R&D Support in Israel - From Objectives to Policy

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Abstract

The R&D endeavor of Israel is drastically affected by governmental R&D support. The support is mostly distributed in accordance to the Israeli "law for the encouragement of industrial R&D", which specifies four policy objectives. Nevertheless, the way to transform these objectives to actual policy entails a complex set of considerations and tradeoffs. It is the purpose of this paper to explain why optimal policy of R&D support cannot be conducted without being backed up by solid ground economic research, one which uncovers the entire realm of tradeoffs. The paper also introduces a formal framework which highlights learning and the creation of competitive advantage.

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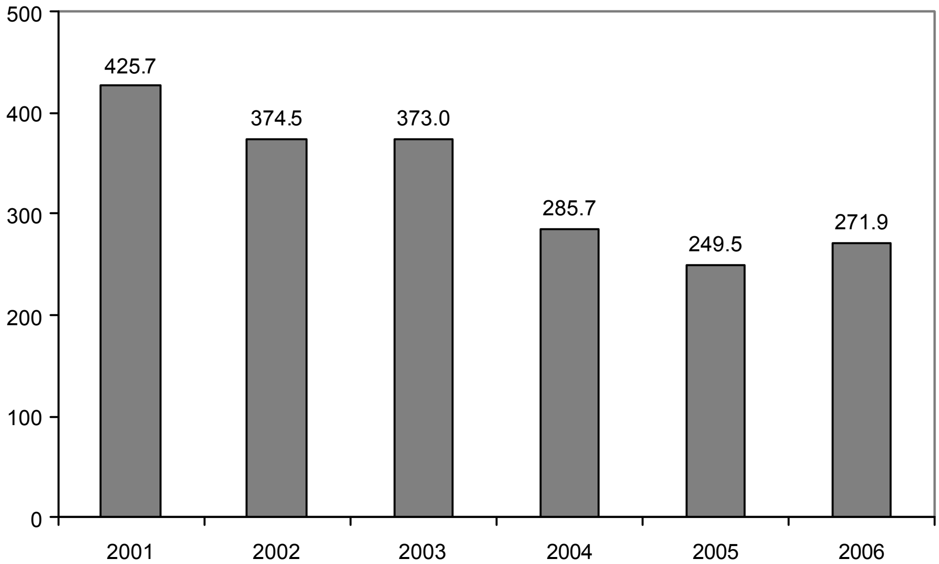
1. Introduction

This paper will attempt to make two contributions to the literature on R&D policy. The first will be addressing some of the tradeoffs of R&D support policy in Israel. This analysis will reveal that below the surface there is an entire realm of connections and tensions between the different policy objectives. The second contribution will be the introduction of a formal model which highlights the somewhat overlooked role of R&D subsidies, in enabling the policymaker to learn about the technological environment. This concept will be analyzed in the context of *Cournot* competition in the product market, and thus will be somewhat offset by the attempts of the policymaker to create a significant competitive advantage to local firms in foreign product markets.

The main government body in charge of innovation policy in Israel is the Office of Chief Scientist (OCS) in the Ministry of Industry, Trade and Labor. Its prominent role in the success of the R&D endeavor in Israel is unquestionable. A review of some of the statistics and empirical research on that subject can be found in Trajtenberg 2001. Teubal 1999 also mentions that there is an important body of opinion stating that venture capital investments in Israel will not take place without OCS R&D support (which is further discussed in some of his other paper). The introduction will be devoted for the understanding of the major trends and changes in R&D support in Israel by the OCS in the past few years.

The OCS budget has been monotonically increasing during the 1990s from about $130 million to more than $400 million by the end of the 90s. Figure 1.1 depicts the evolvement of the OCS budget between 2001 and 2006. During these years there has been an apparent trend of decline in the budget, which decreased by roughly 36% throughout the entire period.

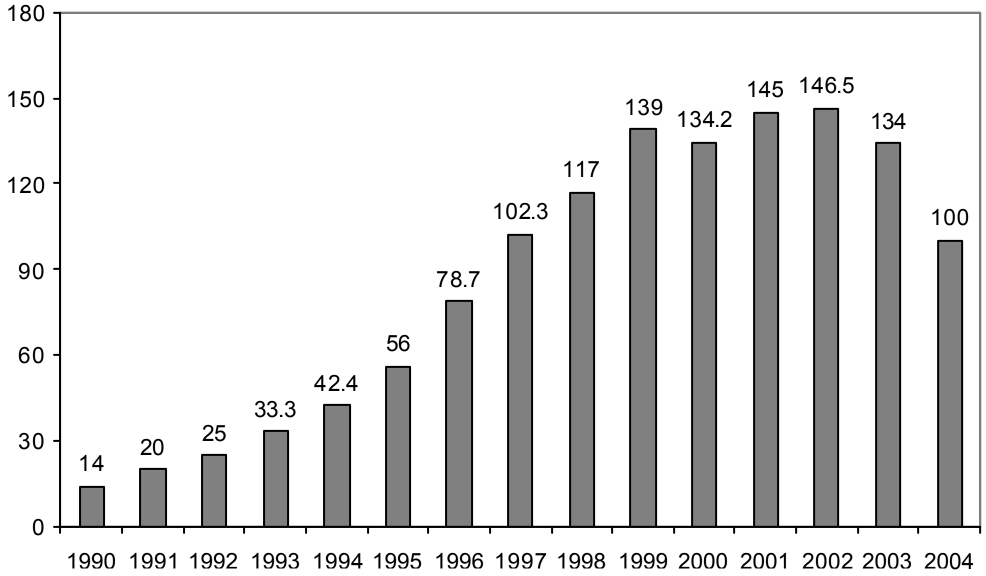
Figure 1.1: OCS Budget for Industrial R&D Support* ($ Million)



* **Source: Loten 2005, converted to USD according to the average exchange rate.**

The budget is spent on industrial R&D support via various programs, such as industry-academy consortia, "incubators" for helping small inventors to commercialize their ideas and more. The main program gives projects that qualify a grant of up to 50% of R&D costs. If the project succeeds, the recipient pays back the grant in installments which are about 3% of the yearly sales of the product. Figure 1.2 depicts the trends in those paybacks, since the beginning of the 1990s. Similar to the trends in the OCS budget, the paybacks have increased monotonically, and quite impressively, during the 1990s. Since 2002 there is a decline the paybacks.

