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NÚMERO 168

Víctor Carreón Rodríguez

COMPETITION IN INNOVATION WITH PUBLIC AND PRIVATE R&D IN THE PHARMACEUTICAL INDUSTRY

Abstract

In this paper we develop a model of competition in innovation to evaluate the following statement made by members of the pharmaceutical industry in the United States. They say that the investment made by government in basic research is important in the process of search for new drugs. Moreover, they argue that such an investment has a positive effect on the investment made by the pharmaceutical firms. In our model, we find that the effect is positive and that there are lagged effects from a minimum of 4 years to a maximum of 14 years. Also, we find that there is a positive effect of the government investment on the expected time of introduction of the new drug into the market. Finally, we find the more firms in the industry the less investment per firm, but the total investment is greater.

Resumen

En este documento desarrollamos un modelo de competencia en innovación para evaluar la siguiente afirmación hecha por los miembros de la industria farmacéutica en los Estados Unidos. Ellos argumentan que la inversión en investigación básica hecha por el gobierno es importante durante el proceso de innovación. Además de que tiene un efecto positivo sobre la inversión realizada por las empresas farmacéuticas. In nuestro modelo, encontramos que el efecto es positivo y además hay un retraso en el efecto. Este retraso va desde un mínimo de 4 años hasta un máximo de 14 años. También encontramos que existe un efecto positivo de la inversión del gobierno sobre el tiempo esperado en el cual la nueva medicina estará lista para ser introducida al mercado. Finalmente, encontramos que entre más empresas hay en la industria menor es la inversión por empresa, pero que la inversión total es mayor

Introduction

There exists an argument from people in the pharmaceutical industry[1] in the United States that suggests that public investment in Research and Development (R&D) has a positive effect on the process of product innovation in this industry and should be increased. It is important to analyze this statement for some reasons. First, firms in the United States have produced almost 50% of the new drugs introduced in the last 20 years. Second, firms in the pharmaceutical industry are planed to invest around $24 billion dollars in 1999 in the look for new and better drugs. Finally, part of the increase in life expectancy and in health is the result of the investment made in R&D by these firms and the government.

In this case, when we talk about product innovation, we mean the discovery of new drugs that will be introduced into the market. The process of drug discovery has some steps. The first, and very important, is to analyze the disease to find its characteristics and its origin. This will point out the main target of the pharmaceutical intervention. This research is conducted in Universities, in some pharmaceutical or biotechnological firms and in some organizations. The main source of funding for this step comes from the National Institutes of Health (NIH), although some major pharmaceutical companies put some resource in this step.

During the 1950s there were only six institutes in the NIH and its investment was around 43 million dollars. In 1998, the NIH grouped 24 institutes and invested around 13.6 billion dollars. The NIH gives almost 80% of its budget to scientist and doctors via grants. All people must compete to get one. The NIH only spends 10% in its own research. In 1986 the Cooperative Research and Development Agreements (CRADAs) was created to help pharmaceutical companies to make a more efficient use of the knowledge produce by the NIH. This would be traduced in more and better drugs for patients. According to the NIH, CRADAs "significantly advance biomedical research by allowing the exchange and use of experimental compounds, proprietary research materials, reagents, scientific advice, and private financial resources between government and industry scientists,"

An example in the lines of this argument is the following. The scientist from the NIH identified the AIDS virus in 1983. In 1987 (four years later), a pharmaceutical firm introduced the first drug treatment for AIDS. Nowadays there are around 60 drugs in the market. Moreover, there are another 113 new drugs in the clinical trials or in the process of being approved by the Food and Drug Administration

[1] As is pointed out in PhMA (1998): "The basic research conducted by the National Institutes of Health helps scientists to better understand the nature of disease and lights the way for the development of treatments. This research should be funded generously".

In this paper we will try to say something about this argument. We will model the competition among pharmaceutical firms to introduce a new drug in the market by using a particular case of the model developed by Carreón-Rodríguez (1998b). In this paper, government plays a role by financing public investment in basic research. The government's investment affects the stock of knowledge that is available to all firms willing to invest in research and development.

