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ALTERNATIVE WAYS OF MEASURING TECHNOLOGY SPILLOVERS - RESULTS WITH FINNISH DATA

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ABSTRACT: A new weighting scheme for estimating spillovers is proposed in the paper. Spillover estimates based on two different weighting schemes on one hand, and on flows and stocks of R&D on the other, are presented. The data cover all industries in the Finnish business sector and the years 1981, 1985, 1989 and 1993. A lot of useful information of the technological connections between industries is found to be lost when more aggregated data are used. The new weighting scheme, based on the overlap of R&D, is shown to overcome some of the problems with the earlier scheme based on correlations. The overlap-based weights are found to produce larger estimates for spillovers, and to take interindustry links based on common research interests better into account. This result applies both to flow measures and stock measures of spillovers. The econometric analysis performed implies that among several technology inputs examined, the strongest effect on total factor productivity comes from the firms' own R&D. The effect of spillovers received from other industries is less clear but may be positive.

KEY WORDS: interindustry technology spillovers, proximity measures, Finland

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TIIVISTELMÄ: Raportissa esitellään uusi tahattomien teknologiavirtojen arviointiin soveltuva tapa painottaa toimialojen tutkimuspanostusta. Lisäksi esitetään kahteen eri painotustapaan ja toisaalta teknologiavirtoihin ja -varantoihin perustuvien laskelmien tuloksia. Aineisto kattaa kaikki Suomen yrityssektoriin kuuluvat toimialat sekä vuodet 1981, 1985, 1989 ja 1993. Tulosten mukaan aineiston aggregointi hävittää hyödyllistä tietoa toimialojen välisistä teknologiakytkennöistä. Uuden painotustavan, joka perustuu tutkimuspanostuksen päällekkäisyyteen, osoitetaan ratkaisevan joitakin aikaisemmin käytettyyn, korrelaatioihin perustuvaan painotustapaan liittyviä ongelmia. Päällekkäisyyteen perustuvien painojen todetaan tuottavan suurempia tahattomia teknologiavirtoja koskevia arvioita ja ottavan paremmin huomioon toimialojen välisiä yhteisiin tutkimusintresseihin perustuvia kytkentöjä. Tämä pätee sekä teknologiavirtoihin että -varantoihin perustuviin arvioihin. Eri teknologiapanosten tuottavuusvaikutuksia koskevan ekonometrisen tarkastelun mukaan suurin vaikutus on yritysten omalla tutkimustoiminnalla. Muilta toimialoilta tulevien tahattomien teknologiavirtojen vaikutus ei ole yhtä selkeä, mutta sekin saattaa olla positiivinen.

AVAINSANAT: toimialojen väliset tahattomat teknologiavirrat, läheisyysindikaattorit, Suomi

YHTEENVETO

Raportin tavoitteena on kehittää edelleen Goton ja Suzukin (1989) esittämää tahattomien teknologiavirtojen (technology spillovers) arviointimenetelmää. Goto ja Suzuki käyttivät toimialojen välisiä, niiden eri tuoteryhmiin kohdistamien tutkimusmenojen korrelaatioita toimialojen teknologista läheisyyttä kuvaavina indikaattoreina painottaessaan toimialalta toiselle kulkeutuvia teknologiavirtoja. Koska tähän painotustapaan liittyy joitakin ongelmia, raportissa esitellään uusi tahattomien teknologiavirtojen arviointiin soveltuva tapa painottaa toimialojen tutkimuspanostusta. Lisäksi esitetään näiden painojen soveltamista muiden toimialojen T&K-varantojen painottamiseen niiden tutkimusmenojen asemesta, jolloin saadaan tahattomista teknologiavirroista kertyviä varantoja koskevat arviot. Raportissa esitetään myös näihin kahteen eri painotustapaan ja toisaalta teknologiavirtoihin ja -varantoihin perustuvien laskelmien tuloksia.

Aineisto kattaa kaikki Suomen yrityssektoriin kuuluvat toimialat sekä vuodet 1981, 1985, 1989 ja 1993. Tulosten mukaan aineiston aggregointi hävittää hyödyllistä tietoa toimialojen välisistä teknologiakytkennöistä. Uuden painotustavan, joka perustuu tutkimuspanostuksen päällekkäisyyteen, todetaan tuottavan suurempia tahattomia teknologiavirtoja koskevia arvioita ja ottavan paremmin huomioon toimialojen välisiä yhteisiin tutkimusalueisiin perustuvia kytkentöjä. Tämä pätee sekä teknologiavirtoihin että -varantoihin perustuviin arvioihin. Vaikka tahattomia teknologiavirtoja koskevien arvioiden suuruus vaihtelee riippuen käytetystä painotustavasta ja virta- tai varantolähestymistavan käytöstä, pääosin samojen toimialojen voidaan todeta olevan tärkeitä tahattomien teknologiavirtojen lähteitä eri arviointitapojen mukaan. Tällaisia toimialoja ovat esimerkiksi koneiden ja elektronisten tuotteiden valmistus, ja myös eräät palvelutoimialat. Eri teknologiapanosten tuottavuusvaikutuksia koskevan ekonometrisen tarkastelun mukaan suurin vaikutus on yritysten omalla tutkimustoiminnalla. Muilta toimialoilta tulevien tahattomien teknologiavirtojen vaikutus ei ole yhtä selkeä, mutta sekin saattaa olla positiivinen.

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1. Introduction[1]

Several methods of measuring spillovers empirically have recently been used. These methods have been surveyed, among others, by Griliches (1992), Mohnen (1990 and 1996) and Nadiri (1993). Mohnen (1990) divides the studies in two main groups. Several of the studies attempt at measuring the welfare effects of the spillover or at evaluating the social rate of return on R&D without specifying the interindustry links of the spillover, whereas another group of studies specifically looks at the links between the source and the receiving sectors.

