Spillovers of Innovation Effects

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The effects of process and product innovation are analyzed in a multisectoral framework. The effect of an innovation in any particular sector propagates throughout the entire economy. A simple measure for the spillover of innovation effects to the other sectors is developed. As a consequence, an alternative viewpoint is obtained for the interpretation of the elements of the Leontief inverse and the traditional measures for interindustry linkages. An empirical application is given for the European Union in 1991.

1. INTRODUCTION

Technological changes, and innovations in particular, are important determinants of economic growth. The effects of innovations propagate throughout the economy and get embodied in other products and production processes. This paper analyzes the propagation of innovation effects in a multisector framework. It attempts to quantify the spillovers to other sectors by answering the following question: What happens to the sectoral structure of production if an innovation takes place in one particular sector, leaving all other things equal? Clearly, this question covers two unrealistic assumptions. First, it may be expected that innovations occur not in one sector at a time, but in many (or all) sectors simultaneously. Second, it may be expected that innovations affect the decisions made by the agents (such as consumers, producers, or the government).
The aforementioned question obviously is of the “what-if” type and its answer thus describes the potential propagation effects. The reason for posing the question in this form is motivated by the difficulties encountered in the literature on analyzing structural changes. For example, take last year’s input–output table as a starting point. All the cumulated effects of innovations are then, together with many other effects, reflected by this year’s table. In answering the question what actually has happened, all these effects have to be disentangled. Structural decomposition techniques have been widely used for this purpose. Major shifts in an economy are distinguished into their key determinants. In most applications, all changes in the production structure are considered as one of those key determinants. Typically, however, this determinant is not decomposed further into its constituent parts, such as technological changes and sectoral innovations. Therefore, it is in this paper chosen to approach the problem from the other side and examine the potential propagation of innovation effects.

Consider a multisector economy and suppose that for the production of good $j$ all products are used as an input, next to the primary factors labor and capital. Assume that the innovation effects are reflected by changes in the input coefficients. Two types of innovation are distinguished. Process innovation means that more output can be produced with the same amounts of the different inputs, affecting the coefficients column-wise. This implies a shift of the production function and the isoquant. Product innovation means that, in each of the $n$ production processes, the same amount of output can be obtained with a smaller amount of this product as an input. Hence, the coefficients in a row are changed.

In a multisectoral framework, innovation in one process or product also affects the production in other sectors. If process innovations take place in sector $k$, this carries over to sector $j$.


\footnote{A rare exception is Van der Linden and Dietzenbacher (1995), where the RAS procedure is applied to decompose coefficient changes into productivity changes, economywide substitution patterns, and sector-specific substitutions.}

\footnote{See, for example, Carter (1970), Davies (1979), or Rose (1984).}
which uses the output of sector $k$, and so forth. If product $k$ is innovated, each process uses less of this product. Indirectly, each process also requires less of any other product $i$ because product $i$ is used in process $k$, and so forth. Propagation of the innovation effects in one sector (or of coefficient changes, in general) may thus be analyzed by examining its spillovers. That is, the extent to which the production in other sectors is affected. In this paper a surprisingly simple measure for these spillovers is developed.

The next two sections present the analytical results for process and product innovation, respectively. Using the standard Leontief model, it turns out that the spillover measures are directly based on the elements and the column sums of the Leontief inverse. Consequently, an alternative interpretation of the elements of the Leontief inverse in terms of innovation propagation is obtained. As an illustration, the empirical results for the European Union in 1991 are discussed in Section 4.

2. PROCESS INNOVATION

The standard Leontief model is given by

$$x = Ax + f,$$

where $x$ is the vector of sectoral outputs and $f$ the vector of final demands (private consumption, government expenditures, investments, and exports). As usual, it is assumed that each of the $n$ sectors produces exactly one good. $A$ is the $n \times n$ matrix of input coefficients. Its typical element $a_{ij}$ denotes the amount of product $i$ required, as an input in process $j$, for the production of one unit of output of good $j$. The model in Equation 1 is solved as

$$x = Lf,$$

with $L = (I - A)^{-1}$. (2)

The matrix $L$ is the Leontief inverse, or multiplier matrix. Its element $l_{ij}$ denotes the additional output of product $i$ as required (directly and indirectly) per additional unit of final demand for good $j$. Or, equivalently, $l_{ij} = \Delta x_j/\Delta f_j$.

An innovation in process $k$ is defined as

$$\bar{a}_k = (1 - \alpha)a_k, \text{ for } i = 1, \ldots, n,$$

with $0 < \alpha < 1$. All other coefficients remain the same (i.e., $\bar{a}_q = a_q$).

