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R&D, Firm Size and Innovation: An Empirical Analysis

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Abstract

Investment in R&D spawns innovations, which in turn foster economic growth. In recent years, researchers have become increasingly aware of the role of industrial innovation in the rate of regional development and economic growth. In order to innovate, firms must invest in R&D (in-house or out-sourcing), and engage highly skilled labor that is able to cope with complex technological problems. The plethora of empirical studies on the determinants influencing R&D expenditure, and thus the rate of innovation, suggests that this investment is related, in different degrees, to firm size, organizational structure, ownership type, industrial branch and location. Large firms tend to invest more in R&D than do small ones. Numerous studies have found that R&D tends to be concentrated in large urban areas, and it plays a more vital role in creating innovation in central than in peripheral areas.

This paper presents a model whose assumption is that expenditure on R&D is influenced by a firm's characteristics – primarily its size, type of industrial branch, ownership type and location. The results obtained in the empirical analysis are based on data collected through personal interviews involving 209 industrial firms in the Northern part of Israel.

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INTRODUCTION

There is ample empirical evidence supporting the hypothesis that R&D expenditures are a *sine-qua-non* for the firm's level of innovation activities (Stokey, 1995; Griliches, 1995; Bayoumi et al., 1999; Hall, 1996; Hall and van Reenen, 1999/2000; Shefer and Frenkel, 1998; Frenkel at al., 2001).

Ever since industrial innovation was recognized as a major force that fosters economic growth, there has been flourishing interest in economic growth models with endogenous technological progress (Romer, 1986, 1990, 1994; Lucas, 1988; Dosi, 1988; Grossman and Helpman, 1990, 1991, 1994; Barro and Sala-i-Martin, 1995; and Aghion and Howitt, 1998). The endogenous economic growth models assume that firms may invest in new technology through expenditure on R&D if they perceive an opportunity to make a profit. Thus, technological progress could explain the persistent growth in output, and consequently in income per capita or "standard of living" (Grosman and Helpman, 1991, 1994; Pack, 1994; Romer, 1994; Stokey, 1995).

Innovation provides new and, at times, unique opportunities for creating new firms and expanding old ones. Consequently their market share is enlarged and, with increasing returns to scale, they enjoy greater production efficiency and a higher rate of economic growth (Schmookler, 1966; Segerstrom, 1991). Greater production efficiency enables industries to expand their domestic market share through import substitution, to increase local consumption and, at the same time, to penetrate new foreign markets and increase their export share (Porter, 1990; Krugman, 1979, 1990, 1991, 1995).

THE DETERMINANTS OF R&D EXPENDITURES (The Hypotheses)

Numerous studies have shown that R&D expenditures constitute the most influential variable in a firm's ability to innovate (Rosenberg, 1985; Nelson, 1986; Dosi, 1988; Freeman and Soete, 1997). Investment in R&D enables firms to hold a competitive edge over their competitors, at least during the first stage of the innovation diffusion process.

1. Firm Size

Previous studies have focused on the positive effect that firm size has on the level of R&D expenditure; that is, the firm's propensity to invest in R&D is positively associated with its size, *ceteris paribus* (see Fisher and Temin, 1973; Nabseth and Ray, 1974; Dosi, 1988; Acs and Audretsch, 1988, 1991, 1991b, 1991c).

It is widely believed that a major proportion of industrial R&D is undertaken by large firms. Therefore, it was assumed that economies of scale exist in expenditures on R&D. The relationship between firm size and R&D activities is particularly interesting in view of the fact that in recent years we have encountered a large number of small firms that engage in innovative activity. This is particularly true of firms belonging to the high-tech industrial branch (Acs and Audretsch, 1993; Kleinknecht, 1989, 1991; Scheirer, 1991). The current study will thoroughly investigate the degree of association between size of firms and rate of investment in R&D activities.