Figure 1.2: OCS Paybacks* ($ Million)



* **Source: Loten 2005**

Over time, parallel to the decline in the paybacks and budget, there has also been a rise in demand for R&D support. Trajtenberg 2001 mentions that, starting 1997, the demand for R&D support greatly exceeded the budget provision by about 50%. Unfortunately, the support program was not meant to be competitive, and the law in Israel does not address the issue of how to allocate a rigid budget for R&D support if the demand exceeds the budget provision. This situation resulted in three major amendments in the R&D support policy of the OCS, as to be described in the following paragraphs.

Since the late 1960s Israel has adopted the principle of "neutrality" in governmental R&D support. The principal basically precludes picking projects according to fields or any other such consideration. The last 10 years are characterized by both explicit and implicit deviations from that principal. Explicitly, in a limited way, the fields of Bio-tech and Nano-technology are favored[1]. Special attention is also given to innovation in the traditional, low-tech industries. Implicitly, by supporting mainly product innovation, rather than process innovation, there is an indirect sectoral bias, favoring ICT.

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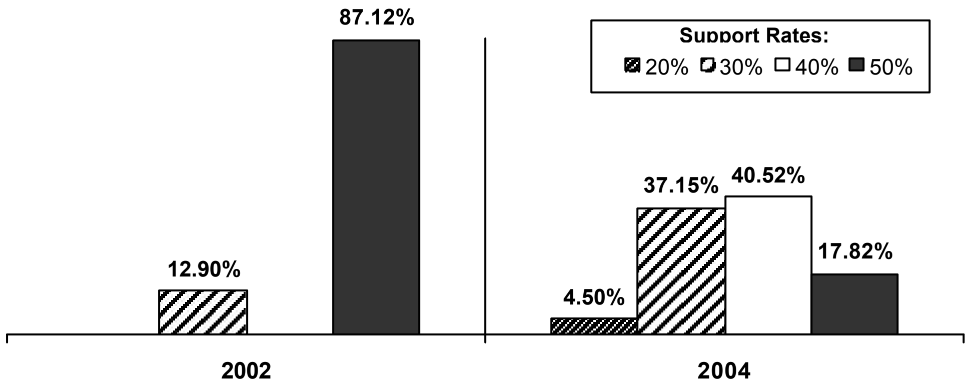
1 See, for example the OCS website http://www.moit.gov.il/NR/exeres/B3EA2391-B57A-480B-9250-AFB85A3D06B7.htm

In that context, even beyond any field favoring, the excess demand for R&D support requires some kind of ranking system between the different projects. Up to about 10 years ago, such a system was not required, since projects just had to pass the eligibility criteria. The main problem is that the ranking system is non-explicit, and thus its efficiency is doubtful.

A third change in policy has occurred in the support rate that the chosen projects receive. The maximal support rate is in accordance with the "matching principle", namely exactly 50% of the budget of the project (and up to 66% for start-ups). In the past, projects have received almost exclusively the maximal support rate. Figure 1.3 illustrates how fast and drastic the transformation in that subject has been. While in the year 2002 almost 90% of the projects received the maximal support rate, two years later, in 2004, less than 18% of the projects obtained that rate.

Figure 1.3: Decline in Support Rates Between 2002 and 2004*



* **Source**: Loten 2005

As to be described later on, both the choice of projects that qualify for support and choice of the support rate is done by a professional research committee.

The paper proceeds as follows. Section 2 reviews the economic rationale for governmental R&D support and the objectives defined in the Israeli law for such a support. Section 3 highlights the complex set of tradeoffs which exist when one tries to transmute these objectives into actual policy. Section 4 introduces a formal model which sketches the policy role in balancing learning vs. creating competitive advantage. Section 5 concludes the paper.

2. The Objectives of the Israeli R&D Support

Technological change has been long known to be one of the most important "engines of growth". Most empirical studies show that *total factor productivity* accounts for at least half of the growth in per capita income and high returns to R&D investments. However, these findings alone are not a sufficient reason to justify governmental intervention in the way the free markets conduct R&D. The first part of this section presents a non-inclusive review of the most common reasons which justify the economic rationale for such an intervention. Its second part compares and contrasts this rationale with the objectives of the R&D support, as defined by the Israeli law.

2.1 The Economic Rationale for Governmental Intervention

The first, and perhaps most important, reason for governmental intervention in R&D is the **gap between social and private returns** to R&D. This concept appears in some of the most influential work written on the economics of R&D, including that of Schumpeter 1942 and Arrow 1962. The main product of successful R&D is knowledge. The use of that knowledge in the production process will inevitably cause it to be available to other firms. These **spillovers** imply that not all the return from the R&D investment is fully appropriable by the creator of the knowledge. Furthermore, the firm does not internalize any potential increase in the consumer surplus generated by that technology. It is mentioned in Trajtenberg 2006 that empirical studies have shown that the social rate of return on R&D expenditures are typically very large, and often exceed private returns by as much as a factor of 3.

The **financing** problem in R&D is unique, and is often a crucial condition for performing R&D. The two main factors which create unusual difficulty in financing R&D, in comparison to the financing of other investments, are the lack of tangible assets and asymmetric information, *vis-à-vis* the prospects of the R&D activity. The latter factor might sometimes be treated, but often at a price of disclosing vital information to competitors. The following paragraphs review some of the papers which have dealt with those issues.

An example of a model which deals with the **information asymmetries** regarding the quality of the project between the inventor and the investor can be found in Leland

and Pyle 1977. They model a problem in which the entrepreneur is better informed about the expected profitability of a project than the investors. One of the means to mitigate this problem is if the entrepreneur can invest some of his own money in the project.

A **disclosure** of vital parts of the outcomes of the R&D is often needed in financing R&D projects, as can be seen in Bhattacharya and Ritter 1983. They have examined a patent race in which one firm is privately informed, and needs to raise external financing in order to resume the research. Raising funds in better terms requires disclosure; this disclosure, in turn, may help its rival firms in their research. Thus, the firm faces a tradeoff between these two alternatives. In a model which allows entry, the disclosure may also affect the number of competitors.