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It is assumed that $A$ is nonnegative and irreducible, and has a dominant eigenvalue smaller than one. Consequently $l_{ij} > 0$ for all $i,j = 1, \ldots, n$ (see, e.g., Takayama, 1985, for these and other conditions).
The same amounts of the inputs yield an increased amount of output in process $k$. Or, in other words, per unit of output of product $k$ the use of each input is decreased with 100$\alpha$ percent. Analogous to Equations 1 and 2, the model is given by $\mathbf{x} = \mathbf{A} \mathbf{x} + \mathbf{f}$, and its solution by $\mathbf{x} = \mathbf{L} \mathbf{f}$.

It should be emphasized that the innovation as defined in Equation 3, is unlikely to be actually observed in exactly this form. The common assumption that each sector produces just one good is too restrictive, in particular at the aggregation level of most published input–output tables. In an ex-post analysis of the effects as they actually have occurred, this assumption would, therefore, cast serious doubts on the results. The present analysis, however, examines the potential for the propagation of innovation effects, under the hypothesis that the innovation takes the form as in Equation 3.

The effects of process innovation can now be measured as follows. Per additional unit of final demand for good $k$, less output needs to be produced. That is, $\Delta \mathbf{x} / \Delta f_k - \Delta \mathbf{x} / \Delta f_k = l_k - l_k$, which is negative because $\mathbf{L} \ll \mathbf{L}$ (see, e.g., Takayama, 1985). Using the series expansion of the Leontief inverse (i.e., $\mathbf{L} = \mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \mathbf{A}^3 + \ldots$) and writing $\mathbf{e}_k$ for the $k$th unit vector, the vector $\Delta \mathbf{x} / \Delta f_k$ can be written as

$$\Delta \mathbf{x} / \Delta f_k = \mathbf{L} \mathbf{e}_k = \mathbf{e}_k + \mathbf{A} \mathbf{e}_k + \sum_{i=2}^\infty \mathbf{A}^i \mathbf{e}_k.$$

Similarly,

$$\Delta \mathbf{x} / \Delta f_k = \mathbf{L} \mathbf{e}_k = \mathbf{e}_k + \mathbf{A} \mathbf{e}_k + \sum_{i=2}^\infty \mathbf{A}^i \mathbf{e}_k = \mathbf{e}_k + (1 - \alpha) \mathbf{A} \mathbf{e}_k + \sum_{i=2}^\infty \mathbf{A}^i \mathbf{e}_k.$$

Thus,

$$\Delta \mathbf{x} / \Delta f_k - \Delta \mathbf{x} / \Delta f_k = -\alpha \mathbf{A} \mathbf{e}_k + \sum_{i=2}^\infty (\mathbf{A}^i - \mathbf{A}) \mathbf{e}_k.$$

Per unit final demand for good $k$, all outputs decrease because the innovated process $k$ requires less of each input. This is the direct effect as given by $-\alpha \mathbf{A} \mathbf{e}_k$. The production of each of these inputs requires (among other inputs) the input of good $k$. In its turn, the production process of good $k$ is innovated and requires

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5 See Van der Linden et al. (1993) for an application of (3) in terms of fields of influences (see, e.g., Hewings et al., 1989, or Sonis and Hewings, 1989, 1992).

6 For vectors and matrices we adopt the following expressions and notations. Positive, $\mathbf{x} \gg 0$, if $x_i > 0$ for all $i$. Nonnegative, $\mathbf{x} \geqslant 0$, if $x_i \geqslant 0$ for all $i$. Semipositive, $\mathbf{x} \succ 0$, if $\mathbf{x} > 0$ and $\mathbf{x} \neq \mathbf{0}$. 
less inputs, and so forth. All these effects are captured by the term \( \sum_{t=2}^n (\bar{A}' - A')e_t \), the indirect effects.

In the same way, the effects of process innovation can be described per additional unit final demand of good \( j \neq k \). From

\[
\Delta \bar{y}_j/\Delta f_j = e_j + \bar{A}e_j = e_j + Ae_j + \sum_{t=2}^{n} \bar{A}e_t,
\]

it immediately follows that

\[
\Delta \bar{y}_j/\Delta f_j - \Delta x_j/\Delta f_j = \sum_{t=2}^{n} (\bar{A}' - A')e_t. \tag{5}
\]

Because \( j \neq k \), the direct effect is absent, implying that all effects are indirect.