2. Location

The idea of paying attention to the specific location of firms with respect to innovation emanated from findings of previous studies in which firms' rate of innovation was seen to be location-specific. For example, high-tech firms located in metropolitan areas were found to be significantly more innovative than firms locates in peripheral areas (Davelaar, 1991; Davelaar and Nijkamp, 1989, 1997; Feldman, 1994; Ciccone and Hall, 1996; Shefer and Frenkel, 1998; Audretsch, 1998; Audretsch and Feldman, 1996).

3. Innovation

A firm's decision to invest in R&D may be influenced by a number of factors, among which is the firm's current level of innovation. Although innovation is most often explained by the extent of in-house R&D efforts, as well as outsourced R&D services, the existence of a causal relationship is conceivable– that is, firms will decide to increase their current level of R&D expenditures in consequence of their past success in generating innovations. Thus we would expect to find a positive relationship between the level of investment in R&D and innovations (Acs and Audretsch, 1998, 1991a; Grossman and Helpman, 1991b; Feldman, 1994; Audretsch, 1995; Kleinknecht, 1996; Freeman and Soete, 1997).

4. Export

High-tech industry is one of the leading export sectors. High-tech firms appear to be more export-oriented than low-tech or traditional firms. The fact that high-tech firms in Israel are export-oriented is consistent with international trade theories of comparative advantage. In 1998, exports from the high-tech sectors accounted for about 37% of Israel's total industrial exports, whereas low-tech firms exported only 8% of output. The importance of this export data is underlined by the relatively small size of the Israeli local market, and the consequent need for firms to develop export sales if they are to continue to grow. Thus, the need to export could account, in part, for the decision made by firms to invest in R&D in order to generate new innovation (Suarez-Villa and Fischer, 1995; Porter, 1990; Grossman and Helpman, 1990; Krugman, 1979, 1991, 1995).

5. Age of Firm

Investment in R&D can be affected by firm size in different ways. Large firms are more likely to secure the funding needed for large scale R&D. By and large, large firms are older than smaller firms. Yet, it may be observed that in the high-tech industrial branch we can find a large number of startups that are young and relatively small. These firms engage intensely in R&D activities. Thus it will be interesting to investigate this hypothesis in the empirical analysis.

6. Firms that belong to a concern

Firms that are part of a concern are more likely to invest a larger amount in R&D than will individual firms. Here, too, it is assumed that a large concern is more able to secure the necessary funding for R&D. Thus, compared to individual firms, the risk involved is smaller for firms that are part of a concern (Frenkel at al., 2001).

7. High-Tech vs. Traditional firms

Variations in the rate of investment in R&D may be associated with the industrial branch of the firms involved. Therefore, it would be appropriate to examine the impact of the industrial branch on the rate of expenditure on R&D. In order to do this, we decided to stratify the sample of firms into two basic industrial groups on the basis of their technological character. The first group, representing the high-tech industries, includes electronics, electro-optic and precision instruments. The second group represents the more traditional industries – plastics and metal products.

The reasons for this division is also connected to the relatively small number of plants affiliated with the metal products industry. The similarity in behavior between traditional industrial sectors (plastics and metal products), on the one hand, and the difference between those industries and the high-tech industries, on the other hand, also lend justification to this grouping. Furthermore, numerous variations in innovative capability have been found to characterize these two industrial groups. The difference is reflected in the high expenditure on R&D made by the high tech industries compared to the traditional industries (see Frenkel at al., 2001; Acs and Audretsch, 1993b).

DATA SOURCE

The data used in this study were collected from a sample of industrial firms in a selected number of fast-growing industrial branches. Identification of fast-growing industries was based on an analysis of the rate of growth in output, employment and exports generated in each of the two-digit industrial branches. Three major industrial branches were selected: electronics (including optics and precision instruments), plastics and metal products. (For more details on the methodology used in identifying fast-growing industries, see Shefer et.al., 2001.)

