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Abstract

The study presents the positive external effects (spillovers) of investments in research and development in manufacturing industries, in Israel and abroad. This examination quantifies the spillover of domestic and imported technologies, through intermediates and capital goods, to establishments that did not participate directly in the research and development process. The analysis examines the interactions between knowledge and R&D variables—including variables that are self-produced knowledge and those that spill over from outside. These interactions are examined among the variables themselves and between the variables and productivity, wages, and exports in the industry.

The estimates are based on a comprehensive data set of fixed prices for seventy-seven aggregate groups (three digits) for the 1990–1994 period. The framework of the analysis is the Cobb-Douglas production function, "input-output coefficients," and a simultaneous model in which output, R&D, capital, and exports are determined together and influenced by spillover, among other things.

The findings indicate that for manufacturing industries in Israel, as in other industrialized countries, R&D spillover has a considerable and significant impact on output and productivity. This finding applies to local R&D and to R&D produced in countries with which Israel maintains trade relations. Both types of R&D spillover were found to have a strong positive influence on self-produced R&D, as well as on wages in the industry and, indirectly, on exports. In fact, acquisition of knowledge and patents from other industries and from abroad contributed positively toward product and total productivity. Not surprisingly, the impact of spillover focused on high-tech industries, in which self-produced R&D and human capital are relatively high.

The rates of return on gross physical capital came to about 14 percent on average, as against 20 percent for (gross) capital from self-produced R&D in the industry. If the estimated returns from spillover are added, in which rates are higher than the direct impact of self-produced R&D according to the findings of the study, then the total social rate of return on investments in industrial R&D (both direct and indirect) will reach 40–50 percent per annum. This reflects the high relative profitability of capital formation in manufacturing R&D. From the perspective of the economy, there is a lack of investment in knowledge, innovation, and, apparently, in human capital as well. This phenomenon is understandable in case where manufacturers receive less than half of the return exchange for their investments in R&D, and the remainder of the return is allocated as a gift to other manufacturing firms.

Key words: R&D, spillovers, social rate of return.

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1. Introduction

This study examines, for the first time in regard to Israel, the overall positive external effects (spillovers) of research and development investment in manufacturing industries in Israel and abroad. The study also attempts to quantify the effects of total knowledge capital stock, including spillover of domestic and imported technology, via intermediates and capital goods, on establishments that did not work for it. Finally, the study assesses the main factors that determine the extent of self-produced R&D capital stock in various manufacturing industries and the interrelations of knowledge and R&D variables—self-produced R&D and that spilled over from elsewhere—among each other and between them and productivity, wages, and exports in the industry.

The conceptual framework is rooted in models of endogenous growth and technological progress, in which firms invest in R&D and innovation and acquire knowledge that enhances their productivity and rates of return. Some of this knowledge spills over, contributes to manufacturing at large, and functions as a increasing return to scale for production and long-term growth.1 There is conclusive evidence that this research, development, invention, and innovation activity has been central in modern economic growth.

Griliches (1979) defines two types of technology spillovers. The first type, rent spillovers, is related to the flow of products among firms. In this type of spillover, the price of any new product rarely reflects the full increase in product quality occasioned by innovation, due to competition pressures. If this product serves as an input in the production process of another firm, the latter firm receives some of the innovation in the product as a gift. The second type of spillover, pure knowledge spillover, is created by means of patents, researchers' mobility, and so on. It is usually assumed that this form of pure knowledge enhances the productivity of self-produced R&D. The present study attempts to examine both types of spillover influence in manufacturing establishments and industries in Israel.

Many studies around the world in recent years show how important the spillover effect is. These empirical studies demonstrate that the external advantages of spillover for firms that engage in R&D equal or even surpass the direct effect.2 Griliches summarizes these findings in his book:3

> R&D spillovers are present, their magnitude may be quite large, and social rates of return remains significantly above private rates.... Estimates imply ... the elasticity of output with respect to aggregate "outside" R&D, between about half of and double the elasticity of output with respect to private R&D.... R&D returns can account for up to half of the growth in output per worker and about three-quarters of measured TFP growth....

Notwithstanding the statistical difficulties that occur in such a study and the differences among studies in terms of estimation methods, definitions, and reliability of data, we found a similar and significant effect of R&D spillover on output and productivity in Israeli manufacturing. The results pointed to statistically significant external spillover effects of domestic R&D performed by other

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[1] See, for example, Grossman and Helpman, 1999; Helpman, 1998; and Griliches, 1998.

[2] Griliches, 1995, 1998. Since many of these empirical studies were performed at the level of countries and not of industries, it is difficult to compare and quantify the local spillover effect in each country individually. A study that overcomes this drawback, including Israel among the observations, was performed by Coe and Helpman, 1995.

[3] *R&D and Productivity, the Economic Evidence,* Chapter 11, "The Search for R&D Spillovers" (first published as an article in 1992).

industries and R&D performed in countries with which Israel has trade relations. It is also evident that this spillover, in its various manifestations, has a considerable positive effect on self-produced R&D, wages in the industry, and, indirectly, exports.

Following the accepted practice, we will use a Cobb-Douglas production function[4] to estimate output, with intermediates, labor hours, physical capital, and intangible knowledge capital as inputs. Several variables will reflect the contribution of technological progress: self-produced R&D capital stock in manufacturing industries, an index for the weighted domestic spillover of this R&D, an indicator of spillover of knowledge and R&D from abroad by means of imports of intermediates, and knowledge transfer effected in two ways: investment in modern machinery and equipment, and establishments in the industry that acquired patents and knowledge.

To create a basis for the estimation, we prepared, at this phase, a set of data in constant prices for seventy-seven aggregate groups (three digits) for the years 1990–1994. The data were processed from surveys of manufacturing, R&D, and innovation, and capital stock, and from other sources at the Israel Central Bureau of Statistics.[5] The spillover variables were based on the value of R&D capital stock in various industries and the weighting was performed by means of "input-output coefficients" for domestic manufacture and imports, after adjustment to the aggregate groups, according to an input-output table for 1992. We assumed that insofar as an industry purchases more intermediates from an R&D-intensive industry, the spillover to this industry will be greater. For example, spillover to an industry that purchases intermediates from an electronics industry should be several times greater than spillover to an industry that obtains a similar proportion of intermediates from textile industries.

Table 1a: Product, Factors, and Productivity in Manufacturing, 1990–1995
(Average annual quantity change, percent)

Product	7.5
Labor hours	4.7
Physical capital	6.4
R&D capital	6.0
Exports	9.0
Product per labor hour	2.7
TFP	2.2

In the first half of the 1990s, Israeli manufacturing was characterized by rapid export-oriented growth, at real annual average rates of 7.5 percent in product and 9 percent in exports (Table 1A). Exports were based largely on sophisticated high-tech products, knowledge, and human capital, mainly in high-tech industries but also in innovative establishments in low-tech industries (Table 1B). This process was based on research and development performed by these industries themselves since the early 1980s and on knowledge and innovation acquired abroad—by means of direct imports and as embodied in intermediates and machinery and equipment investments.

[4] Like previous studies on Israeli manufacturing, we obtained similar results from a more general production function, the "Translog." See Bregman, Fuss, and Regev, 1991, 1995, 1999. A Cobb-Douglas function was also used in a similar study on manufacturing establishments in Switzerland: Arvanitis and Hollenstein, 1988. Theoretically, cost functions could have been estimated as well. See, for example, Bernstein and Nadiri, 1988. However, the data available to use are still insufficient.

[5] A breakdown of data sources and computation of the variables appears in Part 2. For a list of the variables and their definitions, see Appendix F.

Notably, Israeli manufacturing evinces a relatively high rate of R&D investment in comparison with other industrialized countries and a larger share of such investment in turnover (about 2 percent) than the OECD average (Table 7). In terms of per-capita patents approved in the United States, too, Israel has been at the forefront of advanced countries since the early 1990s.[6]

It takes a relatively high level of human capital to perform R&D and take out patents. The variable in our study that reflects this is the proportion of engineers, degree holders, and technicians in employment, a proportion that climbed rapidly in the past decade. However, the labor force at large increased during the period reviewed (1990–1995) by approximately 5 percent per year, this growth included a large number of immigrants whose process of absorption and adjustment to modern manufacturing had just begun.[7] These developments should be reflected in the production and productivity equations that we will discuss in Part 4 below, where we analyze the estimation results. Before we do that, we present the database, the estimation methods, and the conceptual framework in Parts 2 and 3, below. We conclude the study with several remarks on the manufacturing policy warranted.

