Analyzing R&D Multipliers

Erik Dietzenbacher and Bart Los

University of Groningen
Faculty of Economics/SOM Research Institute
P.O. Box 800
NL-9700 AV Groningen
The Netherlands
e-mail: e.dietzenbacher@eco.rug.nl; b.los@eco.rug.nl

Abstract. Traditional R&D multipliers in an input-output context are of a backward nature and reflect the amount of R&D expenditures embodied in one dollar of an industry's final output. From a policy perspective, such multipliers indicate the additional R&D induced by creating additional final output. This paper suggests to adopt also an alternative viewpoint, taking the R&D expenditures as a starting-point. These forward multipliers measure the share of a dollar R&D in industry *i* that is embodied in the final output categories (e.g. exports). From a policy perspective, this allows for measuring the effects of additional R&D expenses in a given industry. It is shown that the two multipliers represent two faces of the same phenomenon. They are empirically applied for OECD countries.

Keywords. Multipliers; R&D expenditures; Product-embodied diffusion

1. Introduction

Innovation is nowadays viewed as one of the major sources of economic growth. Although the principal invention is of crucial importance in this respect, in particular the capacity to exploit its potential economically and opportunities for widespread diffusion throughout the economy are the real driving forces.[1] The diffusion of innovations and the knowledge generated along the way of its realization encompasses two types. Disembodied diffusion is related to the transmission of ideas, knowledge, expertise, etcetera. In an interindustry context, this type of diffusion is typically studied by means of analyzing patent-information flow matrices or patent citation matrices (see Verspagen, 1997), or technological proximity matrices (see Jaffe, 1986, Goto and Suzuki, 1989). With regard to product-embodied diffusion, it is assumed that an initial innovation is embodied in the industry's product, which may involve a completely new commodity or just a quality increase. Since other industries use this product as an intermediate input, the innovation becomes embodied in all products, including those used for final demand purposes (e.g. consumption, investment and exports). This type of interindustry diffusion is usually analyzed by using input-output tables and/or investment flow matrices (see e.g. Terleckyj, 1980, Griliches and Lichtenberg, 1984, Sakurai *et al*., 1997, Papaconstantinou *et al*., 1998, Greenhalgh and Gregory, 2000).[2]

In this paper we study product-embodied diffusion of R&D expenditures. In doing so, it is assumed that R&D expenditures can be taken as a proxy for technological progress involving improvements in the product quality and/or the production process. Another assumption we need to make is that intermediate goods and services act as carriers of the

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1 Recently, increasing attention has been paid to the economic consequences of so-called 'General Purpose Technologies' (GPTs). GPTs are innovations which drastically change modes of operation in a wide range of industries. Examples of GPTs are the steam engine, electricity and the computer. See the contributions in Helpman (1998) for a garden variety of investigations into growth effects of GPTs.

2 See Griliches (1992) and Los (1999) for more elaborate surveys and classifications of interindustry technology diffusion measures.

improved technology. Interindustry transactions then transmit such improvements across industries. In this respect it is assumed that the R&D embodiment in a product is the same for each of its purchasers.

In studying the diffusion of R&D we answer two questions. First, how much R&D is embodied in the final output (e.g. for consumption, investments, or exports) of industry j? Second, how much of the R&D expenditures of industry i is embodied in each type of final output? The first question falls in a category of problems which – in an input-output context – are typically approached by means of backward linkages and multipliers as obtained from the input coefficients (see e.g. Miller and Blair, 1985). We show that the second question can be answered by means of forward multipliers obtained from the so-called output coefficients. The concepts of backward and forward multipliers are in the input-output literature generally viewed as measuring two essentially different things. It turns out, however, that these multipliers measure exactly the same phenomenon but from two alternative viewpoints, as was already suggested by the two questions above. The link between the two multipliers is provided by a single matrix with the R&D embodiment for vertically integrated industries (see e.g. Pasinetti, 1973, Heimler, 1991). The backward multipliers are obtained from its column sums, the forward multipliers from its row sums.

The two questions in this paper have a direct relevance for policy issues. The backward multipliers may, for example, be used to analyze the effects on the industrial R&D expenditures when the demand for exports changes. Also the government may wish to stimulate R&D by giving an impulse in the form of creating extra final demand for the output of some industry. Backward multipliers pinpoint the industry for which the total effects will be the largest. The policy implications of the forward multipliers start at the other end, that is, with a given amount of R&D expenditures. For example, the government may decide to subsidize R&D in a certain industry aiming at a competitive advantage over other countries. The forward multipliers state how much of an additional dollar R&D invested in industry i ends up in the exports. Increasing the R&D expenditures in the industry with the largest multiplier thus yields the largest effects.