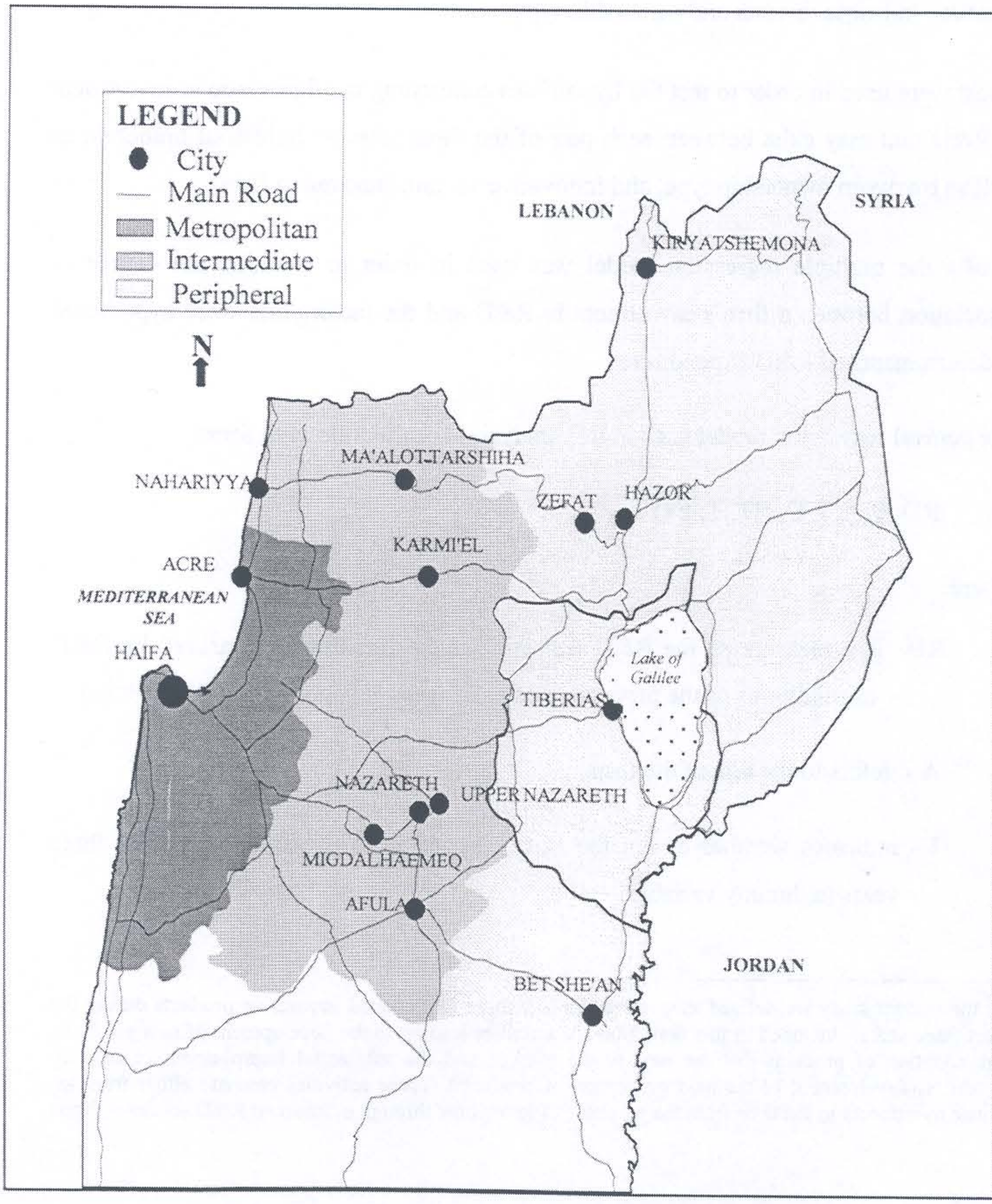
The data were collected in a field survey of a randomly selected sample of firms situated in the northern district of Israel. A questionnaire was constructed for gathering data on the level of the firm. Data concerning innovation activity, as well as information on such characteristics as firm size, R&D activities, location, age of firm, ownership type and industrial branch affiliation, were included in the questionnaire.

