	-0.05	-0.06	-0.13	-0.00	-0.01	1.00	-0.20
31	-0.04	-0.05	-0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.04	-0.02	-0.02	-0.03	-0.04	-0.05	-0.00	-0.02	-0.01	-0.01	-0.03	-0.01	-0.02	-0.03	-0.06	-0.18	-0.08	-0.04	-0.07	-0.02	-0.00	-0.05	1.00

Table 3. Industry diffusive capacity according to a combination of a low intra-sector impact and a high number of positive values in other sectors using the redistribution matrix **M** of table 2. * = threshold value equal or greater than 0.85 for the intra-sector redistribution index.

	High intra-sector impact *	Low intra-sector impact
>= 5 positive values in j sectors	Medium-low diffusive capacity: 10, 16, 17, 22	High diffusive capacity: 12, 13
< 5 positive values in j sectors	Low diffusive capacity: all the other sectors	Medium-high diffusive capacity: 1, 6, 11, 15

5. THE SPILLOVERS' ANALYSIS

This paragraph presents the core results of our analysis. For each sector we consider 62 factors representing the state of technological and productive complementarities (the 31 g_{ij}) and the state of knowledge creation (the 31 R_i) ordered (using the FAST procedure) according to the share of the overall variance explained of each SPILL_j. The impact of the overall R&D expenditure of supplier sector *i* on the spillover of user sector *j* can be therefore split in its components. Results are showed in table 4 and 5, where table 4 reports, for each SPILL_j, the first 5 factors rank positions and table 5 the numerical values of the *first order* and *total order* indices.

Let's start with some comments on table 4. The R&D component, when relevant (from 1 to 3 in the rank position), is always the intra-sector R&D, with the only exception of the R&D of the chemical industry, which has an important role (rank 3) for the "textiles" (3), "rubber and plastic" industry" (10) and "communication apparatus industry" (17), whose R&D has an impact on "computing machines" (15).

The sectors where the (intra-industry) R&D component is very relevant (1 rank position) are mainly high-tech industries, clearly visible in the table 4 (from column 9 to 19): "chemicals" (including pharmaceuticals) (9), "communication equipment and apparatus" (17), "medical and precision instruments" (18), "motor vehicles" (19), "other transport equipment" (20). But they include also "machinery and equipment" (14) and some service activities, such as "financial intermediation" (26), "computer related activities" (28) and the same "research and development services" (29). It results that also high-tech services' spillover is mainly related to the internal research activity.

If we take into consideration the first order index (see, now, table 5), i.e. the explained share of the spillover variance of the intermediate goods users, the (intra-sector) R&D explains a large quota of the variance for the "communication industry" (17; 0.83)[18], the "precision instruments" (18; 0.72), the "motor vehicle sector" (19; 0.80) and "other transportation" (including aerospace) (20; 0.80), while it explains less for the "chemical sector" (9; 0.61) and the "machinery industry" (14; 0.66). The impact that chemical industry R&D has on "textile" (3) and "plastic industries" (10) spillover variance is low and respectively (0.05) and (0.09); the same is for the impact of R&D of the "communication industry" (17) on the "computing sector" (15) in Italy (0.07).

The technical complementarities inherited from the past (i.e., the g_{ij}) have a more widespread role in explaining the spillover variance of each sector than R&D activity. The most diffusive role lays in the "chemical sector", which explains from 1/4 to 1/3 of a large number of industries' spillover variance (see, again, table 5). In some cases the chemical sector's *g* explains a large quota of the variance: "textile" (3; 0.53), "paper products" (7; 0.57), "printing industry" (8; 0.45), "rubber and plastic products" (10; 0.45). It also enter with a 3 or 4 rank position from column 14 to 20 of table 4, i.e. in the high-tech sectors.