The methodology is discussed in the next section. Section 3 presents the empirical results for the United States 1977-1990, a period in which R&D intensities increased strongly in a number of industries.

2. Methodology

2.1. Backward multipliers

Consider an input-output table and let **Z** denote the matrix of intermediate deliveries, **x** the vector of (gross) outputs, and **y** the vector of final demands (or final outputs). Final demands consist of several types, so that **y** = **c** + **i** + **e** - **m**, where **c** denotes consumption (private and government), **i** denotes gross fixed capital formation, **e** denotes the exports, and **m** denotes the competitive imports.

The matrix of input coefficients is obtained by dividing the columns of the intermediate deliveries by the gross outputs. That is,

$$\mathbf{A} = \mathbf{Z}\hat{\mathbf{x}}^{-1} \tag{1}$$

where $\hat{\mathbf{x}}$ denotes the diagonal matrix with the elements of the vector $\mathbf{x}$ on its main diagonal. The typical element $a_{ij} = z_{ij} / x_j$ denotes amount of input i required per dollar of output of product j. The accounting equations are given by $\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{y}$, which yields $\mathbf{x} = \mathbf{L}\mathbf{y}$, where

$$\mathbf{L} \equiv (\mathbf{I} - \mathbf{A})^{-1} \tag{2}$$

denotes the Leontief inverse. Its typical element l_{ij} denotes the output of industry *i* that is required (directly and indirectly) per dollar of final demand for product *j*.

Let the vector **r** denote the R&D expenditures and let the intensities be denoted by $\rho_i = r_i / x_i$, or

$$\rho' = \mathbf{r}'\hat{\mathbf{x}}^{-1} \tag{3}$$

where an accent is used to denote transposition. To satisfy one dollar of final demand for product *j*, industry *i* produces l_{ij} which embodies $\rho_i l_{ij}$ of R&D. Summation over industries *i* yields $\beta_j = \Sigma_i \rho_i l_{ij}$ as the total amount of R&D embodied per dollar of final demand *j*. In vector notation, the backward multipliers are obtained as

$$\beta' = \rho'\mathbf{L} \tag{4}$$

2.2. Forward multipliers

The backward multiplier reflects the direct and indirect embodiment of R&D per dollar of final demand for product *j*. That is, the R&D embodied directly in y_j and, indirectly, in the inputs necessary to produce y_j and in the inputs required for producing the inputs, and so forth. This relates to the question: "Where do the inputs come from?" which is backward in its nature. Forward multipliers are rooted in the opposite question, i.e. "Where do the outputs go to?"[3] This is reflected by using the output coefficients

$$\mathbf{B} = \hat{\mathbf{x}}^{-1}\mathbf{Z} \tag{5}$$

[3] These two questions to distinguish between backward and forward dependencies were put forward in Augustinovics (1970).

Its typical element $b_{ij} = z_{ij} / x_i$ denotes the share of the output of industry *i* that is sold to industry *j*.

Output coefficients and the inverse matrix

$$\mathbf{G} \equiv (\mathbf{I} - \mathbf{B})^{-1} \tag{6}$$

have been widely used for measuring forward linkages (see Beyers, 1976, and Jones, 1976, for the first contributions in this respect). Usually the so-called supply-driven input-output model of Ghosh (1958) is employed as the underlying model, in the same way as the traditional Leontief model is used for backward linkages. For a long time, however, this supply-driven model has been viewed as highly implausible (see Oosterhaven, 1988, for most convincing arguments). Recently, Dietzenbacher (1997) has shown that all the implausibilities vanish, once the suply-driven model is interpreted as a price model instead of as a quantity model (which had been the common viewpoint).

It was shown that the supply-driven model is a rewritten form of the Leontief price model. But where Leontief's price model calculates the new (cost-)price of a product from an exogenous change in the price of some primary factor, the supply-driven model calculates the new production costs of an industry for a given change in the primary costs. As a consequence, the typical element g_{ij} denotes the additional production costs in industry *j* that are made (directly and indirectly) when the primary costs in industry *i* are increased by one dollar. The reasoning is similar to that in the previous subsection. When the primary costs in industry *i* increase by one dollar, the production costs (and hence the output value) in industry *i* increase by one dollar, which is the direct effect. Since a fraction b_{ij} of the output is sold to industry *j*, the production costs in industry *j* increase by b_{ij}. In its turn, industry *j* passes a part (viz. b_{jk}) of this increase on to industry *k*, yielding an increase of $b_j b_{jk}$ in industry *k*, and so forth. All direct and indirect effects together yield $\mathbf{I} + \mathbf{B} + \mathbf{B}^2 + ... = \mathbf{G}$.