The terms \( \Delta x_j/\Delta f_k - \Delta x_j/\Delta f_j \) (for \( i = 1, \ldots, n \)) express the effects of process innovation as embodied in an additional unit final demand for good \( k \). The innovation in process \( k \) has propagated and its effects are also present in the other final demands. The terms \( \Delta x_j/\Delta f_j - \Delta x_j/\Delta f_j \) (with \( j \neq k \)) indicate the effects as embodied in an additional unit final demand for good \( j \).

In constructing a measure for the amount of propagation, the change in the output of sector \( i \) is related to the change in sector \( k \), i.e., the sector where the innovation has taken place.

\[
\Delta \bar{y}_j/\Delta f_j - \Delta x_j/\Delta f_j = \frac{\bar{l}_i - l_i}{\bar{l}_j - l_j} \tag{6}
\]

Next, it is shown that expression 6 equals \( l_{ik}/(l_{kk} - 1) \). Note that this ratio does not depend on \( j \). Therefore, Equation 6 measures the propagation of the innovation in process \( k \), irrespective of the specific structure of final demands.

Observe that \( \bar{A} = A - \alpha(\bar{A}e_k)e_k' \), where a prime is used to denote transposition. Using well-known formulae for the inverse of a sum of matrices (see, e.g., Henderson and Searle, 1981, for an overview) yields

\[
\bar{L} = L - \alpha L A e_k e_k' L / [1 + \alpha e_k' L A e_k].
\]

Using \( LA = L - I \), it follows that

\[
\bar{L} - L = -\alpha(L - I)e_k e_k' L / [1 + \alpha e_k' (L - I)e_k].
\]

The denominator is a scalar which shall be denoted by \( \eta_k \),

\[
\eta_k = 1 + \alpha(l_{kk} - 1).
\]

Notice that \( \bar{L} - L \) is a matrix of rank one. Its typical element \( \bar{l}_{ij} - l_{ij} \) is obtained as \( e_j' (\bar{L} - L)e_i \). Hence,
\[ l_i - l_i = -a_l i_i/\eta_i, \quad \text{for } i \neq k, \]
\[ l_k - l_i = -\alpha(l_{ik} - 1)/\eta_i. \]  
\[ (7) \]

Substituting Equation 7 into 6 yields
\[ \Delta x_i/\Delta f_k - \Delta x_i/\Delta f_i = \frac{l_i}{l_k - 1}, \]
\[ (8) \]
which holds for all \( j = 1, \ldots, n. \)

Note that the ratio in Equation 8 is independent of both \( \alpha \) and the index \( j \). Obviously, the magnitude of the total effects does depend on \( \alpha \) and the specific vector \( f \). Compare, for example, the case after innovation \( \mathbf{x} = \mathbf{A} \mathbf{x} + \mathbf{f} \) with the case before innovation \( \mathbf{x} = \mathbf{A} \mathbf{x} \). Then Equation 7 implies
\[ \bar{x}_i - x_i = -\alpha \sum_j l_{ij}/\eta_i, \]
\[ \bar{x}_k - x_k = -\alpha(l_{ik} - 1)\sum_j l_{ij}/\eta_i. \]

Although the propagation of innovation effects clearly depends upon \( \alpha \) and \( f \), its distribution over the sectors is always the same. This is a consequence of the matrix \( \mathbf{L} - \mathbf{L} \) having rank one.

The spillover of innovation effects is defined as the percentage of the total output change that occurs in sectors \( i \) other than the innovated sector \( k \). Define the \( k \)th column sum of the Leontief inverse as \( c_k \), that is,
\[ c_k = \sum l_{ik}. \]

Then, the spillover of the effects of process innovation in sector \( k \) is given as
\[ s_k = 100\left[ \sum_{i \neq k} (\bar{x}_i - x_i) \right]/\left[ \sum (\bar{x}_i - x_i) \right], \]
which yields
\[ s_k = 100(c_k - l_{ik})/(c_k - 1). \]

Alternative measures that are related to \( s_k \) are the average sectoral spillover defined as \( s_k/(n - 1) \) and the relative spillover 100\((c_k - l_{ik})/(l_{ik} - 1)\), which relates the output changes in sectors \( i \) to the change in the innovated sector \( k \).

