WIFO
ÖSTERREICHISCHES INSTITUT
FÜR WIRTSCHAFTSFORSCHUNG

WORKING PAPERS

# R&D AND PRODUCTIVITY: EMPIRICAL EVIDENCE AT THE FIRM LEVEL

ROBERT WIESER

158/2001

# R&D AND PRODUCTIVITY: EMPIRICAL EVIDENCE AT THE FIRM LEVEL

ROBERT WIESER

WIFO Working Papers, No. 158
October 2001

E-mail address: Robert.Wieser@wifo.ac.at
2001/310/W/

# R&D AND PRODUCTIVITY: EMPIRICAL EVIDENCE AT THE FIRM LEVEL

ROBERT WIESER

Austrian Institute
of Economic Research
P.O.Box 91
A-1103 Vienna
Robert.Wieser@wifo.ac.at

October 2001

## Abstract

In this paper we focus on the empirical evidence on the relationship between research and development expenditures and the productivity of firms. The most widely employed econometric frameworks are the production function and the associated productivity framework. In these setting, productivity growth is related to expenditures on R&D and an attempt is made to estimate statistically the part of productivity growth that can be attributed to R&D. Overall, the results suggest a positive and strong relationship between R&D expenditure and growth of output or total factor productivity. However, the estimated returns vary considerably between the different studies due to differences accross data samples and econometric models, as well as methodological and conceptual issues. In order to attain more valid conclusions from the wide range of estimates, we apply a meta-analysis on the studies surveyed. One result is that the estimated rates of return do not significantly differ between firms in different countries, however, the estimated elasticities do. Another important observation is that estimated elasticities are significantly higher in the 1980s and consistently higher in the 1990s compared to the 1970s. Additionally, we review the evidence on the contribution of R&D spillovers at the firm and industry level. This evidence points to sizeable spillover effects, yealding to social returns to R&D which are more than twice as high as the private returns.

# 1. Introduction[1]

Since *Solow´s* (1957) decomposition of economic growth, many empirical studies have concentrated on the factors which underlie the productivity residual as one of the major factors of productivity growth. Investments in R&D has been one of these factors and the analysis of the relationship between R&D and productivity has played a major role in the economic growth literature. It is now well-known that both the governments of and private firms in most industrialised countries have devoted an increasing amount of resources to R&D. One of the main objectives of economic analysis is to evaluate whether the returns on this investment justify the initial expenditure. To this end, the relationship between R&D and productivity has been investigated at different levels of aggregation: economy, sector, industry and firm. In the present work we are interested in studies at the firm level.

R&D activities add to the existing stock of accumulated knowledge at the firm level. This knowledge stock aims at improving the quality of products or at reducing the production costs of existing goods and services. Furthermore, one of the central tenets of the *new growth theories* is that R&D activities not only affect the economic performance of the firms that undertake them, but also have repercussions on the performances of other firms. These R&D spillovers or technological externalities arise because of the partially `public-good´ nature of knowledge. Government involvement in research and development (R&D) is generally justified on the grounds that the incentives of the private sector to invest in R&D do not adequately reflect the value society derives from that R&D. The larger the divergence between the social and private returns on R&D (spillovers), the stronger is the case for government involvement.

However, in an increasingly global economy, there might be different attitudes towards the efforts in R&D undertaken by firms in various nations. In theory at least, many factors may explain differences in behaviour towards R&D. Geographic localisation, government policies, industry and opportunity effects, as well as firm specific characteristics may be important factors in the decision to devote resources towards R&D activities.

Due to data constraints, studies at the firm level have focused on very few countries, mostly France, Japan and the United States, where data on R&D expenditures at the firm level has been available for over twenty years. Earlier reviews of this empirical research have been provided by *Mairesse* and *Sassenou* (1991), *Griliches* (1992), *Nadiri* (1993), *Australian Industry Commission* (1995), *Mairesse* and *Mohnen* (1995), *Hall* (1996) and *Cincera* (1998). As the Australian Industry Commission points out, it is virtually impossible to be entirely consistent between studies because of the wide range of factors, including the use of different methodologies, a lack of clarity in the way findings are presented, major structural differences in the countries covered, differences in the time periods covered, and whether the returns to R&D are estimated from specifications that use R&D stocks or flow expenditure figures. This paper widens the picture by introducing more recent results, and also attempts to standardise these and give systematic evidence by employing a meta-analysis on the studies under investigation.

[1] I should like to thank K. Aiginger, J. Borrmann, M. Pfaffermayr and R. Winter-Ebmer for helpful suggestions.

The paper is organised as follows. Section 2 introduces the R&D-productivity model, and discusses the econometric framework which is commonly used to evaluate the R&D contribution to productivity (growth) at the micro level. Specific attention is paid to variable measurement issues that are particular to this kind of application. However, we will not adress all the technical estimation problems involved in this kind of analysis. In Section 3, we summarise the most prominent empirical findings of selected econometric studies on the R&D-productivity relationship at the firm level. Then, in order to attain more valid conclusions from the wide range of estimates, we present the results of the meta-analysis. The section closes with a short review of studies at the firm and industry level which have tried to estimate the contribution of R&D spillovers to productivity growth. Section 4 concludes.

## 2. R&D and productivity: Empirical framework

Economists have used two distinct approaches in assessing the contribution of research and development (R&D) expenditures to economic performance: case studies and econometric analysis. While case studies try to identify the benefits from and costs of a particular innovation, the econometric approach concentrates on the contribution of R&D to performance at a higher level of aggregation. The main advantage of the case study approach is its transparency and provision of detailed knowledge about one single firm or one single project. The main disadvantage is its lack of representativeness. Since case studies tend to concentrate on selected successful projects, it is not possible to draw general conclusions from their findings.

Unlike most case studies, econometric studies also incorporate unsuccessful R&D projects in their expenditure or stock figures. The higher level of aggregation at the firm, industry or economy-wide level, coupled with the use of statistical techniques, makes it easier both to draw general conclusions from their findings and to measure the external effects of the R&D-activities, which are accrued by other firms, industries and nations. However, the use of econometric techniques has numerous limitations. Many of them relate to the availability of data. Measurement issues arise both in the case of outputs and in the case of inputs. There is the problem of `quality change´ in the construction of price indices and, most prominently, there are no data on R&D capital stocks in the official accounts, so researchers occasionally have to calculate their own R&D stocks.

### 2.1. Specification Issues

Most econometric studies estimate the relationship between R&D and either output (the production function approach) or production costs (the cost function approach)[2]. Here we concentrate on the

2. Under duality theory, these approaches are related to each other. In theory at least, a cost function can be derived from a given production function and vice versa. In practice, the direct estimation of a production function suffers from the problems of a simultaneity bias that are avoided when estimating cost functions. However, cost function estimations are considerably more complex, as they typically necessitate the estimation of both the cost function and its associated factor

production function approach, of which a variant relates R&D to factor productivity (productivity approach). The analytical tool often used to link productivity growth with R&D is a simple Cobb-Douglas production function. In addition to the traditional inputs, this function includes knowledge capital at the firm level, and one or more terms representing specific pools of R&D that the industry or economy may draw upon:

$$Q_{it} = Ae^{\lambda t} C_{it}^{\alpha} L_{it}^{\beta} K_{it}^{\gamma} X_{it}^{\eta} e^{\varepsilon_{it}} \qquad (1)$$

where Q is output (production, value added or net sales); L is a measure of labour (often the number of employees); C is physical (or tangible) capital; K is research capital; X measures external stocks of R&D available (spillover pool); A is a constant; i and t denote firms and time periods (years); $\lambda$ is the rate of disembodied or autonomous technical change; $\varepsilon$ is a multiplicative error term, reflecting the effects of unknown factors, approximations and other disturbances; $\alpha$, $\beta$, $\gamma$ are the parameters of interest, i.e., the *elasticities* of output with respect to each of the inputs.

Usually, equation (1) is taken in logarithms to enable the estimation of $\alpha$, $\beta$, $\gamma$ and $\eta$. This leads to the following linear regression models:

$$q_{it} = a + \lambda t + \alpha c_{it} + \beta l_{it} + \gamma k_{it} + \eta x_{it} + \varepsilon_{it} \qquad \text{levels (2)}$$

$$\Delta q_{it} = \lambda + \alpha \Delta c_{it} + \beta \Delta l_{it} + \gamma \Delta k_{it} + \eta \Delta x_{it} + \Delta \varepsilon_{it} \qquad \text{first differences (2´)}$$

where lower case letters denote logarithms of variables.

In the way equation (2) is specified, returns to scale with respect to the three inputs can or cannot be assumed as constant. To account for this, equation (2) is re-written by subtracting labour from both sides:

$$(q_{it} - l_{it}) = \lambda + (\mu - 1) l_{it} + \alpha (c_{it} - l_{it}) + \gamma (k_{it} - l_{it}) + \eta (x_{it} - l_{it}) + \varepsilon_{it} \qquad (3)$$

where the coefficient of the logarithm of labour ($\mu$-1) now measures the departure from constant returns.

An alternative specification of equation (2´), suggested by *Griliches* (1973) and *Terleckyj* (1974), directly estimates the `*rate of return*´ to R&D instead of its elasticity. From equation (1) we obtain:

$$\gamma = \frac{\partial Q_{it}}{\partial K_{it}} \frac{K_{it}}{Q_{it}} = \rho_1 \frac{K_{it}}{Q_{it}} \qquad (4)$$

where $\rho$ is the rate of return on (or marginal productivity of) R&D.

By disregarding the depreciation of R&D, i.e., $\Delta k = \Delta K / K = RD / K$, and applying the same transformations to the R&D spillover-stock X, we can re-write equation (2´):

$$\Delta q_{it} = \lambda + \alpha \Delta c_{it} + \beta \Delta l_{it} + \rho_1 (RD/Q)_{it} + \rho_2 (XD/Q)_{it} + \theta_{it} \qquad (5)$$

where RD and XD denote the expenditures on R&D by the firm and the spilloverpool under consideration, respectively.

A variant of this specification relies on a prior measurement of total factor productivity ($\pi$), that is

---

demand equations as a full system. Therefore, data requirements are not easily fulfilled in practice. Among others, *Mohnen*, *Nadiri* and *Prucha* (1986), *Bernstein* and *Nadiri* (1988, 1991), *Bernstein* (1989), and *Mohnen* and *Lépine* (1991) have implemented the dual approach at the meso-economic level. A limited number of studies employ other approaches. For example, *Jaffe* (1986) uses a model that is related to production and cost functions – the profit function, while *Hall* (1993) uses Tobin´s q to estimate the stock market´s valuation of R&D investment.

$$\Delta\pi_{it} = \Delta q_{it} - \overline{\alpha}\Delta c_{it} - \overline{\beta}\Delta l_{it} = \Delta(q-l)_{it} - \alpha\Delta(c-l)_{it}$$

where the elasticity of labour $\overline{\beta}(=1-\overline{\alpha})$ is estimated by the share of labour costs (wages and related charges) in value-added. In this setting, we could just estimate the simple regression

$$\Delta\pi_{it} = \lambda + \rho_1 (RD/Q)_{it} + \rho_2 (XD/Q)_{it} + \theta_{it} \qquad (7)$$

Econometric studies that attempt to estimate the contribution of R&D to productivity within the described framework distinguish themselves not only by the precise specification they adopt, but also by the underlying assumptions and by the type of information they use. In some specifications, R&D *capital* is related to output growth, whereas others relate R&D *intensity* (the ratio of R&D expenditures to value added or sales as an approximation of R&D investment) to output or total factor productivity growth (TFP studies). This has two important consequences: in the first approach, we need a measure of R&D capital in the list of the explanatory variables, in addition to the usual factors of production. The fact that there are no data on R&D capital stocks in the official accounts, which are equivalent to physical capital stock figures, raises the problem of obtaining an R&D capital stock estimate for the firms. To circumvent the major issues involved in measuring such forms of `capital´, a number of studies relies on R&D expenditures which are more easily available.