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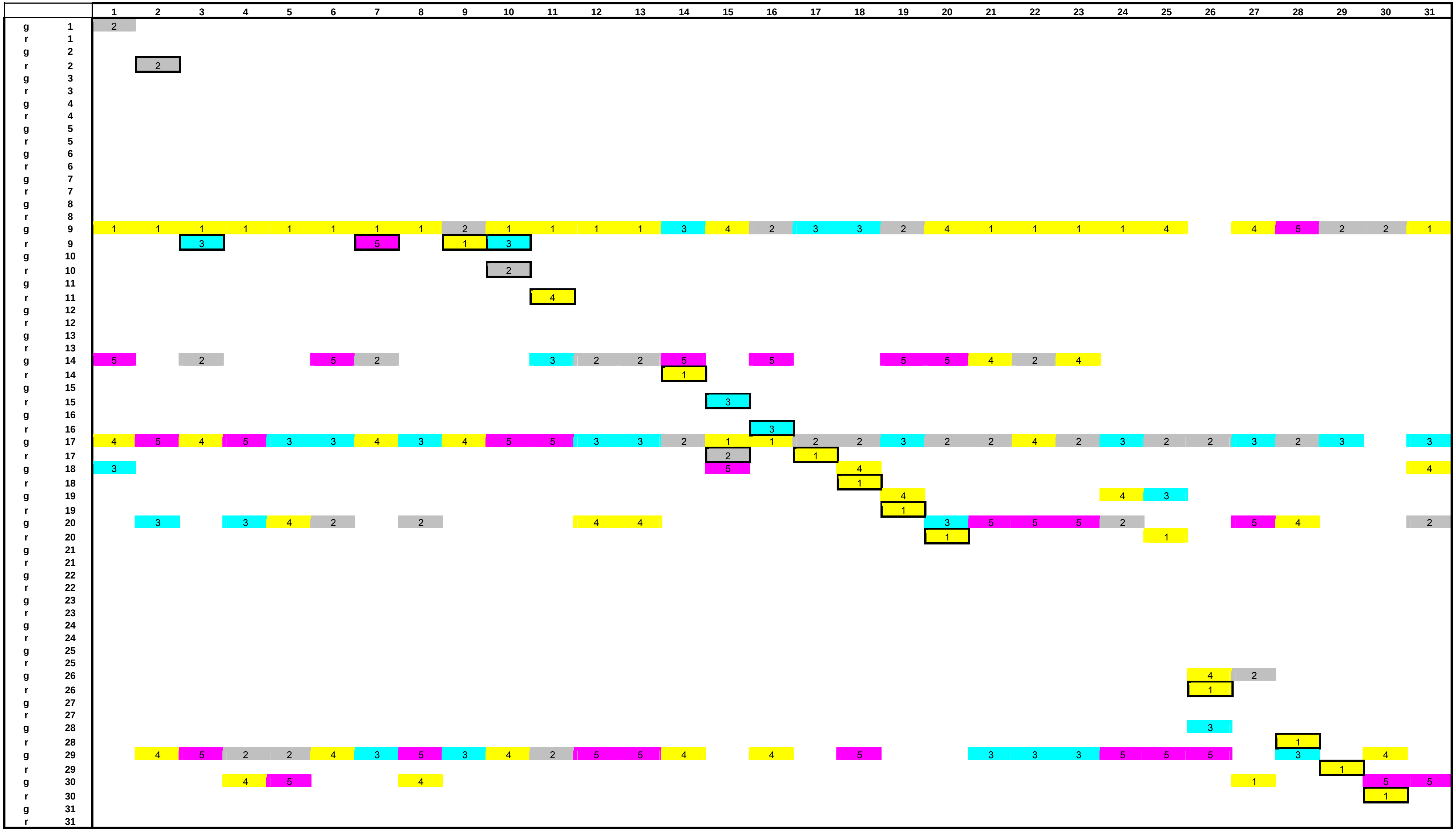
[18] In the brackets the first number refers to the sector ID and the second to its first order sensitivity value.

Table 4. Rank of factors affecting sectoral spillovers according to the first order sensitivity index



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
g	1	2																														
r	1																															
g	2																															
r	2		2																													
g	3																															
r	3																															
g	4																															
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g	5																															
r	5																															
g	6																															
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g	7																															
r	7																															
g	8																															
r	8																															
g	9	1	1	1	1	1	1	1	1	2	1	1	1	1	3	4	2	3	3	2	4	1	1	1	1	4		4	5	2	2	1
r	9			3				5		1	3																					
g	10																															
r	10										2																					
g	11																															
r	11											4																				
g	12																															
r	12																															
g	13																															
r	13																															
g	14	5		2			5	2				3	2	2	5		5			5	5	4	2	4								
r	14														1																	
g	15																															
r	15															3																
g	16																															
r	16																3															
g	17	4	5	4	5	3	3	4	3	4	5	5	3	3	2	1	1	2	2	3	2	2	4	2	3	2	2	3	2	3		3
r	17															2		1														
g	18	3														5			4													4
r	18																		1													
g	19																			4					4	3						
r	19																			1												
g	20		3		3	4	2		2				4	4							3	5	5	5	2			5	4			2
r	20																				1					1						
g	21																															
r	21																															
g	22																															
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g	26																										4	2				
r	26																										1					
g	27																															
r	27																															
g	28																										3					
r	28																												1			
g	29		4	5	2	2	4	3	5	3	4	2	5	5	4		4		5			3	3	3	5	5	5		3		4	
r	29																													1		
g	30				4	5			4																			1			5	5
r	30																														1	
g	31																															
r	31																															

Table 5. *First order* and *total order* sensitivity indices ranked by sector

SPILLOVER 1			
Factor (*k*)	**First order index (S_k)**	**Total order index (S_k^T)**	**$S_k^T - S_k$**
g91	0.35	0.38	0.03
g11	0.09	0.12	0.03
g181	0.08	0.12	0.04
g171	0.07	0.10	0.04
g141	0.06	0.09	0.04
g291	0.05	0.08	0.03
g201	0.04	0.09	0.04
g301	0.03	0.08	0.05
R9	0.03	0.07	0.05
g191	0.02	0.07	0.05
R1	0.02	0.05	0.03
g281	0.02	0.07	0.05
g251	0.01	0.05	0.04
g101	0.01	0.04	0.03
g261	0.01	0.05	0.04
Other factors	0.00	1.91	1.88
Total	0.89	3.37	2.48
$1-\Sigma S_k$	0.11		

SPILLOVER 2			
Factor (*k*)	**First order index (S_k)**	**Total order index (S_k^T)**	**$S_k^T - S_k$**
g92	0.24	0.26	0.02
R2	0.10	0.14	0.04
g202	0.08	0.12	0.04
g292	0.07	0.09	0.02
g172	0.06	0.08	0.02
g142	0.06	0.09	0.03
g302	0.04	0.08	0.04
g22	0.03	0.07	0.03
R9	0.03	0.06	0.03
g192	0.02	0.05	0.03
g102	0.02	0.05	0.03
g252	0.02	0.06	0.04
g282	0.01	0.05	0.03
g182	0.01	0.04	0.03
g242	0.01	0.04	0.03
g262	0.01	0.05	0.04
Other factors	0.02	1.46	1.45
Total	0.83	2.79	1.95
$1-\Sigma S_k$	0.17		