3. PRODUCT INNOVATION

Product innovation in sector \( k \) is defined as
\[ \tilde{a}_{ij} = (1 - \alpha)a_{ij}, \quad \text{for } j = 1, \ldots, n \]
\[ (9) \]
with \( 0 < \alpha < 1. \) All other coefficients remain the same. In matrix notation, Equation 9 is written as \( \mathbf{A} = \mathbf{A} - \alpha \mathbf{e}_k (\mathbf{e}_k \mathbf{A}). \)
Let the final demand for an arbitrary good, say \( j \), be increased. This affects the production in sector \( k \). Directly, because process \( j \) uses less of product \( k \) as an input. And indirectly, because process \( j \) uses all products as an input while each of these products requires less inputs from sector \( k \). This yields

\[
\frac{\Delta x_i}{\Delta f_j} = l_{ij} - l_{i} = e_i'(\mathbf{I} - \mathbf{L})e_j \\
= -\alpha a_{ij} + \sum_{k} e_k'(\mathbf{K} - \mathbf{A})e_j.  
\]

(10)

The first term indicates the direct effect, the second term the indirect effects. An additional final demand of product \( j \) also affects the production in sector \( i \) (\( i \neq k \)). In this case, however, the decrease in production is due only to indirect effects;

\[
\frac{\Delta x_i}{\Delta f_j} - \Delta x_i/\Delta f_j = l_{ij} - l_{i} = e_i'(\mathbf{K} - \mathbf{A})e_j. 
\]

(11)

The measure for propagation is based again on the ratio in Equation 6. Using \( \mathbf{A} = \mathbf{A} - \alpha e_i'\mathbf{e}_j'\mathbf{A} \) and substituting \( \mathbf{AL} = \mathbf{L} - \mathbf{I} \) in the inverse of a sum of matrices yields

\[
\mathbf{I} - \mathbf{L} = -\alpha \mathbf{Le}_i'(\mathbf{L} - \mathbf{I})[1 + \alpha e_i'(\mathbf{L} - \mathbf{I})e_j].
\]

The denominator equals \( \eta_k = 1 + \alpha(l_{kk} - 1) \) again, which gives

\[
l_{ij} - l_{i} = -\alpha a_{ij}/\eta_k, \text{ for } j \neq k, \\
l_{ik} - l_{i} = -\alpha a_{ik}(l_{kk} - 1)/\eta_k.
\]

Substituting these expressions in Equation 6 yields

\[
\frac{\Delta x_i/\Delta f_j - \Delta x_i/\Delta f_j}{\Delta x_i/\Delta f_j} = \frac{l_{ik}}{\eta_k},
\]

(12)

which holds for all \( j = 1, \ldots, n \). Note that this ratio is again independent of both the specific final demand \((f_j)\) and \(\alpha\). The spillover of the product innovation effects is measured as the percentage of the total output change that occurs in the sectors \( i \) (\( i \neq k \)). This yields

\[
s_k = 100(c_k - l_{k})/c_k.
\]

Observe that the spillover \( s_k \) for product innovation is substantially smaller than \( s_k \) for process innovation. As Equation 10 for product innovation shows, \( \Delta x_i/\Delta f_j - \Delta x_i/\Delta f_j \) involves a direct effect, while \( \Delta x_i/\Delta f_j - \Delta x_i/\Delta f_j \) in Equation 11 includes only indirect effects. For process innovation, however, Equations 4 and 5 indicate that either all output changes include a direct effect (i.e., when \( j = k \)) or no output change includes a direct effect (i.e., when \( j \neq k \)).
The terms $l_{ik}/(l_{kk} - 1)$ in Equation 8 and $l_{ik}/l_{kk}$ in Equation 12 provide an alternative interpretation of the elements of the Leontief inverse. For example, $l_{ik}/l_{kk}$ measures the output gain in sector $i$ relative to the output gain in sector $k$, induced by an arbitrary increase of the final demands, when product innovation takes place in sector $k$. That is to say, the propagation to sector $i$ of a product innovation in sector $k$.

4. EMPIRICAL RESULTS

This section presents the results for the European Union for 1991. The calculations are based on a recently prepared 25-sector table for the entire Union, published by Eurostat (see Ungar and Heuschling, 1994). It should be emphasized, however, that this “is a projection of the harmonized national tables for 1985, based on the Eurostat statistics currently available for the aggregates and branches.” The sector classification is given in the Appendix. With respect to the flows in the input–output table, it should be stressed that the figures for sector 23 (credit and insurance) cannot be given an adequate interpretation in terms of economic activity. It appears that this sector predominantly depends on itself, while other sectors show only a minor dependence on sector 23. Due to the accounting rules in the European System of Integrated Economic Accounts (ESA), the imputed charges are recorded as a delivery of the credit sector to itself. Therefore, the corresponding input coefficient amounts to 0.575, which is by far the largest. A consequence is that the diagonal element $l_{kk}$ of the Leontief inverse is also unrealistically large. The same holds for the traditional linkage indicators (i.e., the column sums $c_k$).