Personal interviews were held with senior managers of each of the 209 firms included in this study. The sample included approximately 72% of the total number of firms in the region surveyed that were affiliated with the aforementioned three industrial branches.

The Northern district of Israel is one of Israel's most fascinating regions in terms of the composition of its inhabitants (Jews and non-Jews, veteran settlers as well as new immigrants), settlements type and pattern, and landscape. In 1995 (when the data collection took place), some 1.4 million people, constituting about 26% of the population of Israel, resided in this region, which extends for about 5,000 km2 and accounts for 23% of the total land area of the state.

The Northern district was divided into three sub-regions: (1) the Haifa metropolitan area (central zone); (2) a surrounding intermediate zone (within acceptable commuting distance and including the central and western Galilee); (3) a peripheral zone (removed from metropolitan influence and not within acceptable commuting distance). This last subregion, which offers fewer employment opportunities as well as fewer social, cultural and commercial services, consists of the eastern Galilee and the length of the Jordan Valley, from Metula and Kiryat Shemona in the north to Beit She'an in the south-east (see Map 1).

Map1: Major Area Division of the Northern Region in Israel



Since economic growth is driven to a large extent by technological progress and innovations, and innovation is determined by investment in R&D, it is of paramount importance to identify the factors that most influence the rate of investment in R&D activities.

METHODOLOGY

Three types of statistical models were used in the analysis: analysis of variance (ANOVA); Difference-of-Means "t test"; and Multipile Regression Analysis. ANOVA was used for testing hypotheses concerning the effect of size of firms on the rate of expenditure on R&D. This analysis also included the stratification of the sample by location, industrial branch and ownership type.

T-test were used in order to test the hypotheses concerning the difference in investment in R&D that may exist between each pair of the three selected industrial branches, as well as bwrween ownership type, and innovative vs. non-innovative firms.

Finally the multiple regression model was used in order to examine the degree of association between a firm's investment in R&D and the factors that were hypothesed as determinants of R&D expenditures.

The general regression model used in this analysis is of the following form:

$$RD = f(A, I, C, HT, T, Ex)$$

Where:

RD is a measure of the R&D activities at the firm level (measured by R&D expenditures or the proportion of employees engaged in R&D activities).

A - refers to the **age** of the firm.

I[1]- indicates whether or not the firm engaged in **innovation** in the last three years (a dummy variable)

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[1] In the current study we defined innovative firms as those that created innovative products during the past three years. Included in this definition are activities leading to the development of new products, the adoption of products that are new to the market, and the substantial improvement of existing products (development of the next generation of products). These activities emanate either from in-house nvestments in R&D or from the purchase of know-how through outsourced R&D services. Firms

C - indicates whether or not the firm belongs to a large **concern** (a dummy variable).

HT - indicates whether or not the firm belongs to the **high-tech** group of firms as opposed to the traditional group of firms (a dummy variable).

T - refers to the total annual **turnover** of the firm (in millions of dollars).

Ex - refers to the firm's total receipts from **exports** (in millions of dollars).

In the statistical analyses, we tested alternative specifications of the regression model, utilizing linear and log-linear Ordinary Least Squares (OLS) estimation techniques.

RESULTS

Analysis of Variance (ANOVA) was employed in order to test the degree of statistical association between firm size and R&D activities (Tables 1.1-1.4, and 2.1-2.4). In the first set of tables (1.1-1.4), we have used % of R&D employees of the total work force as a measure of R&D activities, and in the second set of tables (2.1-2.4) % of R&D expenditures of the total turnover as an alternative measure of R&D activities.