Nadiri (1993, p. 17) divides the methodological approaches to estimate the magnitudes of R&D spillovers and their effects on productivity growth into two groups. The "technology flow" approach uses an input-output (I-O) or a technology matrix based on patent data to position the firms or industries in a matrix of technological linkages and examines the spillover effects of R&D undertaken by one firm or industry on the remaining firms or industries. The second approach is an econometric one which estimates the effects of spillover on the costs and structure of production of the receiving firms or industries. This is called the "cost function" approach by Nadiri.

This paper aims at developing further the method for estimating spillovers proposed by Goto and Suzuki (1989). They used the correlations of the vectors of the R&D expenditures of industries across product groups as measures of technological distance between the industries when weighting R&D flows from one sector to another. Since this weighting scheme involves some shortcomings, another weighting scheme is proposed. This scheme takes into account the overlap of the R&D expenditures between each pair of sectors. The use of either set of weights is methodologically related to the

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[1] An earlier draft of the paper was presented at the Sixth Conference of the International Joseph A. Schumpeter Society in Stockholm, June 2-5, 1996. I am indebted to Kari Alho, Rita Asplund, Lucien Randazzese, Petri Rouvinen and Pekka Ylä-Anttila for useful comments. I am also grateful to Reijo Mankinen for solving a computational problem and Sinikka Littu for research assistance. Financial support from the Technology Development Centre (TEKES) and the Finnish Ministry of Trade and Industry is gratefully acknowledged.

technology flow approach mentioned above. A second refinement of the method which is proposed is to use these weights in weighting the R&D stocks of other sectors instead of only current R&D expenditures.

Spillover estimates based on both correlations and the overlap of R&D on one hand, and on flows and stocks of R&D on the other, are presented in the paper. These estimates concern the Finnish business sector and the years 1981, 1985, 1989, and for the flow-based estimates, also 1993. Finally, the importance of spillovers is analysed in a growth-accounting-type framework, where changes in total factor productivity are explained by various technology inputs, among them spillovers. Spillover estimates based on R&D stocks and the two alternative weighting schemes are used in the models. This analysis covers the Finnish manufacturing sector.

2. Spillover estimates based on correlations

2.1. Spillover estimates

In this section the first set of industry-specific spillover estimates are presented for four years: 1981, 1985, 1989 and 1993, and changes in them over time are discussed. In addition, the usefulness of the approach and the sensitivity of the results to varying levels of disaggregation of the data are examined.

The spillover estimates of this section (see also Vuori 1993, 1994a, 1994b and 1995) are based on the same basic ideas as those of Goto and Suzuki (1989), who used industry data on the distribution of R&D expenditures across product groups to calculate measures of interindustry technological distance. These distance measures - or correlations between the distribution vectors - were then used in weighting the research expenditures of other industries to obtain the technology flow or spillover received by each industry. All positive correlations between the distribution vectors of the R&D expenditures of each pair of industries were used in calculating the spillovers. This approach is related to earlier research by Jaffe (1986), who based his distance measures on firm patent data instead of R&D data. The idea behind these measures is that the closer to each other firms or industries are technologically, the more likely are spillovers between them. While Goto and Suzuki only used estimates for spillovers from electronics-related industries, my estimates cover all industries in the business sector.

Table 1. **The most important spillover source industries and size of sent spillovers by years (in current prices), based on correlations, R&D flows and data sets with 24 industries and 32 product groups**

1993		1989	
Industry	**Mill. FIM**	**Industry**	**Mill. FIM**
Machinery	**1334.2**	**Other services and products**	**1522.0**
Electrical products	**1221.0**	**Machinery**	**1055.3**
Chemicals (incl. drugs)	**570.5**	**Electrical products**	**710.9**
Ferrous metals	**519.0**	**Pulp and paper, paper products**	**260.1**
Other services and products	**350.5**	**Wood incl. furniture**	**111.5**
Transport, communication	**207.7**	**Glass, stone, products thereof**	**101.7**
Pulp and paper, paper products	**109.2**	**Instruments**	**101.5**
Instruments	**107.1**	**Trade, hotels and restaurants**	**93.2**
Glass, stone, products thereof	**73.2**	**Food, drink, tobacco**	**90.4**
Trade, hotels and restaurants	**72.5**	**Metal products**	**89.9**
1985		1981	
Industry	**Mill. FIM**	**Industry**	**Mill. FIM**
Machinery	**1544.8**	**Metal products**	**681.8**
Electrical products	**305.7**	**Machinery**	**493.2**
Other services and products	**180.8**	**Wood incl. furniture**	**419.8**
Transport equipment	**150.0**	**Other services and products**	**175.3**
Glass, stone, products thereof	**145.4**	**Transport equipment**	**170.4**
Food, drink, tobacco	**140.1**	**Trade, hotels and restaurants**	**161.7**
Trade, hotels and restaurants	**136.0**	**Rubber and plastic products**	**158.4**
Instruments	**122.3**	**Chemicals (incl. drugs)**	**145.5**
Pulp and paper, paper products	**94.3**	**Pulp and paper, paper products**	**94.6**
Chemicals (incl. drugs)	**86.8**	**Instruments**	**89.5**

Data source: The spillovers were calculated from R&D data from Statistics Finland

Earlier work by the author has suggested that this method, despite its convenience and intuitive appeal, suffers from shortcomings. One of the problems is the fact that the spillover estimates may be sensitive to the level of disaggregation of the data. This matter is examined in section 2.2. Another problem has its origin in using the correlations of the research input vectors. In practice, also negative correlations contain information (which is not unambiguous) on the technological closeness of industries, but the only possibility seems to be to exclude these cases from the estimates (see section 3 and Appendix 1). Therefore, in section 3 a new alternative set of weights for estimating spillovers originating in other sectors is presented.