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[6]Trajtenberg, 1999.

[7] For an extensive analysis of the development of Israeli manufacturing during this time, see *Bank of Israel Reports* for 1994–1997, Chapter 2.

Table 1B: Attributes of R&D and Human Capital in Manufacturing (Percent)

	1993	1997		
	Total	Total	High-tech industries*	Low-tech industries
Proportion of engineers, etc.**	16.8	20.3	31.3	9.1
R&D expenditure:turnover ratio***				
a. Manufacturing at large	1.9	2.4	4.9	0.2
b. Establishments engaging in R&D	6.2	7.7	8.7	1.7
Proportion of enterprises using:				
a. Acquired patents	-	8.6	10.8	6.8
b. Self-developed patents	-	23.0	30.7	16.7
Users of modern equipment	-	40.0	43.4	36.9
Purchasers of knowledge from customers and vendors	-	37.5	40.7	35.1
Purchasers of knowledge from other sources	-	55.4	60.8	50.7

* High-tech industries: chemicals, oil refining, plastic and rubber, machinery and equipment, electricity and electronics, communication equipment, scientific equipment, transport vehicles. See *Survey of Structure of Labour Force, Patterns of Work and Innovation in Manufacturing 1997,* Central Bureau of Statistics (1999), C.S. 16/1999.

** Proportion of engineers, degree holders, and technicians in total employment.

*** R&D including investments.

2. Data and Methods of Estimation

The basic data set for the estimation was created on the basis of standard definitions and methods for manufacturing establishments that employ five workers or more and were active in at least one of the years 1990–1994. Data on output, product, exports, intermediates (domestic manufacture and imported), labor hours, wages and employment, and fixed investment were based on the results of the Central Bureau of Statistics manufacturing surveys for the respective years. The data in these surveys were reclassified in accordance with the *Standard Industrial Classification of All Economic Activities, 1993,* and were combined for the purposes of this study into seventy-seven aggregate groups (three digits).

All the survey data were valued in constant 1990 prices. The current output data were deflated by a domestic sales price index (the Wholesale Prices of Manufacturing Output Index) and export prices by the dollar-denominated Export Price Index, adjusted to an effective exchange rate. Data on inputs of materials were deflated by a weighted price index of imported and domestically manufactured inputs, in accordance with the weights shown in a 1992 input-output table. Product data in 1990 prices were obtained by calculating the difference between the output data and the input data in constant prices.

Gross physical capital stock was determined on the basis of a capital-stock survey that the Central Bureau of Statistics performed at manufacturing establishments on January 1, 1992. For the other years, capital stock in the aggregate groups was worked out using the "perpetual inventory model" method—i.e., adding annual investments and subtracting discards.

The R&D capital stock (R) of the industry, the underpinning of this study, was defined as the cumulative value of civilian R&D investments, in constant prices, in the past seven years.[8] These investments, which include current expenditure for labor and materials and purchase of research equipment, were derived from the annual R&D surveys of the Central Bureau of Statistics. To avoid double-counting, theoretically these R&D expenditures should be subtracted from the respective input lines, such as labor hours and purchase of materials in each industry. (Practically speaking, the subtraction was not performed at the current phase of the study.)

The domestic spillover variable (TSO)[9] was also computed on the basis of this capital stock—the value of R&D spillover from other industries and among establishments in the industry at issue. This value, for industry i, is the total R&D capital stock in each industry multiplied by the rate in which the industry's products serve as production intermediates in industry i (on the basis of direct coefficients derived from the 1992 input-output table, at the level of seventy-seven aggregate groups). Sales of the industry itself are included in these coefficients.

R&D spillover from other countries (FSO) is based on the R&D capital stock of Israel's main trading partners.[10] This stock, for main manufacturing industries, was computed by us for the various countries using the method that we adopted for Israel—adding up annual R&D investments for seven years in constant prices (deflated by product prices). The R&D stock of each country in each industry was multiplied by two rates: a) the rate of imports of intermediates by Israeli manufacturing from this country in total imports of intermediates, and b) the rate of intermediates imports of the aggregate group in Israel from the industry of origin (two digits) abroad, in total purchases of intermediates by the industry (taken from the import coefficients in the aforementioned input-output table). In other words, we assumed that the more intermediates an industry imports from a country that has a well-developed research establishment and from an R&D-intensive industry abroad, the more it will benefit from the knowledge embodied in and related to the importation of its inputs. However, we were unable to take account of differences among aggregate groups in the importation of inputs by country of origin. Also, we did not include R&D spillover occasioned by means of machinery and equipment imports to domestic destinations. Thus, we added a variable that at least partly reflects spillover of knowledge and innovation from abroad: "quality of physical capital" (QKM), the proportion of the industry's machinery and equipment that was acquired in the past five years. This modern equipment would seem to embody much of the R&D and innovation in products, materials, and production processes carried out in the countries of origin.

Innovation was the topic of a recent special survey by the Central Bureau of Statistics (*Survey of Innovation in Manufacturing, 1997*). Our study used the results of this survey, which was aggregated at the division level only, to represent two important indicators in our field of inquiry—the proportion of establishments in the industry that acquired patents and innovations from outside sources (PPA) and the proportion of establishments that acquired knowledge (KNOH). We assumed that the rate of acquisition in each aggregate group resembles that in the division to which

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8 Excluding military R&D not performed by active civilian manufacturing establishments. The assumption of a seven-year average lifespan of R&D was based on prior studies and was found to elicit reasonable results in estimating the production function. In any case, the results are rarely sensitive to a lifespan that approximates this assumption. (See, for example, Bregman and Marom, 1999.)

9 For a broader discussion and formal expression of the various spillover variables, see Part 3 below.

10 We chose the following nine: U.S., Germany, Japan, Italy, U.K., Netherlands, France, Sweden, and Spain. The calculations were performed in 1990 Purchasing Power Parity (PPP) dollars. The current R&D data were culled from OECD, 1996.

it belongs and that the data for 1997 also reflect the mean ratios among the industries for the early 1990s.

A special survey on the structure of manufacturing manpower in 1993 was used to estimate the quality of labor input—the proportion of engineers, degree holders, and technicians in total industry employment (QLN)—and to compute the proportion of shift labor (SHIFT).

3. The Conceptual Framework and Its Application

In accordance with the approach proposed by Griliches (1979, 1992) and his successors, we define spillover capital—knowledge capital that spills over into an industry—as the weighted totality of technological knowledge that comes into the possession of establishments in the industry from all possible sources. We define R_i as the R&D capital stock that exists in industry i. Wij is the "weight," i.e., the effective proportion of knowledge capital in industry j that comes into the possession of industry i.

The total domestic spillover, net of spillover among establishments within the industry, is:

$$(1)\quad SO_i = \sum_j w_{ij} R_j \quad ; \quad i \neq j$$

Domestic spillover, including spillovers among establishments within the industry, is:

$$(2)\quad TSO_i = \sum_j w_{ij} R_j$$

where i and j are the aggregate groups (3 digit industries) of manufacturing industries (from 1 to 77).

The weight (Wij) was determined by the "proximity" of the industries. We assume that this weight is proportional to the input-output ratios between the industries, i.e., the percent of purchases of each industry from the other. These proportions were measured by means of the direct coefficients of purchases of domestic intermediates.[11] This approach provides a good representation of the aforementioned "rent spillover" but is also an indicator of "pure" spillover from other industries, i.e., innovations and technological improvements that are not fully utilized by their producers.[12]

We add the spillover of R&D from abroad that industries gain by importing intermediates. We define RFs as R&D capital stock in manufacturing industries in Israel's trade partners and Vis as the proportion of industry i's imports from industry s in those countries:

Total spillover from R&D capital produced by manufacturing industries abroad is expressed as:

$$(3)\quad FSO_i = \sum_s V_{is} RF_s$$

Thus, conceptually, one may regard the knowledge and R&D capital that spills over as a free public good that all firms may access. Theoretically, however, one should also take account of differences among firms in their level of openness, i.e., the extent to which they allow the private knowledge

[11] Importantly, these coefficients are used only to weight R&D capital stock in industries from which industry i makes purchases. The industry-level distribution of the intermediates themselves, or their variance, has no effect whatsoever on output and productivity. We put this to a practical test in regard to the regression in Table 2 below.