Define export intensities as

$$\boldsymbol{\varepsilon} = \hat{\mathbf{x}}^{-1}\mathbf{e} \tag{7}$$

Its typical element $\varepsilon_j = e_j / x_j$ denotes the fraction of output that is exported. Consumption and investment intensities are defined analogously as $\gamma_j = c_j / x_j$ and $\iota_j = i_j / x_j$. Considering R&D expenditures as costs that are passed on to the buyers of the product, a dollar increase of the R&D in industry *i* implies an increase of g_j in the output value of industry *j* and an increase of $g_{ij}\varepsilon_j$ in the value of exports of product *j*. So $g_{ij}\varepsilon_j$ indicates how much of the dollar increase of R&D in industry *i* is embodied in the exports of industry *j*. The total embodiment of a dollar industry *i*'s R&D expenditures in all exports is given by the forward multiplier $\varphi_i^{\exp} = \Sigma_j g_{ij}\varepsilon_j$. In the same way we have $\varphi_i^{con} = \Sigma_j g_{ij}\gamma_j$ and $\varphi_i^{inv} = \Sigma_j g_{ij}\iota_j$. That is,

$$\boldsymbol{\varphi}^{exp} = \mathbf{G}\boldsymbol{\varepsilon}; \boldsymbol{\varphi}^{con} = \mathbf{G}\boldsymbol{\gamma}; \boldsymbol{\varphi}^{inv} = \mathbf{G}\boldsymbol{\iota} \tag{8}$$

2.3. The link between the multipliers

In the input-output literature backward and forward multipliers are generally viewed as two separate approaches. In this subsection we show that, for the present purpose, the multipliers can be linked to each other. It turns out that they represent the two faces of the same phenomenon.

First, we consider the backward multipliers by taking vertically integrated industries into account (see Pasinetti, 1973, Heimler, 1991). The production of the vertically integrated industry *j* is the production required to satisfy the final demand for product *j*. Let us consider the final demand component exports. The matrix of production for the vertically integrated industries yields $\mathbf{L}\hat{\mathbf{e}}$. Its typical element $l_{ij}e_j$ denotes the production in industry i required for the exports of industry j. Next we define the embodiment matrix $\mathbf{H}$ as

$$\mathbf{H} = \hat{\boldsymbol{\rho}}\mathbf{L}\hat{\mathbf{e}} \tag{9}$$

The typical element $h_{ij} = \rho_i l_{ij} e_j$ denotes the amount of industry i's R&D expenditures embodied in the exports of industry j. The matrix $\mathbf{H}$ has recently been used for studying national innovation systems (see Drejer, 1998, Düring and Schnabl, 1998).[4]

The same type of matrix can be constructed by analogy for the case of forward multipliers. The element g_{ij} denotes the share of a dollar R&D in industry i that is embodied in the output value of industry j. Hence the typical element $r_i g_{ij}$ of the matrix $\hat{\mathbf{r}}\mathbf{G}$ denotes the embodiment of industry i's R&D expenditures in the output value of industry j. Now define

$$\tilde{\mathbf{H}} = \hat{\mathbf{r}}\mathbf{G}\hat{\boldsymbol{\varepsilon}} \tag{10}$$

Its typical element $\tilde{h}_{ij} = r_i g_{ij} \varepsilon_j$ denotes again the amount of industry i's R&D expenditures embodied in the exports of industry j. That is, $\tilde{h}_{ij}$ has the same interpretation as h_{ij}.

Next we show that indeed $\tilde{\mathbf{H}}$ equals $\mathbf{H}$. Observe that from (1) and (5) it follows that $\mathbf{B} = \hat{\mathbf{x}}^{-1}\mathbf{A}\hat{\mathbf{x}}$ and thus $\mathbf{G} = \hat{\mathbf{x}}^{-1}\mathbf{L}\hat{\mathbf{x}}$, using (2) and (6). Then yields

$$\tilde{\mathbf{H}} = \hat{\mathbf{r}}\mathbf{G}\hat{\boldsymbol{\varepsilon}} = \hat{\mathbf{r}}\hat{\mathbf{x}}^{-1}\mathbf{L}\hat{\mathbf{x}}\hat{\boldsymbol{\varepsilon}} = \hat{\boldsymbol{\rho}}\mathbf{L}\hat{\mathbf{e}} = \mathbf{H},$$

using (3) and (7).

[4] See Lundvall (1992), Patel and Pavitt (1994) or de Bresson (1996) for national innovation systems.