The data used are described in Appendix 2. Table 1 lists 10 industries which sent the largest spillovers, calculated using the method described above, for each of the four years. Mostly the ten industries are the same ones in each year, although their rank varies. Machinery and electrical products are, not unexpectedly, in the top-three group in each year (except for electrical products in 1981). It may also be noted that a couple of service industries, namely other services and products, and trade, hotels and restaurants, are important spillover sources in each year. In 1993 ferrous metals appears for the first time in the top-ten group, and is placed as high as on the fourth place.

2.2. *Sensitivity to the level of disaggregation of the data used for estimating spillovers*

Earlier studies by the author (see Vuori 1994b and 1995) using the same method for estimating spillovers have pointed to the fact that the results may be fairly sensitive to the level of disaggregation of data. Since the data for the various years are partly classified and aggregated differently (see Appendix 2), it thus seemed important to get some sort of impression as to how much the spillover estimates may vary according to the level of disaggregation.

Thus, first, the number of pairwise correlations of the distribution vectors of R&D (see previous section) exceeding 0.1, based on differently aggregated data tables were looked at. The value 0.1 is as such arbitrary, but the aim is to leave out the most insignificant connections between the industries. This has been done in Table 2. The general impression conveyed by this table is that aggregating the industries performing the R&D does indeed substantially decrease the number of relevant correlations. However, aggregating the product groups seems to increase the number of relevant correlations to some extent. This can perhaps also intuitively be expected, since firms may more easily find common research areas if broader product categories are discussed.

Table 2. **Number of correlations (> 0.1) between industry-specific distributions of R&D expenditures at varying levels of disaggregation**

Year	Data set (Rows x Columns)	Number of correlations
1981	32 x 32	95
	24 x 32	61
1985	43 x 51	92
	31 x 51	26
	24 x 51	15
	24 x 32	26
1989	47 x 56	53
	24 x 56	17
	24 x 32	26
1993	54 x 56	54
	24 x 56	13
	24 x 32	20

Data source: The spillovers were calculated from R&D data from Statistics Finland

Secondly, for each year the actual spillovers were calculated for an additional, more disaggregated data set (in addition to the four sets discussed in the previous section). Thus, for each year studied, we have two different sets of spillover estimates, one set based on the similar classifications with 24 industries and 32 product groups, and one set based on the most disaggregated data available for that year. Table 3 is a summary of these estimates. As a general conclusion, the total spillover estimates are substantially lower when more aggregated data are used. This implies that a lot of useful information of the technological connections between firms and industries is lost when more aggregated data are used. In relative terms, the size of total spillovers seems to have followed a downward trend. This can be seen when comparing the total spillover estimates with the total R&D expenditures of the business sector in the various years (see last column of Table 3).

Table 3. Size of total spillovers in business sector, estimates according to varying levels of disaggregation

Year	Data set (Rows x Columns)	Total spillovers, mill. FIM	Spillovers, per cent of total R&D expenditures
1981	32 x 32	3754.5	264.7
	24 x 32	2842.5	200.4
1985	43 x 51	5335.7	173.1
	24 x 32	3100.3	100.6
1989	47 x 56	6286.1	114.3
	24 x 32	4464.7	81.2
1993	54 x 56	5404.9	98.3
	24 x 32	4745.9	86.3

Data source: The spillovers were calculated from R&D data from Statistics Finland

3. Alternative measure of spillovers: Overlap of R&D

Although the spillover measure used in the previous section is intuitively appealing and easy to calculate, the use of correlations as measures of technological distance provides some problems. In some situations it is possible that the correlation coefficient gives at least partly a wrong impression of how much or little in common two industries have in terms of their research interests. Arithmetic examples of such situations are given in Appendix 1. For instance, the two industries may have a lot in common by investing relatively small amounts in several common areas but each having one specific area where it invests clearly more than the other industry. In this case the correlation between the two industries' research input vectors by product area may be close to or equal to zero. Intuitively, however, it seems that these industries have much more in common than two such industries that do not have any common research interests at all.

Secondly, industries whose research input vectors yield a negative correlation coefficient, clearly often also have more in common than industries with no common research areas. For practical reasons, the spillover calculations presented in the previous section have excluded all negative correlations. Taking them into account by using, say, the absolute values of the correlations, would not distinguish them sufficiently from closer connections between other industries showing positive correlations. Weighting (the absolute values of) positive and negative correlations also would seem to lead to too arbitrary results. In addition, a high negative correlation may also arise in a situation where the industries have no common research areas. Therefore, it would be difficult to distinguish between negative correlations arising from different situations.

As an attempt out of these problems, in this section another distance measure, or in other words weighting scheme for the calculation of spillovers is proposed. It can be derived from the same basic idea as the measure used above based on pairwise correlations between the research input vectors of industries, namely that the industries are technologically the more close to each other, the more common research interests they have. Thus, the same data on the distributions of the industries' research expenditures across product groups are used as above. Instead of using the correlations between the vectors as weights, however, the weights used in weighting the R&D flows of other sectors are based on the overlap of the research inputs of each pair of industries.[1]

In calculating the overlap measures, the distribution vectors of the industries' research expenditures across product groups are first transformed into shares in total research expenditures of each industry. Thus, the sum of each industry's research expenditures

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[1] I owe this idea of overcoming the problems related to correlations to Lucien Randazzese.

is normalized to one. Next, each pair of vectors is compared in the following way. For non-zero elements of the vectors, the degree of overlap within a product group equals the smaller one of the two industries' respective shares in their total research expenditures. The total degree of overlap between the two industries is the sum of the overlaps across product groups. Obviously, this measure can obtain values ranging from zero to one. It is zero only for industries that do not have any common research interests, and it is one if the two industries invest exactly the same shares of their research outlays in the same product groups. Thus, it is a clear improvement over the correlation measure. Examples of calculating this measure are also given in Appendix 1. Finally, like in the correlation case, the spillovers sent by an industry are calculated by weighting the research expenditures of this industry by the respective distance measure, that is, the degree of overlap.