SPILLOVER 3			
Factor (*k*)	**First order index (S_k)**	**Total order index (S_k^T)**	**$S_k^T - S_k$**
g93	0.53	0.56	0.03
g143	0.05	0.09	0.04
R9	0.05	0.09	0.04
g173	0.04	0.08	0.04
g293	0.04	0.08	0.04
g203	0.03	0.08	0.05
R3	0.03	0.07	0.04
g303	0.03	0.07	0.04
g193	0.01	0.06	0.05
g33	0.01	0.04	0.04
g183	0.01	0.05	0.04
g283	0.01	0.05	0.04
g103	0.01	0.04	0.04
g243	0.01	0.04	0.03
g253	0.01	0.05	0.04
g263	0.01	0.05	0.04
Other factors	0.00	1.83	1.82
Total	0.88	3.33	2.46
$1-\Sigma S_k$	0.12		

SPILLOVER 4			
Factor (k)	**First order index (S_k)**	**Total order index (S_k^T)**	**S_k^T - S_k**
g94	0.39	0.42	0.03
g294	0.08	0.12	0.04
g204	0.07	0.12	0.05
g304	0.06	0.12	0.05
g174	0.06	0.09	0.04
g144	0.04	0.09	0.04
g194	0.02	0.07	0.05
R9	0.02	0.06	0.04
g184	0.02	0.06	0.04
g284	0.01	0.06	0.04
g104	0.01	0.05	0.04
g34	0.01	0.05	0.04
g264	0.01	0.05	0.04
g254	0.01	0.06	0.05
g244	0.01	0.04	0.04
Other factors	0.03	1.97	1.94
Total	0.85	3.43	2.57
$1-\Sigma S_k$	0.15		

SPILLOVER 5			
Factor (k)	**First order index (S_k)**	**Total order index (S_k^T)**	**S_k^T - S_k**
g95	0.28	0.30	0.02
g295	0.19	0.23	0.04
g175	0.06	0.08	0.03
g205	0.05	0.09	0.04
g305	0.04	0.09	0.05
g145	0.04	0.08	0.04
g105	0.03	0.06	0.03
g195	0.02	0.06	0.04
R9	0.02	0.05	0.03
g25	0.01	0.05	0.04
g185	0.01	0.05	0.04
R29	0.01	0.05	0.04
g285	0.01	0.04	0.04
g255	0.01	0.05	0.04
g245	0.01	0.04	0.03
g265	0.01	0.04	0.03
Other factors	0.02	1.60	1.57
Total	0.82	2.96	2.15
$1-\Sigma S_k$	0.18		

SPILLOVER 6			
Factor (k)	**First order index (S_k)**	**Total order index (S_k^T)**	**S_k^T - S_k**
g96	0.37	0.40	0.03
g206	0.08	0.14	0.06
g176	0.07	0.11	0.04
g296	0.07	0.11	0.04
g146	0.06	0.11	0.05
g306	0.05	0.10	0.06
g196	0.03	0.09	0.06
g256	0.02	0.07	0.05
g186	0.02	0.06	0.05
g286	0.01	0.06	0.05
R9	0.01	0.06	0.04
g106	0.01	0.06	0.04
g266	0.01	0.06	0.05
g246	0.01	0.05	0.04
R6	0.01	0.06	0.05
g166	0.01	0.06	0.05
Other factors	0.00	2.18	2.17
Total	0.84	3.78	2.93
$1-\Sigma S_k$	0.16		

SPILLOVER 7

Factor (k)	First order index (S_k)	Total order index (S_k^T)	$S_k^T - S_k$
g97	0.57	0.61	0.04
g147	0.05	0.10	0.05
g297	0.04	0.08	0.04
g177	0.04	0.08	0.04
R9	0.03	0.08	0.05
g307	0.03	0.08	0.05
g207	0.03	0.08	0.05
R7	0.02	0.06	0.05
g107	0.01	0.05	0.04
g197	0.01	0.06	0.05
g187	0.01	0.05	0.04
g287	0.01	0.06	0.05
g247	0.01	0.04	0.04
g257	0.01	0.06	0.05
Other factors	0.00	2.20	2.18
Total	0.87	3.69	2.82
$1-\Sigma S_k$	0.13		

SPILLOVER 8

Factor (k)	First order index (S_k)	Total order index (S_k^T)	$S_k^T - S_k$
g98	0.45	0.48	0.03
g208	0.08	0.13	0.05
g178	0.07	0.11	0.04
g308	0.06	0.11	0.05
g298	0.05	0.09	0.04
g148	0.04	0.08	0.04
R9	0.02	0.06	0.04
g198	0.02	0.07	0.05
g288	0.02	0.06	0.05
g188	0.01	0.06	0.04
g108	0.01	0.05	0.04
g258	0.01	0.06	0.05
g248	0.01	0.04	0.04
g268	0.01	0.05	0.05
Other factors	0.00	2.15	2.13
Total	0.86	3.60	2.75
$1-\Sigma S_k$	0.14		

SPILLOVER 9

Factor (k)	First order index (S_k)	Total order index (S_k^T)	$S_k^T - S_k$
R9	0.61	0.64	0.03
g99	0.29	0.33	0.04
g299	0.01	0.05	0.04
g179	0.01	0.05	0.04
Other factors	0.03	2.15	2.12
Total	0.95	3.22	2.27
$1-\Sigma S_k$	0.05		