Both the backward and the forward multipliers are readily obtained from the embodiment matrix **H**. the column sums of **H** denote the total amount of R&D embodied in the exports of industry *j*. Dividing this number by e_j yields the backward multiplier. The row sums of **H** denote the amount of industry *i*'s R&D as embodied in all industries' exports. Dividing by r_i gives the forward multiplier.

2.4. Separating the induced effects

Next to the total amount of R&D embodied in the exports of industry *j*, it is also relevant to know how much of this embodied R&D originates from other industries.[5] Consider the embodiment matrix **H**. It is clear that all off-diagonal elements (i.e. h_j with $i \neq j$) reflect induced effects. Columnwise, $\Sigma_{i \neq j} h_{ij}$ denotes the amount of R&D by other industries embodied in the exports of industry *j*. Rowwise, $\Sigma_{j \neq i} h_{ij}$ denotes the amount of industry *i*'s R&D embodied in the exports of other industries.

The diagonal elements h_{ii}, however, also comprise induced induced effects. That is, if industry *j* uses inputs from industry *i, i*'s R&D is embodied in *j*'s products, reflecting an indirect R&D flow from *i* to *j*. Now, if in its turn industry *i* uses also inputs from *j*, part of this indirect embodiment flows back from *j* to *i*. This is an induced effect which is also known as an 'interindustry feedback effect'. All such induced effects can be singled out by asking what the result would have been if no induced effects had been taken into account. In this case, each industry would have depended only on itself. All intermediate deliveries between different industries are hypothetically set to zero.[6] For this hypothetical situation the input matrix becomes $\hat{\mathbf{d}}_{\mathbf{A}}$, where $\mathbf{d}_{\mathbf{A}}$ is the main diagonal of the original matrix **A**, i.e. $\mathbf{d}_{\mathbf{A}} = (a_{11},...,a_{nn})'$.

[5] In the input-output literature, this type of indirect effects are often called 'spillovers'. We will not adopt this terminology, however, since in studies of the productivity of R&D the concept of spillovers relates to real externalities: quality improvements or knowledge for which the 'receiver' does not pay the producer. In our context, we do not discriminate between embodied R&D for which is paid and embodied R&D for which is not paid.

[6] One possibility to underpin this hypothetical case is to assume that all inputs from other industries are now purchased as non-competitive imports.

The corresponding embodiment matrix becomes $\overline{\mathbf{H}} = \hat{\rho}(\mathbf{I} - \hat{\mathbf{d}}_{\mathbf{A}})^{-1}\hat{\mathbf{e}}$, which is a diagonal matrix. The typical element $\overline{h}_{ii} = \rho_i e_i /(1 - a_{ii})$ denotes the intra-industry component of the embodiment. The difference $\mathbf{H} - \overline{\mathbf{H}}$ reflects the induced components.

3. Empirical results

This section contains some empirical evidence on the major producers and receivers of embodied R&D, as indicated by the backward and forward multipliers discussed in the previous sections. To this end, we investigated the case of the United States for the years 1977, 1982, 1985 and 1990. For these years, U.S. input-output tables are available in the OECD Input-Output Database (OECD, 1995). The main advantage of these tables is that their industry classification (see Appendix A) is identical to the classification used in the OECD Analytical Business Enterprise R&D (ANBERD) database (OECD, 1997). Hence, the figures on R&D expenditures by industry as contained in ANBERD could easily be used to calculate R&D multipliers. Because the ANBERD data are expressed in current prices, we decided to use the input-output tables in current prices as well.[7] The rows and columns for “producers of government services” and “other producers” were deleted from the intermediate input part of the tables, since they did not use any intermediate inputs. Implicitly, their intermediary deliveries (all very small) were shifted to the value added rows. Our analysis is necessarily limited to the effects of R&D carried out by manufacturing industries, since ANBERD does not offer data on R&D in primary industries and services, except at a very aggregated level (total R&D in services). Inclusion of those data would not fit our aim of an explicit interindustry analysis of embodied R&D flows.

[7] We used the tables with codes USDIOC for intermediate inputs, exports, consumption and investment (private gross fixed capital formation), and took the gross outputs by industry from the USTIOC tables in OECD (1995).

Table 1 presents the backward R&D multipliers. In general, the total backward multipliers appear to have increased over time, which is in line with the increasing R&D intensities in manufacturing as reported in, among others, Los (1999, Ch.1). A strange drop in 1985 is found for “electrical machinery” (17), which may be due to classification problems for highly diversified firms. The well-known high-tech industries “drugs” (8), “office machinery” (16), “radio, TV, and communication” (18) and “aircraft” (21) had the highest backward R&D linkages, whereas the backward linkages for low-tech industries and non-manufacturing industries were very small. These results are not surprising, since the diagonal elements in the Leontief inverse are always large compared to the typical off-diagonal element.