As can be seen from the results obtained for the entire sample, a significantly negative association exists between size of plant and R&D expenditures (see Tables 1.1 and 2.1). This result implies that the small-size firms in our sample engage more intensively in R&D activities than do the large firms. However, when we stratify the sample into the two distinct group of firms, high-tech and traditional, then high-tech plants show a highly negative statistically significant association; for the traditional group of firms, on the other hand, no statistically significant result was observed (Tables 1.2 and 2.2). When we stratify the sample by location, a highly negative statistically significant result was obtained for the group of firms located in the metropolitan and intermediate areas, whereas no significant results were observed for the group of firms located in the peripheral areas (Tables 1.3 and 2.3). Conceivably this result is closely related to the fact that the majority of the high-tech firms were found in the metropolitan and intermediate areas while the traditional firms were concentrated in the peripheral areas.

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that dealt exclusively in developing or adopting innovative processes, or adopting new products not requiring R&D investment were not classified as innovative firms in this study.

Table: 1.1 R&D Employees, % from Total Employment (all Plants)

Size of Plant	Mean	N
- 24	22.15	52
25-49	11.87	51
50-99	4.79	54
100+	8.93	52
Total	11.87	209

F = 7.735 ***Sig. 0.000***

Table: 1.2 R&D Employees, % from Total Employment

	Electronics		**Plastics & Metals**	
Size of Plant	**Mean**	**N**	**Mean**	**N**
- 24	39.38	29	4.21	23
25-49	28.98	18	2.53	33
50-99	6.85	16	3.92	38
100+	17.61	23	2.04	29
Total	24.32	86	3.16	123

F = 5.864 ***Sig. = 0.001;*** ***F = 1.396*** ***Sig. = 0.247***

Table: 1.3 R&D Employees, % from Total Employment

	Metro+Interm. Areas		Peripheral	
Size of Plant	**Mean**	**N**	**Mean**	**N**
- 24	24.62	44	8.58	8
25-49	15.98	34	3.65	17
50-99	5.16	31	4.29	23
100+	11.36	39	1.63	13
Total	15.06	148	4.11	61

F = 5.278 Sig. = 0.002; F = 1.965 Sig. = 0.178

Table: 1.4 R&D Employees, % from Total Employment

	Concern		Others	
Size of Plant	**Mean**	**N**	**Mean**	**N**
- 24	52.62	5	18.91	47
25-49	22.84	10	9.19	41
50-99	5.62	6	4.69	48
100+	17.74	21	3.00	31
Total	21.37	42	9.47	167

F = 3.370 Sig. = 0.028 F = 8.545 Sig. = 0.000

Table: 2.1 R&D Expenditure, % from Total Turnover (all Plants)

Size of Plant	Mean	N
- 24	16.44	46
25-49	11.72	44
50-99	2.96	51
100+	6.09	43
Total	9.16	184

F = 4.676 *Sig. 0.004*

Table: 2.2 R&D Expenditure, % from Total Turnover

	Electronics		Plastics & Metals	
Size of Plant	**Mean**	**N**	**Mean**	**N**
- 24	28.51	25	2.07	21
25-49	27.45	17	1.81	27
50-99	5.42	16	1.84	35
100+	10.90	20	1.90	23
Total	19.03	78	1.89	106

F = 3.939 *Sig. = 0.012;* *F = 0.031* *Sig. 0.992*

Table: 2.3 R&D Expenditure, % from Total Turnover

	Metro+Interm. Areas		Peripheral	
Size of Plant	**Mean**	**N**	**Mean**	**N**
- 24	17.45	38	11.65	8
25-49	18.51	25	2.78	19
50-99	3.10	28	2.80	23
100+	7.32	34	1.44	9
Total	11.69	125	3.79	59

F = 3.550 Sig. = 0.017; F = 2.821 Sig. = 0.047

Table: 2.4 R&D Expenditure, % from Total Turnover

	Concern		Others	
Size of Plant	**Mean**	**N**	**Mean**	**N**
- 24	55.83	4	12.69	42
25-49	23.30	7	9.53	37
50-99	5.13	6	2.67	45
100+	11.18	19	2.05	24
Total	17.49	36	7.13	148

F = 4.445 Sig. = 0.010; F = 3.839 Sig. = 0.011

As for the effect of ownership type on the rate of investment on R&D, a statistically significantly negative association was found to prevail in both groups of firms – those that are part of a large concern and individually owned firms. Nevertheless, the magnitude of the expenditure on R&D (as measured in empoloyment and money) in the group of firms that belong to a concern is by far larger, more than twice on average (Tables 1.4 and 2.4).