Furthermore, in the first approach, it is assumed that the estimated elasticities of R&D are constant across cross-sectional units, whereas in the second approach it is assumed that the `rate of return´ to R&D is constant across cross sectional units. As pointed out by *Capron* (1993), this alternative approach turns out to be more consistent with the optimal R&D behavioural choice of firms, compared to the elasticity approach that assumes a common elasticity of output with respect to R&D capital, when the relationship is estimated across firms. Indeed, to the extent that the production technology is specific to each firm, firms will use different factor shares, and if inputs are used at their competitive equilibrium levels, firms are unlikely to have the same output elasticities[3].

Besides these specification issues, there are also methodological and data issues, as well as econometric problems involved in this kind of estimation. The next section discusses some of the most severe measurement issues that arise both in the case of outputs and in the case of inputs. There are also a number of sources of misspecifications which afflict the production function estimates. Two of them, the simultaneity and the identification issue, have been discussed by *Griliches* and *Mairesse* (1998). As these problems raise a number of difficult technical questions, which are out of the scope of this paper, we do not explore these further here.

## 2.2. Methodological and data issues

An important difficulty raised by the production function framework is related to the construction of the R&D capital stock at the firm level. Actually, the perpetual inventory method (PIM) originally proposed by

---

3. See *Griliches* and *Mairesse* (1998) for a discussion of the `identification problem´ in the measurement of production functions.

*Griliches* (1979) is the most commonly used method for constructing firm knowledge capital. This method assumes that the current state of knowledge is a result of present and past R&D expenditures discounted by a certain rate of depreciation[4].

However, this formulation suffers from two important drawbacks. First, the magnitude of the depreciation rate is unknown[5]. Second, since the available history of R&D is usually not very long, we need a method by which we can construct the initial knowledge stock. Unfortunately, the initial R&D capital stock figures are quite sensitive to the growth and depreciation rates used[6].

Another well-known issue encountered when estimating the contribution of R&D relates to the problem of *double counting*. Irrespective of whether R&D is measured as a stock, expenditure or intensity figure, expenditures on labour and physical capital used in R&D should be removed from the measures of labour and physical capital used in production. *Schankerman* (1981) clearly demonstrates that the failure to remove this double counting biases the estimated R&D coefficients downwards[7]. That is, the true returns are likely to be *higher* than those estimated. When the coefficients (elasticities) are converted to marginal products, this difference is magnified even more[8].

In addition to the issues specific to the R&D variable, problems also arise in the *measurement of output and the other inputs* entering the production function. Regarding output measurement, one of the most acute issues, at least at the micro level, is the way in which it is deflated. The first major drawback is that price deflators are usually not available at the firm level. Instead, more aggregate price indexes are used, in general at the two-digit industry level, which raises several problems for industries characterised

3. *Coe* and *Helpman* (1995) provide the most detailed explanation of any study as to how their stocks of R&D capital were derived.
5. As *Griliches* (1979, pp. 101-102) points out: `The question of depreciation is much more complicated for social research and development capital measures at the industry or national level. The fact that private knowledge loses its privacy and hence its value is a private loss, not a social one. Nevertheless, there is likely also to be some depreciation in social knowledge. ......The real problem here is our lack of information about the possible rates of such depreciation. The only thing one might be willing to say is that one would expect such social rates of depreciation to be lower than the private ones.´
6. While the magnitude of the estimated stock may vary according to the depreciation rate, it does not follow that the elasticity estimates themselves are sensitive to the stock figure. Using a wide ranging sensitivity test on the rate of depreciation (from 0 to 100 per cent), *Hall* and *Mairesse* (1993) demonstrate that the choice of depreciation rate in constructing R&D capital does not make much difference to the R&D elasticity estimates, although it does change the average level of measured R&D capital greatly, and thus the implied rates of return.
7. This finding has been confirmed by a number of other studies, including *Cuneo* and *Mairesse* (1984), *Griliches* and *Mairesse* (1984), *Hall* and *Mairesse* (1993) and *Mairesse* and *Hall* (1996).
8. Virtually all of the TFP studies, plus most of the earlier studies, do not adjust for this double counting and, based on *Schankerman* (1981), their estimates are likely to be lower than if they had done so (all other things being equal). However, many of these studies are subjected to countervailing biases, so the net effect is less certain. For example, due to their use of R&D expenditure figures, most of the TFP studies do not allow for depreciation. This would lead to an overestimation of the return to R&D, in comparison to the situation had depreciation been taken into account.

by imperfect competition or for large, multi-product firms which have subsidiaries in many countries.[9] The second shortcoming is that such price deflators do not incorporate changes in output quality, and as a result underestimate the `true´ output.

Regarding the measurement of the traditional inputs, allowances should also be made for corrections of quality differences in labour and physical capital. For instance, if the substantial quality improvements achieved by the computer industry are not taken into account, the contribution of such devices to the productivity gains of the firms using them as inputs in the production function will be underestimated. *Griliches* (1979, p. 106) terms this mismeasurement of where the actual productivity gain occurs a 'productivity transfer' and it reflects the fact that quality improvements are not fully reflected in the official price indices. Furthermore, according to *Griliches* and *Mairesse* (1984), as long as the inputs are not corrected by the maximal production capacity rates, variations in these inputs affect the measurement of productivity[10].

Another major issue concerns *spillovers*, the effect of knowledge capital outside the firm or industry in question on the within-industry productivity[11]. Most empirical studies do not account for potential spillover benefits between and within industries. Clearly, the degree of transferability of knowledge depends on the type of knowledge and the industries involved. Insufficient data exists to adequately differentiate between intra-industry flows of embodied and disembodied R&D, and between process and product R&D. To deal with this, researchers implicitly assume that all knowledge is embodied R&D or that the usage of knowledge between industries mirrors the usage of commodities between industries. In most studies, the R&D capital stock of an industry is merely the sum of the R&D capital stocks of each firm contained in that industry. Instead of just adding together the stocks of R&D capital to derive a pool of potential spillover benefits, some researchers weight them according to their 'technological proximity' — a measure of how transferable knowledge is between industries. The weights indicate how relevant the R&D of one industry is likely to be to the current industry, with a higher weight indicating that its R&D is likely to have greater relevance to the current industry. The weights are typically calculated using one of two approaches, although other methods may be used[12].

---

9. For instance, if a firm manufactures two products, one in country A and the other in country B, which price deflator of which country should be used if we only observe total sales? Moreover, if these products are in two different two digit level industries, e.g., a drug and a chemical product, which price deflator of which industry should we retain?
10. Here also, if we assume that these rates of capacity utilisation are more or less similar among firms within a given industry and for a given time period, then such business cycle effects should be attenuated by including appropriate industry and time dummies.
11. As *Griliches* (1979, p. 103) comments: `The level of productivity achieved by one firm or industry depends not only on its own research efforts but also on the level of the pool of general knowledge accessible to it. Looking at a cross section of firms within a particular industry, one will not be able to distinguish such effects. If the pools of knowledge differ for different industries or areas, some of it could be deduced from inter-industry comparisons over time and space. Moreover, the productivity of own research may be effected by the size of the pool or pools it can draw upon.´
12. Whilst both methods of measuring technological proximity are open to criticism, they are an improvement on the assumption that knowledge is 'homogeneous'. See Griliches (1992) for an extensive discussion on the measurement issues involved.

The first method involves identifying those industries that are likely to benefit from patents taken out and those industries taking out the patents. The use of patents makes this approach more plausible for embodied knowledge than for disembodied knowledge, and for product R&D, as opposed to process R&D. The major drawback of this approach is that it is resource intensive, as it requires a considerable amount of information and is extremely time consuming. It also involves some subjective judgement. *Cohen* and *Levin* (1989, pp. 1063–1064) discuss in detail the problems associated with using patents in this manner. The major studies using patents as measures of technological proximity include *Griliches* and *Lichtenberg* (1984), *Scherer* (1982, 1983, 1984, 1993), *Englander et al*. (1988), *Sterlacchini* (1989) and *Mohnen* and *Lepine* (1991).

The second method used to calculate the weights for technological proximity is based on input-output linkages. One justification of this approach is that the usage of commodities in production may reflect the usage of the knowledge associated with that commodity. This line of reasoning is again more plausible for embodied knowledge than it is for disembodied knowledge, and for product R&D, as opposed to process R&D. Examples of studies using this method include *Terleckyj* (1974, 1980), *Goto* and *Suzuki* (1989) and *Sterlacchini* (1989).

## 2.3. Econometric estimation methods

Among the different approaches to estimate the relationship between R&D and productivity, many studies have adopted panel data econometric methods. In such a setting, the typical dataset contains observations on a cross section of firms over several time periods[13]. Compared to purely cross-section data, the main advantages are more informative data, more variability, less collinearity among the variables, more degrees of freedom, and more efficiency. However, the main benefit is identification, i.e., the possibility of holding unobserved productivity components in a firm constant (see *Baltagi*, 1995).