INSERT TABLE 1 ABOUT HERE

The rightmost panel of Table 1 shows that most of the variation for the total backward R&D multipliers is indeed due to the intra-industry effect. Nevertheless, the highest induced multipliers are found for the same industries. Only “chemicals” (7), “drugs” (8) and, to a lesser extent, “radio, TV, and communication” (18) lose their leading position. “Plastics” (10) and “other transport” (19) rank substantially higher when induced effects are the focus of the analysis, which indicates that the production of these commodities requires relatively much R&D-intensive intermediate inputs produced by other industries.

INSERT TABLE 2 ABOUT HERE

Table 2 presents the forward multipliers for the U.S. industries with respect to exports. Contrary to their backward multipliers, the forward multipliers for the non-manufacturing industries are sometimes rather large, in particular for the primary industries “agriculture”(1) and “mining” (2). As opposed to many services industries, their outputs can be traded well, so *if* the primary industries would do some (registered) R&D, they would affect the R&D embodied in exports to a significant extent: of each R&D dollar, about 17 cents would ultimately be exported. The highest total forward multipliers are found for “office machinery” (16) and “aircraft” (21). This time, their high-tech nature cannot be held responsible for their high ranking. Apparently, these U.S. industries produce relatively much for foreign customers, or for other industries with a high export share. A quick glance at the right panel of Table 2 immediately shows that the high forward R&D multipliers with respect to exports for these industries vanish as soon as only induced effects are taken into account. In that case, the metals-related industries like “iron and steel” (12) and “non-ferrous metals” (13) turn out to score highest: large parts of their relatively large total forward multipliers were due to deliveries to industries with high export shares (e.g. office machinery and aircraft), or the suppliers of these industries.

INSERT TABLE 3 ABOUT HERE

Table 3 shows the forward multipliers with respect to consumption.[8] Since by far the largest part of U.S. final demand deliveries are used for consumption purposes, these multipliers are generally very high. Only for industries which mainly produce investment export goods (“machinery”, 15, and “office machinery”, 16), relatively low multipliers are found. Of every (hypothetical) R&D dollar in “food” (3), “restaurants” (27), “financial services” (30) and “personal services” (32), more than 90 cents would be embodied in consumption goods. When only induced effects are considered, the primary industries appear to be most important.

[8] Consumption comprises both private consumption and government consumption.

INSERT TABLE 4 ABOUT HERE

Finally, the forward multipliers with respect to investment are documented in Table 4.[9] Some paradoxical results are found in this table. For 1977, 1982 and 1990, the indirect and induced multipliers appear to be higher than the total multipliers for a number of industries, which is impossible under the assumption of nonnegative investment. A closer look at the underlying data shows that investment demand (in terms of gross fixed capital formation) for the commodities produced by these industries was negative indeed. Therefore, not too much attention should be paid to the differences between the left and the right panels of Table 4. Clearly, heavy manufacturing industries have the highest forward R&D multipliers with respect to deliveries of capital goods. The highest value, however, is found for “construction” (25).

4. Summary and Conclusions

In this paper we presented a unified framework to analyze interindustry flows of embodied R&D. The traditional analysis of backward R&D multipliers, which indicate how much R&D is involved in the production of a unit of final demand for an industry’s product, was complemented with an analysis of forward R&D multipliers, which indicate how much of the R&D spent in an industry is embodied in various categories of final demand. We showed that both types of multipliers can be derived from one matrix, which has been used by others to study national systems of innovation. Finally, we presented an

[9] We did not include changes in stocks in our multiplier analysis, because we prefer to consider multipliers with respect to capital goods rather than with respect to stocked intermediate inputs.

empirical illustration for the United States between 1977 and 1990, using mutually compatible input-output tables and R&D data compiled by the OECD.

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Appendix A: Industry classification

	Description	ISIC rev. 2
1	Agriculture, forestry and fishing	1
2	Mining and quarrying	2
3	Food, beverages and tobacco	31
4	Textiles, apparel and leather	32
5	Wood products and furniture	33
6	Paper, paper products and printing	34
7	Industrial chemicals	351+352-3522
8	Drugs and medicines	3522
9	Petroleum and coal products	353+354
10	Rubber and plastic products	355+356
11	Non-metallic mineral products	36
12	Iron and steel	371
13	Non-ferrous metals	372
14	Metal products	381
15	Non-electrical machinery	382-3825
16	Office and computing machinery	3825
17	Electrical apparatus	383-3832
18	Radio, TV and communication equipment	3832
19	Shipbuilding and other transport	3841+3842+3844+3849
20	Motor vehicles	3843
21	Aircraft	3845
22	Professional goods	385
23	Other manufacturing	39
24	Electricity, gas and water	4
25	Construction	5
26	Wholesale and retail trade	61+62
27	Restaurants and hotels	63
28	Transport and storage	71
29	Communication	72
30	Finance and insurance	81+82
31	Real estate and business services	83
32	Community, social and personal services	9

* "Shipbuilding" is aggregated with "other transport" since no separate R&D data are available for these industries.