[12] As we explain in detail below, we added two variables that represent the direct transfer of knowledge from other domestic industries and from abroad.

and innovation that they have produced to spill over without recompense.[13] This depends, among other things, on how effectively the establishment protects its patents and secrecy, the nature of the knowledge, and the complexity of the innovations. On the other hand, firms that receive the spillover must have technological intake abilities such as basic knowledge and appropriate human capital. In our study, some of this heterogeneity among firms is obscured by use of the industry-wide mean, but our empirical measurements can take it into account, partly, by inserting two additional variables in the production cycle: the proportion of establishments in the industry that acquired knowledge and the proportion of those that acquired patents from outside sources.

We propose a simple model in which establishments in a given industry generate output (Q) using intermediates (M), labor input (L), physical capital (K), and self-produced R&D capital (R). An additional variable is the knowledge capital that spills over from other industries (SO, TSO) and from abroad (FSO). Output also depends, evidently, on the general state of technology in the industry—the quality of physical capital and labor, the proportion of shift labor, industry size, rate of exports, and rate of knowledge and patent acquisitions.

Let us assume, for the time being, that a Cobb-Douglas production function is suitable for Israeli manufacturing, as several previous studies have shown. (For a complete list of the variables, see the Appendix).

The **output** equation is:

$$(4)\quad Q_i = AM_i^{\alpha} L_i^{\beta} K_i^{\gamma} R_i^{\delta} SO_i^{\lambda} FSO_i^{\varphi} QKM^{\mu} \sum_s Z_{is}^{\theta_s}$$

and the corresponding **product** equation is:

$$(5)\quad Y_i = AL_i^{\beta} K_i^{\gamma} R_i^{\delta} SO_i^{\lambda} FSO_i^{\varphi} QKM^{\mu} \sum_s Z_{is}^{\theta_s}$$

where the Zs are all the other variables mentioned above—quality of labor (QLN), physical capital utilization rate (SHIFT), purchase of knowledge rate (KNOH), purchase of patents rate (PPA), percent of immigrants (OLIM), etc.

Below we present the functions in log form—with the logs represented in lower-case letters—and delete the industry sign:

$$(6)\quad q = a + \alpha m + \beta l + \gamma k + \delta r + \lambda so + \varphi FSO + \mu QKM + \sum_s \theta_s z_s$$

We obtain the **labor productivity**—output per labor hour—equation by removing the log of L from both sides of Equation (6):

$$(7)\quad q - l = a + \alpha(m-l) + \gamma(k-l) + \delta(r-l) + \lambda so + \varphi FSO + \mu QKM + \sum_s \theta_s z_s$$

Fixed return to scale is defined here as $\alpha + \beta + \gamma + \delta = 1$; we examine this hypothesis by adding ℓ to Equation (7) as a separate variable.

[13] See Arvanitis and Hollenstein, 1998, for a list of articles that discuss this issue.

Total factor productivity is defined conventionally, i.e., assuming a fixed return to scale for the primary factors, labor and physical capital only.[14]

$$\text{(8) TFP} = y - (Se)\, l - (1\text{-}Se)\, k = a + \lambda r + \delta so + \varphi FSO + \mu QKM + \theta_s \sum_s z_s$$

where Se is the portion of return on labor (total wages paid) in manufacturing product. In other words, the output of two industries that use equal quantities of physical capital and labor will be different mainly due to differences in R&D capital, spillover to these industries, and quality of labor and capital—differences that are defined as TFP.

The **Translog** equation is a second-order approximation of any production function; its suitability for Israeli manufacturing was explored in the studies mentioned in note 4. It is phrased in the following way:

$$\text{(9)}\quad q = a + \sum_i^4 b_i x_i + 1/2 \sum_i^4 b_i (x_i)^2 + \sum_i^4 \sum_k^4 b_{ik} x_i x_k + \sum_s c_s v_s$$

where x_i = m, l, k, and r, and v_s = so, fso, qkm, and z.

Appendix B presents the results of the estimation and shows how the factor elasticities in this function were computed.

To examine the spillover effect on self-produced R&D and to obtain a more comprehensive picture of the other factors that determine the size of an industry's R&D capital stock, we estimated an "R&D equation." Since R&D capital stock is defined as total annual R&D investment in the past seven years, this equation reflects the factors that determine these investments. The economic logic that dictates the participation of these factors goes without saying. Let us assume, pursuant to several empirical trials, that the equation is exponntial and looks like this:

$$\text{(10)}\qquad R_i = A \cdot QLN^{\alpha} EXR \cdot KL^{\beta} SO^{\delta} FSO^{\lambda} RR \cdot PPA^{\gamma} QKM^{\phi} OLIM^{\varphi} EMP^{\eta}$$

We estimate it directly (by logs) and by using a simultaneous model, in which R&D capital stock is determined in conjunction with output and with wages or exports. The simultaneous equations are based on the assumption that output-productivity, R&D, and exports (or wages) are endogenous variables. Thus, for example, the spillover variables affect both output and productivity and also R&D capital, wages, and exports. (We explain this at greater length below in the section that analyzes the estimation results.)

4. Results of the Estimation

The main results of this phase of the research—including output, product, and productivity equations; and R&D, wage, and export equations—are shown in Tables 2–6. The stability of the results stands out from the first glance. The coefficients of the intermediate, labor, and capital inputs (K and R) in the production equations are statistically significant in all alternative regressions and in magnitudes that coincide acceptably with the results of other studies on manufacturing in Israel and abroad.[15] The elasticity of the intermediates, with output as the

[14] And on the ordinary assumption that each production factor obtains the value of its marginal output in consideration.

[15] For example, the studies cited in notes 4 and 19, in which the results of other studies are presented for comparison purposes.

dependent variable, is 0.75 and the coefficients are 0.14 for labor, 0.09 for physical capital, and for 0.03 self-produced R&D to (Table 2, Equation 1).[16] Almost all the results show, more or less, that production takes place under terms of fixed return to scale—for materials, labor, physical capital, and self-produced R&D capital (i.e., $\alpha + \beta + \gamma + \delta = 1$).

The focal point of concern in this study is the effect of the R&D variables—self-produced R&D (R) and external R&D that spills over from other industries and establishments in Israel (TSO) and from Israel's trade partners (FSO). The general picture elicited by the regressions in Table 2 and the simultaneous model in Tables 5 and 6 shows that R&D spillover has a considerable and statistically significant effect on output and productivity, in addition to its direct local effect on the industry where it is performed. Acquisition of knowledge and patents from other industries and from abroad also has a significant positive effect on product and TFP (Table 2, Part 2). Overall, exogenous R&D and knowledge appear to contribute appreciably to the growth of manufacturing in Israel, to a degree that surpasses its direct contribution. The findings also point to the relationship and, evidently, the dependency of self-produced R&D on that performed elsewhere in Israel and abroad.

We also obtained reasonable results for the effects of other variables, such as a significant positive coefficient of rate of exports and quality of labor as "explanatory factors" in self-produced R&D, and a significant negative coefficient of share of immigrants in the production function. A more detailed presentation and a more thorough analysis of the findings follow.

a. Production and Productivity Equations

Notably, the coefficients of the variables—other than materials, labor, and capital—should reflect not only the effect on output or product but also the direct effect on productivity and production efficiency. Every added increment of product above the level generated by the primary production factors is defined here, in the conventional way, as added productivity. Thus, we may interpret the positive coefficient of the rate of modern equipment, for example, in all output functions (expressed in logs; see Table 2) in the following way: on average, every 10 percent increase in capital quality in a manufacturing industry may lead, *ceteris paribus,* to a 0.3 percent increase in output (approximately 1 percent in product). Moreover, all of the increment is a real increase in industry productivity.[17]

R&D capital stock in this study, as noted above, is estimated as the total annual R&D investment, in constant prices, in the past seven years.[18] Experience from previous studies[19] shows that the main conclusions do not change substantially when alternative assumptions, especially with respect to the lifespan of R&D investments, are used. The regressions in Table 2 and Appendix A, as well as the Q equations in Tables 5 and 6, show the direct impact of this capital stock on output and the effect that self-produced R&D shares with the effect of spillover from Israel and abroad.

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[16] In terms of product (i.e., output less intermediates), these come to 0.54 for labor, 0.35 for physical capital, and 0.12 for R&D capital. The physical capital coefficient in direct measurement of the product equation, according to Regression (1) in Appendix A2, is 0.10.

[17] Since the data set used to estimate the production equations is mainly a latitudinal cross-section, the discussion concerns a difference in inter-industry quality of capital that explains differences in output and productivity.