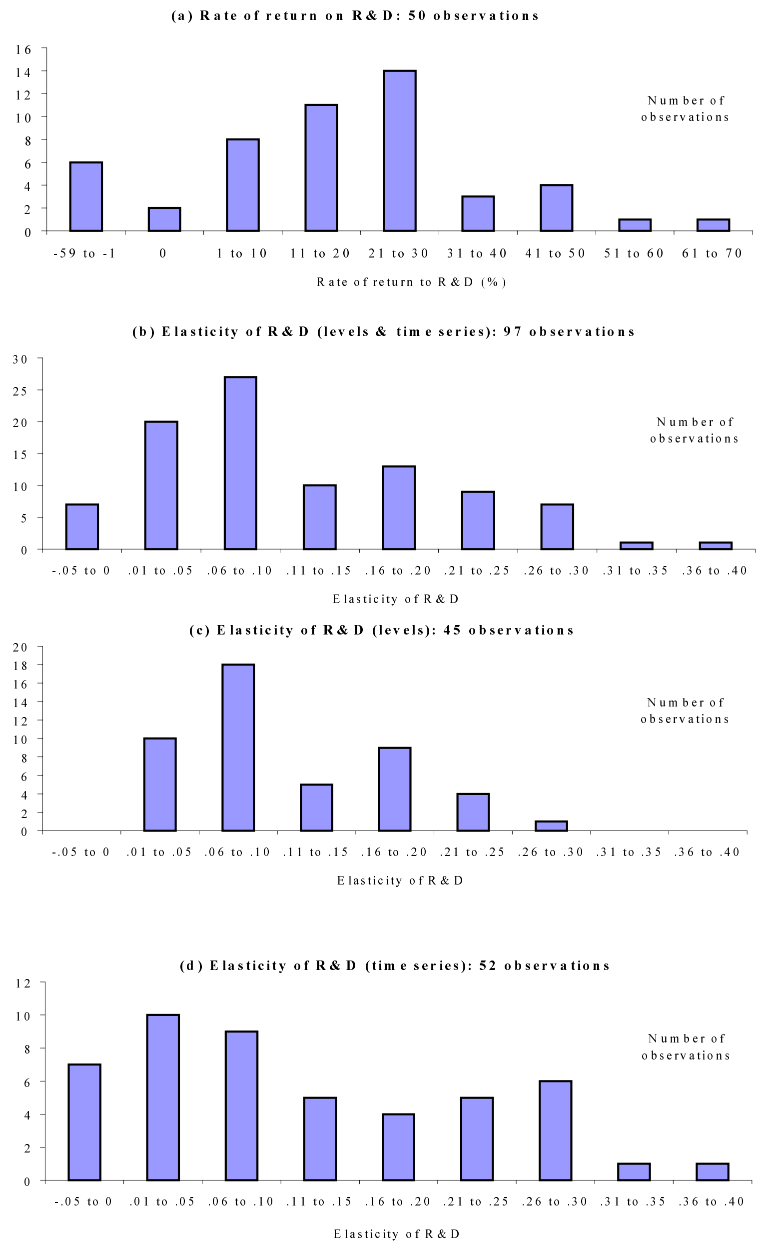
To ease the comparability of the studies reported in the next section, they have been ranked according to whether the variables entering the production function are taken in levels or in time series dimensions (i.e., growth rates or within transformations). The *cross section estimates* of the relationship between R&D and productivity are obtained from regressions that are carried out for variables in levels for a given year. Level estimates may also be obtained by so-called *total* regressions over all firm-year level observations by means of OLS. Regressions which are based on the means of the growth rates of variables for individual firms over several years provide *between* estimates, while *within* estimates are obtained from the deviations of the variables from their firm means. Regressions may also use first differences or long differences, which also wipe out firm-specific effects which are constant over time.

13. The cross-sectional variation is in most cases much larger than the temporal one, i.e., the main source of heterogeneity is found across firms.

# 3. The empirical evidence

This section reviews some of the main econometric studies that have investigated the relationship between R&D and productivity growth at the micro level.

*FIGURE 1: Distributions of private returns on industrial R&D*



The studies surveyed use two groups of specifications. The first group measures the percentage increase in output or (total) factor productivity that occurs in response to a one percent increase in R&D (the elasticity of R&D); the second group measures the change in total output or (total) factor productivity that results from a one (dollar) unit increase in R&D (the marginal product or rate of return to R&D). As has been mentioned above, the latter formulation assumes, first, that it is the rate of return to R&D which is constant across firms and not the elasticity of the R&D capital stock, and, second, that the rate of depreciation of this capital is negligible.

## 3.1 Direct (private) returns to R&D

Figure 1 illustrates the distribution of the private rates of return and the elasticities of R&D, obtained from the studies presented in tables 2 to 4 below. Panel (a) and (b) include the frequency distributions of all observations on the rates of return and the elasticities; panels (c) and (d) group the elasticity estimates into level and time series estimates, respectively.

Table 1 provides summary statistics on the distributions. The overall average private rate of return to R&D, with respect to the studies presented in table 2, if significant, was 28.8% per year, with a standard deviation of 13.3 percentage points. The overall mean elasticity of R&D from tables 3 and 4, if significant, was .152, with a standard deviation of .088. If we partition the distributions of the elasticity estimates into those resulting from level estimates and those resulting from times series estimates, the mean elasticities were .122 in levels and .188 in the time dimension, with the associated standard deviations of .066 and .099, respectively.

*TABLE 1: Ranges of estimates in selected studies*

| Estimate | | Number of observations | Mean | Std | Median | Minimum | Maximum |
|---|---|---|---|---|---|---|---|
| Rate of Return (%) | | | | | | | |
| | significant only | 29 | 28.8 | 13.3 | 27.0 | 7.0 | 69.0 |
| | all observations | 50 | 16.7 | 22.8 | 20.1 | -55.0 | 69.0 |
| Elasticity: levels & time series | | | | | | | |
| | significant only | 73 | .152 | .088 | .115 | .027 | .380 |
| | all observations | 97 | .121 | .095 | .100 | -.016 | .380 |
| Elasticity: levels | | | | | | | |
| | significant only | 40 | .122 | .066 | .102 | .027 | .292 |
| | all observations | 45 | .111 | .069 | .099 | .008 | .292 |
| Elasticity: time series | | | | | | | |
| | significant only | 33 | .188 | .099 | .185 | .041 | .380 |
| | all observations | 52 | .112 | .112 | .100 | -.016 | .380 |

### *3.1.1 Estimates of the rates of return to R&D*

The first set of studies reported in Table 2 directly estimates the `rate of return´ to R&D. All the results reported by these studies (except the ones by *Griliches* and *Mairesse* (1984) and *Bartelsman et al.* (1996)) are based on pooled first differenced regressions, i.e. total first difference estimates.

Table 2

Three main conclusions emerge from the estimates reported in Table 2. First, the average estimated rate of return to the firm undertaking R&D investment is in the order of 29%, with a lower bound of 7% (*Link*, 1981) and an upper bound of 69% (*Sassenou*, 1988).

Secondly, we can conclude from these estimates that downward biases arise when no corrections are made for the *double counting* of R&D (*Hall* and *Mairesse*, 1995, *Bartelsman et. al*., 1996) and that estimates are lower when *industry dummies* are introduced into the productivity model (*Griliches* and *Mairesse*, 1984, *Odagiri* and *Iwata*, 1986, *Sassenou*, 1988, *Griliches* and *Mairesse*, 1990, *Wakelin*, 2000).

Thirdly, the rates of return to R&D obtained for firms in different *countries* seem to be rather comparable. In particular, *Griliches* and *Mairesse* (1983) and *Griliches* and *Mairesse* (1990) estimate the contribution of the R&D intensity of French, Japanese and US firms to the growth rate of sales by controlling for specific industry effects. The estimated rates of return to R&D are about 31% for French firms, 30% for Japanese, and 27% for US firms.

### *3.1.2 Elasticity of R&D: Level dimension estimates*

The studies reported in Table 3 assessed the output elasticity of R&D stock on the basis of a level specification of the production function. One interesting question is, whether the R&D-productivity relationship has changed over *time*. In the study of *Schankerman* (1981) the estimates are performed for different industry sectors in 1963. The estimates that are statistically significant range from .034 (Electric equipment) to .292 (Aircraft industry). His estimated elasticity of .104 for chemicals is very close to the one obtained in *Minasian* (1969) for firms operating in the same industry sector during the 1950´s (11%). *Hall* and *Mairesse* (1995) obtain an estimate of .18 for the R&D elasticity of French firms during the 1980's. This result is again very close to the one reported by *Cunéo* and *Mairesse* (1984) for the 1970s (.203). On the other hand, in *Griliches* (1980), the estimated elasticity of R&D in 1963 is .07, which is less than the corresponding result of .12 for 1972 in his 1986 study. *Cincera* (1998) finds increasing elasticities in the cross sectional dimension and at the same time a sharp decline in the temporal estimates, and concludes that there may be a mismatch between business cycles and R&D patterns over time, which could not be accounted for in the simple Cobb-Douglas model at hand.

*Schankerman´s* (1981) results indicate that a *double counting* bias is present and quite important for some industries such as aircraft (800%) and electrical equipment (600%). For other industries, such as chemicals and oil and motor vehicles, the downward bias is still present, but is less important: 50% and

30% respectively. *Cunéo* and *Mairesse* (1984), *Hall* and *Mairesse* (1995), *Mairesse* and *Hall* (1996) and *Bartelsman et al*. (1996) all confirm the results obtained by Schankerman. Cunéo and Mairesse and Mairesse and Hall observe a downward bias to the order of about 80% for French firms. In *Bartelsman et al*. (1996), correction for double counting leads to an increase of the R&D elasticity from .01 to .05 for the period 1985-1989 and from .04 to .10 for the 1989-1993 period.

Table 3

*Griliches* (1986) reports estimates with *industry dummies* as additional explanatory variables of the production function. In this case, the estimated R&D elasticity is .03 lower (.09 compared to .12 without industry dummies). *Sassenou* (1988) reaches a similar conclusion in his analysis of Japanese firms. The elasticities of R&D reported in his study are lower when industry dummies are included[14].

*Griliches* and *Mairesse* (1984) investigate 133 US firms, and find an elasticity of R&D with respect to sales of .05. However, the estimated R&D elasticity for *scientific firms* is .19, which is higher than the findings reported for other firms in their sample. This result is confirmed by the results obtained by *Sassenou* (1988), who reports a somewhat larger elasticity of R&D for scientific firms (16%) compared to other firms (.10). However, the R&D elasticity reported by *Cunéo* and *Mairesse* (1984) is lower for scientific French firms (elasticity of .11) than for other ones (.20). One possible explanation may arise from the fact that both US and Japanese firms in the scientific sector are much less reliant on government funding than is the case for French firms. Since publicly-funded R&D is in general more fundamentally-based, it is likely that its contribution to the productivity performance of private firms is less important than the returns to privately financed R&D.

Comparing the estimates of the studies by *Griliches* (1980) and *Sassenou* (1988), it follows that the contribution of R&D to productivity is quite similar for US and Japanese firms. Furthermore, the value of .15 reported in the analysis by *Harhoff* (1994) for a sample of 443 German firms is quite comparable to similar results obtained for French firms. On the other hand, his result appears to be higher than the findings for US and to some extent for Japanese firms. *Bartelsman et al*. (1996) provide estimates for Dutch manufacturing firms. On the whole, the estimated coefficients reported in their analysis are lower than the corresponding ones obtained in other *countries*. *Cincera* (1998) investigates R&D elasticities for 625 firms in different countries between 1987 and 1994. He finds comparable estimates for US firms (.09) and European firms (.10). However, in the case of Japan, the estimate is much lower (.02).

---

14. However, the interpretation of these sectorial dummies is ambiguous. Quoting *Mairesse* and *Mohnen* (1995, p. 37), `On the one hand, the indicators may correct the estimates for the bias resulting from the erroneous omission from the production function of structural variables strongly correlated to the sectorial characteristics. On the other hand, their presence may itself be a source of distortion to the extent that they reflect in part the return to research resulting from technological opportunities. The latter are probably essential to explain the greater tendency to carry out research in certain sectors. Thus, scientific sectors benefit from a more solid and broader knowledge base, on which it may be easier to devise a research program and achieve profitable innovations.´

*Cunéo* and *Mairesse* (1984) experiment with value added and sales as the output variables. Considering sales instead of value added as the dependent variable leads to a higher elasticity of R&D capital (.18 for sales versus .11 for value added). The study by *Mairesse* and *Hall* (1996) uses two datasets for the USA and France to investigate the R&D-productivity relationship. For the French data, the estimates using sales give results that are quite similar to those using value added[15]. Furthermore, the authors use two different measures of sales as the dependent variable: sales deflated by a single manufacturing sector deflator, and sales deflated by a two-digit level deflator. Whereas the latter deflator raises the estimated R&D capital coefficient in France slightly, the increase in the USA is substantial (about 500%). In the opinion of the authors, the reason for this difference stems from the way the US deflator is constructed. Actually, this deflator is based on a hedonic price index for computers and, as a consequence, while computers became much more powerful and much less expensive during the 1980s, the price index for this industry declined by about 80% during this period. In France, on the other hand, the computing deflator does not capture the tremendous decline in the price of raw computing power, so deflation at the industry level does not have the same effect on the estimated productivity of R&D.