Table 1: Backward R&D multipliers, U.S., various years

	Total backward multipliers (x100)				Induced backward multipliers (x100)			
	1977	1982	1985	1990	1977	1982	1985	1990
1 AGRI	0.48	0.57	0.61	0.52	0.48	0.57	0.61	0.52
2 MING	0.28	0.22	0.23	0.33	0.28	0.22	0.23	0.33
3 FOOD	0.66	0.83	0.94	0.85	0.41	0.52	0.52	0.44
4 TEXT	0.75	1.00	1.24	1.00	0.62	0.82	0.99	0.71
5 WOOD	0.72	0.89	0.80	0.72	0.39	0.51	0.55	0.44
6 PAPE	0.82	0.96	0.86	0.88	0.40	0.52	0.50	0.42
7 CHEM	3.15	4.19	4.68	4.06	0.40	0.43	0.86	0.38
8 DRUG	9.24	12.34	13.35	14.33	0.44	0.41	0.68	0.42
9 OIL	1.27	1.37	1.61	1.78	0.28	0.25	0.32	0.37
10 PLAS	2.23	2.61	2.60	2.35	0.93	1.15	1.58	1.13
11 NFMP	1.32	1.80	2.20	1.52	0.39	0.53	0.48	0.42
12 IRON	1.05	1.86	1.09	0.99	0.51	0.62	0.49	0.68
13 NFMT	1.50	1.92	1.74	1.88	0.60	0.81	0.59	0.78
14 METP	1.13	1.39	1.39	1.37	0.60	0.76	0.67	0.63
15 MACH	2.00	2.67	2.42	2.36	0.73	0.83	0.82	0.75
16 OFFI	21.22	18.21	21.48	24.28	1.53	1.69	2.12	1.44
17 ELEC	7.19	7.12	2.97	5.49	0.67	0.94	0.90	1.04
18 RTVC	9.95	11.36	14.39	11.11	0.60	0.77	1.00	0.63
19 OTHT	1.56	1.79	2.50	2.67	0.94	0.99	1.05	1.13
20 MOTO	4.43	6.06	5.22	6.59	0.86	1.00	0.87	0.85
21 AIRC	27.49	26.04	32.45	21.14	1.23	1.13	1.37	1.13
22 INST	6.77	9.38	10.34	7.29	0.91	1.16	1.28	1.03
23 OTHM	1.93	2.85	2.15	2.39	0.57	0.85	0.69	0.74
24 UTIL	0.30	0.32	0.27	0.31	0.30	0.32	0.27	0.31
25 CONS	0.70	0.78	0.74	0.57	0.70	0.78	0.74	0.57
26 TRAD	0.12	0.15	0.15	0.15	0.12	0.15	0.15	0.15
27 REST	0.29	0.35	0.33	0.27	0.29	0.35	0.33	0.27
28 TRAN	0.43	0.55	0.50	0.40	0.43	0.55	0.50	0.40
29 COMM	0.32	0.45	0.38	0.28	0.32	0.45	0.38	0.28
30 FINS	0.12	0.22	0.13	0.12	0.12	0.22	0.13	0.12
31 BUSS	0.13	0.14	0.11	0.13	0.13	0.14	0.11	0.13
32 PERS	0.50	0.59	0.54	0.50	0.50	0.59	0.54	0.50