Finally, the **lack of tangible assets as collaterals** calls for strong monitoring in order to prevent moral-hazard issues. Bougheas 2004 has built a theoretical model in order to explain the empirical evidence which indicates that in countries with strong banking systems, small firms can rely on them in order to finance R&D, while in other countries similar firms have difficulties to raise debt in the capital markets, and have to rely on their internal funds. Banks, are assumed to have better bargaining power in the ex-post renegotiations, as well as better ability to monitor whether the funds are invested in R&D, or misused. As a result, there may be a vital advantage for banks in financing R&D over the capital markets

A last example of the role a governmental R&D support may serve can be found in Spencer and Brander 1983. They have concentrated on cost-reducing process innovation, and found a role for government R&D subsidies to enable domestic firms to capture rents from their foreign rivals. In particular, these R&D subsidies allow the domestic firm a **credible commitment** on its R&D level, hence turning it into a leader in the sequential game. They also show that such subsidies are domestically welfare increasing only in the absence of export subsidies.

2.2 The Law for the Encouragement of Industrial R&D

As stated in its preface, the Israeli "law for the encouragement of industrial R&D" has been legislated in order to achieve the following four objectives:

1) Creating jobs in the Israeli industry and promoting employment of personnel with scientific or technological background.

2) Producing a positive added value for the Israeli economy. The law defines *added value* as economic benefits which are created as a result of the R&D effort, beyond the profits of the person or organization directly involved in the R&D.
3) Developing a science-intense industry in Israel, while utilizing the country's existing technological and scientific infrastructure and human capital.
4) Improving Israel's current-account balance, by the manufacture and export of knowledge-intense products.

These objectives constitute the pillars on which the entire Israeli R&D support system stands. On the face of it, the objectives seem to be pretty straight forward and worthy. However, the following section, will attempt to bring to light some of the complexity in creating a policy aiming to achieve those objectives, and create a balance between them.

Furthermore, I would like to claim that even though not formally stated, at least two more implicit objectives of the Israeli R&D support exist. First, and foremost, the subsidies have to be such that they would change behavior. Trivially, no policymaker would like to simply substitute private money with public money. R&D support should be aimed at projects that otherwise would not be perused. Alternatively, the support should result in an increase in the overall R&D expenditure. This is sometimes referred to in the literature as "additionality", and indeed many of the empirical academic literature on R&D support focuses on the estimation of it[2].

The second implicit objective has to do with the uncertain nature of any R&D endeavor. If possible, the R&D support should result in as many successful R&D attempts as possible. That is to say, that *ceteris paribus* a policy maker should prefer R&D projects with the largest probability of success. Of course, given that it is known in advance that a project would fail, it should not be subsidized. Later on this paper we will see that this objective is not fully met by the Israeli policy.

[2] In that context, see, for example, Klette and Møen (1998) for a study of Norway and Lach 2000 for a study of Israel.

3. From Objectives to Policy

This section discusses how certain policy tools may contribute to achieving the objectives of the law. More than trying to offer policy recommendations, the goal of this section is to reveal how complex the tradeoffs between the different objectives can be. I would, therefore, like to claim that it would be impossible for a professional committee to grasp the entire realm of tensions and tradeoffs, without being equipped with very precise economic models which would bring them to light.

Let us start by thinking about the objective of producing a positive added value for the Israeli economy. If we are interested, indeed, in maximizing the technological spillovers, it would be reasonable to direct the R&D support to firms which operate in well established fields in Israel. On the other hand, in their well known paper, Cohen and Levinthal 1989 argue that it would be necessary for a firm to be actively involved in R&D in order build up its “absorptive capacity”, a trait which will enable it to absorb spillovers from external sources. Trajtenberg 2006, therefore, mentions that supporting a field with relatively negligible local participants might be most efficient in capturing international spillovers flows. Finally, maximizing the spillovers to consumers, namely increasing the consumer surplus, is likely to happen when the support is directed at firms that sell to a large and competitive local market.

Note that the definition of the a positive added value for the Israeli economy, as stated by the law, is very broad and therefore might also capture macro economic indicators. Explicitly, reducing inequality, promoting growth or creating counter-cyclical forces might also fall under the definition of “economic benefits which are created as a result of the R&D effort, beyond the profits of the person or organization directly involved in the R&D”. In the context of inequality, when one thinks of the private benefits gained by the firms which receive governmental R&D support, it might be reasonable to look at the holding structure of the recipient firms, so as to avoid directing a large share of the budget to firms held by a small number of tycoons. Furthermore, having a policymaker with risk aversion-like traits, who will distribute the support to various fields, may reduce the magnitude of business cycles, moderating the variance of the GDP and making it less affected by various economic shocks, such as changes in factor prices. In the discussion which follows, references will be made to how different policy tools may further affect some of those macro economic indicators.

Let us move now to the objective of job creation. Some obvious means of achieving that objective would be for the policymaker to favor labor-intense industries, and promote innovations which would maximize the quantities produced in equilibrium. Such a policy may be more affective in industries with low-skilled labor, and also in turn help reduce inequality by reducing unemployment. Indeed, the OCS in Israel, noticing that R&D flourishes mainly in the high-tech industry, which employs only a small fraction of the workforce, has recently decided to focus on innovation and technology adoption in traditional, low-tech industries[3]. Nonetheless, such sectors usually focus on non-innovative R&D. Papers, such as Davidson and Segerstrom 1998, point out situations in which only innovative R&D subsidies lead to faster economic growth, while imitative ones actually lead to slower growth in the economy. Moreover, concentrating on industries with high-skilled workers might be more in line with the objectives of promoting employment of personnel with scientific or technological background and developing a science-intense industry in Israel. However, such a policy might promote inequality. Trajtenberg 2006 has suggested subsidizing the supply side of the high-skilled labor market, which might be good for equality, while in the same time promote the high-tech industries. Such a policy, on the other hand, reduces the average wage of high-tech workers, and thus may bring the best of them to seek better opportunities abroad.