Table 4. Number of alternative distance measures exceeding 0.1 and size of estimated total spillovers in business sector, based on data sets with 24 industries and 32 product groups

Year	Number of correlations	Total correlation-based spillovers, mill. FIM	Number of overlap measures	Total overlap-based spillovers, mill. FIM
1981	61	2842.5	90	3557.4
1985	26	3100.3	66	5741.2
1989	26	4464.7	50	8349.0
1993	20	4745.9	43	7296.3

Data source : R&D statistics from Statistics Finland, calculations by the author.

Spillovers were estimated using this method and the most comparable data sets with 24 industries and 32 product groups for the years 1981, 1985, 1989 and 1993. Table 4 gives a brief summary of the results. For comparison, results based on the correlation-based spillover measure are repeated in the table. The fourth column of the table shows the number of overlap measures exceeding 0.1 in value. While the size of these two distance measures cannot be compared as such, the idea of looking in both cases at the number of measures exceeding this (arbitrary) value is to provide an impression of the number of at least potentially important links between industries when using either measure. As can be expected, the number of such links is clearly higher in each year when using the overlap measure. Partially as a natural consequence of this, also the calculated spillovers are much larger than when using the measure based on correlations.

Table 5. The most important spillover source industries and size of sent spillovers by years, based on overlap measure, R&D flows and data sets with 24 industries and 32 product groups

1993		1989	
Industry	Mill. FIM	Industry	Mill. FIM
Electrical products	1754.3	Other services and products	2235.2
Machinery	1443.1	Electrical products	1500.2
Chemicals (incl. drugs)	1163.5	Machinery	1454.2
Other services and products	795.2	Instruments	511.3
Ferrous metals	650.5	Chemicals (incl. drugs)	445.5
Instruments	487.6	Pulp and paper, paper products	329.3
Pulp and paper, paper products	196.2	Energy and water	284.6
Transport, communication	154.7	Transport equipment	280.8
Trade, hotels and restaurants	104.1	Glass, stone, products thereof	241.4
Metal products	101.9	Metal products	207.0
1985		**1981**	
Industry	Mill. FIM	Industry	Mill. FIM
Machinery	1982.8	Machinery	842.6
Electrical products	816.1	Metal products	502.7
Other services and products	510.9	Wood incl. furniture	429.1
Transport equipment	424.3	Chemicals (incl. drugs)	417.8
Chemicals (incl. drugs)	318.1	Other services and products	287.2
Trade, hotels and restaurants	280.1	Transport equipment	190.4
Instruments	226.8	Trade, hotels and restaurants	171.6
Glass, stone, products thereof	225.3	Rubber and plastic products	141.5
Pulp and paper, paper products	215.5	Instruments	119.3
Food, drink, tobacco	196.9	Pulp and paper, paper products	91.6

Data source : R&D statistics from Statistics Finland, calculations by the author.

More detailed results based on the overlap measure are shown in Table 5. It shows the ten most important spillover source industries and the estimated size of the spillovers sent by them in each year. The results can be readily compared with those of Table 1 above. In general the size of the spillovers is substantially larger for each industry when using the overlap measure, as can be expected on the basis of the summary information of Table 4. In 1993, nine of the ten most important spillover source industries are the same ones as when using the correlation-based measure, although they appear in a slightly different order. Glass and stone products are replaced by metal products in the top-ten group when using the overlap-based measures instead of the correlation-based measures. In 1989, seven of the ten most important spillover sources are the same ones as when using the correlation-based measure. The food and the wood industries and trade, hotels and restaurants are replaced by chemicals, energy and water, and transport equipment in the top-ten group when using overlaps instead of correlations. There are also several changes in the ranks within the top-ten group. Instead, in both 1985 and 1981 the top-ten group of industries is exactly the same when using either measure. However, in these years also there are a few differences in the ranks within the top-ten group.

Thus, the new measure of technological distance presented in this section seems to produce qualitatively at least partly similar results as the spillover measure based on correlations, but it clearly takes better into account a large number of links between industries which may be overlooked when using the correlation-based measure.

4. One step further: Stock-based spillovers

The two spillover measures used above are similar in the sense that both sets of weights, those based on correlations and the ones based on the overlap of R&D, are used to estimate, how much of the annual R&D expenditures invested in other sectors can be expected to flow to sectors with similar research interests. However, it is quite generally agreed that the effects of technology may last for several years, and thus also a spillover concept which would be based on technology stocks instead of annual technology flows seems, at least in principle, to be preferable. This section presents a further refinement of the two spillover measures presented above, to see how using stocks affects the results.

Ideally, spillover stocks should be estimated by cumulating annual spillovers from each sector to other sectors and then using some assumptions about the rates of depreciation for such stocks in a similar way as when estimating physical capital or own R&D stocks. However, a substantially simpler approach was adopted here to obtain a first approximation of the spillover stocks. The same weights (correlations or overlap of R&D expenditures) for the selected years as were used for calculating the flow spillovers above, were used in weighting the own R&D stocks of the industries sending the spillovers. The R&D stocks have been estimated by Statistics Finland (see Appendix 2 for details). Thus, the spillovers received are assumed to be proportional to the R&D stocks in use in the sending industries, which as such seems to be a reasonable assumption.