Table 1 presents the results for the diagonal elements $l_{kk}$ of the Leontief inverse, its column sums $c_k$, the spillovers $s_k$ of process innovation effects, and the spillovers $s Ä k$ of product innovation effects. The spillovers are recorded as a percentage of the total innovation effects. The rankings are presented in the columns under number.

The results in Table 1 indicate that for a process innovation in sector $k$, on average 80.5 percent of the total output change occurs in sectors other than $k$. The spillovers range from 42.4 percent

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7 Ungar and Heuschling (1994, p. 4) state that “This special accounting rule in the ESA makes the indicators for this branch difficult to interpret and they are, therefore, mostly omitted” in their own analysis.
Table 1: Spillovers of Innovation Effects in the European Union, 1991

<table>
<thead>
<tr>
<th>Sector $k$</th>
<th>$I_{kk}$</th>
<th>#</th>
<th>$c_k$</th>
<th>#</th>
<th>$s_k$</th>
<th>#</th>
<th>$s_k$</th>
<th>#</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 = agriculture</td>
<td>1.250</td>
<td>7</td>
<td>2.078</td>
<td>7</td>
<td>76.8</td>
<td>18</td>
<td>39.8</td>
<td>14</td>
</tr>
<tr>
<td>2 = fuel</td>
<td>1.322</td>
<td>6</td>
<td>1.604</td>
<td>20</td>
<td>46.7</td>
<td>24</td>
<td>17.6</td>
<td>25</td>
</tr>
<tr>
<td>3 = metals</td>
<td>1.603</td>
<td>2</td>
<td>2.501</td>
<td>2</td>
<td>59.8</td>
<td>23</td>
<td>35.9</td>
<td>16</td>
</tr>
<tr>
<td>4 = minerals</td>
<td>1.160</td>
<td>11</td>
<td>1.954</td>
<td>14</td>
<td>83.2</td>
<td>15</td>
<td>40.6</td>
<td>11</td>
</tr>
<tr>
<td>5 = chemicals</td>
<td>1.385</td>
<td>4</td>
<td>2.193</td>
<td>4</td>
<td>67.7</td>
<td>21</td>
<td>36.9</td>
<td>15</td>
</tr>
<tr>
<td>6 = met. prod.</td>
<td>1.109</td>
<td>14</td>
<td>2.040</td>
<td>9</td>
<td>89.5</td>
<td>10</td>
<td>45.6</td>
<td>3</td>
</tr>
<tr>
<td>7 = machinery</td>
<td>1.150</td>
<td>12</td>
<td>2.029</td>
<td>10</td>
<td>85.4</td>
<td>12</td>
<td>43.3</td>
<td>8</td>
</tr>
<tr>
<td>8 = office eq.</td>
<td>1.079</td>
<td>17</td>
<td>1.954</td>
<td>13</td>
<td>91.7</td>
<td>8</td>
<td>44.8</td>
<td>6</td>
</tr>
<tr>
<td>9 = electr.</td>
<td>1.134</td>
<td>13</td>
<td>1.904</td>
<td>16</td>
<td>85.1</td>
<td>13</td>
<td>40.4</td>
<td>12</td>
</tr>
<tr>
<td>10 = transp. eq.</td>