Other potential tradeoffs may also rise between job creation and the development of a science-intense industry. Consider, for example, a potentially very common type of R&D project, which is intended to replace low-skilled labor with machinery. Such a project, if successful, destructs low-skilled jobs, thus creating inequality, stimulate growth and encourage the science-intense industry. Another such example would be restricting production to Israel, which encourages local employment, yet may create production inefficiencies[4].

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[3] See the Chief Scientist's memo #03-2006 from December 2006 (http://www.moit.gov.il/NR/rdonlyres/93A5BE5A-2851-42D1-A2B0-270EF2E1A811/0/tasiamasoratit3.pdf)

[4] Recently, the law has undergone a revision, which loosened some of the restrictions on firm which receive governmental support from moving production out of Israel. (http://www.moit.gov.il/NR/rdonlyres/4D86F055-40ED-4536-8BDE-7B7C8D2E9978/0/1996.pdf)

Targeting the change in the expected profits of the firms, as a result of the R&D project, surely helps the industry, and in particular the science-intense sector. However, the policymaker might want to favor exporting firms, in order to achieve the objective of improving the current-account balance of Israel.

Consider now the aforementioned implicit objectives. Trajtenberg 2001 discusses how and whether the size of the firm should be considered. When a smaller firm receives R&D support, there is a larger chance that the subsidy actually changes behavior, since usually less of the spillovers can be internalized and less internal funds are available. This also implies that more spillovers, or "added value", are to be expected. Moreover, a smaller firm is more likely to face a financial market failure, which might serve as a reason for governmental intervention. On the other hand, a larger firm will probably have more chance of turning the idea into a profitable product.

Finally, consider what would be the optimal support rate. As seen in the introduction, the support rates have dropped quite dramatically in Israel in a period of only a couple of years. Note, however, that lower support rates might screen out projects with large gaps between the social and private return to R&D. At the same time, projects which would anyway be pursued are left unharmed. This is exactly the opposite of the screening effect that should be aimed at. Giebe, Grebe and Wolfstetter 2006, for instance, suggest that mechanisms, such as bidding, might be used for inducing applicants to reveal information about their true need for funding, namely their support rate threshold. Moreover, they claim that even if the threshold was known, an optimal allocation should be conducted on the basis of the ranking of the complete allocations rather than on the ranking of individual projects.

To make things even more complicated, it is worth mentioning Trajtenberg 2001, who claimed that the bundling of the policy tools might not be optimal. For instance a conditional loan might prove useful for overcoming financial market imperfections. Alternatively, when trying to bridge the gap between social and private returns to R&D, a straight subsidy might by appropriate. Finally, tax credits and other instruments might prove to be most efficient for inducing firms to operate in Israel. Teubal 1999, for instance, calls for a holistic view of R&D policy, meaning that the multiplicity of possible tools does not mean that each should be considered separately.

I hope that by now the reader is convinced that achieving the objectives defined by the law is nothing but a trivial problem, even if the technological merits are somehow known to the committee. The overwhelming complexity of the decision calls for a more structural, systematic method for choosing the qualifying projects for support and the rate of such a support. It is very hard to believe that an experts committee will be able to grasp the entire realm of economic tradeoffs without the use of specifically designed structured economic models. An optimal decision will, therefore, also have to be based upon meticulous data utilization and supportive information systems within the OCS.

4. A Simple Model of Learning vs. Competitive Advantage

Officials of the Israeli OCS have recently publicly expressed their dilemma of whether or not to focus their support in R&D on fewer industries. The question of whether to distribute the subsidies across industries or to concentrate on a small number of industries, which appear to have the most prospects, seems to be an essential question in R&D policy. Furthermore, if concentration seems to constitute the better policy, where should the R&D support be directed at?

Some very distinguished scholars have expressed their opinion against governmental influence in directing R&D. Nelson 1987 argues that "committees of experts are unreliable judges of precisely where the bets should be laid even if, or particularly if, they are forced to arrive at agreement". When Trajtenberg 2001 talks about the virtues of "neutrality", which has been an important principal in the Israeli R&D policy in the past, he claims that "it avoided one of the main potential dangers of any industrial policy, namely, the 'picking of winners' by government officials". Nevertheless, in the same breath he also suggests deviation from neutrality in favor of biotechnology.

In the psychological literature, intelligence is typically defined in terms of a person’s ability to adapt to the environment and to learn from experience[5]. I would like to claim that the same goes for an intelligent policy. The OCS has extraordinary data which is unavailable to any firm in the industry, which consists of the history of successes and

[5] See Sternberg, Robert J., 2005. The Theory of Successful Intelligence. *Interamerican Journal of Psychology* 39, 189-202.

failures in R&D, and is constantly updated. There is a need for an R&D support policy which will direct the Israeli R&D endeavor in accordance with the analysis of a meticulous system that would utilize its own endogenous data, and be flexible enough to constantly adjust to the changing technological environment.

The absurdity of the current policy is that there is no coherent mechanism which would prevent even the same failing idea from receiving governmental support over and over again. This results in at least three inefficiencies. Firstly, public money is wasted on projects which are bound to fail. Secondly, with a limited budget, some projects which might *ex-ante* have better prospects do not receive governmental support. Finally, the firm which gets the support for the poor project is bound to waste its own R&D budget. Obviously, past failures are not a guarantee for a failing future projects, especially in the presence of a changing technological environment. Nevertheless, this does not imply that recurring failures are not a good enough reason for diverging some of the budget towards directions with better prospects.

To the best of my knowledge, a model that binds together the subsidy policy with the ability of the policymaker to learn about the technological environment is unprecedented. This section will introduce a simple framework for approaching such a learning process. Such a process will demonstrate constant tensions between exploration and exploitation. The creation of competitive advantage will act as an additional force which will offset some of the weight towards exploitation, rather than exploration. The analysis is based on Shalem 2006, in which the concepts of learning about the technological environment were constructed mainly for the analysis of competition and coordination between firms.

4.1 The Basic Setup and Assumptions

The models of this section were built bearing the example of the Israeli R&D in mind. That is reflected by assuming a limited R&D budget, which generates R&D successes for local firms, mainly for the purpose of competition in foreign markets. The basic framework will be kept throughout this section, where the different examples use some variations in the complementary assumptions[6].