The most important sources of stock spillovers estimated using the two sets of weights are shown in Table 6 for the years 1981, 1985 and 1989. As is to be expected, the stock spillovers are much larger than the flow spillovers of Tables 1 and 5 above. In addition, and similarly as with the flow spillovers, the estimates based on the overlap of R&D are clearly larger than those based on correlations.

In 1989, when using the overlap measure in calculating the spillover stocks, eight of the ten most important source industries are the same ones as when using the correlation measure. The food and the wood industries which appear on the top-ten list for the correlation measures are replaced by chemicals and energy and water in the overlap case. The first three industries (machinery, electrical products and other services) appear in the same order in the two cases, but otherwise the ranks vary to some extent. In 1985 the ten most important source industries are exactly the same ones. Here also

Table 6. The most important spillover source industries and size of sent spillovers by years, according to correlation and overlap-based stock measures and data sets with 24 industries and 32 product groups

Correlation-based spillover stocks		Overlap-based spillover stocks	
Industry	Mill. FIM	Industry	Mill. FIM
1989		1989	
Machinery	6223.9	Machinery	8576.6
Electrical products	2690.2	Electrical products	5676.8
Other services and products	1776.4	Other services and products	2608.9
Pulp and paper, paper products	1573.0	Instruments	2024.5
Metal products	516.0	Pulp and paper, paper products	1991.7
Instruments	402.0	Chemicals (incl. drugs)	1700.2
Food, drink, tobacco	362.8	Metal products	1188.6
Glass, stone, products thereof	335.2	Transport equipment	1102.7
Transport equipment	318.1	Glass, stone, products thereof	795.1
Wood incl. furniture	242.1	Energy and water	677.8
1985		1985	
Machinery	5181.4	Machinery	6650.8
Electrical products	1579.7	Electrical products	4217.5
Pulp and paper, paper products	712.5	Pulp and paper, paper products	1628.8
Food, drink, tobacco	578.3	Chemicals (incl. drugs)	1161.8
Instruments	435.7	Other services and products	908.7
Glass, stone, products thereof	338.3	Food, drink, tobacco	813.0
Other services and products	321.6	Instruments	808.4
Chemicals (incl. drugs)	317.2	Metal products	688.6
Metal products	287.1	Transport equipment	638.2
Transport equipment	225.6	Glass, stone, products thereof	524.3
1981		1981	
Machinery	1695.3	Machinery	2896.0
Pulp and paper, paper products	860.0	Chemicals (incl. drugs)	2306.6
Chemicals (incl. drugs)	803.0	Electrical products	1942.9
Metal products	565.5	Pulp and paper, paper products	832.6
Instruments	514.8	Instruments	686.2
Electrical products	437.6	Other services and products	562.4
Other services and products	343.3	Metal products	417.0
Wood incl. furniture	342.9	Non-ferrous metals	388.1
Rubber and plastic products	292.7	Wood incl. furniture	350.5
Transport equipment	291.4	Transport equipment	325.7

Data source : R&D statistics from Statistics Finland, calculations by the author.

the first three appear in the same order, and the rest in a slightly different order. In 1981, nine of the ten industries are the same ones. Rubber and plastic products, which appear on the list with correlation spillover stocks, are replaced by non-ferrous metals in the overlap list. Machinery again holds the top place in both cases, but from the second place on the ordering of the industries differs between the two measures.

When comparing the correlation-based spillover stock measures with the corresponding flow measures (Table 1), the top-ten industries are almost the same ones. Trade, hotels and restaurants, which appears on the top-ten list for the flow measures in each year investigated, is not included in the lists for the stock measures of Table 6. This industry is replaced by transport equipment in 1989, by metal products in 1985, and by electrical products in 1981.

The comparison of the overlap-based stock and flow (Table 5) measures, in turn, reveals that in 1989, with a somewhat different ordering, the industries included in the top-ten lists are the same. In 1985, trade, hotels and restaurants are again (as with the correlation measure) replaced by metal products when using the stock measure instead of flows. In 1981, there are two differences between the top-ten lists: trade, hotels and restaurants, and rubber and plastic products, are replaced by electrical products and non-ferrous metals when using the stock measure.

Thus, although the rankings of the industries vary somewhat according to which of the four measures is used, the general picture of which industries are important spillover sources is fairly similar across the measures. Most consistently, machinery, electrical products and other services, which appear on each of the four lists among the top-seven industries (and very often, among the top-three), are the industries having the strongest potential for producing spillovers for other industries. Another important spillover source industry is pulp and paper products, but there is more variation in its importance across the years and the different measures.

5. Spillovers and productivity

5.1. *Model specifications*

In the following, the effects of various technology inputs on total factor productivity are analysed econometrically. The analysis is based on a traditional growth accounting framework, where the "residual" is explained by technological change. The analysis is made at the industry level. The technology inputs considered in the analysis of the effects of the various technology inputs on total factor productivity (TFP) are: the firms' own R&D, technology inputs embodied in domestic and foreign intermediate goods, technology inputs embodied in domestic and foreign capital goods, and technology spillovers received from other domestic industries.

We will examine the relationship between technological change and productivity using the following general model:

$$(1) \qquad \Delta TFP / TFP = a_0 + \Sigma a_i X_i + u \quad (i = 1,...,n),$$

where $\Delta TFP / TFP$ is the average annual (percentage) change in total factor productivity in the period studied, a_0 is a constant, the X_i :s are the technology input variables used in explaining changes in TFP, and the a_i :s are the elasticities to be estimated, describing the effect of a change in the given technology input on the change in productivity. u is an error term, and the subscript i refers to the i'th technology variable. All the technology variables are in intensity form, that is, they have been divided by the value of gross output in each industry.