The set up is the following. There are N firms engaged in an innovative race. Firms make investments in research and development in order to innovate and to introduce a new drug into the market. The first firm, and only the first, that does so gets a reward. The government invests resources in basic research (by giving grants to universitics, scientists, doctors, or by doing research by its own to produce basic knowledge).

The results that are important for us from this model are the following. First, the investment per firm in R&D decreases as the number of firms in the industry increases. However, total industry investments are larger in a more competitive industry. Also, the expected time of introduction of the new drug is shorter for more competitive industries even though the probability of introduction by any single firm decreases with competition. Second, private investments in R&D are increasing in the government's investment. For this reason, the expected time of introduction of a new drug is shorter the higher the government's investment. Finally, in our empirical analysis, we find that there is a positive effect of the investment made by government on the investment made by the firms in the industry. Moreover, we find that there is a lag of at least 4 years, and it can last about 12-14 years.

The structure of this paper is as follows. In the next Section we present the theoretical model and derive some results. In Section II, we compare these results with the socially optimal ones. We present the empirical analysis for the pharmaceutical industry in Section III. Conclusions are made in Section IV.

I. Model

In this Section we set up a model of product innovation that will be applied to the pharmaceutical industry. This model is a particular case of the model developed by Carreón-Rodríguez (1998b). In the context of this industry, a new refers to a new drug that is found by some pharmaceutical o biotechnological firm. In this case, we assume that the number of firms in the industry is fixed. The date at which a new drug will be ready to be introduced into the market is given by a probability distribution induced by the amount of money committed to R&D. This probability function is also affected by the investment in basic research made by the government via the National Institutes of Health. The first firm that comes up with the new drug gets a perpetual flow of rewards.[2] It is the only one that gets the perpetual reward; all the remaining firms make a loss given by the size of the committed investment in R&D.[3] Thus, if there are only two firms in the industry that make the same investments, only one of them might get the reward.

Think of an industry with N identical firms engaged in a game of product innovation. Each firm, denoted by i, invests resources in R&D. The present value of its investment is rx_i, where r is the cost (normalized to one) and x_i is the money allocated to R&D. We assume that these costs are binding, so that at the end of the game every firm has committed x_i to R&D. This implies that firms are not allowed to change their decisions when they get more information. With its investment, the ith firm buys a random variable, denoted by $\tau(x_i)$, induced by x_i that gives the uncertain date at which the new drug will be successfully completed[4]. That is, it gives the uncertain date at which the new drug will be introduced into the market. This random variable gives the *technological uncertainty* that the ith firm is facing in this setting.

The environment faced by the ith firm is also affected by the government's investments in basic research. Suppose that the government invests the amount of z to produce basic knowledge $f(z)$. This knowledge affects the technology uncertainty faced by all the firms in the industry. Assume that $f(z)$ is strictly increasing and concave with $f(0)=0$ and $\lim_{z\to\infty} f_z(z)=0$. The very first firm that comes up with the new drug gets a constant perpetual flow of rewards, denoted by V, which is assumed to be known by all the firms in the industry. Think of V resulting from the production of the new drug in a monopolistic situation, which arise from the fact that this firm will get a patent for the new drug.

For simplicity, we assume that the distribution function governing the behavior of the uncertain date of introduction, $\tau(x_i)$, is given by the exponential function:

$$pr\{\tau(x_i,h_i)\le t\} = 1-e^{-f(z)g(x_i)t}$$

that is, $pr\{\tau(x_i)\le t\}$ denotes the probability that firm i will introduce the new drug before certain date t.

For the exponential distribution function, we know that

$$E[\tau(x_i,h_i)] = \frac{1}{f(z)g(x_i)}$$

[2] It is implicitly assumed that the firm that finds the new drug keeps its secret. Analogously, we can say that this firm gets a patent that lasts forever

[3] This creates a social waste of resources because there will be a "duplication of efforts"

[4] In this way, we capture the chance or serendipity that plays a role in the search for new drugs.

which gives the expected time of introduction of the new drug by the i th firm.