### *3.1.3 Elasticity of R&D: Time series estimates*

The studies reported in Table 4 use the time series dimension of the data. Some studies are based on the growth rates of the variables (total or between first difference estimates or long difference estimates), while others rest on deviations from the means of the variables (within transformation).

Table 4

Disparities between estimates arising from the cross-sectional (level) and time-series dimensions is a common feature of panel data econometrics. In these cases, most authors give preference to the time-series estimates (generally the `within-firm´ estimates). However, according to *Mairesse* (1990), it is an open question, as to whether we should give preference to the time series estimates or the level estimates. Both groups of estimates might be prone to bias and lack robustness. On the one hand, cross-sectional estimates may be biased due to the omission of variables charactersising firms. This biases may lead to an overestimation of the true value of the elasticity of R&D capital. On the other hand, tim-series estimates may lack robustness because of the collinearity of phsical and R&D capital with time. Biases may also results from random measurement errors in variables, from an inadequate specification of lags occurring in the relationship between productivity and its factors, and from the omission of variables reflecting short term adjustments to business cycle fluctuations by the firm, such as hours of work and capacity utilisation. As *Mairesse* and *Sassenou* (1991) note, one point that these various biases have in common ist that they may be relatively minor for cross-sectional estimates on the levels of variables, but are likely to be magnified in time-series estimates based on changes in these variables.

15. There is no measure of value added in the US data.

However, in some respects, the results from Table 4 tend to confirm those in the level dimension. Corrections for double counting lead to higher estimates (*Cuneo* and *Mairesse* 1984); the impact of R&D on productivity seems to be higher for US firms than for European firms, which in turn, surpasses Japanese firms (*Cincera* 1998, within), and there is no clear indication, whether scientific firms show larger elasticities of R&D than other firms (*Griliches* and *Mairesse* 1984; *Cuneo* and *Mairesse* 1984).

## 3.2 A meta-analysis of the estimated returns to R&D

This section presents the results of a meta-analysis of the studies on the R&D-productivity relationship reported in tables 2 to 4. We would like to have more consistent answers to the following questions: (1) Has the relationship between R&D and productivity changed over time? (2) Can we observe differences in the contribution of R&D to the productivity of firms in different countries? (3) Are there industries in which R&D contributes more to productivity than in others? (4) Do the estimates depend on the analytical methodology used?

To answer this questions, we collect the different outcomes (rate of return on R&D, elasticity of R&D) found in the various studies, and their associated standard errors. In order to explain the variations in results across the sample of studies, we estimate an equation as follows:

$$Y_j = \beta_0 + \sum_{k=1}^{K} \beta_k Z_{jk} + e_j \qquad j=1,2,\ldots,N$$

where $Y_j$ is the reported estimate of the returns to R&D (rate of return; elasticity) in study j from a total of N studies, and $Z_{jk}$ are meta-independent variables which proxy characteristics of the empirical studies in the sample. The variables of interest in Z are the time periods covered, the countries, the industries and the methods. Additionally, we control for differences in specifications and the econometric model. That is, we utilise all information in tables 2 to 4. The results of the meta regressions are reported in Table 5[16].

Column (1) shows the results of the reported estimates of the rate of return to R&D. The regression is based on 50 observations (i.e., 50 regressions) from the 17 studies in table 2. US manufacturing firms in the 1970s comprise the reference category (basis), so that the coefficients of the other variables measure the extent to which they differ from the basis. The results suggest that there are neither country specific effects nor time period or sector specific effects, i.e., there is no (statistically significant) variation across time periods, countries and industry groups in the estimated rates of return to R&D.

16. To deal with the heteroscedasticity problem, we employ a weighted least squares (WLS) estimation with standard errors of the estimates (the Yjs) as analytical weights.

*TABLE 5: R&D and growth: Results of Meta-Regression*[a]

| | Rate of return | | Elasticity | | | | | |
|---|---|---|---|---|---|---|---|---|
| | (1) | | (2) | | (3) | | (4) | |
| | | | levels | | time series | | levels & time s. | |
| Independent Dummy Variable | est. | s.e. | est. | s.e. | est. | s.e. | est. | s.e. |
| USA | b | | b | | b | | b | |
| Japan | .11 | (.131) | -.07 | (.061) | -.05 | (.042) | -.05 | (.031)** |
| Europe | -.12 | (.335) | -.08 | (.052) | -.06 | (.046) | -.07 | (.034)* |
| World (mixed) | -.21 | (.387) | -.06 | (.065) | .11 | (.037)* | .08 | (.028)* |
| 1950s | .01 | (.539) | .05 | (.090) | -.01 | (.070) | .00 | (.055) |
| 1960s | -.11 | (.261) | -.12 | (.070)** | .16 | (.073)* | .04 | (.047) |
| 1970s | b | | b | | b | | b | |
| 1980s | .10 | (.192) | .08 | (.071) | .06 | (.049) | .07 | (.036)** |
| 1990s | .31 | (.389) | -.01 | (.079) | .06 | (.048 | .05 | (.036) |
| manufacturing (mixed) | b | | b | | b | | b | |
| scientific only | -.06 | (.221) | .04 | (.051) | -.04 | (.041) | -.02 | (.029) |
| others | -.34 | (.221) | .01 | (.057) | -.11 | (.034)* | -.09 | (.028)* |
| TFP-VA (Total Factor productivity - value added) | b | | | | | | | |
| TFP-VA-Industry Dummies | -.24 | (.303) | | | | | | |
| TFP-Sales (Total Factor Productivity - Sales) | -.52 | (.240)* | | | | | | |
| TFP-Sales-Industry Dummies | -.38 | (.586) | | | | | | |
| VA (value added) | -.38 | (.274) | b | | b | | b | |
| VA-Double Counting | -.36 | (.272) | .10 | (.026)* | .08 | (.051) | .08 | (.027)* |
| VA-Industry Dummies | -.63 | (.426) | -.07 | (.059) | | | .03 | (.077) |
| Sales | -.21 | (.170) | .09 | (.039)* | .04 | (.045) | .05 | (.031) |
| Sales-Industry Dummies | -.29 | (.226) | | | | | | |
| Sales-I1Def (single sector deflator) | | | -.02 | (.100) | -.03 | (.061) | -.02 | (.046) |
| Cross section | | | b | | | | .00 | (.031) |
| Totals | | | -.12 | (.076) | | | -.02 | (.051) |
| Between | | | | | b | | b | |
| Totals, F.D. (First differences) | | | | | .16 | (.069)* | .08 | (.052) |
| L.D. (Long differences) | | | | | .10 | (.065) | .04 | (.049) |
| Within | | | | | .05 | (.065) | -.04 | (.048) |
| constant | .29 | (.267) | .18 | (.063)* | .05 | (.070) | .12 | (.049)* |
| Num. of obs. | | 50 | | 45 | | 52 | | 97 |
| F | | 1.65 | | 1.91 | | 6.48 | | 7.16 |
| $R^2$adj. | | .19 | | .24 | | .63 | | .55 |

a Weighted Least Squares Regression with the reported standard errors as analytical weights
Note: b = reference category (Basis)
* (**) = statistically significant at the 5% (10%) level

Columns (2) to (4) show the meta-regressions for the estimated elasticities in levels specifications and time series specifications, and combined. Contrary to what has been the case in the rate of return regression, we now observe significant country and time effects, as well as industry effects. In the combined regression (4), the estimated elasticities are significantly lower for Japan and Europe. Also, the estimated elasticities were significantly higher in the 1980s compared to the 1970s, and there are industries (machinery, motor vehicles and miscellaneous) which obtain significantly lower returns on R&D compared to manufacturing as a whole.

Many researchers have focused their attention on possible changes in the productivity of R&D over time, and some of them have documented the collapse of what had been a relatively strong R&D effect (see the discussion above). However, the higher elasticities reported in Table 5 for the 1980s (and probably the 1990s as well), compared to the 1970s, suggest that R&D opportunities are not exhausted at all and might well be promising in the future.

The significantly lower elasticity estimates in Japan and Europe compared to the US can be interpreted in different ways. First, it might be the case that US firms on average spend more of their money on R&D, relative to their sales, than Japanese and European firms do. That is, R&D intensity in the US might be higher. Secondly, R&D use in US firms might be more efficient. Third, both might be the case.

In their comprehensive survey of econometric studies on R&D and productivity at the firm level, *Mairesse* and *Sassenou* (1991) deal a lot with methodological and data issues that are particular to this kind of estimation. They do this on a more facultative basis by concentrating on the results of the individual studies under investigation. Our meta analysis allows us to deal with this more systematically, and there are several interesting aspects: First, most of the estimates on the methodological variables in columns (2) to (4) are not significant. This points to rather robust results as regards our main variables of interest in the meta regressions (countries, time periods, and sectors). Second, the significant coefficient of the VA-Double counting Dummy confirms the alleged downward bias that arises if we do not correct for double counting of R&D expenditures in our data. As most studies do not account for this, their reported elasticity estimates are too low on average. Third, there is no significant result as regards the inclusion of industry dummies. In order to guard against biased cross-sectional estimates due to the omission of industry characteristics, authors generally include industry dummy variables into their regressions. In so doing, the mean differences between industries are wiped out, and the resulting estimates are solely based on between firms, but within industry, differences. Allthough the estimates in columns (1) and (2) have the expected (negativ) sign, they are not significant. This points to the view that industry effects are less satisfactory substitutes for the `true´ variables that have been omitted.

Finally, what *Hall* and *Mairesse* (1995) term the `most robust result´in this kind of studies, that is a pattern of estimates which yields an R&D capital elasticity in the cross-section dimension which is statistically significant and large, whereas the estimates in the time dimension, which control for permanent differences accross firms, whether within, long-differenced, or first-differenced, typically are much smaller and often statistically insignificant, is not confirmed by the results of the meta-analysis. On the one hand, we do not find any significant differences between level and time series estimates. On the other hand, contrary to the authors view, estimates in the time dimension (with the exception of the within estimates) seem to be higher on average than level estimates. Whether this is in fact true is not only an interesting econometric phenomenon, it may also have important consequences form a policy perspective. If the within-firm measure is a better indicator of what happens when a firm invests in R&D, and the between-firm measure gives a better idea of the industry or economy-wide productivity gains which might be induced by R&D subsidies, than higher cross sectional estimates point to nontargeted as against targeted R&D subsidies. If the estimates in the time dimension are higher, targeted subsidies might be more appropriate.

## 3.3 Spillovers

So far we have explored the empirical relationship between R&D and productivity at the firm level without taking possible spillover effects into account, i.e., the distinction between private and social returns on R&D. Although the contribution of R&D spillovers to productivity growth has long since been acknowledged, it is only recently that the empirical measurement of the magnitude and direction of such effects has become a major point on the research agenda for the economics of innovation. The measurement and assessment of the impact of R&D spillovers within and between industry sectors should help governments to better identify the scientific and technological policies necessary for the enhancement of innovative activities at the firm level. Table 6 summarises the findings reported in some selected studies which have focused on the measurement of technological spillovers on the economic performances of firms.