The model specifications which are estimated are fairly similar to those used by Terleckyj (1980). However, Terleckyj divided the direct technology intensity variable differently, that is, into R&D funded by the private and the public sector, and embodied technology into privately and publicly funded technology inputs purchased from other sectors. In addition he had a few other explanatory factors. Another difference is that technology flow concepts were used instead of technology stocks as in the present study.

The same kind of ideas form the basis also of the studies by, for example Sveikauskas (1981) and Link (1983). In one of Goto's and Suzuki's (1989) models changes in industry-based TFP are explained by technology intensity based on the firms' own R&D and intensity based on purchased inputs. In another model specification an additional explanatory factor is the spillover intensity from electronics-related industries to other industries. Spillovers were calculated similarly as the correlation-based flow measures in this study, but not for other industries than electronics-related ones. Moreover, embodied technology inputs were not divided into components.

5.2. *Econometric results*

This section contains results from using econometric models of the type presented in the previous section. The data and the variables used are described briefly in Appendix 2. In the first stage, average annual (percentage) changes in total factor productivity (TFP) over three separate periods combined are explained by several technology variables. The periods studied are 1981 to 1985, 1985 to 1989, and 1989 to 1993, respectively. The models contain time dummies for the periods 1985 to 1989 and 1989 to 1993. Embodied technology was divided according to type (intermediate goods vs. capital goods). The two alternative spillover stock measures presented above are used in alternative model specifications to see whether they behave differently. All explanatory variables are as of the first year of each four-year period studied. Thus, average TFP changes in 1981 to 1985 are explained by the 1981 technology variables etc. The direct (own-R&D-based) and capital-embodied technology variables are based on stock concepts (as opposed to the current year's flows only; for further details on the variables, see Virtaharju and Åkerblom 1993). The variable for technology embodied in domestic and foreign intermediate inputs is based on flows.

Results for the basic model specifications with four technology variables (direct technology, technology embodied in capital and intermediate goods, and spillovers) are shown in the first two columns of Table 7. In both models (M1 and M2) direct (own

R&D-based) technology obtains a positive and significant coefficient. The coefficients for the embodied technology variables are also positive but non-significant. In contrast, and contrary to expectations, both spillover variables (the correlation-based measure in model M1 and the overlap-based measure in model M2) obtain a negative and significant coefficient. The time dummy for the middle period (1985 to 1989) is positive and significant at the 10 per cent level.

The "wrong" sign of the spillover variables is somewhat puzzling. A closer look at the data reveals that the intermediate technology and the spillover variables are positively correlated with the direct technology variable. This could mean that there are interactions among the variables which may affect the results. To see if this is the case, several interaction variables were tried. The only one of these that obtained a significant coefficient, was the product of the intermediate goods technology and the spillover variables. Results for model specifications including this variable are shown as Models M3 and M4 in Table 7. In the case of both spillover variables, the interaction term is negative. The inclusion of this variable affects the results significantly: the signs of the spillover stock variables are reversed, and the coefficients become significant.

To see if this result holds also when the timing of the effects of the technology variables on TFP is different, another periodisation was next tried. The period studied was divided into two subperiods (1981 to 1987 and 1987 to 1993) instead of three. Models M5 and M6 in Table 8 correspond to Models 3 and 4 in Table 7, with only the periodisation having changed. The results for both the direct technology variable and the spillover variables are qualitatively fairly similar to those in Table 7. The spillover variables are less significant than in the three-period case, but close to the 10 per cent significance level. The results for the capital goods and intermediate goods are slightly different, but their coefficients remain insignificant.

Another thing which may cause some instability in the results was also noted in the data. Among the 20 industries studied, there is one which behaves clearly differently from the rest: While in general industries with high own R&D intensity obtain relatively small spillovers, the instruments and optical equipment industry shows clearly above-average values for both variables over the years studied. To see how this may affect the estimation results above, a dummy variable for this industry was added to the models. Indeed, this industry seems to affect the results strongly: the dummy variable obtains a large negative and significant coefficient. The results for the specification including the correlation-based spillover variable are shown as Model M7 in Table 8. The coefficient for the spillover variable becomes extremely small and nonsignificant. For the corresponding specification with the overlap-based spillover variable (not shown in the table), the coefficient is negative but nonsignificant.

Table 7. Estimation results for models with 3 subperiods

Variable	Model			
	M1	M2	M3	M4
constant	2.37 (2.48)	2.48 (2.52)	1.52 (1.52)	1.48 (1.44)
direct	0.18 (2.35)	0.20 (2.43)	0.20 (2.46)	0.23 (2.67)
capital	0.03 (0.04)	0.01 (0.01)	-0.01 (-0.01)	-0.03 (-0.04)
intermediate	0.16 (0.33)	0.11 (0.34)	0.35 (0.99)	0.33 (0.96)
spilloverstock	-0.08 (-2.12)		0.09 (1.55)	
overlapstock		-0.05 (-2.04)		0.06 (1.88)
interm x spillover			-0.05 (-2.18)	-0.03 (-2.63)
timedum85	1.51 (1.35)	1.65 (1.47)	2.13 (1.79)	2.24 (1.86)
timedum89	-0.94 (-0.54)	-0.66 (-0.38)	-0.96 (-0.56)	-0.71 (-0.41)
R^2	0.25	0.25	0.28	0.30
Adjusted R^2	0.16	0.17	0.18	0.20
SEE	4.26	4.24	4.20	4.15
F statistic	2.88	2.97	2.89	3.15
Number of observations	60	60	60	60

Note. The dependent variable is average annual changes (%) in total factor productivity in the periods 1981-85, 1985-89 and 1989-93. direct = direct technology intensity (TI) (technology stock based on R&D expenditures, divided by gross output; all other technology variables have also been divided by gross output); capital = TI of domestic and foreign capital goods; intermediate = TI of domestic and foreign intermediate goods; spilloverstock = TI calculated from correlation-based domestic stock spillovers received; overlapstock = TI calculated from overlap-based domestic stock spillovers received; interm x spillover = the product of intermediate and either spilloverstock or overlapstock according to the equation; timedum85 = dummy variable, equal to 1 in the period 1985 to 1989; timedum89 = dummy variable, equal to 1 in the period 1989 to 1993. t statistics in brackets after the coefficients, calculated from heteroscedasticity-corrected standard errors (according to White, 1980).