Table 2: Forward R&D multipliers, U.S. exports, various years

	Total forward multipliers (x100)				Induced forward multipliers (x100)			
	1977	1982	1985	1990	1977	1982	1985	1990
1 AGRI	18.22	18.99	14.65	17.66	4.61	4.71	3.98	6.18
2 MING	12.39	13.98	12.82	15.24	7.78	9.18	8.46	10.95
3 FOOD	6.97	6.94	5.97	9.03	1.73	1.50	1.20	1.65
4 TEXT	6.83	6.97	6.29	11.83	1.96	1.88	1.98	3.19
5 WOOD	5.86	7.49	6.83	10.41	2.34	2.93	2.84	3.00
6 PAPE	8.69	9.35	7.57	16.00	4.11	4.53	3.94	5.61
7 CHEM	17.44	21.31	18.95	26.40	6.80	7.34	5.52	9.32
8 DRUG	11.92	11.33	15.57	11.38	1.75	1.42	5.50	1.74
9 OIL	8.08	11.10	10.62	12.55	4.64	5.66	4.32	5.01
10 PLAS	12.24	14.00	13.41	20.35	8.03	9.30	8.76	11.83
11 NFMP	8.34	9.54	8.17	12.91	4.66	5.12	4.31	6.33
12 IRON	15.68	19.01	14.21	30.57	12.08	14.73	11.66	21.41
13 NFMT	17.47	23.80	19.38	37.21	11.52	13.76	11.52	19.15
14 METP	10.55	12.32	9.50	26.53	5.91	6.93	5.44	10.18
15 MACH	18.85	22.87	16.14	24.07	3.15	3.72	3.34	5.08
16 OFFI	25.58	26.25	29.43	45.23	0.90	0.78	0.54	1.09
17 ELEC	15.86	18.90	16.60	28.93	5.20	6.06	5.20	8.77
18 RTVC	18.02	18.10	17.17	32.26	3.90	3.76	3.67	6.24
19 OTHT	6.54	9.82	6.42	13.07	1.13	1.54	1.30	1.63
20 MOTO	13.60	15.26	13.44	23.32	0.75	0.78	0.75	1.16
21 AIRC	29.67	27.53	22.36	37.74	0.75	0.68	1.17	0.92
22 INST	16.82	19.16	16.72	18.94	2.12	2.46	2.25	4.38
23 OTHM	8.53	8.88	8.54	13.90	1.52	1.50	1.37	2.00
24 UTIL	4.97	5.96	4.84	6.19	4.68	5.80	4.72	5.94
25 CONS	1.49	1.44	0.92	2.14	1.48	1.42	0.90	2.11
26 TRAD	5.79	6.93	5.25	6.91	2.54	3.13	2.20	3.17
27 REST	2.28	2.66	2.33	3.25	2.18	2.43	2.18	3.09
28 TRAN	12.58	15.84	11.19	20.35	4.49	5.25	3.61	5.76
29 COMM	4.70	5.45	4.48	6.38	3.11	4.09	3.15	4.43
30 FINS	3.06	6.11	5.33	6.57	2.44	2.84	2.19	2.30
31 BUSS	4.55	4.91	4.09	6.27	2.99	3.62	3.06	4.54
32 PERS	2.18	2.12	2.61	2.43	1.41	1.44	1.75	1.39

Table 3: Forward R&D multipliers, U.S. consumption, various years

	Total forward multipliers (x100)				Induced forward multipliers (x100)			
	1977	1982	1985	1990	1977	1982	1985	1990
1 AGRI	75.84	78.98	82.01	77.76	59.81	60.95	59.78	59.35
2 MING	70.08	75.28	75.72	63.54	66.28	71.99	71.99	59.68
3 FOOD	90.71	91.80	92.33	89.68	20.62	20.54	19.85	19.16
4 TEXT	80.26	87.66	85.43	78.32	13.59	11.83	14.49	15.17
5 WOOD	52.25	56.05	53.87	46.70	28.40	27.94	30.91	23.56
6 PAPE	81.55	83.52	84.10	79.89	42.24	45.53	44.58	44.76
7 CHEM	65.92	68.24	69.95	62.58	45.69	47.09	42.51	40.98
8 DRUG	82.91	85.60	73.71	86.20	29.03	22.74	40.88	27.20
9 OIL	78.11	80.01	79.51	76.98	36.26	36.50	37.47	30.56
10 PLAS	63.17	67.95	67.54	61.75	46.13	51.99	50.44	48.58
11 NFMP	50.79	51.57	50.03	50.11	44.50	44.54	41.95	42.13
12 IRON	46.06	48.43	47.96	41.12	43.26	46.01	46.85	42.23
13 NFMT	44.80	51.63	46.55	37.22	41.77	43.52	43.77	38.44
14 METP	49.21	51.04	49.14	45.59	39.41	40.92	37.51	44.16
15 MACH	28.81	31.54	36.67	28.46	18.15	20.56	19.83	18.06
16 OFFI	22.51	18.28	18.93	15.47	8.65	6.48	4.23	4.23
17 ELEC	44.90	45.99	44.14	40.89	25.14	26.21	25.34	26.88
18 RTVC	44.02	41.98	49.27	35.99	15.18	14.69	12.95	15.36
19 OTHT	48.17	55.54	70.09	63.53	6.85	7.89	9.38	7.11
20 MOTO	54.54	56.87	52.24	49.30	8.72	12.95	9.73	9.90
21 AIRC	56.44	53.09	69.75	49.74	3.73	2.89	5.70	2.80
22 INST	42.79	42.97	44.46	39.97	18.64	18.60	19.65	17.88
23 OTHM	76.84	74.65	80.97	74.07	17.46	16.34	16.31	17.45
24 UTIL	85.81	86.24	89.97	87.73	38.55	39.54	44.00	36.18
25 CONS	38.68	34.98	33.55	39.99	17.51	16.27	12.78	18.89
26 TRAD	78.57	78.88	80.90	81.58	18.27	18.94	17.29	17.19
27 REST	93.38	93.76	93.90	93.63	20.32	22.58	20.49	20.66
28 TRAN	73.41	73.14	70.08	70.10	37.21	38.94	33.71	35.29
29 COMM	82.90	83.55	88.72	83.75	38.48	39.75	40.77	42.14
30 FINS	91.25	89.28	89.24	90.44	24.25	24.10	23.35	17.51
31 BUSS	85.24	85.54	86.60	84.70	31.01	33.37	34.84	37.49
32 PERS	94.54	95.06	94.83	95.74	12.56	11.88	16.80	9.21