Only a small number of studies have estimated the impact of spillovers at the firm level. Some of these studies have based their investigations on the impact of spillovers on production costs, rather than on productivity gains (total factor productivity growth). Another important point that differentiates these studies is the proximity measure considered in the establishment of the spillover pool. Among the studies reported in Table 6, two main approaches for modelling these proximities must be distinguished. The first one attaches the same weight to the R&D of all firms, and the second one locates firms into a patent space.[17]

All the studies reported in Table 6, except the last two, examine the impact of technological spillovers on productivity growth. Furthermore, all studies, with the exception of *Branstetter* (1996), which takes Japanese and US firms into consideration, and *Cincera* (1998), which considers European firms as well, are based on samples of firms operating in a single country. The first three and the last two studies use an unweighted sum of the R&D of all other firms. The other studies implement *Jaffe´s* framework (1986, 1989), in which the technological proximity between firms is characterised by their relative position in a patent space. Besides these differences, some studies distinguish between local (LS) and external (ES) or domestic (NS) and foreign (IS) components of the spillover pool. The local stock is defined as the pool of spillovers generated by firms which are specialised in similar technological activities, whereas the external stock comprises spillovers from firms in technologically different activities.

In most cases, the estimated elasticities and/or rates of return of R&D spillovers are significant and positive. *Jaffe* (1988) finds a positive effect of spillovers generated by firms which are technologically close in his sample of US firms in the 1970s. *Cincera* (1998), who applied a similar approach to a sample of US firms during the period 1987 to 1994, found estimates which are remarkably close to the ones reported by Jaffe. The only important difference concerns the local spillover component, which is somewhat higher in Cincera´s study.

*Bernstein* (1988) provides econometric evidence on the private and social returns on R&D in Canada, and distinguishes between intra-industry and inter-industry spillovers. He identifies the relative and

---

17. See *Griliches* (1992) and *Mohnen* (1996) for reviews.

absolute importance of spillovers according to the fact that social rates of return on R&D investments are substantially higher than private rates of return. In fact, inter-industry spillovers are relatively small for all of the sample industries (2%). Conversely, intra-industry spillovers are relatively large, particularly in industries that have a relatively high propensity to spend on R&D (up to 24%). In a related study, *Bernstein* and *Nadiri* (1989) find significantly positive intra-industry spillovers in four US industries (9%-16%).

*Griliches* (1992) summarises the results of econometric studies of rates of return on privately and publicly funded R&D in the United States. In absolute terms, the excess of the social over the private rates of return (spillovers) tends to cluster in the range of 18% to 20%. In relative terms, spillovers seem to create a gap between the private and social returns that is equal to 50% to 100% of the private rate of return. Additionally, he highlights the fact that there is no differential return between federal versus private R&D dollars at the firm level, although differences are evident at the industry level. It is suggested that the latter result reflects the differential rates of government R&D funding across industries.

In a recent paper, Branstetter (2001) provides estimates of the relative impact of intranational and international knowledge spillovers on innovation and productivity at the firm level, using panel data from the USA and Japan. His results suggest that spillover effects are more national than international in scope. This is confirmed by the results of *Cincera* (1998) for the USA, but not for Japan. Unable to find consistent effects for Europe, he concludes that,

> the sensitivity of firms to spillovers differs significantly among the three geographic areas. Indeed, the United States, Japan and Europe seem to adopt a very different behaviour. While US firms are mainly concerned with their national spillover stock, Japanese firms are more receptive to the international stock and European firms do not seem to particularly benefit from either sources of spillovers (p. 195).

Table 6

The *Australian Industry Commission* (1995) has summarised several studies at the industry level, which assess the returns on R&D. First, from the studies in table 7, the mean ratio of national (that is, private plus total spillover returns) to industry (that is, private plus intra-industry spillovers) returns on R&D is approximately 2.5 (90/37). That is, the social return on R&D is on average at least twice as high as the private return. Second, although it is not possible to directly compare intra- with inter-industry spillovers at the industry level, the latter appear to be more significant than the former. The mean inter-industry return amounts to 73%, compared to the returns of 37% at the industry level. Hence, if private rates of return (from which the firm profits) are positive, inter-industry spillovers must on average be more important than intra-industry spillovers.

*TABLE 7: Industry level econometric studies assessing the impacts of spillovers[a]*

| Study | Country | Time period covered | Rate of return to[b] Industry[c] | Firms in other industries | National[d] |
|---|---|---|---|---|---|
| Bernstein - Nadiri (1989) | USA | 1958 - 81 | 19 to 37 | 2 to 145 | 21 to 172 |
| Bernstein - Nadiri (1991) | USA | 1957 - 86 | 25 to 39 | 0 to 113 | 28 to 142 |
| Griliches - Lichtenberg (1984) | USA | 1959 - 78 | 11 to 31 | 69 to 90 | 41 - 62 |
| Scherer (1982) | USA | 1948 - 78 | 19 to 43 | 64 to 147 | 103 |
| Scherer (1984) | USA | 1973 - 78 | 29 | 74 to 104 | 103 |
| Sveikauskas (1981) | USA | 1959 - 69 | 7 to 25 | 50 | 57 to 75 |
| Terleckyj (1974) | USA | 1948 - 66 | 12 to 37 | 45 to 187 | 73 to 107 |
| Terleckyj (1980) | USA | 1948 - 66 | 25 to 27 | 82 to 183 | 107 to 110 |
| Wolff - Nadiri (1987) | USA | 1947 - 72 | 11 to 19 | 10 to 90 | 21 to 109 |
| Bernstein (1989) | Canada | 1963 - 83 | 34 to 57 | 0 to 70 | 39 to 104 |
| Hanel (1988) | Canada | 1971 - 82 | 50 | 100 | 150 |
| Mohnen - Lepine (1988) | Canada | 1975 - 83 | 15 to 284 | 2 to 90 | 21 to 329 |
| Goto - Suzuki (1989) | Japan | 1978 - 83 | 26 | 80 | 106 |
| Sterelacchini (1989) | UK | 1954 - 84 | 2 to 33 | 7 to 32 | 18 to 56 |
| Unweighted mean | | | 37 | 73 | 90 |
| Standard deviation | | | 53 | 55 | 67 |

a adapted from Australian Industry Commission (1995)
b gross rates of return (in some cases net rates of return have been converted to a gross rate of return assuming a depreciation rate of 10%; see AIC(1995))
c Industry return includes both The firm undertaking R&D and Other firms within the same industry returns
d National returns includes both the Industry and Ohter firms in other industries returns. As those industries wioth the lowest (highest) rate of return to the industry may not be those with the lowest (highest) rate of return to Firms in other industries, the National total may not represent the sum of the ranges.

# 4. Conclusions

In this paper, we have analysed the contribution of R&D to the growth performance of firms by reviewing the main empirical findings in the literature. The quantitative assessment of the R&D contribution to economic performance shows that R&D activities are an important factor in the explanation of growth. The main empirical findings may be summarised as follows:

First, despite considerable variation of the estimated returns to R&D from one study to another the results clearly suggest a positive and strong relationship between R&D expenditures and growth of output or total factor productivity. The reported private rates of return, if significant, are in a range of 7% to 69% and the elasticities are in a range of .02 to .38. The associated median (mean) rate of return is 27% (29%), and the median (mean) elasticity is .11 (.15).

Second, the studies confirm that R&D leads to the accruement of spillover benefits by other firms. The estimated elasticities and/or rates of return of R&D spillover variables are in most cases significant and positive. The spillover benefits observed in industry studies are on average two times higher than the private rates of return, yielding mean social rates of return (i.e., private return plus spillovers) to R&D to the order of 90% to 100%. Furthermore, most studies indicate that spillovers between industries are more important than those within industries.

Third, the studies indicate that the rates of return often vary between industries, sometimes significantly, but there is little consensus in the literature as to which industries generate higher returns and by how much these returns exceed those of other industries. The results of a meta-analysis suggest that there are some industries which exhibit below average elasticities of R&D compared to manufacturing as a whole. On the other hand, we could not confirm that the returns earned by scientific firms are consistently higher than the average.

Fourth, there is no clear picture as to whether the returns to R&D have changed over time. Several studies have found that the growth contribution of R&D has declined. However, there are also numerous studies which do not find any evidence of a decline over time. The meta-results indicate a significantly higher elasticity in the 1980s and consistently higher estimates for the 1990s, as compared to the 1970s. This suggests that R&D opportunities are not exhausted at all, and might well be promising in the future.

Fifth, most researchers conclude that the rates of return to R&D are of comparable magnitudes in different countries. This is confirmed by our meta-analysis. However, the elasticities are significantly lower in Europe and Japan, as compared to the US. Whether this is due to a higher R&D intensity or a more efficient use of R&D capital in the US or both is not clear. If R&D intensity in Europe is too low, political measures should be directed towards increasing the R&D expenditures initiated by European firms. If, however, R&D is less efficiently implemented by European firms, traditional measures (i.e., subsidisation or special forms of taxation for R&D) will not be effective. In this case, measures directed towards organisational and structural change within firms and industries might be more appropriate.

## References:


Antonelli, Cristiano (1994), Technological districts localized spillovers and productivity growth. The Italian evidence on technological externalities in the core regions, *International Review of Applied Economics*, 8 (1), 18-30.

Australian Industry Commission (1995), *Research and development*, Report no. 44. Canberra: Australian Government Publishing Service.

Baltagi, Badi H. (1995), *Econometric analysis of panel data*, New York: John Wiley and Sons.

Bartelsman, Eric J., van Leeuwen, George, Nieuwenhuijsen, Henry and Zeelenberg, Kees (1996), R&D and productivity growth: Evidence from firm-level data in the Netherlands, *Netherlands Official Statistics*, 11 (Autumn), 52-69.

Bernstein, Jeffrey I. (1988), Costs of production, intra- and inter-industry R&D spillovers: Canadian evidence*, Canadian Journal of Economics*, 21 (2), 324-47.

Bernstein, Jeffrey I. (1989), The Structure of Canadian interindustry R&D spillovers and the rates of return to R&D, *Journal of Industrial Economics*, 37 (3), 315-28.

Bernstein, Jeffrey I. and Nadiri, Ishaq M. (1988), Interindustry R&D spillovers, rates of return, and production in high-tech industries, *American Economic Review*, 78 (2), 429-34.

Bernstein, Jeffrey I. and Nadiri, Ishaq M. (1989) Research and Development and intraindustry spillovers: An empirical application of dynamic duality, *Review of Economic Studies*, 56, 249-69.

Bernstein, Jeffrey I. and Nadiri, Ishaq M. (1991) Product Demand, cost of production, spillovers and the social rate of return to R&D, *NBER Working Paper* no. 3625, Cambridge, Mass.: National Bureau of Economic Research.

Branstetter, Lee G. (1996), Are knowledge spillovers international or intranational in scope? Microeconomic evidence from the US and Japanese R&D intensive sectors, *NBER Working Paper* no. 5800, Cambridge, Mass.: National Bureau of Economic Research.

Branstetter, Lee G. (2001) Are knowledge spillovers international or intranational in scope? Microeconometric evidence from the U.S. and Japan, *Journal of International Economics*, 53, 53-79.

Capron, Henri (1993) *Economic quantitative methods for the evaluation of the impact of R&D programmes – A state of the art*, Luxembourg: Commission of the European Communities, Science and Technology Policy Series.