Finally, a model specification with both the interaction variable and the dummy variable for the instruments industry was tried. Results for the correlation-case are shown as Model 8 in Table 8. In this case, the interaction variable is not significant any more. The instruments dummy is still large but less significant than before. The spillover variable is positive but still nonsignificant. For the corresponding specification with the overlap spillover variable, the results are again slightly different. Here, the instruments dummy turns out small, positive but non-significant. The spillover variable is positive but non-significant, and the interaction variable negative and non-significant. Thus, the effect of the outlier industry seems to be strong, and an interaction between spillovers and technology embodied in intermediate technology seems to be present, but it is not possible to detect their effects simultaneously.

Thus, there are clear indications that spillovers received from other industries may have a positive effect on total factor productivity. However, in view of the mixed results above concerning possible interactions among the variables and the effects of an outlier industry, it seems early to draw very firm conclusions. In addition, in the specifications where the interaction variable between spillovers and technology embodied in intermediate goods was significant, the intermediate goods variable itself was non-significant, and thus it is not possible to make conclusions on the magnitudes of the effects of these variables together.

In an earlier study (Vuori 1997), using a different spillover variable (a correlation-based flow measure), the effect of spillovers on TFP came out more clearly than in this study. While the use of stock measures for spillovers is preferable in principle, it may be possible that the timing of spillover effects are different from the effects of direct R&D and embodied technology, which could affect the results.

Of the technology variables analysed, the strongest effect on total factor productivity seems to come from direct technology, which is based on the firms' own R&D activities. Embodied technology does not seem to explain TFP on the basis of these models.

Table 8. Estimation results for models with 2 subperiods

Variable	Model			
	M5	M6	M7	M8
constant	2.55 (2.00)	2.62 (1.88)	2.95 (2.30)	2.74 (1.92)
direct	0.28 (2.87)	0.33 (3.11)	0.35 (2.77)	0.34 (2.61)
capital	0.41 (0.61)	0.38 (0.57)	0.48 (0.74)	0.49 (0.74)
intermediate	0.004 (0.01)	-0.06 (-0.18)	-0.36 (-1.05)	-0.28 (-0.70)
spilloverstock	0.11 (1.29)		0.0005 (0.01)	0.05 (0.56)
overlapstock		0.07 (1.27)		
interm x spillover	-0.06 (-2.21)	-0.04 (-2.25)		-0.02 (-0.57)
instrumdum			-9.29 (-1.99)	-7.92 (-1.30)
timedum87	-1.30 (-0.96)	-1.03 (-0.74)	-1.28 (-0.95)	-1.30 (-0.95)
R^2	0.37	0.41	0.39	0.39
Adjusted R^2	0.25	0.30	0.28	0.26
SEE	3.48	3.37	3.42	3.46
F statistic	3.20	3.78	3.51	2.94
Number of observations	40	40	40	40

Note. The dependent variable is average annual changes (%) in total factor productivity in the periods 1981-87 and 1987-93. direct = direct technology intensity (TI) (technology stock based on R&D expenditures, divided by gross output; all other technology variables have also been divided by gross output); capital = TI of domestic and foreign capital goods); intermediate = TI of domestic and foreign intermediate goods; spilloverstock = TI calculated from correlation-based domestic stock spillovers received; overlapstock = TI calculated from overlap-based domestic stock spillovers received; interm x spillover = the product of intermediate and either spilloverstock or overlapstock according to the equation; instrumdum = dummy variable, equal to 1 for the instruments industry and 0 for other industries; timedum87 = dummy variable, equal to 1 in the period 1987 to 1993. t statistics in brackets after the coefficients, calculated from heteroscedasticity-corrected standard errors

For most specifications, the two alternative spillover measures behaved fairly similarly in the econometric analysis, with some differences when the instruments dummy was added to the model. It seems that the technology variables examined may be so closely connected to each other that it is somewhat difficult to find out their separate effects.

6. Concluding remarks

Spillover estimates based on two different weighting schemes (proximity measures) on one hand, and on flows and stocks of R&D on the other, are presented in the paper. The proximity measures are based on correlations and the overlap of R&D, respectively. The spillover estimates concern the Finnish business sector and the years 1981, 1985, 1989 and 1993.

When calculating spillovers using flows and the correlation-based method, the total spillover estimates were in general found to be substantially lower when more aggregated data were used. This implies that a lot of useful information of the technological connections between firms and industries is lost when more aggregated data are used.

The new overlap-based weighting scheme is found to produce larger estimates for spillovers, and to take inter-industry links based on common research interests better into account. This result applies both to flow measures and stock measures of spillovers. Qualitatively the two weighting schemes produce fairly similar results, in that in general the same industries are among the most important spillover sources for other industries. Such industries include machinery and electrical products, and also a few service sectors ('other services', and trade, hotels and restaurants). The most important source industries have mainly remained the same, but their rank varies over the years.

The econometric analysis performed implies that among several technology inputs examined, the strongest effect on total factor productivity comes from the firms' own R&D. There are also clear indications that spillovers received from other industries may have a positive effect, but on the basis of this study this conclusion is not very strong. Qualitatively, the two alternative stock-based spillover measures produced fairly similar results also in the econometric analysis.