Table 4: Forward R&D multipliers, U.S. investment, various years

	Total forward multipliers (x100)				Induced forward multipliers (x100)			
	1977	1982	1985	1990	1977	1982	1985	1990
1 AGRI	3.94	3.32	6.20	3.81	3.92	3.28	5.65	3.78
2 MING	13.66	11.58	11.57	19.24	13.22	11.18	11.14	9.42
3 FOOD	0.98	0.87	1.11	0.75	1.04	0.93	1.10	0.82
4 TEXT	6.34	6.43	7.63	7.57	5.26	4.67	5.87	5.65
5 WOOD	37.27	38.12	32.21	41.74	30.05	27.48	23.48	24.11
6 PAPE	6.78	7.03	8.18	3.63	7.40	7.45	7.57	6.32
7 CHEM	12.10	12.41	11.16	9.59	11.55	12.12	10.68	9.89
8 DRUG	1.91	1.89	7.41	1.30	1.67	1.24	7.04	1.17
9 OIL	9.75	10.35	9.15	7.51	9.75	10.32	9.12	7.60
10 PLAS	19.02	18.80	18.75	16.31	18.43	18.66	18.18	16.86
11 NFMP	36.94	39.35	40.13	35.80	36.72	39.35	39.80	36.14
12 IRON	32.51	39.27	38.08	27.58	35.29	41.62	37.53	29.90
13 NFMT	31.27	28.77	35.05	23.36	32.60	36.20	34.42	27.23
14 METP	35.81	38.20	40.20	27.27	28.36	30.70	29.27	29.53
15 MACH	47.97	47.18	42.19	46.25	9.00	10.09	10.18	8.44
16 OFFI	47.94	53.92	52.55	39.04	1.97	1.52	1.21	1.56
17 ELEC	34.66	36.74	37.75	28.68	20.10	22.79	19.65	18.55
18 RTVC	34.55	38.84	32.61	30.63	6.54	7.99	7.15	6.81
19 OTHT	42.70	36.38	23.63	23.90	1.46	1.54	1.83	0.90
20 MOTO	27.54	28.87	31.50	29.26	1.74	1.52	2.70	1.52
21 AIRC	13.04	13.00	13.56	11.34	1.61	1.25	2.58	0.87
22 INST	37.51	37.91	37.56	39.40	5.09	4.95	6.33	4.07
23 OTHM	10.21	16.69	10.09	9.47	3.68	3.37	4.09	3.67
24 UTIL	7.83	8.31	8.13	5.75	7.83	8.30	8.13	5.74
25 CONS	59.48	63.67	65.58	57.78	2.33	2.05	1.49	2.08
26 TRAD	14.11	14.45	13.42	11.21	7.49	8.13	6.79	5.67
27 REST	3.82	3.65	3.86	2.99	3.81	4.31	3.86	2.99
28 TRAN	11.82	11.69	9.32	9.20	10.44	10.35	8.24	7.87
29 COMM	11.60	11.15	9.55	9.69	6.36	7.13	6.44	5.06
30 FINS	5.11	4.72	4.48	2.88	5.09	4.71	4.46	2.88
31 BUSS	9.46	9.69	9.44	8.82	6.64	7.65	7.76	6.46
32 PERS	2.87	2.91	4.07	1.75	2.72	2.80	3.77	1.63