Cincera, Michele (1998) *Technological and Economic Performances of International Firms*, Ph.D. thesis, Université Libre de Bruxelles, Belgium.

Clark, Kim and Griliches, Zvi (1984), Productivity Growth and R&D at the Business Level: Results of the PIMS Data Base, in Z. Griliches (ed.), *R&D, Patents and Productivity*, Chicago: University of Chicago.

Coe, David T. and Helpman, Elhanan (1995) International R&D Spillovers*, European Economic Review,* 39 (5), 859-87.

Cohen, Wesley M. and Levin, Richard C. (1989) Empirical studies of innovation and market structure, in R. Schmalensee and R. D. Willig (eds.), *Handbook of Industrial Organisation* vol. II, Amsterdam: Elsevier Science Publishers, B.V.

Cunéo, Phillipe and Mairesse, Jacques (1984) Productivity and R&D at the firm level in French manufacturing, in Z. Griliches (ed.), *R&D, Patents and Productivity*, Chicago: University of Chicago.

Dempster, Peter (1994) Empirical estimates of external returns to business expenditure on R&D: An introduction to the literature*, BIE Working Paper* no. 91, Canberra: Bureau of Industry Economics.

Englander, Steven A., Evenson, Robert E. and Hanazaki, Masaharu (1988) R&D, innovation and the total factor productivity slowdown, *OECD Economic Studies*, no. 11 (Autumn), 7–42.

Fecher, F. (1990) Effects directs et inderects de la R&D sur la productivite: une analyse de l´industrie manufacturiere Belge, *Cahiers Economiques de Bruxelles*, 128 (4), 459-82.

Goto, A., Suzuki, K. (1989) R&D capital, rate of return on R&D investment and spillover of R&D in Japanese manufacturing industries, *Review of Economics and Statistics*, 71 (4), 555-64.

Griliches, Zvi (1973) Research expenditures and growth accounting, in Z. Williams (ed.), *Science and technology in economic growth*, London: Macmillan.

Griliches, Zvi (1979) Issues in assessing the contribution of research and development to productivity growth*, Bell Journal of Economics*, 10 (1), 92-116.

Griliches, Zvi (1980) R&D and the productivity slowdown, *American Economic Review*, 70 (2), 343-48.

Griliches, Zvi (1986) Productivity, R&D and basic research at the firm level in the 1970s, *American Economic Review*, 76, 141-54.

Griliches, Zvi (1992) The search for R&D spillovers*, Scandinavian Journal of Economics*, 94, 29-48.

Griliches, Zvi (1998) R&D and productivity: The unfinished business, in: Z. Griliches (ed.), *R&D and productivity: The econometric evidence*, University of Chicago Press.

Griliches, Zvi and Lichtenberg, Frank (1984) Inter-industry technology flows and productivity growth: A re-examination, *Review of Economics and Statistics,* vol. 66, no. 2, 324–29.

Griliches, Zvi and Mairesse, Jacques (1983) Comparing productivity growth: An exploration of French and US industrial and firm data, *European Economic Review*, 21, 89-119.

Griliches, Zvi and Mairesse, Jacques (1984) Productivity and R&D at the firm level, in Z. Griliches (ed.*), R&D, Patents and productivity*, University of Chicago Press.

Griliches, Zvi and Mairesse, Jacques (1990) R&D and productivity growth: Comparing Japanese and US manufacturing firms, in: C. Hulten (ed.), *Productivity growth in Japan and the United States*, University of Chicago Press.

Griliches, Zvi and Mairesse, Jacques (1998) Production functions: The search for identification, in: The Ragnar Frisch centennial symposium, S. Ström (ed.). *Economic Society Monograph Series*. Cambridge: Cambridge University Press.

Hall, Bronwyn H. (1993) The stock market´s valuation of R&D investment during the 1980s, *American Economic Review*, 83 (2), 259-64.

Hall, Bronwyn H. and Mairesse, Jacques (1993) Exploring the productivity of Research and Development in French manufacturing firms, no. 9326, Institut National de la Statistique et des Etudes Economiques, Paris, 1– 45.

Hall, Bronwyn H. and Mairesse, Jacques (1995) Exploring the relationship between R&D and productivity in French manufacturing firms, *Journal of Econometrics*, 65, 263–93.

Hall, Bronwyn H. (1996) The private and social returns to research and development, in B. Smith and C. Barfield (ed.), *Technology, R&D, and the economy*, Washington, D.C., Brookings Institution and AEI.

Hanel, Petr (1988) L'Effet des depenses en R&D sur la productivite de travail au Quebec, *L'Actualite Economique*, 64 (3), 396–415.

Harhoff, Dietmar (1994) R&D and productivity in German manufacturing firms, *ZEW discussion paper* no. 94-01, Mannheim: Zentrum für Europäische Wirtschaftsforschung.

Jaffe, Adam B. (1986) Technological opportunity and spillovers of R&D: Evidence from firms´ patents, profits and market value, *American Economic Review*, 76, 984-1001.

Jaffe, Adam B. (1988) R&D Intensity and productivity growth, *Review of Economics and Statistics*, 70, 431-37.

Jaffe, Adam B. (1989) Characterizing the `technological position´ of firms, with application to quantifying technological opportunity and research spillovers, *Research Policy*, 18, 87-97.

Klette, Tor J. (1994) R&D, spillovers and performances among heterogeneous firms – An empirical study using microdata, *Discussion Paper* no. 133, Research department, Statistics Norway.

Lichtenberg, Frank R. and Siegel, Donald (1991) The impact of R&D investment on productivity – New evidence using linked R&D – LRD data, *Economic Inquiry*, 19 (2), 535-51.

Link, Albert N. (1981) *Research and development activity in U.S. Manufacturing*, New York.

Link, Albert N. (1983) Inter-firm technology flows and productivity growth, *Economics Letters*, 11 (2), 179-84.

Los, Bart and Verspagen, Bart (1996) R&D spillovers and productivity: Evidence from U.S. manufacturing microdata, paper presented at the 6th Conference of the International Joseph A. Schumpeter Society, June 2-5, 1996, Stockholm, Sweden.

Mairesse, Jacques (1990) Time-series and cross-sectional estimates on panel data: Why are they different and why should they be equal?, in J. Hartog, G. Ridder and J. Theeuwes (eds.), *Panel data and labor market studies*, Elsevier Science Publishers B.V., North-Holland.

Mairesse, Jacques and Cunéo, Phillipe (1985), Recherche-développement et performances des entreprises: une etude econométrique sur données individuelles, *Revue Economique*, 36, 1001-42.

Mairesse, Jacques and Sassenou, Mohamed (1991) R&D and productivity: A survey of econometric studies at the firm level, *NBER Working Paper* no. 3666. Cambridge, Mass.: National Bureau of Economic Research.

Mairesse, Jacques and Mohnen, Pierre (1995) R&D and productivity: A survey of the econometric literature. Institut National de la Statistique et des Etudes Economiques (INSEE), Paris, Mimeograph.

Mairesse, Jacques and Hall, Bronwyn H. (1996) Estimating the productivity of research and development: An exploration of GMM methods using data on French and United States manufacturing firms, *NBER Working Paper* no. 5501. Cambridge, Mass.: National Bureau of Economic Research.

Mansfield, Edwin (1980) Basic research and productivity increase in manufacturing, *American Economic Review*, 70, 863-73.

Mansfield, Edwin (1973) Determinants of the speed of application of new technology, in B. R. Williams (ed.*), Science and Technology in Economic Growth*, London: McMillan Press.

Minasian, Jora R. (1962) The Economics of research and develompment, in R. Nelson (ed.), *The rate and direction of inventive activity: Economic and social factors*, National Bureau of Economic Research.

Minasian, Jora R. (1969) Research and development, production functions, and rates of return, *American Economic Review*, 59 (2), 80-86.

Mohnen, Pierre and Lépine, Normand (1988) Payments for technology as a factor of production, *Cahier no. 8810*, Departement des Sciences Economiques, Université du Quebec a Montreal.

Mohnen, Pierre and Lépine, Normand (1991) R&D, R&D spillovers and payments for technology: Canadian evidence, *Structural Change and Economic Dynamics*, 2 (1), 213-28.

Mohnen, Pierre, Nadiri, Ishaq M. and Prucha, Ingmar R. (1986) R&D, production structure and rate of return in the US, Japanese and German Manufacturing Sector: A Non-Separable Dynamic Factor Demand Model, *European Economic Review*, 30, 749-71.

Mohnen, Pierre (1996) R&D externalities and productivity growth, *STI Review*, 18, 39-66.

Nadiri, Ishaq M. (1993) Innovations and technological spillovers, *NBER Working Paper* no. 4423. Cambridge, Mass.: National Bureau of Economic Research.

Odagiri, Hiroyuki (1983) R&D expenditures, royalty payments, and sales growth in Japanese Manufacturing corporations, *Journal of Industrial Economics*, 32 (1), 61-71.

Odagiri, Hiroyuki and Iwata, Hitoshi (1986) The Impact of R&D on productivity increase in Japanese Manufacturing companies, *Research Policy*, 15, 13-19.

O´Mahoney, Mary and Vecchi, Michela (2000) Tangible and intangible investment and economic performance: Evidence from company accounts, in P. Buigues, A. Jacquemin and J.-F. Marchipont (eds.), *Competitiveness and the value of intangible assets*, Edward Elgar Publishing Limited.

Pakes, Ariel and Schankerman, Mark (1978) The rate of obsolescence of patents, research gestation lags and the private rate of returns to research resources, *Discussion Paper* no. 659, Harvard Institute of Economic Research.

Pakes, Ariel and Schankerman, Mark (1984) The rate of obsolescence of patents, research gestation lags, and the private rate of return to research resources, in Z. Griliches (ed.), *R&D, Patents and Productivity*, Chicago: University of Chicago.

Raut, Lakshmi K. (1995) R&D spillovers and productivity growth: Evidence from Indian private firms, *Journal of Development Economics*, 48 (1), 1-23.

Sassenou, Mohamed (1988) *Recherche-developpement et productivite dans les entreprises Japonaises: Une etude econometrique sur donnes de panel*, These de doctorat, Ecole des Hautes Etudes en Sciences Sociales, Paris.

Schankerman, Mark (1981) The effects of double-counting and expensing on the measured returns to R&D, *Review of Economics and Statistics*, 63, 454-58.

Scherer, Frederic M. (1982), Inter-industry technology flows and productivity growth, *Review of Economics and Statistics,* vol. 64, no. 4, 627–34.

Scherer, Frederic M. (1983) Concentration, R&D, and productivity change, *Southern Economic Journal*, July, 221–25.

Scherer, Frederic M. (1984) Using linked patent and R&D data to measure inter-industry technology flows, in Z. Griliches (ed.), *R&D, Patents and Productivity*, Chicago: University of Chicago Press.

Scherer, Frederic M. (1993) Lagging productivity growth: Measurement, technology and shock effects, *Empirica*, 20 (1), 5–24.

Solow, Robert M. (1957) Technical change and the aggregate production function, *Review of Economics and Statistics*, 31, 312-20.

Sterlacchini, Alessandro (1989) R&D, innovations and total factor productivity growth in British manufacturing, *Applied Economics*, 21 (11), 1549–62.