[18] Practically speaking, at this phase of the study, we used the value of "R&D capital services" as a variable in the production function. This has no effect on elasticity since capital services are (roughly) a multiple of gross R&D capital stock (R*0.171=SR).

[19] Bregman and Marom (1998); Bregman, Fuss, and Regev (1991, 1999); Griliches (1984), Raut (1994).

Table 2: Direct and Indirect (Spillover) Effects of Manufacturing R&D on Growth and Productivity, Aggregate Groups, for 1990–1994

(Cobb-Douglas production function, LS estimates)

Dependent variable	(1)		(2)		(3)		(4)	
	Output (Q)		Output (Q)		Output (Q)		Output (Q)	
Explanatory factor	Coeffi.	t	Coeffi.	t	Coeffi.	t	Coeffi.	t
Constant	-0.491	-4.9	0.536	4.5	0.540	5.1	0.076	0.5
Intermediates	0.748	54.3	0.756	59.5	0.779	67.6	0.769	58.8
Labor	0.142	11.5	0.146	12.9	0.137	13.8	0.137	11.7
Physical capital	0.091	7.7	0.082	7.5	0.072	7.5	0.090	8.2
R&D capital	0.031	9.2	0.016	3.7	0.015	4.3		
- Domestic spillover (TSO)			0.027	4.1				
- SO					0.018	3.6	0.027	4.9
FSO								
Knowledge acquisition								
Equipment quality	0.031	3.1	0.024	2.6	0.017	2.1	0.020	2.0
Pct of immigrants			-0.045	-4.3	-0.055	-5.8	-0.058	-5.1
RESW					0.176	8.4	0.189	8.2
A. R-squared	0.991		0.992		0.994		0.992	
S.E. of R.	0.089		0.081		0.071		0.084	
N	231		231		231		231	

* TSO—total domestic spillover among establishments in the industry itself.

Note: All variables apart from the wage function residual (RESW—an indication of the level of human capital) are in logs. The observations are for seventy-seven aggregate groups (three digits). N=231. The regression is for the three years 1990, 1992, and 1994.

Table 2 (continued): Indirect (Spillover) Effects of Manufacturing R&D on Growth and Productivity, Aggregate Groups, for 1990–1994

(Further continuation of Table 2 in Appendix A1)

Dependent variable	(5)		(6)		(7)		(8)	
	Output (Q)		Product (Y)		Product (Y)		TFP	
Explanatory factor	Coeffi.	t	Coeffi.	t	Coeffi.	t	Coeffi.	t
Constant	0.352	3.2	-0.360	-0.9	-2.059	-5.6	3.016	15.4
Intermediates	0.754	57.9						
Labor	0.148	12.8	0.539	16.8	0.539	10.8		
Physical capital	0.087	7.8	0.357	12.3	0.375	8.4		
R&D capital	0.010	2.1	0.059	4.2	0.064	3.4	0.063	4.1
- Domestic spillover (TSO)	0.025	3.3	0.050	2.4			0.088	3.5
spillover (SO)					0.055	2.1		
Quality of equipment	0.027	2.8	0.147	5.2	0.106	2.4		
Quality of labor	0.401	2.8						
Patent acquisition			0.061	2.1	0.056	1.2	0.070	1.8
Knowledge acquisition								
Shift labor							1.128	3.7
Pct of immigrants			-0.122	-3.7			-0.169	-4.1
RESW								
A. R-squared	0.092		0.924		0.937		0.516	
S.E. of R.	0.083		0.259		0.230		0.323	
N	231		231		77		231	

Note: All variables apart from the proportion of shift labor in the TFP regression (no. 8) are in logs. The observations are for seventy-seven aggregate groups (three digits). Where N=231, the regression is for the three years 1990, 1992, and 1994. Where N=77, the data are averages for the industry in 1990, 1991, 1992, and 1994. (For additional results, see Appendices A1 and A2.)

The following example illustrates the extent of the effect. If R&D capital stock in all manufacturing industries is increased by 10 percent, product will grow by 1.1–1.4 percent. (All such growth, as stated, is defined as an increase in TFP.) This is a direct result of self-produced R&D in the industry and of R&D spillover from other industries. According to most of the regressions, the indirect effect of R&D performed by other industries and in other establishments in the industry itself (TSO)[20] is stronger (up to twice as high if not more) than that of self-produced R&D in the industry (R) when both effects are active and are measured together. The effect of R&D performed by foreign manufacturing establishments (FSO), estimated in this study by means of intermediates only, is statistically significant but smaller.[21] The effect of imported modern equipment should be added to that. Apparently, then, even if the industry itself does not invest in R&D, it may benefit strongly from R&D performed by other industries and in other countries. Thus, Regression 12 in the continuation of Table 2 (Appendix A) shows that, on average, an industry may increase its output per labor hour (labor productivity) by approximately one-fourth by doubling its exertions in purchasing R&D-intensive intermediates and modern machinery and equipment.

Perceptible differences in definitions, computation methods, and data make it very difficult to compare our results with those of other empirical studies in other countries. For example, most studies on foreign technology spillover were performed at the country level and not at that of the firm or the industry. Even so, we should note that usually these studies showed higher output elasticities of spillover from other countries than those of domestic R&D.[22] In our case, the FSO index does not seem to show this, but this index should be augmented with the spillover effect of the importation of modern equipment. Be this as it may, our estimate includes not only self-produced R&D but also spillover from other establishments or industries—a spillover that is not researched separately at the country level.

Notably, the variables for spillover (domestic and foreign) and knowledge are statistically significant in all function forms presented here—for output (including materials), product, and productivity—in various combinations of control variables. Clearly, however, the strong correlations among some variables[23] keep us from inserting all of them into one equation. We should stress in particular the correlations and cross-effects among the various R&D and spillover variables. An example is the considerable and significant effect of imported R&D (as embodied in FSO and, in part, in QKM) on domestic R&D, as shown in Table 4, on which we comment at greater length below.

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[20] A recently published study on manufacturing establishments in several American high-tech industries shows that the main spillover at the aggregate group level (three digits) originates in other establishments in that industry and not externally (Orlando, 2000). Accordingly, we emphasize TSO in our study but also present the results for SO.

[21] Regressions 3, 10, and 12 in Table 2 (and Appendix A1), and Appendix B. When one compares the size of the coefficients in the regressions, one should take account of the differences in the dependent variable. The value of product is between one-fourth and one-third that of output.

[22] Coe and Helpman, 1995. This result pertains to small countries; in large countries (G-7), the effects of self-produced R&D surpass those of international R&D, as one would expect.

[23] See also the correlations matrix in Appendix C.

In this context, there is also reason to discuss the striking absence of the quality-of-labor effect (represented by the proportion of engineers, degree holders, and technicians in employment) in most production equations, although its important contribution to growth and productivity is undoubted. This absence occurs because the contribution of the labor-quality effect is partly indirect, effected mainly via domestic R&D, but also related to imported R&D and exports. It requires high-level skilled manpower to perform manufacturing R&D and take in imported innovations. There is a strong correlation between an industry's level of labor skill and its level of performance and intake of innovation. Thus, quality of labor as measured here also represents R&D in part. Indeed, in the simultaneous model this quality has a substantive and statistically significant effect on R&D and, only through it, on productivity.

Spillover and High-Tech Industries

It is of interest to examine the domestic spillover effect in two groups of industries—high-tech and low-tech. If we define high-tech industries as those in which the quality-of-labor value (proportion of professionals in employment—QLN) exceeds the median, we find that only in this group does domestic spillover have a substantial and significant effect. Low-tech industries, most of them are not engaged in R&D, are evidently unable properly to absorb the abundance of knowledge that flows from the outside (Table 3, Columns 1 and 2). When we toughen the criterion of high-tech to include only industries that also have relatively high-level R&D services, we obtain a similar result (Table 3, Columns 3 and 4). This indicates that R&D investments and intake of knowledge from other establishments is a method that high-tech industries have used to increase their growth and productivity significantly over the past decade.