[6] The market setting is partly based on D'Aspremont and Jacquemin 1988.

For simplicity assume that there are no technological spillovers. Moreover, we will concentrate on non-patentable, cost-reducing process innovation. In each industry, local firms compete *a-la-Cournot* in a foreign product market.

More explicitly, in each period consider a two-stage model. In each period the problem of the policymaker boils down to whether to give a subsidy for R&D to the local firm in the *Right* industry or to the one in the *Left* one. Each industry consists of one local firm, competing with one foreign firm, in a foreign market.

Stage *I*:

The policymaker is assumed to be risk-neutral and fully informed. His objective function is the aggregate profits of the two local firms. He has to choose which one of the local firms will get the subsidy. For simplicity, the foreign firms are assumed not be involved in R&D. The subsidy policy is assumed to be fully effective, in the sense that only the local firm which receives the subsidy performs R&D. Furthermore, it is assumed that the R&D project is fully funded by the subsidy. The outcome of that endeavor is then revealed - either a success or a failure. Let P_i denote the probability of success in industry i, where $i \in \{Left, Right\}$. Further assume that all the firms are *ex-ante* identical, yet the successes in research are cumulative, in the sense that each firm has a cost of production, which is a function of its own production, q_i, and the number of previous successes, $S_i(t)$:

$$\begin{cases} C_i^{Foreign} = Aq_i^{Foreign} \\ C_i^{Local} = \left[A - xS_i^{Local}(t)\right]q_i^{Local} \end{cases} \tag{1}$$

where $i \in \{Left, Right\}$ and $A, x > 0$

Stage *II*:

In this stage there is *Cournot* competition in both markets between local and foreign firms. For simplicity, we will assume that in both markets there is the same linear inverse demand function $D_i^{-1}(Q_i)$, where $Q_i = q_i^{Local} + q_i^{Foreign}$ is the total quantity produced. D_i^{-1} is assumed linear:

$$D_i^{-1} = a - bQ_i, \text{ with } a, b > 0, \text{ where } i \in \{Left, Right\} \tag{2}$$

4.2 Competitive Advantage and the Direction of R&D Support

This first setting demonstrates a somewhat known outcome in industrial organization. The main idea is that very symmetric oligopoly results in lower profit to firms than in a case in which one firm is much more efficient than its competitors and thus gains some monopolistic power. When analyzed in the context of R&D subsidies, this property will induce subsidy concentration, in order to create a considerable competitive advantage.

Explicitly, consider a two-period model, in which the probability of success in R&D in each industry is equal to 1. In such a framework the policymaker basically has to decide whether to give a subsidy in both periods to the same industry, namely concentration, or to give the subsidy in the second period to the industry which has not received one in the first period, namely subsidy spreading.

The profits of a local firm in an industry *i*, under *Cournot* competition are:

$$\begin{aligned} p_i^{Local} &= (a-bQ_i)q_i^{Local} - \left[A - xS_i^{Local}(t)\right]q_i^{Local} = \\ &= \left[a - A + xS_i^{Local}(t) - b\left(q_i^{Local} + q_i^{Foreign}\right)\right]q_i^{Local} \end{aligned} \tag{3}$$

The quantities that will be produced in equilibrium are:

$$\begin{cases} q_i^{Local} = \dfrac{a - A + 2xS_i^{Local}(t)}{3b} \\ q_i^{Foreign} = \dfrac{a - A - xS_i^{Local}(t)}{3b} \end{cases} \tag{4}$$

The discussion will be restricted to cases where all firms produce a positive quantity. Explicitly, the following condition is assumed to hold:

$$a > A + 2x \tag{5}$$

The per-period profit functions, contingent on the R&D outcomes, are therefore:

$$p_i^{Local} = \frac{1}{9b}\left[a - A + 2xS_i^{Local}(t)\right]^2 \tag{6}$$

We can now characterize the optimal subsidy policy and get the following proposition:

Proposition 1 (Competitive Advantage) When there are symmetric industries with *Cournot* competition in each of them, a policymaker concerned with the aggregation of the profits of local firms should concentrate R&D subsidies to a single industry, in order to maximize competitive advantage.

Proof. The aggregation of the profits of the local firms, in the first period, is equal in each of the possible actions of the policymaker. Without loss of generality, assume that in the first period the policymaker chooses to give a subsidy to the local firm in the *Right* industry. In the second period, the policymaker has to choose whether to concentrate his subsidies, i.e. choosing *Right* again, or spreading the subsidies across industries, i.e. choosing *Left*. The second period aggregation of profits of the local firms, contingent on the policymaker choosing *Right*, is:

$$E\left[p_{Right}^{Local} + p_{Left}^{Local} \middle| Right\right] = \frac{1}{9b}\left[a - A + 4x\right]^2 + \frac{1}{9b}\left[a - A\right]^2 \quad (7)$$

While his payoffs when he chooses *Left* are:

$$E\left[p_{Right}^{Local} + p_{Left}^{Local} \middle| Left\right] = \frac{1}{9b}\left[a - A + 2x\right]^2 + \frac{1}{9b}\left[a - A + 2x\right]^2 \quad (8)$$

And so we get:

$$E\left[p_{Right}^{Local} + p_{Left}^{Local} \middle| Right\right] - E\left[p_{Right}^{Local} + p_{Left}^{Local} \middle| Left\right] = 8x^2 > 0 \quad (9)$$

This completes the proof. ||

The simple setting presented here demonstrates a known property of a constant return to scale oligopolistic competition, which is that aggregate profits are lower with symmetric competitors than when there is one firm which is much more efficient than its competitors. This is a result of the ability of the more efficient firm to obtain a larger market share than its competitors. Note that it is easy to see that the results also hold under an increasing return to scale economy or a convex demand function.

Such a policymaker must, therefore, bear in mind that concentrating R&D subsidies in a single firm or industry might result in one very profitable local firm, with a large market share, which might be more profitable than the aggregate profits of firms, with very little market shares in a wide range of industries.