SPILLOVER 10

Factor (k)	First order index (S_k)	Total order index (S_k^T)	$S_k^T - S_k$
g910	0.45	0.48	0.03
R10	0.13	0.16	0.03
R9	0.09	0.13	0.04
g2910	0.07	0.10	0.03
g1710	0.05	0.08	0.03
g1910	0.02	0.06	0.04
g1410	0.02	0.04	0.03
g2010	0.02	0.05	0.03
g3010	0.01	0.04	0.03
g1810	0.01	0.04	0.03
Other factors	0.01	1.81	1.78
Total	0.88	2.99	2.11
$1-\Sigma S_k$	0.12		

SPILLOVER 11

Factor (k)	**First order index (S_k)**	**Total order index (S_k^T)**	**$S_k^T - S_k$**
g911	0.38	0.41	0.03
g2911	0.08	0.12	0.04
g1411	0.05	0.09	0.04
R11	0.05	0.09	0.04
g1711	0.05	0.08	0.03
g2011	0.04	0.08	0.04
g3011	0.04	0.09	0.05
g1911	0.03	0.08	0.05
R9	0.03	0.06	0.04
g1811	0.02	0.05	0.04
g2811	0.01	0.05	0.04
g1011	0.01	0.04	0.03
g2511	0.01	0.05	0.05
g2611	0.01	0.05	0.05
g2411	0.01	0.04	0.03
Other factors	0.01	1.85	1.80
Total	0.83	3.23	2.40
$1-\Sigma S_k$	0.17		

SPILLOVER 12

Factor (k)	**First order index (S_k)**	**Total order index (S_k^T)**	**$S_k^T - S_k$**
g912	0.37	0.40	0.03
g1412	0.08	0.12	0.04
g1712	0.08	0.11	0.03
g2012	0.05	0.09	0.04
g2912	0.04	0.07	0.03
g3012	0.04	0.08	0.04
g1912	0.03	0.08	0.04
R9	0.03	0.07	0.04
R12	0.03	0.06	0.03
g1812	0.02	0.05	0.04
g1012	0.01	0.05	0.04
g2812	0.01	0.05	0.04
g2612	0.01	0.05	0.04
g1212	0.01	0.04	0.03
g2512	0.01	0.05	0.04
g2412	0.01	0.04	0.03
Other factors	0.02	1.81	1.78
Total	0.85	3.22	2.37
$1-\Sigma S_k$	0.15		

SPILLOVER 13

Factor (k)	**First order index (S_k)**	**Total order index (S_k^T)**	**$S_k^T - S_k$**
g913	0.23	0.26	0.03
g1413	0.11	0.15	0.04
g1713	0.10	0.13	0.03
g2013	0.07	0.11	0.04
g2913	0.07	0.10	0.03
g3013	0.05	0.10	0.05
g1913	0.05	0.09	0.04
R13	0.03	0.06	0.03
g1813	0.03	0.06	0.03
R9	0.02	0.05	0.03
g2813	0.02	0.05	0.03
g1013	0.01	0.04	0.03
g2613	0.01	0.05	0.03
g1613	0.01	0.05	0.04
g2513	0.01	0.04	0.04
g2413	0.01	0.03	0.03
g1313	0.01	0.04	0.04
Other factors	0.03	1.50	1.48
Total	0.87	2.91	2.04
$1-\Sigma S_k$	0.13		

SPILLOVER 14

Factor (k)	**First order index (S_k)**	**Total order index (S_k^T)**	**$S_k^T - S_k$**
R14	0.66	0.69	0.03
g1714	0.07	0.09	0.02
g914	0.07	0.08	0.02
g2914	0.03	0.04	0.02
g1414	0.03	0.05	0.02
g2014	0.02	0.05	0.02
g1914	0.02	0.04	0.02
g3014	0.01	0.04	0.03
g1814	0.01	0.03	0.02
R9	0.01	0.02	0.02
g1014	0.01	0.02	0.02
Other factors	0.03	0.98	0.93
Total	0.97	2.13	1.17
$1-\Sigma S_k$	0.03		

SPILLOVER 15

Factor (k)	**First order index (S_k)**	**Total order index (S_k^T)**	**$S_k^T - S_k$**
g1715	0.81	0.86	0.05
R17	0.07	0.11	0.05
R15	0.02	0.07	0.05
g915	0.01	0.06	0.04
g1815	0.01	0.05	0.04
g2915	0.01	0.05	0.04
Other factors	0.01	2.50	2.50
Total	0.94	3.70	2.77
$1-\Sigma S_k$	0.06		

SPILLOVER 16

Factor (k)	**First order index (S_k)**	**Total order index (S_k^T)**	**$S_k^T - S_k$**
g1716	0.23	0.26	0.03
g916	0.18	0.21	0.03
R16	0.16	0.20	0.04
g2916	0.08	0.11	0.03
g1416	0.05	0.08	0.03
g2016	0.04	0.08	0.04
g1816	0.03	0.07	0.04
g1916	0.02	0.06	0.04
g3016	0.02	0.06	0.04
g1016	0.02	0.05	0.03
R17	0.01	0.04	0.03
R9	0.01	0.05	0.04
g2816	0.01	0.05	0.04
g1616	0.01	0.05	0.04
Other factors	0.00	1.78	1.78
Total	0.87	3.15	2.28
$1-\Sigma S_k$	0.13		

SPILLOVER 17

Factor (k)	**First order index (S_k)**	**Total order index (S_k^T)**	**$S_k^T - S_k$**
R17	0.83	0.86	0.03
g1717	0.11	0.15	0.04
g917	0.01	0.03	0.03
Other factors	0.02	1.91	1.88
Total	0.97	2.95	1.98
$1-\Sigma S_k$	0.03		