<td>1.180</td>
<td>9</td>
<td>2.158</td>
<td>5</td>
<td>84.5</td>
<td>14</td>
<td>45.3</td>
<td>5</td>
</tr>
<tr>
<td>11 = food</td>
<td>1.233</td>
<td>8</td>
<td>2.281</td>
<td>3</td>
<td>81.8</td>
<td>17</td>
<td>45.9</td>
<td>2</td>
</tr>
<tr>
<td>12 = textiles</td>
<td>1.343</td>
<td>5</td>
<td>2.093</td>
<td>6</td>
<td>68.6</td>
<td>20</td>
<td>35.8</td>
<td>17</td>
</tr>
<tr>
<td>13 = paper</td>
<td>1.392</td>
<td>3</td>
<td>1.995</td>
<td>12</td>
<td>60.6</td>
<td>22</td>
<td>30.2</td>
<td>20</td>
</tr>
<tr>
<td>14 = plastics</td>
<td>1.088</td>
<td>16</td>
<td>2.055</td>
<td>8</td>
<td>91.6</td>
<td>9</td>
<td>47.0</td>
<td>1</td>
</tr>
<tr>
<td>15 = oth. manuf.</td>
<td>1.177</td>
<td>10</td>
<td>2.018</td>
<td>11</td>
<td>82.6</td>
<td>16</td>
<td>41.7</td>
<td>9</td>
</tr>
<tr>
<td>16 = building</td>
<td>1.070</td>
<td>19</td>
<td>1.915</td>
<td>15</td>
<td>92.4</td>
<td>7</td>
<td>44.1</td>
<td>7</td>
</tr>
<tr>
<td>17 = trade</td>
<td>1.035</td>
<td>22</td>
<td>1.518</td>
<td>23</td>
<td>93.3</td>
<td>3</td>
<td>31.8</td>
<td>19</td>
</tr>
<tr>
<td>18 = lodging</td>
<td>1.007</td>
<td>25</td>
<td>1.846</td>
<td>17</td>
<td>99.2</td>
<td>1</td>
<td>45.4</td>
<td>4</td>
</tr>
<tr>
<td>19 = inland tr.</td>
<td>1.025</td>
<td>23</td>
<td>1.713</td>
<td>19</td>
<td>96.5</td>
<td>2</td>
<td>40.2</td>
<td>13</td>
</tr>
<tr>
<td>20 = m&amp;air tr.</td>
<td>1.062</td>
<td>20</td>
<td>1.821</td>
<td>18</td>
<td>92.4</td>
<td>5</td>
<td>41.7</td>
<td>10</td>
</tr>
<tr>
<td>21 = auxil. tr.</td>
<td>1.077</td>
<td>18</td>
<td>1.532</td>
<td>22</td>
<td>85.6</td>
<td>11</td>
<td>29.7</td>
<td>22</td>
</tr>
<tr>
<td>22 = communic.</td>
<td>1.020</td>
<td>24</td>
<td>1.266</td>
<td>25</td>
<td>92.4</td>
<td>6</td>
<td>19.4</td>
<td>23</td>
</tr>
<tr>
<td>23 = credit</td>
<td>2.370</td>
<td>1</td>
<td>3.379</td>
<td>1</td>
<td>42.4</td>
<td>25</td>
<td>29.9</td>
<td>21</td>
</tr>
<tr>
<td>24 = other m.s.</td>
<td>1.104</td>
<td>15</td>
<td>1.341</td>
<td>24</td>
<td>69.6</td>
<td>19</td>
<td>17.7</td>
<td>24</td>
</tr>
<tr>
<td>25 = non-m.s.</td>
<td>1.040</td>
<td>21</td>
<td>1.558</td>
<td>21</td>
<td>92.9</td>
<td>4</td>
<td>33.3</td>
<td>18</td>
</tr>
<tr>
<td>Average</td>
<td>1.217</td>
<td></td>
<td>1.950</td>
<td></td>
<td>80.5</td>
<td></td>
<td>36.9</td>
<td></td>
</tr>
</tbody>
</table>