4.3 Learning and the Direction of R&D Support

Let us now focus on the tension between building a competitive advantage and the need of the policymaker to get familiar with new technological fields. The assumption in the simple model presented here is, therefore, that there is a stable technological environment, with some directions with unknown prospects.

Explicitly, consider once again, a two-period game. However, assume now that the probability of success in each period in the *Right* industry is known to be P_{Right}. On the other hand, the policymaker is assumed to be less familiar with the *Left* industry and its technological field, and there is uncertainty regarding the per-period probability of success in that industry. For simplicity assume that the policymaker estimates that the probability of success in the *Left* industry is either 0 or 1 in both periods, with equal probabilities.

Equations (3) - (6) still hold in this case. However, under the current setup, the actions of the policymaker in the second period can be contingent on the outcome of the R&D in the first period. Therefore, there are eight possible strategies for the policymaker, which are hereby summarized in Table 1:

Table 1

Strategy Number	First Period Action	Second Period Action	
		Success in first period	Failure in first period
1	*Right*	*Right*	*Right*
2	*Right*	*Right*	*Left*
3	*Right*	*Left*	*Right*
4	*Right*	*Left*	*Left*
5	*Left*	*Right*	*Right*
6	*Left*	*Right*	*Left*
7	*Left*	*Left*	*Right*
8	*Left*	*Left*	*Left*

Notice that if the policymaker chooses to give the subsidy to the local firm in the *Right* industry in the first period, he believes that the chance of success in the *Left* industry is 50%. However if he gives the subsidy to the local firm in the *Left* industry in the first periods, he will know in the second period if the chance of success is 0 or 1 in that industry. We can use this property in order to characterize the optimal subsidy policy. Thus we get the following proposition:

Proposition 2 (Learning) When $0 < P_{Right} < 0.6$, and under *Cournot* competition in the product market, a policymaker concerned with the aggregation of the profits of local firms should first give subsidies to local firms in an industry in which the chances of success are unknown, in order to learn about the probability of success in that industry.

Proof. The ex-ante expected aggregate profits of local firms, contingent on the policymaker's strategy, are hereby presented in Table 2:

Table 2

Strategy Number	Expected Aggregate Profits of Local Firms
1	$\frac{1}{9b}\left\{4(a-A)^2+12P_{Right}x(a-A)+\left[8\left(P_{Right}\right)^2+12P_{Right}\right]x^2\right\}$
2	$\frac{1}{9b}\left\{4(a-A)^2+\left[4\left(P_{Right}\right)^2+6P_{Right}+2\right]x(a-A)+\left[12\left(P_{Right}\right)^2+6P_{Right}+2\right]x^2\right\}$
3	$\frac{1}{9b}\left\{4(a-A)^2+\left[-4\left(P_{Right}\right)^2+14P_{Right}\right]x(a-A)+\left[-4\left(P_{Right}\right)^2+14P_{Right}\right]x^2\right\}$
4	$\frac{1}{9b}\left\{4(a-A)^2+\left[8P_{Right}+2\right]x(a-A)+\left[8P_{Right}+2\right]x^2\right\}$
5	$\frac{1}{9b}\left\{4(a-A)^2+\left[4P_{Right}+4\right]x(a-A)+\left[4P_{Right}+4\right]x^2\right\}$
6	$\frac{1}{9b}\left\{4(a-A)^2+\left[2P_{Right}+4\right]x(a-A)+\left[2P_{Right}+4\right]x^2\right\}$
7	$\frac{1}{9b}\left\{4(a-A)^2+\left[2P_{Right}+6\right]x(a-A)+\left[2P_{Right}+10\right]x^2\right\}$
8	$\frac{1}{9b}\left\{4(a-A)^2+6x(a-A)+10x^2\right\}$

Recalling that by definition $0<P_{Right}<1$ and that by assumption $a-A>2x>0$, it is easily verified that strategy 7 dominates strategies 5, 6 and 8. Let p_s^{Policy} denote the *ex-ante* expected aggregate profits of local firms, when the policymaker plays strategy s:

$$p_7^{Policy}-p_5^{Policy}=\frac{1}{9b}\left\{\left[-2P_{Right}+2\right]x(a-A)+\left[-2P_{Right}+6\right]x^2\right\}>0$$

$$p_7^{Policy}-p_6^{Policy}=\frac{1}{9b}\left\{2x(a-A)+6x^2\right\}>0 \qquad (10)$$

$$p_7^{Policy}-p_8^{Policy}=\frac{1}{9b}\left\{2P_{Right}x(a-A)+2P_{Right}x^2\right\}>0$$

If we now add the assumption that $0 < P_{Right} < 0.6$, we will get that strategy 7 also dominates strategies 1, 2, 3 and 4:

$$
\begin{aligned}
p_7^{Policy} - p_1^{Policy} &= \frac{1}{9b}\left\{\left[-10P_{Right} + 6\right]x(a-A) + \left[-8\left(P_{Right}\right)^2 - 10P_{Right} + 10\right]x^2\right\} > 0 \\
p_7^{Policy} - p_2^{Policy} &= \frac{1}{9b}\left\{\left[-4\left(P_{Right}\right)^2 - 4P_{Right} + 4\right]x(a-A) + \left[-12\left(P_{Right}\right)^2 - 4P_{Right} + 8\right]x^2\right\} > 0 \\
p_7^{Policy} - p_3^{Policy} &= \frac{1}{9b}\left\{\left[4\left(P_{Right}\right)^2 - 12P_{Right} + 6\right]x(a-A) + \left[4\left(P_{Right}\right)^2 - 12P_{Right} + 10\right]x^2\right\} > 0 \\
p_7^{Policy} - p_4^{Policy} &= \frac{1}{9b}\left\{\left[-6P_{Right} + 4\right]x(a-A) + \left[-6P_{Right} + 8\right]x^2\right\} > 0
\end{aligned}
\qquad (11)
$$

This completes the proof. ||

The reader can check further to find that if $0.66 < P_{Right} < 1$, strategy 1 dominates the others. For values of $0.6 < P_{Right} < 0.66$, the optimal strategy is ambiguously 1 or 7, depending on the parameters of the demand and production functions.