SPILLOVER 18

Factor (*k*)	First order index (S_k)	Total order index (S_k^T)	$S_k^T - S_k$
R18	0.72	0.75	0.03
g1718	0.10	0.13	0.04
g918	0.04	0.08	0.03
g1818	0.03	0.07	0.04
g2918	0.03	0.07	0.04
g2018	0.01	0.05	0.04
g1418	0.01	0.04	0.04
Other factors	0.01	2.14	2.12
Total	0.95	3.33	2.38
$1-\Sigma S_k$	0.05		

SPILLOVER 19

Factor (*k*)	First order index (S_k)	Total order index (S_k^T)	$S_k^T - S_k$
R19	0.80	0.80	0.00
g919	0.05	0.05	0.00
g1719	0.05	0.05	0.00
g1919	0.03	0.03	0.00
g1419	0.02	0.02	0.00
g2919	0.02	0.02	0.00
g2019	0.01	0.01	0.00
g1819	0.01	0.01	0.00
g3019	0.01	0.01	0.00
Other factors	0.00	0.00	0.00
Total	1.00	1.00	0.00
$1-\Sigma S_k$	0.00		

SPILLOVER 20

Factor (*k*)	First order index (S_k)	Total order index (S_k^T)	$S_k^T - S_k$
R20	0.89	0.89	0.00
g1720	0.03	0.03	0.00
g2020	0.03	0.03	0.00
g920	0.01	0.01	0.00
g1420	0.01	0.01	0.00
g1820	0.01	0.01	0.00
g2920	0.01	0.01	0.00
g1920	0.01	0.01	0.00
Other factors	0.00	0.00	0.00
Total	1.00	1.00	0.00
$1-\Sigma S_k$	0.00		

SPILLOVER 21

Factor (*k*)	First order index (S_k)	Total order index (S_k^T)	$S_k^T - S_k$
g921	0.33	0.36	0.03
g1721	0.09	0.13	0.03
g2921	0.09	0.12	0.03
g1421	0.06	0.10	0.04
g2021	0.05	0.09	0.04
g3021	0.04	0.08	0.05
R21	0.03	0.08	0.05
g1821	0.03	0.07	0.04
g1921	0.03	0.07	0.05
R9	0.02	0.06	0.04
g1021	0.02	0.05	0.03
g2821	0.01	0.05	0.04
g2621	0.01	0.05	0.04
g2521	0.01	0.05	0.04
g2421	0.01	0.04	0.03
Other factors	0.03	1.83	1.79
Total	0.86	3.23	2.37
$1-\Sigma S_k$	0.14		

SPILLOVER 22

Factor (k)	First order index (S_k)	Total order index (S_k^T)	$S_k^T - S_k$
g922	0.30	0.33	0.03
g1422	0.10	0.14	0.04
g2922	0.10	0.13	0.04
g1722	0.09	0.13	0.03
g2022	0.05	0.09	0.04
g1822	0.04	0.07	0.04
g3022	0.03	0.08	0.05
g1922	0.02	0.07	0.05
g2822	0.02	0.07	0.04
R9	0.02	0.06	0.04
R22	0.01	0.04	0.03
g1622	0.01	0.06	0.04
g1022	0.01	0.05	0.04
g2622	0.01	0.05	0.04
g2522	0.01	0.05	0.04
Other factors	0.03	1.90	1.88
Total	0.85	3.32	2.47
$1-\Sigma S_k$	0.15		

SPILLOVER 23

Factor (k)	First order index (S_k)	Total order index (S_k^T)	$S_k^T - S_k$
g923	0.18	0.20	0.02
g1723	0.16	0.18	0.02
g2923	0.09	0.12	0.03
g1423	0.08	0.11	0.03
g2023	0.07	0.11	0.04
g3023	0.06	0.10	0.04
g1923	0.04	0.08	0.04
g1823	0.02	0.06	0.03
R9	0.02	0.05	0.03
g2823	0.02	0.05	0.03
g1023	0.01	0.04	0.03
g1623	0.01	0.05	0.04
R17	0.01	0.04	0.02
g2623	0.01	0.04	0.03
R29	0.01	0.04	0.03
g2523	0.01	0.04	0.03
g2423	0.01	0.03	0.03
R20	0.01	0.05	0.05
Other factors	0.03	1.35	1.31
Total	0.85	2.74	1.88
$1-\Sigma S_k$	0.15		

SPILLOVER 24

Factor (k)	First order index (S_k)	Total order index (S_k^T)	$S_k^T - S_k$
g924	0.13	0.15	0.02
g2024	0.12	0.16	0.04
g1724	0.11	0.13	0.02
g1924	0.10	0.13	0.02
g2924	0.07	0.09	0.02
g1424	0.07	0.09	0.02
R24	0.05	0.07	0.02
R9	0.03	0.05	0.02
g3024	0.03	0.06	0.03
g1824	0.03	0.06	0.03
R20	0.02	0.07	0.04
R29	0.02	0.04	0.03
R17	0.02	0.03	0.02
R19	0.01	0.04	0.03
R30	0.01	0.03	0.02
g2824	0.01	0.04	0.02
g2624	0.01	0.04	0.03
g1024	0.01	0.03	0.02
g2524	0.01	0.03	0.02
g1624	0.01	0.03	0.03
Other factors	0.03	1.00	0.97
Total	0.90	2.37	1.47
$1-\Sigma S_k$	0.10		