for credit (sector 23) to 99.2 percent for lodging (sector 18). In interpreting the results, recall that for a process innovation the direct effect is either absent or affects all sectors. The indirect effects are related to the total (i.e., direct plus indirect) use of inputs in sector $k$. The spillovers are thus connected to the extent to which the innovated sector $k$ depends, directly plus indirectly, on inputs from the other sectors. As a consequence, sectors that depend predominantly on itself will exhibit low spillovers. Sectors with large diagonal elements $I_{kk}$ will typically have small spillovers $s_k$. This correlation is fairly strong in the sense that for most sectors the rankings of $I_{kk}$ and $s_k$ add up to approximately 26. Exceptions in this respect are fuel (sector 2), communication services (sector 22) and other market services (sector 24). The results for these sectors indicate that it may not be sufficient to focus on $I_{kk}$ only,
but that $l_{kk}$ should be viewed in combination with $c_k$. For example, fuel has a diagonal element $l_{kk}$ that is somewhat above average, its column sum $c_k$, however, is rather small implying that there is little dependence on the other sectors. On the whole, the larger spillovers of process innovation effects are reported for the service sectors. These sectors typically depend to a large extent on other sectors.

The spillovers of product innovation effects are found to be larger for the manufacturing sectors than for the service or raw materials sectors. On average, 36.9 percent of the total output change due to a product innovation in sector $k$ takes place in the other sectors. The spillovers range from 17.6 percent for fuel (sector 2) to 47.0 percent for rubber and plastic products (sector 14). The spillovers for product innovation are found to be, roughly speaking, two to three times smaller than those for process innovation. The basic difference between the spillovers for process innovation and those for product innovation is caused by the direct effect. In the case of a process innovation there are either no direct effects involved or they affect all sectors. Product innovation, however, directly affects the production of sector $k$. The subsequent indirect effects then describe the dependence of sector $k$ on the production sectors (including itself). The spillovers measure the output change in all other sectors as a percentage of the total output change. The inclusion of the direct effect explains why the spillovers $s_{ik}$ are two to three times smaller than the spillovers $s_{ik}$.

A widespread measure for sectoral interdependencies (or linkages) in an input–output table are the column sums $c_k$ of the Leontief inverse. They are interpreted as the sector’s dependence on inputs (both directly and indirectly) and are usually termed total, or direct plus indirect, backward linkages. Rasmussen (1956) has argued that the column sum ($c_k$), the column sum minus 1 ($c_k - 1$), and the column sum minus its diagonal element ($c_k - l_{kk}$) are all relevant for calculating the strength of an industry’s backward linkages (although the column sum has become the traditional measure). Diamond (1976, p. 762) reports that, when the analysis is carried out on all three measures, “typically incompatible rankings of industries will be derived.”

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8 See, for example, Oosterhaven (1981), Miller and Blair (1985), or Dietzenbacher (1992) for overviews, also of alternative linkage measures.
9 He refers to Diamond (1973, pp. 487–521) for a demonstration of this, using Turkey as a case study.
Table 1 may serve as a further illustration of this. The rankings of \( c_k \) and \( s_k \) (or \( c_k \) and \( s_k \) respectively) differ by five or more places in no less than 19 (resp. 14) sectors.

The spillovers have been expressed as the percentage of the total output change that occurs in sectors other than the innovated sector. This percentage was independent of the “size” of the innovation (i.e., \( \alpha \)) or the final demand vector \( f \). The magnitude of the spillovers, however, does depend on \( \alpha \) and on \( f \). To get some indication of the size of the spillovers in money terms, calculations were carried out for \( \alpha = 0.01 \), while for \( f \) the final demand vector in the original input–output table was taken. The total output change is obtained as \( e'(x - \bar{x}) \), where \( e' = (1, \ldots, 1) \) denotes the summation vector. The total output decreases if \( \alpha \) is positive. Therefore, the total effect is measured as the output reduction (which is a positive number).

In the case of a process innovation in sector \( k \), the total effect is

\[
t_k = e'(x - \bar{x}) = \alpha(c_k - 1)x_k/\eta_k. \tag{13}
\]

Note that \( \eta_k = 1 + \alpha(l_{kk} - 1) \) so that the relation in Equation 13 is nonlinear. For \( \alpha = 1 \) percent, however, \( \eta_k \) ranges from 1 to 1.014 (or 1.006 if sector 23 is excluded). This implies that for small values of \( \alpha \) the expression in Equation 13 is approximately linear in \( \alpha \). That is, \( t_k = \alpha(c_k - 1)x_k \), expressing that the total effect depends on the size of the innovated sector (i.e., \( x_k \)) and on its backward linkages (i.e., \( c_k \)). Given the average value of 1.950 for \( c_k \) in Table 1, this means that a 1 percent process innovation in sector \( k \) would induce a reduction in total output that equals on average 0.95 percent of this sector’s output. The magnitude of the spillovers is given by \( s_k t_k \) in Table 2.

For a product innovation the total effect is obtained as

\[
\bar{t}_k = e'(x - \bar{x}) = \alpha c_k(x_k - f_k)/\eta_k. \tag{14}
\]

For small \( \alpha \) again, this yields \( \bar{t}_k \approx \alpha c_k(x_k - f_k) \). The total effect thus depends on the intermediate deliveries sold by sector \( k \) (i.e., \( x_k - f_k \)) and on its backward linkages (i.e., \( c_k \)).

The results are given in Table 2 and they show that also in magnitude the spillovers of process innovation are substantially larger than the spillovers of product innovation, which holds for each sector. Intuitively speaking, this may, on the one hand, seem obvious because the spillovers as a percentage were for process innovation two to three times larger than for product innovation. On the other hand, however, one might be inclined to expect that
part of this is offset. Because the effects of product innovation included a direct effect (reflecting the dependence on sector $k$), it might be expected that $\tilde{t}_k > t_k$ for certain sectors. Equations 13 and 14 show that $\tilde{t}_k > t_k$ if and only if $x_k > c_k f_k$. This is the case if the final demand $f_k$ is only a minor part of the output $x_k$. Or, in other words, if the intermediate deliveries supplied by sector $k$ form a large part of its output $x_k$. In its turn, this often reflects a strong dependence on inputs provided by sector $k$. The results in Table 2 show that this holds for the sectors 1–6, 13, 14, 19, and 21–24.