Acquisition of knowledge and patents also has a significant positive effect on product and productivity, as Regressions 4, 6, and 8 in Table 2 show. Acquisition of patents by firms in this industry enhances R&D (Regression 2 in Table 4 and Table 5). The interrelations sometimes find only partial expression in the equations—the larger the share of exports in an industry, the greater the industry's cumulative investment in R&D. As stated, R&D capital stock, in turn, contributes to growth and productivity. There is also a positive correlation between the rate of exports in the industry and R&D spillover from other industries and from abroad; this apparently attests to openness and to the interdependency of imports and exports in high-tech industries, which are characterized by high R&D intensivity and nourish each other with highly innovative intermediates.[24]

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[24] Thus, export establishments are more inclined to innovate than establishments that manufacture for the domestic market. By implication, they have greater superior learning and intake abilities. See Geroski, 1995.

Table 3: Direct and Indirect Effects of Manufacturing R&D on Growth and Productivity, High-Tech and Low-Tech Aggregate Groups, 1990–1994

Dependent variable:	(1)		(2)		(3)		(4)	
Output	High-tech*		Low-tech**		High-tech*		Low-tech**	
Explanatory factors:	Coeffi.	t	Coeffi.	t	Coeffi.	t	Coeffi.	t
Constant	0.460	2.8	0.590	3.4	0.391	2.1	0.554	3.3
Intermediates	0.746	42.8	0.779	41.7	0.734	38.9	0.772	38.5
Labor	0.177	11.2	0.098	5.1	0.165	9.7	0.114	5.3
Physical capital	0.085	6.2	0.089	5.3	0.095	6.4	0.086	5.1
R&D capital	0.007	1.1	0.015	2.2	0.019	2.0	0.009	1.0
- Domestic spillover	0.031	3.0	0.003	0.3	0.028	2.5	0.006	0.5
Equipment quality	0.027	1.5	0.041	2.7	0.014	1.1	0.052	2.9
Pct of immigrants	-0.027	-2.3	-0.078	-3.2	-0.023	-1.5	-0.051	-2.1
A. R-squared	0.993		0.993		0.991		0.993	
S.E. of R.	0.076		0.081		0.077		0.081	
N	115		116		111		104	

Note: All variables are in logs. Observations are for seventy-seven aggregate groups (three digits). The regression is for data pertaining to 1990, 1992, and 1994.

* Defined by the quality of labor value (QLN); high-tech industries are those in which QLN exceeds the median, 1.047.

** Defined by two indicators—quality of labor and R&D capital (R).

The proportion of immigrants in employment, 22 percent at the end of the research period, has a negative significant effect on productivity and efficiency in all production functions examined.[25] This apparently reflects two phenomena. The first is related to the difficult and sometimes protracted acculturation of immigrants, generally, and of those with experience and schooling that do not coincide with those required in high-tech manufacturing, relative to manufacturing in their countries of origin, particularly. The second has to do with the effect of unskilled labor relative to high-human-capital labor. Our equations do not represent quality of labor in a fully appropriate way and, as stated, the closest variable to the level of human capital is the proportion of engineers and technicians. This variable, however, corresponds to the R&D variable and does not fit into most of the equations. We suppose that the share-of-immigrants variable also represents differences among

[25] See also Hercowitz, Lavi, and Melnick (1999), who discuss the effect of various factors, including the share of immigrants in employment, on productivity in the business sector.

industries in the share of unskilled labor generally. As such, it is an alternative indicator of the labor quality that appears in the production function in the form of homogeneous labor hours.

b. Determining the Level of R&D Capital Stock in an Industry

The level of R&D investment depends primarily on an appropriate supply of human capital. The higher the rate of engineers, degree holders, and technicians, the larger the R&D capital stock. Conversely, a high rate of unskilled workers in an industry seems to thwart R&D (Tables 4 and 5). Furthermore, there is a significant positive correlation between an industry's openness to foreign trade and its self-produced R&D capital stock. The correspondence with exports is especially salient: industries with high rates of exports invest lavishly in new products, efficiencies, and renovation of production processes in order to remain competitive in foreign markets. The relationship is probably bidirectional; R&D investments enhance the rate of exports of most products that have a limited domestic market.

As expected, we found a significant positive correlation between self-produced R&D in an industry and R&D spillover from other industries and from abroad. Apparently more spillover facilitates more self-produced R&D, and industries in this condition tend perceptibly to influence each other and create a general climate of innovation and pooling of knowledge. Patent acquisition and self-produced domestic R&D also march hand-in-hand.

Additional findings from the regressions in Tables 4 and 6 show that R&D capital depends on physical capital and its quality. The more intensive the physical capital (capital stock per labor hour) is, the more can be invested in R&D. Obviously, quality of capital has the same kind of effect, in accordance with the foregoing discussion of the effects of modern equipment.

Table 4: Factors that Determine R&D Capital Stock in Manufacturing Industries, 1990–1994

	(1)		(2)	
Dependent variable:	R&D capital stock		R&D capital stock	
Explanatory factors	Coefficient	t	Coefficient	t
Constant	-8.02	-12.0	-7.1	-9.0
Labor quality			9.	4.8
Rate of exports	3.4	8.7	2.	5.9
Capital intensivity (KL)	0.8	6.3	0.	5.0
Domestic spillover (SO)	0.3	4.5	0.	2.3
Foreign spillover	0.4	5.8	0.	3.5
Employment	0.1	5.6	0.	5.1
Patent acquisition			0.	2.4
Rate of return (RRk)			1.	3.8
Equipment quality	0.3	2.6		
A. R-squared	0.6		0.	
S.E. of R.	1.2		1.	
N	231		2[illegible]	

Note: All variables other than percent of exports and rate of return are in logs. The observations are for seventy-seven aggregate groups (three digits). When N=231, the regression is for the three years 1990, 1992, and 1994.

Notably, these R&D equations do not suffice fully to "explain" the supply of R&D capital, as further indicated by the relatively low explanatory coefficient (R^2 = 0.64–0.70). Indeed, one can imagine additional factors that determine R&D capital supply but do not appear here, such as the industry's rate of public R&D subsidization.[26] This supposition is reinforced by the significant positive coefficient of rate of return on physical capital, which reflects the rate of industry profitability, in Regression in Table 4. R&D investment, like any other investment, undoubtedly depends on the possibilities of financing.

c. The Simultaneous Model—R&D, Output, and Wage

We present this limited three-equation system to stress the interrelations between R&D, productivity, and wage. In particular, we will examine, once again within this framework, the direct and indirect effects of R&D spillover from other industries and from abroad (Table 5). By using the 3SLS method with auxiliary variables in the estimation, we intend to prevent bias that may result

[26] In this matter, see research report by Zvi Griliches and Haim Regev (1999) on government R&D subsidies and productivity in Israeli manufacturing.

from a correlation between the independent variables and the residuals and to reinforce the validity of the previous findings.

Table 5: Output, R&D, and Wage—Simultaneous Model
System: SYSEXR90 (231 observations)
Estimation Method: Iterative Three-Stage Least Squares*
Sample: 2 619 IF ANAF>99 AND YEAR<>93 AND YEAR<>91

	Coefficient	t-Statistic
Eq. QL: C—Constant	1.171	11.1
ML—Intermediates	0.758	68.8
L—Labor	0.002	0.4
KL—Physical capital	0.070	6.6
RL—R&D capital	0.027	3.1
TSO—Domestic spillover	0.019	1.8
QKM—Quality of equipment	0.018	2.0
OLIM—Percent of immigrants	-0.042	4.2
Eq. RL: C—Constant	-12.341	-9.3
QLN—Quality of labor	4.795	2.3
EXR—Rate of exports	2.827	7.6
RR—Rate of return	0.853	1.9
QL—Labor productivity	1.552	6.3
SO—Domestic spillover	0.230	3.0
FSO—Foreign spillover	0.341	5.0
EMP—Employment	-0.047	-2.4
Eq. WL: C—Constant	1.745	4.7
QLN—Quality of labor	0.580	1.2
TSO—Domestic spillover	0.031	1.2
QL—Labor productivity	0.334	6.3
QKM—Quality of equipment	-0.071	-2.8
OLIM—Percent of immigrants	-0.182	-5.0
RL—R&D intensivity	0.069	2.7

* For a more detailed presentation of the auxiliary variables and the statistics, see Appendix E.

The framework of the model *presumes* that labor productivity is determined simultaneously with R&D and wage per labor hour, i.e., that QL, RL, and WL are endogenous variables. Theoretically, the increase in output per labor hour allows for more R&D and higher wages, R&D enhances productivity and output and affects wages. Wages, in turn, may affect R&D and output.