The simple setting presented here demonstrates the role of R&D in enabling the policymaker to learn about the different directions of the technological environment and their prospects. It should be noted that the factors that induce concentration, discussed in the previous model, are also active in this model.

The interesting implications of Proposition 2 can be emphasized when concentrating on the range $0.5 < P_{Right} < 0.6$. Proposition 2 implies that the policymaker should give a subsidy to the *Left* industry in the first period, and then change to the *Right* industry if, and only if, the R&D conducted in the *Left* industry has failed. In a way, there is more uncertainty, or at least more ambiguity, in the *Left* industry, and also an *ex-ante* per-period lower probability of success. Nevertheless, the incentives for learning about the technological environment overcome the other factors.

4.4 R&D Support with Dynamic Learning

This last variation of the model will elaborate on the previous by assuming a dynamic environment. Specifically we will assume unknown per-period probability of success in each direction, with no priors. Moreover, an exogenous technological breakthrough in one of them will permanently increase its success probability, in a way that will change the ranking of the two technologies. As mentioned above, Cohen and

Levinthal 1989 have introduced the concept of the "absorptive capacity", which basically implies that the firm has to be involved in R&D in order to absorb spillovers. In the present setup, however, the R&D endeavor of the local firm enables the policymaker to absorb information about the technological environment, rather than direct technological benefits. The model in unique in the sense that the ability to learn about the dynamic technological environment, via the R&D successes of rival firms, is binded with the firm's own R&D effort. We will see that under this setting a policymaker can improve the performance of the local firms by diverging budgets to direction which seem to have more prospects. Nevertheless, there will always be some support given to the other direction, in order to maintain the flexibility of the policy and the ability of the policymaker to learn about the technological environment.

More explicitly, consider now a multi-period model. In each period a policymaker has to decide whether to give a subsidy for R&D in the *Right* industry or in the *Left* industry. The per-period probabilities of success in each industry, namely P_{Left} and P_{Right}, are unknown to the policymaker throughout the game. In the first period let $P_{Left} = PL$ and $P_{Right} = PR$. Without loss of generality, assume that $PL < PR$. These per-period success probabilities persist for a few periods, until in period BT an exogenous technological breakthrough occurs in the *Left* industry, and the probability of success in that industry rises to PLB, where $PLB > PR$.

The information set which is available to the policymaker at each period is the history of choices and R&D successes of the local firms. The equilibrium in the product market is fairly similar to that of the previous models, except that a large number of successes in the same industry may now result in a monopoly in that industry. See the appendix for more details.

A strategy for the policymaker would assign a probability for subsidizing the *Right* industry, given the history at that time, namely $\widehat{P}(t)$. Obviously, with the complementary probability the subsidy will be given to the *Left* industry. The complexity of the model will force us to analyze the actions of the policymaker as a "black box", and not as a result of an optimization problem. We will consider six possible strategies. The trivial ones will randomly choose the direction of the subsidy, or choose one direction and persist with it. Another benchmark strategy is the "Tech fully informed", which in every period gives the subsidy to the direction with most prospect. This strategy is obviously unattainable given the policymaker information set. Finally, the more interesting strategies will assign a probability for choosing *Right* which will evolve over time and will diverge more of the budget to one direction either by how technologically successful it has been or how profitable the R&D investment has been in that direction. Table 3 presents the results of a certain numerical example. See the appendix for more details, regarding the mechanisms used and the values assigned to the parameters.

Table 3

Regime>>		Random	TechAnt	EconAnt	Right	Left	Average Right/Left	Tech fully informed
Subsidy Policy	Left	500	878	746	0	1,000	500	950
	Right	500	122	254	1,000	0	500	50
Local Successes	Total	741	854	814	598	880	739	884
Local Sales	Left	33,786	54,919	48,274	1,000	66,138	33,569	62,411
	Right	24,132	9,944	14,438	46,478	1,000	23,739	5,865
	Total	57,917	64,864	62,712	47,478	67,138	57,308	68,275
Local Profits	Left	507,554	1,467,540	1,313,120	333	1,962,375	981,354	1,798,624
	Right	251,506	52,925	189,901	944,242	333	472,287	11,660
	Total	759,060	1,520,465	1,503,022	944,575	1,962,709	1,453,642	1,810,284
% Monopoly	Left	96%	93%	95%	0%	98%	49%	94%
	Right	97%	84%	94%	98%	0%	49%	98%

Notice that the "Random" policy represents a case in which knowledge about past successes in research is either useless or unusable. Whereas the "Fully informed" policy represents a case in which there is always a perfect utilization of the momentary direction that is with most technological prospects. It might, therefore, prove useful to look at the main results relative to these two benchmark cases, as presented in Table 4:

Table 4

Regime>>	Random	TechAnt	EconAnt	Average Right/Left	Tech fully informed
Aggregated Local Successes	0%	78%	51%	-2%	100%
Aggregated Local Sales	0%	67%	46%	-6%	100%
Aggregated Local Profits	0%	72%	71%	66%	100%

It would be dangerous to derive policy recommendations from this simple example. However, some interesting insights can be inferred by the results. First of all, notice that the two "Ant" policies, which represent flexible, learning policies, have done better than the "Random", "Left" and "Right" policies. This phenomenon is especially visible in the number of R&D successes. Obviously the "Tech ant" is better in that criterion, and is only second to the unrealistic "Tech fully informed" policy.

Secondly, there is a substantial difference between a policymaker who is aware of the technological prospects in each industry, and one who is aware of the prospects of the marginal increase in profits. Myopic considerations might not be efficient in the long run. After the technological breakthrough, the "Econ Ant" policy will tend to stick to the traditional industry, in order to exploit the competitive advantage that was built there. However, when taking into account considerations of a longer time horizon, and if the technological change is persistent enough, there should be a shift to the industry with the superior technology. Further analysis indeed shows that "Econ Ant" policy attain better results that the "Tech Ant" policy under shorter horizon. Therefore, the optimal policy choice depends on the beliefs on how dynamic is the technological environment. In this context, it is also worth noting that, in accordance with the results of the previous models, the "Average Right/Left" policy, which simply concentrates subsidies in a single industry, without prior knowledge on the technological environment, has attained a much better result than the "Random" policy.