SPILLOVER 25

Factor (k)	**First order index (S_k)**	**Total order index (S_k^T)**	**$S_k^T - S_k$**
g2025	0.19	0.22	0.03
g1725	0.15	0.17	0.02
g1925	0.08	0.11	0.03
g925	0.07	0.09	0.02
g2925	0.07	0.09	0.02
R20	0.06	0.10	0.04
R25	0.05	0.07	0.02
g1425	0.05	0.07	0.02
g3025	0.04	0.07	0.04
g1825	0.03	0.06	0.03
R17	0.02	0.04	0.02
g2825	0.02	0.04	0.02
R29	0.01	0.04	0.03
g1025	0.01	0.03	0.02
g2625	0.01	0.03	0.02
g2525	0.01	0.03	0.02
R9	0.01	0.02	0.02
g1625	0.01	0.03	0.03
R19	0.01	0.03	0.02
Other factors	0.00	1.03	1.00
Total	0.90	2.37	1.47
$1-\Sigma S_k$	0.10		

SPILLOVER 26

Factor (k)	**First order index (S_k)**	**Total order index (S_k^T)**	**$S_k^T - S_k$**
R26	0.46	0.49	0.03
g1726	0.08	0.10	0.02
g2826	0.07	0.10	0.03
g2626	0.06	0.09	0.03
g2926	0.05	0.08	0.03
g3026	0.04	0.09	0.04
g926	0.04	0.06	0.02
g2026	0.03	0.07	0.03
g1426	0.01	0.04	0.03
g1926	0.01	0.04	0.03
R28	0.01	0.04	0.03
g2526	0.01	0.04	0.03
g1826	0.01	0.03	0.03
Other factors	0.02	1.44	1.43
Total	0.90	2.71	1.81
$1-\Sigma S_k$	0.10		

SPILLOVER 27

Factor (k)	**First order index (S_k)**	**Total order index (S_k^T)**	**$S_k^T - S_k$**
g3027	0.28	0.37	0.08
g2627	0.14	0.18	0.04
g1727	0.14	0.17	0.03
g927	0.09	0.12	0.02
g2027	0.05	0.10	0.05
g2827	0.05	0.08	0.03
g2927	0.05	0.07	0.03
g1427	0.03	0.06	0.04
g1927	0.02	0.07	0.05
g1827	0.01	0.05	0.04
g2527	0.01	0.05	0.04
g1027	0.01	0.06	0.05
g1627	0.01	0.06	0.05
R26	0.01	0.04	0.03
g2427	0.01	0.05	0.04
Other factors	0.02	2.07	2.05
Total	0.93	3.60	2.67
$1-\Sigma S_k$	0.07		

SPILLOVER 28

Factor (k)	**First order index (S_k)**	**Total order index (S_k^T)**	**$S_k^T - S_k$**
R28	0.42	0.46	0.03
g1728	0.19	0.22	0.03
g2928	0.11	0.13	0.02
g2028	0.04	0.09	0.05
g928	0.04	0.07	0.03
g3028	0.03	0.05	0.03
g1428	0.02	0.07	0.05
g2828	0.01	0.03	0.02
R17	0.01	0.04	0.03
g1928	0.01	0.05	0.05
g1828	0.01	0.05	0.05
R29	0.01	0.03	0.02
Other factors	0.01	1.82	1.79
Total	0.91	3.11	2.20
$1-\Sigma S_k$	0.09		

SPILLOVER 29

Factor (k)	**First order index (S_k)**	**Total order index (S_k^T)**	**$S_k^T - S_k$**
R29	0.94	0.98	0.03
g929	0.01	0.01	0.00
Other factors	0.01	0.20	0.20
Total	0.96	1.19	0.23
$1-\Sigma S_k$	0.04		

SPILLOVER 30

Factor (k)	**First order index (S_k)**	**Total order index (S_k^T)**	**$S_k^T - S_k$**
R30	0.33	0.36	0.02
g930	0.08	0.10	0.01
g1730	0.08	0.10	0.01
g2930	0.07	0.09	0.01
g3030	0.07	0.09	0.02
g2030	0.05	0.08	0.02
g2830	0.02	0.04	0.02
g1430	0.02	0.04	0.02
g1930	0.02	0.04	0.02
g1830	0.01	0.03	0.02
g2630	0.01	0.03	0.02
g2530	0.01	0.02	0.02
g1030	0.01	0.03	0.02
R29	0.01	0.03	0.02
Other factors	0.04	0.93	0.93
Total	0.83	2.01	1.18
$1-\Sigma S_k$	0.17		

SPILLOVER 31

Factor (k)	**First order index (S_k)**	**Total order index (S_k^T)**	**$S_k^T - S_k$**
g931	0.22	0.24	0.02
g2031	0.18	0.22	0.04
g1731	0.09	0.11	0.02
g1831	0.07	0.10	0.03
g3031	0.05	0.09	0.04
g1931	0.05	0.08	0.04
g2931	0.04	0.07	0.02
g1431	0.04	0.07	0.03
R9	0.04	0.06	0.03
R20	0.03	0.08	0.05
g2831	0.02	0.05	0.04
g2631	0.01	0.04	0.03
g2531	0.01	0.04	0.03
R18	0.01	0.03	0.02
R17	0.01	0.03	0.02
g1031	0.01	0.03	0.03
Other factors	0.01	1.42	1.38
Total	0.89	2.76	1.87
$1-\Sigma S_k$	0.11		

The other industry which plays a relevant role, independently from the R&D knowledge content, is the "communication industry" (17), whose *g* is within the 1 and 2 rank position for the high-tech sectors, from column 15 to 21 (except column 19, "motor vehicles", where it ranks 3), and in the 2 position for the "machinery industry" (14). There, it explains only a low share of the spillover variance, with the exception of the "computing machinery" where it is in a 1 rank position and explains 0.81 of the variance. In the other sectors the communication industry perform a 3 to 5 rank position. The service sector spillover variance is explained mainly by technical complementarities coming from a variety of manufacturing and non-manufacturing sectors.