The spillovers for process innovation ($s_k$) are two to three times as large as those for product innovation ($\tilde{s}_k$). Due to the differences in the magnitude of the total effects $t_k$ and $\tilde{t}_k$, the magnitude of the spillovers exhibits a larger variation. The ratio between $s_k t_k$
and $\bar{s}_k$ ranges from 1.2 in sectors 3 and 4, to 15.7 in sector 25. This ratio is found to be small for the raw materials sectors and large for service sectors.

5. CONCLUSIONS

In a multisector economy the effects of innovations propagate and get embodied in the products of other sectors. In this paper the propagation was analyzed of the effects of two specific types of innovation. First, process innovation was defined as the case where a sector produces more output with the same amounts of the different inputs. Second, product innovation meant that each sector produces the same amount of output with less input of the innovated product.

The spillovers of innovation effects were defined as the percentage of the total output change that occurs in sectors $i$ other than the innovated sector $k$. It was shown that the spillovers are independent of the “size” of the innovation and of the specific structure of final demands. The spillover measures are directly related to the diagonal elements of the Leontief inverse and its column sums. This allowed for an alternative interpretation of the elements of the Leontief inverse.

As an application, the spillovers were measured for the European Union in 1991. It was found that for a process innovation in sector $k$, on average 80.5 percent of the total output change occurs in sectors other than $k$. Typically, sectors that depend predominantly on itself—reflected by large diagonal elements—exhibit low spillovers. The larger spillovers of process innovation effects were reported for the service sectors. These sectors are characterized by a large dependence on other sectors. The spillovers of product innovation effects were found to be two to three times smaller than those of process innovation. This was caused by the fact that a product innovation affects the output of the innovated sectors directly. The larger spillovers were reported for the manufacturing sectors, rather than for the service or raw materials sectors. On average, 36.9 percent of the total output change—due to a product innovation in sector $k$—takes place in the other sectors. Also, the magnitude of the spillovers was found to be larger for process innovation than for product innovation. The differences, however, showed a much more varied pattern.
## Appendix: Sector classification

<table>
<thead>
<tr>
<th>Sector $k$</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>agriculture, forestry, and fishery products</td>
</tr>
<tr>
<td>2</td>
<td>fuel and power products</td>
</tr>
<tr>
<td>3</td>
<td>ferrous and nonferrous ores and metals</td>
</tr>
<tr>
<td>4</td>
<td>nonmetallic mineral products</td>
</tr>
<tr>
<td>5</td>
<td>chemical products</td>
</tr>
<tr>
<td>6</td>
<td>metal products (except machinery and transport equipm.)</td>
</tr>
<tr>
<td>7</td>
<td>agricultural and industrial machinery</td>
</tr>
<tr>
<td>8</td>
<td>office and data processing machines, etc.</td>
</tr>
<tr>
<td>9</td>
<td>electrical goods</td>
</tr>
<tr>
<td>10</td>
<td>transport equipment</td>
</tr>
<tr>
<td>11</td>
<td>food, beverages, tobacco</td>
</tr>
<tr>
<td>12</td>
<td>textiles and clothing, leather, footwear</td>
</tr>
<tr>
<td>13</td>
<td>paper and printing products</td>
</tr>
<tr>
<td>14</td>
<td>rubber and plastic products</td>
</tr>
<tr>
<td>15</td>
<td>other manufacturing products</td>
</tr>
<tr>
<td>16</td>
<td>building and construction</td>
</tr>
<tr>
<td>17</td>
<td>recovery, repair services, wholesale and retail trade</td>
</tr>
<tr>
<td>18</td>
<td>lodging services</td>
</tr>
<tr>
<td>19</td>
<td>inland transport services</td>
</tr>
<tr>
<td>20</td>
<td>maritime and air transport services</td>
</tr>
<tr>
<td>21</td>
<td>auxiliary transport services</td>
</tr>
<tr>
<td>22</td>
<td>communication services</td>
</tr>
<tr>
<td>23</td>
<td>credit and insurance</td>
</tr>
<tr>
<td>24</td>
<td>other market services</td>
</tr>
<tr>
<td>25</td>
<td>nonmarket services</td>
</tr>
</tbody>
</table>


## REFERENCES