Practically, as we have seen, R&D performed by other manufacturing industries (spillover) has a significant positive effect on the industry's own R&D and on productivity. Thus, the productivity and R&D equations in the model resemble those presented above. The wage-per-labor-hour equation shows that the greater the R&D spillover, the higher the real average wage per labor hour in the industry. This may be due to higher productivity occasioned by the spillover, but labor productivity (QL) already appears separately in the wage equation with a significant positive effect. By implication, R&D spillover by means of intermediates purchases has an additional direct effect on wage. Sophisticated and innovative intermediates may require more skilled handling by workers, i.e., a higher quality of labor. As we noted above, the proportion of engineers and similar workers does not provide a full measurement of quality of labor; this variable also finds expression indirectly, via R&D spillover. Spillover from other countries, by means of imported intermediates, has a substantial but indirect effect on productivity and wage. The main conduit seems to be domestic R&D.

The significant negative effect of the percent of immigrants on average wage in the industry is understandable in view of the claim, expressed above, that to some extent this variable also represents the share of unskilled labor. However, we have no satisfactory economic explanation for the significant negative sign of the capital-quality variable in the wage function.

d. The Simultaneous Model—R&D, Output, and Exports

In Table 6, we estimated the output, R&D, and export equations simultaneously. These data, too, covered three years (1990, 1992, 1994). The results for output and R&D strongly resemble those previously obtained:

Table 6: Output, R&D, and Wage—Simultaneous Model
System: SYSEXR **(231 observations)**
Estimation Method: Iterative Three-Stage Least Squares*
Sample: 2 619 IF ANAF>99 AND YEAR<>93 AND YEAR<>91
Convergence achieved after 7 iterations

	Coefficient	**t-Statistic**
Eq. Q: C—Constant	0.629	3.9
ML—Intermediates	0.760	64.2
L—Labor	0.158	14.5
K—Physical capital	0.069	6.2
R—R&D capital	0.022	2.3
TSO—Domestic spillover	0.027	2.5
QKM—Quality of equipment	0.015	1.8
OLIM—Percent of immigrants	-0.041	-4.1
Eq. R: C—Constant	0.764	-8.6
EXR—Rate of exports	6.569	5.5
RRk—Rate of return	3.322	7.0
KL—Capital intensivity	0.644	4.1
FSO—Foreign spillover	0.289	3.9
RESW—Human capital	0.656	1.7
PPA—Patent acquisition	0.240	1.6
EMP—Employment	0.129	2.2
Eq. EXR: C—Constant	-1.800	-9.1
KL—Capital intensivity	0.001	3.3
SO—Domestic spillover	0.022	2.1
QLN—Quality of labor	1.556	7.5
KNOH—Knowledge acquisition	0.005	2.8
OLIM—Percent of immigrants	0.005	2.7
RESW—Human capital	0.115	2.2

* For a more detailed presentation of the auxiliary variables and the statistics, see Appendix E.

Output and productivity are affected no less by domestic spillover than by the R&D itself. The main impact on productivity of knowledge, R&D, and patents that spill over from abroad is indirect, effected in self-produced R&D. Notably, in the R&D and export functions we used a surrogate for the quality-of-labor variable: the wage-function residual (RESW). We assumed that this residual would reflect the level of human capital and labor skill that the other variables did not measure well, as explained above. It does seem to be a worthy surrogate.

The estimation results also show that the more intensive physical capital is in an industry, the higher the industry's rate of exports. The higher the rate of engineers and technicians, the more knowledge is acquired and the more R&D spills over from other industries. The positive effect of immigrants on the rate of exports is commensurably with the negative correlation in the wage equation in the previous model. The higher the proportion of immigrants, the lower the average wage in the industry and the more industry products are competitive in global markets.

e. Rates of Return on Capital in Manufacturing

Rates of return on physical and R&D capital, at the individual level and for the economy at large, were computed by means of the corresponding elasticities in the production function.[27] Importantly, the computation also depends on the mean absolute amount of output (or product) and capital and is especially sensitive to data reliability and methods of computing R&D capital stock, such as the assumption concerning the lifespan of the annual R&D investment. Thus, the elasticities prove to be more reliable than the rates of return since, as it turned out, they are less sensitive to choice of lifespan. Notwithstanding this disclaimer, it seems to us that the results of the study point to appreciably higher rates of return on self-produced R&D capital than on physical capital. On average, in various specifications of the production function, we obtained 14 percent rates of return on gross physical capital and 20 percent on (gross) self-produced R&D capital in the industry. (See table in Appendix D.) The return occasioned by R&D spillover from other industries is added to this; this return, as stated above, exceeds even the direct effect of the R&D itself.[28] Overall, then, we find that the social rate of return on R&D investments in Israeli manufacturing (direct and indirect) comes to 40–50 percent per year, indicating that the economy derives much greater benefit from investment in manufacturing R&D than from fixed investment.[29] From the standpoint of the economy, this reflects a state of underinvestment in knowledge, innovation, and, evidently, human capital in the second half of the 1980s and the first half of the 1990s. This is not surprising, since manufacturers received less than half the return on their investments in this field in direct form; the rest was bestowed as a gift to other manufacturing firms.

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[27] This rate (RR) reflects the added product occasioned by one unit of capital. We may measure it from both the output equations and the product equations, by multiplying the corresponding elasticity by the ratio of mean output to mean capital: $RR_k = \frac{\partial Q}{\partial K} = \gamma_k \frac{\overline{Q}}{\overline{\overline{K}}}$ for physical capital and, accordingly, $RR_r = \gamma_r \frac{\overline{Q}}{\overline{\overline{R}}}$ for R&D capital.

[28] In most cases, the elasticities of the spillover variable (TSO) surpass those of self-produced R&D (R).

[29] Other studies abroad have elicited similar results; they, too, imply that the social rate of return on R&D investments is much higher than the personal rate of return. See, for example, Bernstein and Nadiri (1988) and Griliches (1998).

5. Several Remarks on Industrial Policy

The main rationale and, apparently, the only justification for having a public policy on R&D are market failures of the private sector in adjusting R&D investment to its "optimum" level.[30] The market failures in manufacturing are usually related to an external advantage—knowledge spillover—which, as stated, is the advantage of technological knowledge that the firm that produced it does not utilize. This knowledge, which often spills over with no return to its owner, may cause R&D investment to contract. The market failures prevent correct estimation of the consideration for risk in these R&D investments or reduce the consideration per unit of risk. In principle, then, the especially high riskiness of these R&D investments, in which the results are not assured, justifies government intervention.

Table 7: Rates and Funding of Manufacturing R&D (Percent), International Comparison

	Country	**Share of R&D in output (1993–1995)***	**Share of government funding of business-sector R&D, 1995****	
1	Sweden	3.77	10.3	(9) **(Ranking)**
2	Japan	2.13	1.6	(18)
3	U.S.	2.08	18.4	(2)
4	Finland	2.07	6.1	(14)
5	Germany	1.99	9.0	(11)
6	France	1.95	13.0	(5)
7	**Israel**	**1.90**	**25.2**	**(1)**
8	U.K.	1.87	11.9	(7)
9	Denmark	1.63	5.8	(15)
10	Canada	1.37	9.7	(10)
11	Norway	1.34	16.0	(3)
12	Belgium	1.33	7.2	(13)
13	Netherlands	1.28	8.4	(12)
14	Ireland	1.22	4.5	(16)
15	Australia	0.82	3.0	(17)
16	Italy	0.79	12.2	(6)
17	Iceland	0.70	14.4	(4)
18	Spain	0.52	10.6	(8)
OECD mean		**1.73**	**9.0**	

* Source for OECD countries: OECD, *Main Science and Technology Indicators,* 1977–2, p. 25. For Israel: Central Bureau of Statistics, *Surveys of Research and Development in Manufacturing,* including current expenditures and fixed investments.

** Source: Central Bureau of Statistics, *National Expenditure on Civilian Research & Development 1989–1997,* S.P. 1086, 1998, p. 81.

[30] Tassey (1998).