These results are definitely different if compared with what we found out by looking only at the redistribution matrix derived from matrix **G**: the "chemical industry" role was absent there, while the "communication industry" had only a medium-low diffusive role. These results are, instead, similar to what Drejer (2000) found studying the industrial interdependence in different national systems of innovation expressed by embodied R&D flows: the results "show that the national systems tend to cluster in two main bulks. One is centred around industrial chemicals and/or pharmaceuticals and the other is centred around communication equipment". As a confirmation, we obtain only a correlation of 0.55 between the Leontiev multiplier matrix **G** and our matrix of knowledge flows $\mathbf{G}\cdot\hat{\mathbf{R}}$.

Our outcome is different from what resulted in Marengo e Sterlacchini (1990) who applied the indirect method to Italy for 1982 and found out a high correlation between the rank of sectors by R&D intensity and the rank for R&D diffuser role. We share with Leoncini and Montresor (2001), on the contrary, some similar results but also differences. The authors in their analysis of the Italian technological system, based on I-O tables of intermediate goods transactions and R&D data for the years 1982-85-88-90 for 22 sectors (including manufacturing, agriculture, energy industry, electricity/gas distribution, and service sectors) use a backward spillover model and follow a different method of analysis (the *network analysis*). They compare the position of sectors over time in terms of technology dependence and technology diffusion. The authors find out that high-tech sectors in Italy are weakly technology diffusive, with the exception of the chemical industry. This result remains aggregated (since the separate effect of "linkages" and "R&D" is indistinguishable in their methodology) and is presented as a *bias* resulting from the combination of a high sectoral intensity of R&D and a pervasive technology incorporated in material intermediate goods. In our case it is more clear that the role of the chemical industry is to be attributed to the technical linkages more than to the R&D component.

Leoncini and Montresor (2001) find out also that the weakly diffusive role of the high-tech sectors in Italy remained stable over time; this can be confirmed by our analysis, where the high-tech sectors' R&D impacts mostly on the own intra-sectoral spillover and there are not relevant linkages between high-tech industries, even in terms of material exchanges.

As to the role of the "information industry" (15) we found, as Leoncini and Montresor[19], a low connection between this sector and the others in Italy, since neither R&D nor material connections have a relevant effect on the other sectors' spillover. The "communication industry" (17), instead, is largely pervasive, but the impact on the user sectors' spillover does not derive from the R&D component and it explains only a small part of the spillover variance. The communication industry impact is particularly low in traditional sectors, while it has a relatively higher rank position in the high-tech industries and in some services (computer services, transports, storage and communication), but always not for the R&D component.

Our application allows also to identify sectors where the spillover variance is explained (at least to some extent) also by "interactions" among factors. The share of total spillover variance explained by interactions (the $1-\sum S_k$ in table 5) could be probably taken as an indicator of sectoral complexity. To identify

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[19] Also other analysis found out the low role of knowledge diffuser played by the IT industry in Italy (see Cioffi and Potì, 1997).

sectors most affected by interactions we fix a threshold-value greater than the 15% of the total spillover variance explained by interactions. “Dressing of leather and related articles” (5) presents the greatest value of 0.18; it means that the 18% of its spillover variance is due to factors interactions; “food, beverage and tobacco products” (2), “other non-metallic mineral products” (11) and “other business activity” (30) share the common value of 0.17; “wood and products of wood and cork” (6) performs, finally, a value of 0.16. All the other sectors present values equal or lower than 0.15. Those highlighted above represent sectors with a high internal product differentiation due to the two-digit grouping (they are mainly characterized by the suffix “other”). It means that, at this level of analysis, complexity coincides with differentiation to be interpreted, nevertheless, just as a classification matter without any specific industrial meaning. On the other hand, the low level of interactions effect found in the other sectors seems due to the spillover formula adopted that, even if non-linear, looks very close to an additive model[20].

6. DISCUSSION AND CONCLUSION

The analysis of the inter-industrial R&D spillovers through an intermediate total-requirement I-O table has some intrinsic limits: first of all, it should be useful to combine it with a capital goods transaction table, which are more important R&D carriers for some sectors, such as services (van Mejil, 1997). But data are not always available[21]. Moreover, it should be necessary to complement the study of inter-industrial embodied knowledge spillovers with an analysis of disembodied knowledge exchanges, within and among productive subsystems. In particular, user-producer interactions can enhance innovation processes (information from users on their needs and on their “learning by using”) and the use of goods (information from suppliers on the use value characteristics of the products and solutions of user problems). This is especially the case of less standardized and more complex products.

Following the embodied R&D spillover approach, we adopted the Leontief *forward multiplier,* which analyses the effect related to other sector’s R&D utilization and can have some policy implications (showing which sector’s R&D supply induces a larger effect). The analysis shows which sectoral inputs explain relevant fractions of the recipient industries’ *potential* spillover (since, as Drejer (2003), the user spillover level depends also on the demand level) and when these inputs have innovative (R&D) content, inducing new activities down in the value chain.