Sveikauskas, Leo (1981) Technological inputs and multifactor productivity growth, *Review of Economics and Statistics*, 63 (1), 275-82.

Terleckyi, Nester E. (1974), *Effects of R&D on the productivity growth of industries: An explanatory study*, Washington, D.C.: National Planning Association.

Terleckyi, Nester E. (1980) Direct and indirect effects of industrial research and development on the productivity growth of industries, in J. N. Kendrick and B. N. Vacara (eds.), *New developments in Productivity Measurement and Analysis*, Chicago: University of Chicago Press.

Wakelin, Katharine (2000) Productivity growth and R&D expenditure in UK Manufacturing firms, GLM Research Paper 2000/20, Centre for Research on Globalisation and Labour Markets, University of Nottingham.

Wolff, Edward N. and Nadiri, Ishaq M. (1987) *Spillover effects, linkage structure, technical progress and research and development*, C.V. Starr Research Report no. 87/43.

*TABLE 2: Firm level econometric estimates of the rate of return to R&D*

| Study | Country | Time period covered | Nr. of firms, industries | Specification[b] | Econometric model[c] | Rate of return | s.e.[d] |
|---|---|---|---|---|---|---|---|
| Minasian (1962) | USA | 1947-57 | 18, Chemicals | TFP - VA | pooled, F.D. | .25 | (.04)* |
| Mansfield (1980) | USA | 1960-76 | 16, Petrol. & Chemicals | TFP - VA | pooled, F.D. | .27 | (.07)* |
| Odagiri & Iwata (1986) | Japan | 1966-73 | 135 | TFP - VA | pooled, F.D. | .20 | (.11)** |
| " | " | " | " | TFP-VA-ID | " | .17 | (.13) |
| " | " | 1974-82 | 135 | TFP - VA | " | .17 | (.06)* |
| " | " | " | " | TFP-VA-ID | " | .11 | (.06)** |
| Griliches & Mairesse (1984) | USA | 1966-77 | 133 | Sales | pooled, calc. | .35 | |
| " | " | " | " | " | within, calc. | .64 | |
| Odagiri (1983) | Japan | 1969-81 | 123, scientific sectors | TFP-Sales | pooled, F.D. | .26 | (.10)* |
| " | " | " | 247, other sectors | " | " | -.47 | (.29) |
| Link (1981) | USA | 1971-76 | 174 | TFP - VA | pooled, F.D. | -.00 | (.03) |
| " | " | " | 19, Transport | " | " | .15 | (.21) |
| " | " | " | 33, Chemicals | " | " | .07 | (.03)* |
| " | " | " | 34, Mechanical | " | " | .05 | (.07) |
| Lichtenberg & Siegel (1991) | USA | 1972-85 | 5240 | TFP-Sales-ID | pooled, F.D. | .13 | (.02)* |
| Griliches & Mairesse (1983) | USA, France | 1973-78 | 343 US + 185 French | Sales | pooled, F.D. | .28 | (.06)* |
| " | " | " | " | Sales-ID | " | .12 | (.06)* |
| " | USA | " | 343 | Sales | " | .19 | (.11)** |
| " | " | " | 57, Drugs | " | " | .41 | (.23)** |
| " | " | " | 62, Chemicals | " | " | -.10 | (.36) |
| " | " | " | 65, Electronics | " | " | -.06 | (.19) |
| " | " | " | 47, Electrical equipment | " | " | -.44 | (.33) |
| " | " | " | 112, Machinery | " | " | .11 | (.27) |
| " | France | " | 185 | " | " | .31 | (.07)* |
| " | " | " | 47, Drugs | " | " | .27 | (.15)** |
| " | " | " | 30, Chemicals | " | " | .00 | (.23) |
| " | " | " | 37, Electronics | " | " | .12 | (.11) |
| " | " | " | 34, Electrical equipment | " | " | .45 | (.24)** |
| " | " | " | 39, Machinery | " | " | -.55 | (.38) |
| Griliches & Mairesse (1990) | Japan | 1973-80 | 406 | Sales | pooled, F.D. | .56 | (.23)* |
| " | " | " | " | Sales-ID | " | .30 | (.21)** |
| " | USA | " | 525 | Sales | " | .41 | (.09)* |
| " | " | " | " | Sales-ID | " | .27 | (.10)* |
| " | Japan | " | 406 | Sales | pooled, F.D., calc | .20 | (.21) |
| " | USA | " | 525 | " | " | .25 | (.10)* |
| Sassenou (1988) | Japan | 1973-81 | 394 | Sales | pooled, F.D. | .69 | (.19)* |
| " | " | " | " | VA | " | .22 | (.11)* |
| " | " | " | " | VA-ID | " | -.02 | (.07)* |
| Link (1993) | USA | 1975-79 | 302 | TFP-Sales | pooled, F.D. | .06 | (.04) |
| Goto & Suzuki (1989) | Japan | 1976-84 | 13, Drugs | TFP - VA | pooled, F.D. | .42 | (.12)* |
| " | " | " | 5, Electrical | " | " | .22 | (.10)* |
| " | " | " | 3, Motor vehicles | " | " | .33 | (.14)* |
| Fecher (1990) | Belgium | 1981-83 | 292 | TFP-Sales-ID | pooled, F.D. | .04 | (.06) |
| " | " | " | 113, scientific sector | " | " | .05 | (.04) |
| Hall & Mairesse (1995) | France | 1980-87 | 197 | VA | pooled, F.D. | .23 | (.05)* |
| " | " | " | " | VA-DC | " | .27 | (.06)* |
| " | " | " | " | VA | L.D. | .04 | (.05) |
| " | " | " | " | VA-DC | " | .06 | (.06) |
| Bartelsman & al. (1996) | Netherlands | 1985-89 | 209 | VA-DC | L.D. | .22 | (.08)* |
| " | " | 1989-93 | 159 | " | " | .17 | (.08)* |
| Cincera (1998) | World | 1987-94 | 625 | Sales | pooled, F.D. | .38 | (.06)* |
| " | " | 1989-93 | 2445 (unbalanced) | " | " | .05 | -0.04 |
| Wakelin (2000) | UK | 1988-96 | 98 | Sales | | .34 | (.18)* |
| " | " | " | " | Sales-ID | " | .28 | (.21) |

a adapted and extended from Mairesse and Sassenou (1991); Mairesse and Mohnen (1995) and Cincera (1998).
b TFP = total factor productivity; VA = value-added; ID = inclusion of industry dummies; DC = correction for the double counting of R&D; I2Def = Industry 2 digit level deflators
c SPPI = sector-level producer price index; F.D. = first differences; L.D. = long diff.
d Standard Error, * (**) = statistically significant at the 5% (10%) level

*TABLE 3: Estimates of the elasticity of R&D, level dimensions[a]*

| Study | Country | Time period covered | Nr. of firms, industries | Specification[b] | Econometric model | Elasticity | s.e.[c] |
|---|---|---|---|---|---|---|---|
| Shankerman (1981) | USA | 1963 | 110, Chemicals and Oil | VA | Cross-section | .10 | (.04)* |
| " | " | " | " | VA-DC | " | .16 | (.03)* |
| " | " | " | 187, Metals & Machinery | VA | " | .02 | -0.02 |
| " | " | " | " | VA-DC | " | .10 | (.02)* |
| " | " | " | 101, Electric. Equipment | VA | " | .03 | (.02)** |
| " | " | " | " | VA-DC | " | .23 | (.03)* |
| " | " | " | 34, Motor vehicles | VA | " | .07 | (.05)* |
| " | " | " | " | VA-DC | " | .10 | (.05)* |
| " | " | " | 31, Aircraft | VA | " | .03 | (.03)* |
| " | " | " | " | VA-DC | " | .30 | (.05)* |
| " | " | " | 419, Miscellaneous | VA | " | .04 | (.01)* |
| " | " | " | " | VA-DC | " | .06 | (.01)* |
| Griliches (1980) | USA | 1963 | 883 | VA | Cross-section | .07 | (.01)* |
| Griliches (1986) | USA | 1972 | 491 | VA | Cross-section | .11 | (.02)* |
| " | " | " | " | VA-ID | " | .09 | (.02)* |
| Sassenou (1988) | Japan | 1976 | 394 | VA | Cross-section | .10 | (.01)* |
| " | " | " | 112, Scientific | " | " | .16 | (.03)* |
| " | " | " | " | ID | " | .07 | (.02)* |
| Minasian (1969) | USA | 1948-1957 | 17 | VA | Total | .11 | (.01)* |
| Griliches-Mairesse (1984) | USA | 1966-1977 | 133 | Sales | Total | .05 | (.01)* |
| " | " | " | 77, Scientific | " | " | .18 | (.01)* |
| Cuneo-Mairesse (1984) | France | 1972-1977 | 182 | VA | Total | .20 | (.01)* |
| " | " | " | 98, Scientific | VA | " | .11 | (.01)* |
| " | " | " | " | VA-DC | " | .21 | (.01)* |
| " | " | " | " | Sales | " | .18 | (.02)* |
| Harhoff (1994) | Germany | 1977-1989 | 443 | Sales | Total | .15 | |
| Hall-Mairesse (1995) | France | 1980-1987 | 197 | VA | Total | .18 | (.01)* |
| " | " | " | " | VA-DC | " | .25 | (.01)* |
| Mairesse - Hall (1996) | USA | 1981-1989 | 1073 | Sales-I1Def | Total | .03 | (.01)* |
| " | " | " | " | Sales | " | .25 | (.01)* |
| " | France | 1981-1989 | 1232 | Sales-I1Def | " | .10 | (.01)* |
| " | " | " | " | Sales | " | .10 | (.01)* |
| " | " | " | " | VA | " | .09 | (.00)* |
| " | " | " | " | VA-DC | " | .16 | (.00)* |
| Bartelsman & al. (1996) | Netherlands | 1985-1989 | 209 | VA | Total | .01 | (.02)* |
| " | " | " | " | VA-DC | " | .05 | (.01)* |
| " | Netherlands | 1989-1993 | 159 | VA | " | .04 | (.02)* |
| " | " | " | " | VA-DC | " | .16 | (.00)* |
| Cincera (1998) | World | 1987-1994 | 625 | Sales | Total | .11 | (.01)* |
| " | " | " | " | Sales-ID | " | .19 | (.01)* |
| " | " | " | " | Sales-GD | " | .08 | (.01)* |
| " | " | 1987-1990 | " | Sales | " | .09 | (.01)* |
| " | " | 1991-1994 | " | " | " | .12 | (.01)* |
| " | Europe | 1987-1994 | 101 | Sales | " | .10 | (.01)* |
| " | Japan | " | 133 | " | " | .02 | (.01)* |
| " | USA | " | 378 | " | " | .09 | (.01)* |
| " | World | 1980-1994 | 2445 (unbalanced) | " | " | .13 | (.00)* |
| O´Mahoney - Vecchi (2000) | Europe, USA | 1988-1997 | 783 | Sales | Total | .03 | (.01)* |

a adapted and extended from Mairesse and Sassenou (1991); Mairesse and Mohnen (1995) and Cincera (1998).
b VA = value-added; DC = correction for double counting of R&D; ID = inclusion of industry dummies; GD = inclusion of country dummies; I1Def = single manufacturing sector deflator (Sales is usually deflated by 2- or 3-digit industry deflators)
c Standard Error, * (**) = statistically significant at the 5% (10%) level