At first glance, the government should increase its subsidization of these investments, either directly or by means of a tax exemption, in order to optimize their level. Notably, however, Israel currently subsidizes manufacturing R&D investment both directly (with grants at 50 percent of investment in new products and up to 66 percent in start-up enterprises) and by participating in pre-competitive generic technology research (joint programs among several industrial establishments and academia) and funding technology incubators and basic research in universities and research institutes. In an international comparison of rates of R&D expenditure in manufacturing output, Israel resided in the upper third of the twenty-four OECD countries (on average for 1993–1995) and, among countries that released their data, had the highest rate of government funding in total business-sector R&D—about 25 percent on average (Table 7). The existence of underinvestment despite relatively high government involvement may indicate that the subsidization method is inefficient, i.e., that it evidently supports, among other things, investments that would be made even without the government funding. In practice, the distinction between subsidizing physical capital and subsidizing R&D has become blurred. As we demonstrated above, knowledge spillover also occurs by means of modern equipment that firms acquire, and this equipment is partly subsidized. Thus, grants awarded under the Encouragement of Capital Investments Law actually serve the further purpose of encouraging R&D and knowledge transfer. This topic of subsidies lies outside the purview of the present study; the Sapir Forum for Economic Policy recently took it up for discussion.[31] There may be a correspondence between the size of subsidized establishments and the effectiveness of the subsidies. Only comprehensive research at the establishment level can look into this matter and other issues.

[31] *Economics Quarterly* 46, November 1999. (See especially Morris Touval, “A R&D Strategy for Israel,” and Zvi Griliches and Haim Regev.)

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Appendices

Appendix A1

Direct and Indirect (spillover) Effects of Manufacturing R&D on Growth and Productivity
(Continuation of Table 2)

	(9)		(10)		(11)		(12)	
Dependent variable:	Output (Q)		Labor productivity (QL)		Product (Y)		Product per labor hour (YL)	
Explanatory factors:	Coeffi.	t	Coeffi.	t	Coeffi.	t	Coeffi.	t
Constant	0.111	0.8	0.235	2.1	-1.585	-3.7	-1.904	-1.904
Intermediates	0.744	38.8	0.750	38.6				
Labor	0.146	9.1	-0.002	-0.2	0.541	11.5	-0.027	-0.027
Physical capital	0.090	5.6	0.085	5.2	0.358	8.5	0.394	0.394
R&D capital	0.015	2.5	0.022	3.9	0.054	2.8	0.063	0.063
- Domestic spillover (TSO)	0.028	2.9						
Foreign spillover				1.9	0.015			
Quality of equipment	0.024	1.8			0.107	2.6	0.134	2.6
Pct of immigrants	-0.048	-3.1	-0.069	-4.2	-0.134	-2.7		
A. R-squared	0.995		0.978		0.944		0.758	
S.E. of R.	0.066		0.070		0.216		0.214	
N	77		77		77		77	

Note: All variables are in logs. The observations are for seventy-seven aggregate groups (three digits). When N=77, the data are averages for the industry in the years 1990, 1991, 1992, and 1994. When the dependent variable is output or product per labor unit (QL, YL), the capital variables are also per labor unit (RL, KL) and the labor variable (L) measures return to scale.

Appendix A2

Direct and Indirect (Spillover) Effects of Manufacturing R&D on Product and Productivity, Manufacturing Aggregate Groups, 1990–1994

(Cobb-Douglas production function, LS estimates)

	(1)		(2)		(3)	
Dependent variable:	Product (Y)		Product (Y)		Product (Y)	
Explanatory factors:	Coeffi.	t	Coeffi.	t	Coeffi.	t
C-constant	-4.227	-15.5	-3.509	-12.3	-0.360	-0.9
L-labor	0.559	16.2	0.521	16.3	0.539	16.8
K-physical capital	0.090	11.2	0.359	12.3	0.357	12.3
R&D capital	0.100	9.2	0.088	8.8	0.059	4.2
QKM – equipment quality			0.155	5.4	0.147	5.2
OLIM - immigrants			-0.146	-4.4	-0.122	-3.7
TSO – domestic spillover					0.050	2.4
SO - splillover						
PPA - patents					0.061	2.1
A. R-squared	0.904		0.921		0.924	
S.E. of R.	0.291		0.263		0.259	
N	231		231		231	

Note: All variables are in logs. The observations are for seventy-seven aggregate groups (three digits). When N=231, the regression is for the three years 1990, 1992, and 1994.

Appendix B

Translog

LS // Dependent Variable is LQ

Sample(adjusted): 158 618 IF ANAF>99 AND YEAR<95 AND YEAR<>93 AND YEAR<>91

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C—constant	3.914	1.079	3.6	0.000
LM	1.188	0.196	6.1	0.000
LL	0.570	0.291	2.0	0.052
LK	-0.733	0.214	-3.4	0.001
LR	0.005	0.052	0.1	0.915
MM	0.100	0.037	2.7	0.007
LL2	0.089	0.037	2.4	0.018
KK	0.100	0.024	4.2	0.000
RR2	0.003	0.003	1.2	0.239
M2L	-0.046	0.026	-1.8	0.075
MK	-0.072	0.026	-2.7	0.007
MR	-0.025	0.007	-3.6	0.000
L2K	-0.026	0.029	-0.9	0.374
L2R	0.018	0.007	2.5	0.013
KR	0.009	0.005	1.9	0.056
TSO—domestic spillover	0.021	0.006	3.3	0.001
FSO—foreign spillover	0.017	0.005	3.3	0.001
QKM—equipment quality	0.020	0.008	2.4	0.016
OLIM—proportion of immigrants	-0.034	0.012	-2.9	0.004
RESW—human capital	0.176	0.020	8.7	0.000

Adjusted R-squared 0.995 S.E. of regression 0.065 Included observations: 231

XM=0.768 XK=0.073 XL=0.147 XR=0.009

XR=C(5)+C(9)*@MEAN(LR)+C(12)*@MEAN(LM)+C(14)*@MEAN(LL)+C(15)*@MEAN(LK)

XK=C(4)+C(8)*@MEAN(LK)+C(11)*@MEAN(LM)+C(13)*@MEAN(LL)+C(15)*@MEAN(LR)

XM=C(2)+C(6)*@MEAN(LM)+C(10)*@MEAN(LL)+C(11)*@MEAN(LK)+C(12)*@MEAN(LR)

XL=C(3)+C(7)*@MEAN(LL)+C(10)*@MEAN(LM)+C(13)*@MEAN(LK)+C(14)*@MEAN(LR)

Appendix C

Correlation Matrix

	Y	Q	M	L	K	R	W90	EXR	EMP	QKM	RR
Y	1.00	0.86	0.68	0.79	0.83	0.70	0.96	0.33	0.76	0.00	-0.07
Q	0.86	1.00	0.96	0.70	0.86	0.48	0.78	0.19	0.68	0.09	-0.09
M	0.68	0.96	1.00	0.57	0.78	0.30	0.59	0.10	0.56	0.13	-0.08
L	0.79	0.70	0.57	1.00	0.63	0.34	0.78	0.11	0.99	-0.08	-0.17
K	0.83	0.86	0.78	0.63	1.00	0.45	0.72	0.36	0.61	-0.08	-0.22
R	0.70	0.48	0.30	0.34	0.45	1.00	0.68	0.51	0.32	-0.04	0.08
W90	0.96	0.78	0.59	0.78	0.72	0.68	1.00	0.31	0.76	-0.07	-0.16
EXR	0.33	0.19	0.10	0.11	0.36	0.51	0.31	1.00	0.11	-0.12	-0.01
EMP	0.76	0.68	0.56	0.99	0.61	0.32	0.76	0.11	1.00	-0.08	-0.16
QKM	0.00	0.09	0.13	-0.08	-0.08	-0.04	-0.07	-0.12	-0.08	1.00	0.39
QLN	0.60	0.44	0.31	0.22	0.46	0.77	0.61	0.59	0.20	0.01	0.04
RR	-0.07	-0.09	-0.08	-0.17	-0.22	0.08	-0.16	-0.01	-0.16	0.39	1.00
TSO	0.46	0.29	0.16	0.16	0.29	0.77	0.45	0.57	0.15	-0.04	0.09
SO	0.40	0.24	0.12	0.13	0.25	0.72	0.41	0.57	0.12	-0.04	0.09
FSO	0.41	0.23	0.11	0.13	0.22	0.69	0.41	0.55	0.11	-0.03	0.16
SHFT	-0.08	-0.02	0.02	-0.13	0.10	-0.14	-0.14	-0.08	-0.15	0.18	-0.02
OLIM	-0.43	-0.39	-0.33	-0.24	-0.38	-0.39	-0.43	-0.17	-0.23	-0.04	0.01
PPA	0.17	0.16	0.14	-0.06	0.17	0.18	0.15	0.34	-0.08	-0.04	0.10
KNO	0.18	0.13	0.10	-0.06	0.15	0.32	0.12	0.45	-0.07	0.00	0.19
PY	-0.03	0.07	0.11	0.08	0.04	-0.04	-0.05	-0.11	0.07	0.08	-0.07
PQ	0.07	0.09	0.09	0.11	0.08	0.05	0.05	-0.01	0.10	0.04	-0.06
PM	0.12	0.09	0.07	0.10	0.09	0.11	0.11	0.03	0.09	-0.04	-0.06
RESw	0.09	-0.08	-0.15	-0.02	-0.04	0.02	-0.13	0.04	-0.03	0.05	-0.07