First of all, by comparing the result from the matrix of *redistribution indices* (by Roland-Holst and Sancho, 1992) applied to the Italian un-weighted *forward* linkages matrix and the result from the knowledge-weighted *forward* linkages (the spillover analysis), just few different sectors appear to be the “industrial locomotive” (Drejer, 2003): chemical industry and communication industry, instead of basic metals and metal products. The relevance of using a knowledge weighted linkage specification for finding out what are the sources of economic dynamics in a productive system is indicated by Drejer (2003) and gives clear results for Italy.

R&D weighted linkages (within the Leontief inverse matrix) allow for the identification of sectors which are economic drivers and *potential* diffusers of knowledge. But their R&D activity is not automatically distributed with their spillover supply (probably some user sector benefits more), neither is completely and instantaneously embodied in the produced goods (Marengo and Sterlacchini, 1990), or it can be used within the same supplier sector[22]. If we compare an intermediate goods matrix and an innovation matrix, for identifying how many cells are empty, it can easily result that innovation flows are concentrated only in a

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[20] Clearly results depend on the spillover formula adopted. According to the literature we have used the standard R&D weighted arithmetic mean. Nevertheless, other formulas could be properly used, such as geometric or harmonic means. An interesting further effort should be to test the robustness of results on the basis of different-from-arithmetic spillover formulas.

[21] This is the case of Italy, where the last I-O table for capital goods available is for 1992.

[22] As Scherer (2003), the meaning of the diagonal as R&D innovation process is an aspect asking for more control.

(more or less large, depending on the sectoral aggregation) part of the economic matrix. This could be even more so if we could check the distribution of the firm R&D expenditure by product within industrial R&D statistics.

Many scholars (see paragraph 1) suggest to match technological and transaction-based matrices, but this is not always possible or it can be very time-consuming (see Scherer, 2003). In sum, when applying the spillover analysis to a I-O matrix it is necessary at least to have a way for identifying when the weight of an external R&D contribution result to be relevant, always associated to its carrier (linkages), but at the same time considered by itself. Our methodology allows for both to rank separately the linkage effect from the R&D effect, and also to get an economic meaning by the identification of how much the supplier's R&D explain the user's spillover variance.

Some specific aspects are**:** we use only the intermediary goods I-O table but, as suggested by Meijl (1997), R&D spillovers embodied in intermediate goods are relatively more important for medium and low-tech sectors characterizing Italy. Certainly, then, the R&D transfer for some user sectors, such as services, and for some supplier sectors, such as machinery and equipment, is underrepresented: but our application (only for the year 2000), does not suffer from the fact that we don't take into account cost variation transfer from supplier to the users' spillover since, in our setting, prices are supposed fixed in the short-run.

We find out that the intra-sectoral use of R&D is the dominant aspect. This result, that is partly due to the sectoral aggregation, is currently interpreted as the dominance of process innovation but, as Scherer (2003) pointed out, this aspect could be better adjusted by checking more in depth the individual industry R&D process fraction.

Finally, R&D effect on user spillover is certainly a function of their absorptive capacity and of user-producer information exchanges, which is different among sectors. Both factors should be considered for a better adjusting of our results.

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ANNEX A: TWO-DIGIT CLASSIFICATION OF ECONOMIC SECTORS ACCORDING TO THE NACE REV.1 CLASSIFICATION

Sector ID	**Sectoral description**
1	MINING, QUARRYING, COKE, REFINED PETROLEUM PRODUCTS AND NUCLEAR FUEL
2	FOOD PRODUCTS, BEVERAGES AND TOBACCO PRODUCTS
3	TEXTILES
4	WEARING APPAREL, DRESSING AND DYEING OF FUR
5	TANNING AND DRESSING OF LEATHER; RELATED ARTICLES
6	WOOD AND PRODUCTS OF WOOD AND CORK
7	PULP, PAPER AND PAPER PRODUCTS
8	PUBLISHING, PRINTING AND REPRODUCTION OF RECORDED MEDIA
9	CHEMICALS AND CHEMICAL PRODUCTS (INCLUDING FARMACEUTICALS)
10	RUBBER AND PLASTIC PRODUCTS
11	OTHER NON-METALLIC MINERAL PRODUCTS
12	BASIC METALS
13	FABRICATED METAL PRODUCTS (EXCEPT MACHINERY AND EQUIPMENT)
14	MACHINERY AND EQUIPMENT
15	OFFICE, ACCOUNTING AND COMPUTING MACHINERY
16	ELECTRICAL MACHINERY AND APPARATUS
17	RADIO, TV & COMMUNICATION EQUIPMENT AND APPARATUS
18	MEDICAL, PRECISION, OPTICAL INSTRUMENTS, WATCHES AND CLOCKS
19	MOTOR VEHICLES, TRAILERS AND SEMI-TRAILERS
20	OTHER TRANSPORT EQUIPMENT
21	FURNITURE, MANUFACTURING N.E.C. AND RECYCLING
22	ELECTRICITY, GAS, STEAM, WATER SUPPLY AND DISTRIBUTION
23	CONSTRUCTION
24	WHOLESALE AND RETAIL TRADE; RESTAURANTS AND HOTELS
25	TRANSPORT; STORAGE AND COMMUNICATION
26	FINANCIAL INTERMEDIATION
27	REAL ESTATE AND RENTING
28	COMPUTER AND RELATED ACTIVITIES
29	RESEARCH AND DEVELOPMENT
30	OTHER BUSINESS ACTIVITIES
31	COMMUNITY, SOCIAL AND PERSONAL SERVICES

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