Finally, it is important to note that even when one of the industries displays better technological prospects, the policymaker always uses a probabilistic rule for the choice of subsidy direction. The dynamic technological environment, therefore, forces an everlasting tradeoff between exploitation and exploration. This indicates that an optimal policy will be ever learning and adjusting to its environment.

5. Summary and Discussion

It was John F. Kennedy who once said that "efforts and courage are not enough without purpose and direction". This paper has been aiming at stressing the need for the construction of appropriate frameworks for thinking about how to direct R&D support in Israel, in order to best achieve its purpose. The first part of the paper has established that transmuting the objectives of the Israeli law into actual policy entails an overwhelming complex set of considerations. Consequently, there is a need for a methodological examination of R&D policy Israel, in order to supply the policymakers with a toolbox for making decisions regarding distribution of R&D subsidies in Israel.

The paper also makes one small step in that direction by introducing a unique model which binds together the direction of the R&D support with the ability of the policymaker to learn about the prospects of the technological environment in that direction. When put in the context of a dynamic technological environment, it induces an everlasting path of balancing exploitation and exploration. In the context of a *Cournot* competition in the product market, exploitation is somewhat driven by the need to establish a significant competitive advantage to local firms in the foreign product markets.

Appendix

This appendix presents complementary information regarding the model of section 4.4, namely the equilibrium in the product market, the policy regimes and values assigned to the parameters in the numerical example.

Equilibrium in the Product Market

Before concentrating the analysis on the effect of the direction of R&D on the economy, let us first derive the analytical solutions in the product market, contingent on the amount of successes in research each firm has had.

When competition is kept, equations (3) and (4) still hold, and thus the per period profit function is represented in equation (6). Whenever one of the local firms becomes a monopoly at time t, its per-period profits becomes:

$$p_i^{Local} = (a - bq_i^{Local})q_i^{Local} - \left[A - xS_i^{Local}(t) \right] q_i^{Local} \tag{12}$$

The quantities that will be produced in equilibrium are therefore:

$$q_i^{Local} = \frac{a - A + xS_i^{Local}(t)}{2b} \tag{13}$$

The Policy Regimes

While each firm is assumed to be profit-maximizing in the product market, the choice of the subsidy direction is assumed to be a “black box". A strategy for the policymaker is a probability function in each period for choosing *Right*, namely $\widehat{P}(t)$. The following six policy regimes were considered:

“Random”:

Under this strategy, regardless of the history, there is an equal chance of choosing each direction:

$$\widehat{P}(t) = 0.5 \tag{14}$$

“Tech Ant”:

This policymaker will use a rule of thumb, which is a variation of an "ant algorithm", presented in Dorigo, Bonabeau and Theraulaz 2000. The probability of choosing *Right* in any period will be proportion to a signal function, which will be called "pheromone". The “Tech Ant” policymaker updates the amount of pheromone in accordance to the number of successes in R&D in each industry. Explicitly, the choice of direction is done according to the following mechanism[7]:

$$\widehat{P}(t) = \frac{\left[t_{Right}(t) + R\right]}{\left[t_{Left}(t) + R\right] + \left[t_{Right}(t) + R\right]} \tag{15}$$

Where

$$\begin{aligned} &t_k(0) = Start \\ &t_k(t+1) = (1-r)t_k(t) + h\Delta t_k(t), \text{ where } 0 < r < 1 \end{aligned} \tag{16}$$

and $\Delta t_k(t)$ is the number of successes on time *t* in industry k.

It is nice to see that much like real ants, t_k represent the amount of pheromone on edge k, and thus entails in a single number the history of successes in that industry.

“Econ Ant”:

The “Econ Ant” policymaker will update the amount of pheromone in accordance to the marginal increase in profits, due to the successes in R&D in each industry. Explicitly, the choice of direction is done according to the following mechanism:

$$\widehat{P}(t) = \frac{\left[t_{Right}(t) + R\right]}{\left[t_{Left}(t) + R\right] + \left[t_{Right}(t) + R\right]} \tag{17}$$

Where

$$\begin{aligned} &t_k(0) = Start \\ &t_k(t+1) = (1-r)t_k(t) + h\Delta t_k(t), \text{ where } 0 < r < 1 \end{aligned} \tag{18}$$

[7] For a more elaborated discussion on the "ant algorithms" and their intriguing relation to R&D investment, see Shalem 2006.

and $\Delta t_k(t)$ is the marginal increase in profits on time *t-1* in industry k.

"Tech Fully Informed":

A technology fully informed policymaker has perfect knowledge about the chances of success in R&D in each direction. It is assumed that this type of policymaker does not have the ability to translate the research success into expected profits in each market.

Explicitly:

$$\hat{P}(t) = \begin{cases} 1 & t < BT \\ 0 & t \geq BT \end{cases} \tag{19}$$

where *BT* is the time in which the scientific breakthrough occurs.

"Left":

A policymaker that only gives subsidy to the *Left* direction:

$$\hat{P}(t) = 0 \tag{20}$$

"Right":

A policymaker that only gives subsidy to the *Right* direction:

$$\hat{P}(t) = 1 \tag{21}$$

List of Parameters (specific to section 4.4)

Start - The initial amount of Pheromone in each edge.

r - The evaporation ratio of the Pheromone at each period.

h - The magnitude to which each new success adds to the Pheromone.

R - The "Reservation" quantity of Pheromone.

Periods - Number of periods in the game.

BT - The time in which the exogenous scientific breakthrough occurs.

PR - The per-period probability of success in the *Right* direction.

PL - The per-period probability of success in the *Left* direction, prior to the technological breakthrough.

PLB - The per-period probability of success in the *Left* direction, following the technological breakthrough.

The Values Assigned to the Parameters

The following values were used for all the policy regimes:

Periods - 1000

A - 100

x - 0.1

a - 101

b - 1/3

BT - 51

PR - 60%

PL - 50%

PLB - 90%

While the following values were used for the "Ant" policy regimes:

	Tech Ant	Econ Ant
Start	0.4	0.6
r	0.07	0.065
h	0.7	0.85
R	0.2	0.6

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