	TSO	SO	FSO	SHIFT	OLIM	PPA	KNOH	PY	PQ	PM
Y	0.46	0.40	0.41	-0.08	-0.43	0.17	0.18	-0.03	0.07	0.12
Q	0.29	0.24	0.23	-0.02	-0.39	0.16	0.13	0.07	0.09	0.09
M	0.16	0.12	0.11	0.02	-0.33	0.14	0.10	0.11	0.09	0.07
L	0.16	0.13	0.13	-0.13	-0.24	-0.06	-0.06	0.08	0.11	0.10
K	0.29	0.25	0.22	0.10	-0.38	0.17	0.15	0.04	0.08	0.09
R	0.77	0.72	0.69	-0.14	-0.39	0.18	0.32	-0.04	0.05	0.11
W90	0.45	0.41	0.41	-0.14	-0.43	0.15	0.12	-0.05	0.05	0.11
EXR	0.57	0.57	0.55	-0.08	-0.17	0.34	0.45	-0.11	-0.01	0.03
EMP	0.15	0.12	0.11	-0.15	-0.23	-0.08	-0.07	0.07	0.10	0.09
QKM	-0.04	-0.04	-0.03	0.18	-0.04	-0.04	0.00	0.08	0.04	-0.04
QLN	0.76	0.73	0.80	-0.10	-0.46	0.36	0.50	-0.02	-0.01	-0.01
RR	0.09	0.08	0.16	-0.02	0.01	0.10	0.19	-0.07	-0.06	-0.06
TSO	1.00	0.90	0.70	-0.18	-0.36	0.23	0.36	-0.06	0.06	0.14
SO	0.90	1.00	0.73	-0.18	-0.32	0.17	0.32	-0.07	0.05	0.13
FSO	0.70	0.73	1.00	-0.18	-0.18	0.29	0.54	0.06	0.04	0.03
SHIFT	-0.18	-0.18	-0.18	1.00	0.24	0.13	0.02	0.06	-0.02	-0.09
OLIM	-0.36	-0.32	-0.18	0.24	1.00	-0.13	-0.12	0.10	0.07	0.06
PPA	0.23	0.17	0.29	0.13	-0.13	1.00	0.64	-0.03	0.00	-0.05
KNOH	0.36	0.32	0.54	0.02	-0.12	0.64	1.00	-0.06	-0.05	-0.08
PY	-0.06	-0.07	0.06	0.06	0.10	-0.03	-0.06	1.00	0.82	0.54
PQ	0.06	0.05	0.04	-0.02	0.07	0.00	-0.05	0.82	1.00	0.88
PM	0.14	0.13	0.03	-0.09	0.06	-0.05	-0.08	0.54	0.88	1.00

Appendix D

Rates of Return on Physical and R&D Capital (Percent)

	Physical capital (gross)	R&D capital (gross)	R&D capital (net)
Mean:	**14.1**	**20.5**	**34.2**
From production function—mean data			
—Output	13.2	16.0	26.7
—Product	18.2	18.1	30.2
From three-year production function:			
—Output	12.0	16.4	27.3
—Product	18.2	22.6	37.7
Simultaneous model:			
With W—output	10.0	15.5	25.9
With EXR—output	8.8	19.9	33.1
Regression excl. spillover (TSO):			
—Output	14.0	26.8	44.6
—Product	18.2	29.0	48.3

1) The computation was performed by means of capital coefficients culled from regressions that include the spillover (TSO) variable, except for the last two.

Appendix E

Table 5: Output, R&D, and Wage—Simultaneous Model (detailed presentation)

Equation: LQL=C(1)+C(2)*LML+C(3)*LL+C(4)*LKL+C(5)*LRL+C(6)*LTSO4+C(7)*LQKM+C(8)*LOLIM

Observations: 231

R-squared	0.972	4.512
Adjusted R-squared	0.971	0.485
S.E. of regression	0.083	1.527

Equation: LRL=C(10)+C(11)*LQLN+C(12)*EXR+C(13)*RR+C(14)*LQL+C(15)*LFSON+C(16)*LSO4+C(18)*EMP

Observations: 231

R-squared	0.684	-1.008
Adjusted R-squared	0.674	1.949
S.E. of regression	1.113	276.400

Equation: LWL=C(20)+C(21)*LQLN+C(22)*LTSO4+C(23)*LQL+C(24)*LQKM+C(26)*LOLIM+C(27)*LRL

Observations: 231

R-squared	0.657	2.986
Adjusted R-squared	0.648	0.409
S.E. of regression	0.242	13.172

The model:

LQL=C(1)+C(2)*LML+C(3)*LL+C(4)*LKL+C(5)*LRL+C(6)*LTSO4+C(7)*LQKM+C(8)*LOLIM @ LML LL LKL LTSO4 LQKM LOLIM LPPA PY LKNOH LFSON C

LRL=C(10)+C(11)*LQLN+C(12)*EXR+C(13)*RR+C(14)*LQL+C(15)*LFSON+C(16)*LSO4+C(18)*EMP @ LQLN EXR RR LFSON LSO4 LPPA PY EMP LKNOH RESW LKL C

LWL=C(20)+C(21)*LQLN+C(22)*LTSO4+C(23)*LQL+C(24)*LQKM+C(26)*LOLIM+C(27)*LRL@ LQLN LTSO4 LQKM LOLIM LKNOH EXR LKL PQ LFSON C

Table 6: Output, R&D, and Exports—Simultaneous Model (detailed presentation)

Equation: **LQ**=C(1)+C(2)*LM+C(3)*LL+C(4)*LK+C(5)*LR
+C(6)*LTSO4+C(7)*LQKM+C(8)*LOLIM @ LM LL LK LTSO4
LQKM LOLIM LPPA PY LKNOH LFSON QLN C

R-squared	0.992	Mean dependent var	6.267
Adjusted R-squared	0.992	S.D. dependent var	0.927
S.E. of regression	0.083	Sum squared resid	1.520

Equation: **LR**=C(10)+C(11)*RESW+C(12)*EXR+C(13)*RR
+C(14)*LKL+C(15)*LFSON+C(17)*LPPA
+C(18)*EMP @ RR LKL LFSON RESW LPPA PY EMP
LKNOH C

R-squared	0.546	Mean dependent var	0.747
Adjusted R-squared	0.532	S.D. dependent var	2.071
S.E. of regression	1.417	Sum squared resid	447.855

Equation: **EXR**=C(30)+C(31)*KL+C(32)*TSO4+C(33)*QLN
+C(34)*KNOH+C(36)*OLIM+C(37)*RESW @ KL TSO4 QLN KNOH QKM OLIM RESW PPA
EMP PQ C

R-squared	0.409	Mean dependent var	0.264
Adjusted R-squared	0.393	S.D. dependent var	0.237
S.E. of regression	0.184	Sum squared resid	7.616

Appendix F
List of Variables

Y	Product
Q	Output
M	Intermediates input
L	Labor input (labor hours)
K	Physical capital (buildings, machinery and equipment, and motor vehicles)
R	R&D capital stock
W	Labor wage
EXR	Rate of exports
EMP	Employment
QKM	Quality of physical capital (percent of investment in past five years in machinery and equipment stock)
QLN	Quality of labor (proportion of engineers, degree holders, and technicians in employment)
TSO	Value of R&D spillover from other industries and among establishments in the same industry
SO	Value of R&D spillover from other industries only
FSO	Value of R&D spillover from other countries
PPA	Proportion of establishments in the industry that acquired patents and innovations
KNOH	Proportion of establishments in the industry that acquired knowledge
SHIFT	Proportion of hours worked in second and third shifts
RRk	Rate of return on physical capital (earnings as percent of physical capital)
OLIM	Share of recent immigrants in employment
PY	Product price index
PQ	Output price index
TFP	Total factor productivity—product less the weighted input of labor and physical capital
RESW	Residual in the wage function—represents quality of labor (human capital) not fully accounted for by other variables

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Simcha Bar-Eliezer and Arie Bregman

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