*TABLE 4: Estimates of the elasticity of R&D, temporal dimensions[a]*

| Study | Country | Time period covered | Nr. of firms, industries | Specification[b] | Econometric model[c] | Elasticity | s.e.[d] |
|---|---|---|---|---|---|---|---|
| Griliches (1980) | USA | 1957-1965 | 883 | PFP-ID | Between | .08 | (.01)* |
| " | " | " | 110, Chemicals & Petroleum | PFP | " | .09 | (.04)* |
| " | " | " | 187, Metals & Machinery | " | " | .10 | (.02)* |
| " | " | " | 101, Electric. Equipment | " | " | .11 | (.03)* |
| " | " | " | 34, Motor vehicles | " | " | .13 | (.07)* |
| " | " | " | 31, Aircraft | " | " | .11 | (.08)* |
| " | " | " | 419, Miscellaneous | " | " | .05 | (.01)* |
| Griliches - Mairesse (1983) | USA, Japan | 1973-1978 | 343 + 185 | Sales | Between | .02 | (.03) |
| Sassenou (1988) | Japan | 1973-1981 | 394 | VA | Between | .04 | (.04) |
| Cincera (1998) | World | 1987-1994 | 625 | Sales | Between | .10 | (.01)* |
| Mairesse - Hall (1996) | France | 1981-1989 | 1232 | Sales-I1Def | Total, F.D. | -.00 | (.00) |
| " | " | " | " | Sales | " | -.00 | (.00) |
| " | " | " | " | VA | " | -.00 | (.00)** |
| " | USA | 1981-1989 | 1073 | Sales-I1Def | " | .01 | (.02) |
| " | " | " | " | Sales | " | .09 | (.03)* |
| Cincera (1998) | World | 1987-1994 | 625 | Sales | Total, F.D. | .33 | (.04)* |
| " | " | 1987-1990 | " | " | " | .38 | (.07)* |
| " | " | 1991-1994 | " | " | " | .26 | (.05)* |
| " | Europe | 1987-1994 | 101 | " | " | .27 | (.10)* |
| " | Japan | " | 133 | " | " | .29 | (.11)* |
| " | USA | " | 378 | " | " | .29 | (.04)* |
| " | World | 1980-1994 | 2445 (unbalanced) | " | " | .28 | (.02)* |
| O´Mahoney - Vecchi (2000) | Europe, USA | 1988-1997 | 783 | Sales | Total, F.D. | .33 | (.05)* |
| " | " | " | 157, Chemicals | " | " | .35 | (.07)* |
| " | " | 1993-1997 | 362 , Machinery | " | " | .19 | (.04)* |
| " | USA | " | 151, Machinery | " | " | .30 | (.06)* |
| " | Japan | " | 107, Machinery | " | " | .11 | (.08) |
| " | Europe | " | 104, Machinery | " | " | .07 | (.08) |
| Cincera (1998) | World | 1987-1994 | 625 | Sales | L.D. | .21 | (.09)* |
| Mairesse - Cuneo (1985) | Japan | 1974; 1979 | 390 | | L.D. | .02 | (.10) |
| Bartelsman & al. (1996) | Netherlands | 1985-1989 | 209 | VA-DC | L.D. | .25 | (.08)* |
| " | " | 1989-1993 | 159 | " | " | .18 | (.08) |
| Minasian (1969) | USA | 1948 - 1957 | 17 | VA | Within | .08 | (.07) |
| Griliches - Mairesse (1984) | USA | 1966 - 1977 | 133 | Sales | Within | .09 | (.02)* |
| " | " | " | 77, Scientific | " | " | .02 | (.03) |
| Cuneo-Mairesse (1984) | France | 1972-1977 | 182 | VA | Within | .05 | (.04) |
| " | " | " | 98, Scientific | VA | " | .14 | (.05)* |
| " | " | " | " | VA-DC | " | .17 | (.05)* |
| " | " | " | " | Sales | " | .03 | (.04)* |
| Sassenou (1988) | Japan | 1973 - 1981 | 394 | VA | Within | -.01 | (.01) |
| Hall-Mairesse (1995) | France | 1980-1987 | 197 | VA | Within | -.00 | (.04) |
| " | " | " | " | VA-DC | " | .07 | (.04)* |
| Mairesse - Hall (1996) | USA | 1981-1989 | 1073 | Sales-I1Def | Within | .04 | (.01)* |
| " | " | " | " | Sales | " | .17 | (.01)* |
| " | France | 1981-1989 | 1232 | Sales-I1Def | " | .01 | (.01) |
| " | " | " | " | Sales | " | .01 | (.01) |
| " | " | " | " | VA | " | -.02 | (.01) |
| Cincera (1998) | World | 1987-1994 | 625 | Sales | Within | .24 | (.04)* |
| " | " | 1987-1990 | " | " | " | .29 | (.07)* |
| " | " | 1991-1994 | " | " | " | .24 | (.05)* |
| " | Europe | 1987-1994 | 101 | " | " | .10 | (.04)* |
| " | Japan | " | 133 | " | " | .07 | (.04)* |
| " | USA | " | 378 | " | " | .19 | (.03)* |
| " | World | 1980-1994 | 2445 (unbalanced) | " | " | .21 | (.01)* |

a adapted and extended from Mairesse and Sassenou (1991); Mairesse and Mohnen (1995) and Cincera (1998).
b VA = value-added; DC = correction for double counting of R&D; ID = inclusion of industry dummies; GD = inclusion of country dummies;
I1Def = single manufacturing sector deflator (Sales is usually deflated by 2- or 3-digit industry deflators)
c F.D. = first differences; L.D. = long diff.
c Standard Error, * (**) = statistically significant at the 5% (10%) level

*TABLE 6: Firm level econometric studies assessing the impacts of spillovers[a]*

| Study | Country | Time period covered | Nr. of firms, industries | Specification | weighting matrix | spillover variable [b] | elasticity or rate of return (%) |
|---|---|---|---|---|---|---|---|
| **production function appr.** | | | | | | | |
| Raut (1995) | India | 1975-86 | 192 | Cobb-Douglas | Unweighted sum | DNS | .06%* to .36%* |
| Antonelli (1994) | Italy | 1984-85 | 92 | Cobb-Douglas, F.D. | Unweighted sum | DNS | insignificant |
| Klette (1994) | Norway | 1989-90 | 804 plants, 3 industries | non parametric productivity analysis | Unweighted sum of R&D in plants: within same business line within same group | D | significant% |
| " | " | " | " | | across lines of business within same firm | D | insignificant% |
| " | " | " | " | | across lines of business within same group | D | significant% |
| Fecher (1990) | Belgium | 1981-83 | 292 | Cobb-Douglas L.D. | I/O flows | K/S | 2%* |
| " | | " | " | " | " | NS/S | .5%* |
| " | | " | " | " | " | IS/S | -1% |
| Harhoff (1994) | Germany | | 443 | | Position (of firm) in R&D space | | .03* |
| Jaffe (1988) | USA | 1972-77 | 434 | Cobb-Douglas L.D. | Position (of firm) in patent space | K/S | 1.3%*-15%* |
| " | | " | " | " | | Dln(LS) | .10%-.25%* |
| " | | " | " | " | | D(ES/LS) | .00035 |
| Jaffe (1989) | USA | 1972-77 | 434 | Cobb-Douglas L.D. | " | DK | .03* |
| " | " | " | " | " | " | DNS | .13* |
| " | " | " | " | " | " | DK+DNS | .01 |
| " | " | " | low tech | " | " | DNS | .13* |
| " | " | " | medium tech | " | " | DNS | .15* |
| " | " | " | hi-tech | " | " | DNS | .17* |
| Branstetter (1996) | USA | 1983-89 | 209 | Cobb-Douglas L.D. | Position (of firm) in patent space | DK | .36* |
| " | " | " | " | " | " | DNS | .83** |
| " | " | " | " | " | " | DIS | -.48 |
| " | Japan | 1983-89 | 205 | " | " | DK | .01 |
| " | " | " | " | " | " | DNS | .70* |
| " | " | " | " | " | " | DIS | .38 |
| Los & Verspagen (1996) | USA | 1974-93 | 485 | Cobb-Douglas Within | Position (of industry) in patent space | K | .02* |
| " | | " | | " | Position (of industry) in patent space | TS | .51* |
| " | | " | | " | Unweighted sum | TS | .53* |
| Cincera (1998) | World | 1987-94 | 625 | Cobb-Douglas Within | Position (of firm) in patent space | Dln(TS) | 1.11* |
| " | " | " | " | " | " | Dln(LS) | 0.25* |
| " | " | " | " | " | " | Dln(ES) | 0.59* |
| " | " | " | " | " | " | Dln(NS) | -0.31* |
| " | " | " | " | " | " | Dln(IS) | 1.03* |
| " | " | " | " | Cobb-Douglas F.D. | " | Dln(TS) | 0.94* |
| " | " | " | " | " | " | Dln(LS) | .24* |
| " | " | " | " | " | " | Dln(ES) | .60* |
| " | " | " | " | " | " | Dln(NS) | -.19* |
| " | " | " | " | " | " | Dln(IS) | .65* |
| " | Europe | 1987-94 | 101 | Cobb-Douglas Within | " | Dln(NS) | .13 |
| " | " | " | " | " | " | Dln(IS) | .32 |
| " | " | " | " | Dobb-Douglas F.D. | " | Dln(NS) | .13 |
| " | " | " | " | " | " | Dln(IS) | .06 |
| " | Japan | 1987-94 | 133 | Cobb-Douglas Within | " | Dln(NS) | -.17 |
| " | " | " | " | " | " | Dln(IS) | .91* |
| " | " | " | " | Dobb-Douglas F.D. | " | Dln(NS) | -.23 |
| " | " | " | " | " | " | Dln(IS) | 1.46* |
| " | USA | 1987-94 | 378 | Cobb-Douglas Within | " | Dln(NS) | .69* |
| " | " | " | " | " | " | Dln(IS) | -.02 |
| " | " | " | " | Dobb-Douglas F.D. | " | Dln(NS) | .59* |
| " | " | " | " | " | " | Dln(IS) | -.43 |
| **Cost function appr.** | | | | | | | |
| Bernstein (1988) | Canada | 1978-88 | 680, 7 industries | Translog Pool | Unweighted sum | IntraS | 17%* to 24%* |
| " | " | " | " | | | InterS | 2%* |
| Bernstein & Nadiri (1989) | USA | 1965-78 | 48, 4 industries | Translog Pool | Unweighted sum | IntraS | 9* to 16* |

a adapted from Mohnen (1996) and Cincera (1998)
b NS=national stock; IS=international stock; LS=local stock; ES=external stock; TS=total stock
Note: By local stocks, we mean spillovers generated by firms which are specialised in similar technological activities, whereas, by external stocks, we meann spillovers generated by firms which operate in different technological spaces

Medieninhaber (Verleger), Hersteller: Österreichisches Institut für Wirtschaftsforschung • Wien 3, Arsenal, Objekt 20 • A-1103 Wien, Postfach 91 • Tel. (43 1) 798 26 01-0 • Fax (43 1) 798 93 86 • http://www.wifo.ac.at/ • Verlags- und Herstellungsort: Wien



Verkaufspreis: ATS 100,00 bzw. EUR 7,27