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Appendix 1: Numerical examples of distance measures

This Appendix contains numerical simplified examples of how the two measures of technological distance (or in fact, closeness) used in the paper to calculate spillovers behave when two industries have more or less common research areas. For simplicity, assume that there are five product areas among which the firms in the industries can divide their R&D expenditures. To begin with, these expenditures are normalized so that their sum is one, that is, the research input vectors shown below contain the shares in each industry's total research expenditures that are invested in each product group. We distinguish between six different cases. The following table shows the research input vectors for each of the two industries and the corresponding distance measures, that is, correlations and the degree of overlap.

Case	Industry A	Industry B	Correlation	Overlap
1	(0, 0.2, 0.2, 0.2, 0.4)	(0.2, 0.4, 0.2, 0, 0.2)	0	0.6
2	(0, 0.2, 0.3, 0.5, 0)	(0, 0.2, 0.3, 0.5, 0)	1	1
3	(0, 0.2, 0.3, 0.5, 0)	(0, 0, 0.1, 0.4, 0.5)	0.15	0.5
4	(0, 0.2, 0.2, 0.2, 0.4)	(0.4, 0.2, 0.2, 0.2, 0)	-1	0.6
5	(0, 0, 0.1, 0.4, 0.5)	(0.3, 0.3, 0.2, 0, 0)	-0.96	0.1
6	(0.6, 0.4, 0, 0, 0)	(0, 0, 0.2, 0.3, 0.5)	-0.83	0

In cases 1, 2 and 4 the two industries concerned have common research interests in three product groups. However, in cases 1 and 4 the correlations are zero and -1 respectively, which according to method of calculation used implies that there are no spillovers between the industries. In case 3 there are two common product groups and the correlation is positive but low. Finally, cases 5 and 6 are examples of situations where a high negative correlation may be due to different reasons: In case 5 the industries have one common research area but in case 6 there is none.

Thus, of the above six cases, four would not be included in the spillover calculations when using the correlations as measures of technological closeness. In contrast, the overlap measure leaves out, as seems correct, only the case where the industries concerned have no common research interests at all.

Appendix 2: Data

R&D data by industries performing the research and divided by product groups which the research concerned were used for the years 1981, 1985, 1989 and 1993. These data have been obtained from Statistics Finland. The level of aggregation when making comparisons across years is affected by slightly varying industry and product group classifications used in the years concerned. In addition, secrecy rules prevent in some cases getting data for part of the firms or plants otherwise than grouped in some larger industry classes. Thus, in the data for 1985 a large number of the units concerned were in larger industry groups in the machinery and equipment industries. The 1993 data differs from the published data in the sense that it was not possible to assess the R&D expenditures of the total business sector for the more detailed level, so the figures represent the sample of firms surveyed instead of the total business sector.

On the basis of the data available, an effort was made to make the industry classifications as similar as possible across the four years studied. This meant that several of the industries had to be aggregated in order to get approximately the same content for each industry class. Thus, starting from data tables with 32 to 54 industries and 32 to 56 product groups, depending on the year studied, this aggregation procedure led to data tables with 24 industries and 32 product groups for each year concerned. The spillovers were calculated for all industries in the business sector; of the 24 industries covered 17 are manufacturing sectors.

The technology intensity study by Virtaharju and Åkerblom (1993) contains estimates of technology intensities concerning direct (own-R&D-based) and embodied technology for 1981, 1985 and 1989, and all of these are used in this study. Virtaharju and Åkerblom used the stock concept both for the technology consisting of the firms' own R&D (called direct technology stock) and for the technology embodied in investment goods. The additions to the technology stock of each industry consist of weighted (binomial weights) annual R&D expenditures of firms. For estimating the technology embodied in intermediate and investment goods, input-output, national accounts and R&D data were used.

The technology flow from sector i to sector j is based on the technology intensity of sector i and a modified total domestic requirements coefficient that gives the purchase of intermediate or investment goods from sector i to sector j as per units of its output. The estimates of the technology embodied in imported goods used in production were based on data on the R&D intensities of the most central countries importing to Finland (Sweden, Germany, France, United Kingdom, Japan, United States). The stock measures for technology embodied in imported capital goods were based on the assumption that for those countries, the relation between the flow-based R&D intensities and stock-based intensities are the same as in Finland (for further details, see Virtaharju and Åkerblom 1993).

The spillover estimates in this study made by the author concern the years 1981, 1985, 1989, and 1993. The first set of estimates is based on the methodology used by Goto and Suzuki (1989). All pairwise correlations between the distribution vectors of the industries' R&D expenditures by product groups were used in calculating the spillovers. The spillover received by industry i is a weighted sum of other industries' R&D expenditures, where the above-mentioned correlations between industry i and each relevant industry are used as weights. The second set of spillover estimates uses a similar procedure of weighting the other industries' R&D expenditures, but instead of correlations uses the measure of overlap of R&D proposed in the text (see also Appendix 1). The third and the fourth sets of spillovers estimated were calculated otherwise similarly as the first and second ones, but the weights (correlations and overlap of R&D, respectively) were used to weight the R&D stocks (instead of current R&D expenditures) of the industries sending the spillovers.

The data on total factor productivity (TFP) for the period 1981 to 1993 were obtained from Statistics Finland for 22 manufacturing industries. These data are based on national accounts and related capital stock estimates. Labour input was measured by hours worked and capital input by net capital stocks. The cost shares for labour and capital were used in weighting the labour and capital input changes when calculating the TFP changes. Of the 22 industries, food, beverages and tobacco were combined into one industry and textiles and clothing likewise into one industry, so that the final number of industries in the regressions is 20. To obtain a comparable industry classification for the technology variables, they were aggregated where necessary, by using the corresponding values for gross output as weights.

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