Tables 3.1-3.2 and 4.1-4.2 present the results of the statistical analysis (t-test) conducted between firms affiliated with high-tech industries and the traditional industries.

The results show that a highly significant difference exists between the various industrial branches (at the 1% level). When a similar analysis was conducted between the plastics and metal products industries, no statistical difference was observed. This result lends justification to the stratification of the industries into the two major groups: high-tech and traditional.

What is also interesting, but not very surprising, is to note the magnitude of the mean values of the investment in R&D between the innovative and the non-innovative firms (see bottom of Tables 3.1-3.2 and 4.1-4.2). Naturally these large differences in the rate of expenditure on R&D activities in these two distinct groups of firms were found to be highly statistically significant (at the 1% level)

Table 5 reports the regression results. Four models were used in which the explanatory variable, R&D activities, was introduced in different forms. R&D was introduced in a Ln formin the first and third models, but not in models 2 and 4. As can be observed, the F-value of the regression in all cases is significant at the 1% level. About 50% of all variations in the dependent variable are explained by the independent variables used in the regression.

As can be observed in models 2 and 4, in which the independent variable was introduced as a raw value, there are more significant coefficients than in the results obtained in models 1 and 3.

Table: 3.1 Total Number of Employees in R&D

	N	Mean	t value
Electronics x Plastics	86 79	22.52 2.25	2.913**
Electronics x Metals	86 44	22.52 2.39	2.884**
Metals x Plastics	44 79	2.39 2.25	0.212
Part of a Concern x Independent	42 96	37.90 4.31	2.424**
Innovative x non-innovative	111 98	18.70 1.47	3.170**

** *Significant at the 1 percent level.*

* *Significant at the 5 percent level.*

Table: 3.2 % R&D Employees From Total Employees

	N	Mean	T value
Electronics x Plastics	86 79	24.32 3.19	7.309**
Electronics x Metals	98 44	24.32 3.10	7.075**
Metals x Plastics	44 79	3.10 3.19	-0.098
Part of a Concern x Independent	42 96	21.37 13.52	1.630
Innovative x non-innovative	111 98	20.34 2.27	7.609**

** *Significant at the 1 percent level.*

* *Significant at the 5 percent level.*

Table: 4.1 R&D Expenditures in $m (from total annual turnover)

	N	Mean	T value
Electronics x Plastics	82 69	2.22 0.15	2.361**
Electronics x Metals	82 39	2.22 0.20	2.306**
Metals x Plastics	39 69	0.20 0.15	0.636
Part of a Concern x Independent	38 86	4.25 0.31	2.144*
Innovative x non-innovative	98 92	1.93 0.11	2.481**

** *Significant at the 1 percent level.*

* *Significant at the 5 percent level.*

Table: 4.2 % R&D Expenditure (from total annual turnover)

	N	Mean	T value
Electronics x Plastics	78 68	19.03 1.79	5.609**
Electronics x Metals	78 38	19.03 2.06	5.414**
Metals x Plastics	39 69	2.06 1.79	0.362
Part of a Concern x Independent	36 82	17.49 10.71	1.312
Innovative x non-innovative	94 90	16.46 1.53	5.682**

** *Significant at the 1 percent level.*

* *Significant at the 5 percent level.*

Table 5: Regressions Results of the Determinants of R&D Activities

Model†	**1**	**2**	**3**	**4**
Constant	-10.17 (-4.96)**	30.10 (7.90)**	-5.23 (-1.48)	94.07 (5.53)**
Age of firm	-3.35 E-02 (-0.72)	-0.30 (-3.50)**	-8.08E-02 (-1.07)	-2.42 (-2.31)**
Innovation (dummy)	12.13 (10.68)**	12.70 (6.02)**	17.93 (9.83)**	11.47 (4.53)**
Concern (dummy)	2.205 (1.54)	5.24 (1.97)*	3.88 (1.68)	9.66 (2.80)**
Electronic (dummy)	8.42E-02 (0.70)	10.63 (4.75)**	-5.48 (-2.82)**	8.00 (2.91)**
Ln turnover (annual $m)	-0.14 (-1.35)	-1.50 (-7.76)**	-0.13 (-0.73)	-5.28 (-5.24)**
Ln export (m $)	0.184 (5.15)**	4.52 E-02 (0.68)	0.24 (4.11)**	0.22 (2.44)**
Number of observations	192	192	179	176
F	37.41**	43.7**	29.1**	20.4**
Adj. R^2	0.53	0.57	0.49	0.40

†Model 1: dependent variable – Ln employees in R&D.

Model 2: dependent variable – percent employees in R&D.

Model 3: dependent variable – Ln expenditure on R&D.

Model 4: dependent variable – percent expenditure on R&D.

Note: Figures in parentheses are t values.

* **Significant at 5 percent level (t>1.96).**

** **Significant at 1 percent level (t>2.30).**

The most striking, robust coefficient is the one estimated with the innovation dummy variable. This result was expected, and it is consistent in all four models estimated. Furthermore, the coefficients associated with firms that belong to the high-tech industrial branch (a dummy variable) were found to be large in value and significant at the 1% level in models 2 and 4. This result implies that firms in the high-tech group are likely to invest more in R&D activities compared to firms in the more traditional groups. Similarly firms that belong to a large concern are likely to invest more in R&D activities compared to individual firms.

A firm's age and level of turnover appear to have a significant, but negative, effect on the firm's level of investment in R&D activities; that is, younger firms incline to invest more in R&D activities than do older firms ceteris paribus, and smaller firms (as measured by turnover) invest more in R&D activities compared to larger firms ceteris paribus. This interesting result is contrary to the result obtained in previous empirical studies (see discussion presented above). It is conceivable that this result is due to the fact that at the time of the survey, a large number of high-tech startups began operating in Israel, including in the northern region. These new, relatively small firms sometimes engaged entirely in R&D activities, with no or very little output. The phenomenon could very well explain this outcome. The effect of a firm's export on its expenditures on R&D was found to be relatively small in magnitute and statistically not very significant.

The F-values computed for all four regressions are all statistically significant at the 1 percent level; and the level of explanations obtained, as depicted in the values of the adjusted R-squares, are all around 50%.

SUMMARY AND CONCLUSIONS

R&D activity is a catalyst for innovative industrial activities, and ultimately it is responsible for the growth in productivity and total revenue. The share of labor engaged in R&D as well as the rate of investment in R&D were found to be very closely related to firm size in a high-tech group of firms. However, this relationship is negative and statistically significant. Thus, our finding does not concur with previous studies, in which a positive relationship was observed between firm size and the rate of investment in R&D activities. The rate of investment in R&D is not associated with firm size in the plastics and metals industries. Industrial branch and a firm's location affect the rate of R&D expenditures, however defined. In peripheral areas, the degree of association between the rate of investment in R&D and firm size is quite weak.

The magnitude of the expenditure on R&D in the group of firms that belongs to a concern is by far larger than that of individually owned firms. Highly significant difference was found to exists between firms affiliated with the high-tech industries and the traditional industries. When a similar analysis was conducted between the plastics and metal products industries, no statistical difference was observed in the rate of the expenditure on R&D. The magnitude of the mean values of the investment in R&D between the innovative and non-innovative firms were found to be large and highly statistically significant.

The level of export increases monotonously with firm size regardless of industrial branch or location. Nevertheless, the rate of exports among high-tech firms is substantially greater than that found among the traditional group of firms. Approximately 50% of the variation in the firms' R&D expenditures can be explained by such variables as innovation, industrial branch affiliation, total revenue, export orientation and age of firm.

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