Now, we state some assumptions to make the computation simpler.

Assumption 1. Firms' expectations are rational

Assumption 2. $g(x)$ is twice continuously differentiable and strictly increasing in x satisfying

$$g(0) = 0 = \lim_{x \to \infty} g_x(x) \tag{1}$$

From Assumption 1, all firms know the exact set up of the model. Moreover, they know the behavior of each other. Thus, firm i knows that any rival firm may introduce the new drug before it with a positive probability. To formalize this, let $\bar{\tau}_i$ be the random variable representing the unknown date at which any rival may be able to introduce the new drug. This random variable represents firm i's *market uncertainty*. Since firms' expectations are rational, we can express $\bar{\tau}_i$ as follows:

$$\bar{\tau}_i = \min_{1 \le j \ne i \le N} \{\tau(x_j)\}$$

This expression gives the unknown date at which any rival firm will introduce the new drug before firm i finds its own drug.

Assumption 3. There are no private externalities in the innovative process so that the random variables $\tau(x_i)$ may be taken as independent.[5]

This Assumption makes our analysis closer to the property rights approach, which emphasizes the importance of patent protection. This is a very strong assumption in this model. However, it allows any firm to fully appropriate the returns from its investments, namely V, by introducing the new drug before any other firm.

From Assumption 3 we have that the probability of the new drug being introduced by any firm, other than i, before certain date t is given by

$$pr\{\bar{\tau}_i \le t\} = 1 - e^{-f(z)a_i t}$$

where

$$a_i = \sum_{j \ne i} g(x_j)$$

is the degree of rivalry faced by the ith firm. The ith firm takes a_i as a constant. That is, we are assuming a Cournot competition, where each firm assumes that its actions will have no effect on the decisions of their rivals.

[5] This is to say that there are no spillovers from the research of the firms. Also, it assumes there is no theft of secrets. All the knowledge is kept behind the walls of the innovating firm.

For any time $t \geq 0$, the ith firm will get the revenue flow V only if it is the first firm to find the new drug. This will happen if it is the case that

$$\tau(x_i) \leq \min\{\bar{\tau}_i, t\}$$

Integrating the joint density of $(\tau(x_i), \bar{\tau}_i)$ over the relevant region, we have

$$pr\{\tau(x_i) \leq min\{\bar{\tau}_i, t\}\} = \frac{g(x_i)}{a_i + g(x_i)}[1 - \exp\{-f(z)(g(x_i) + a_i)t\}]$$

Let ρ be the discount rate, assumed the same for all firms. By assuming that these firms are profit-maximizers, the ith firm chooses x_i, given a_i, z, ρ, and V to maximize its expected discounted profits. So, it solves the following problem:

$$\max_x \Pi(x; fa_i, z, \rho, V) = \max_x \left\{ \frac{Vf(z)g(x)}{\rho(f(z)a_i + \rho + f(z)g(x))} - x \right\} \tag{2}$$

If $\Pi(x; fa_i, z, \rho, V) \geq 0$ for some x, then from Assumption 2, we know that a global maximum exists.

Assumption 4: $\Pi(x; fa_i, z, \rho, V) \geq 0$ for some x when $N = 1$ (that is, in case of no rivalry, so that $a_i = 0$).

This Assumption is just needed in order to get an interesting problem for the case in which there is just one pharmaceutical o biotechnological firm in the industry. Otherwise, we would have no problem at all since this monopoly would have no incentives to look for new drugs.

If there is an interior solution, it must satisfy the following first-order condition (where we omit the argument z for simplicity):

$$\frac{(fa_i + \rho)fg_x(x)}{[fa_i + \rho + fg(x)]^2} - \frac{\rho}{V} = 0 \tag{3}$$

The second-order condition requires the following expression must be satisfied

$$(fa + \rho + fg)fg_{xx} - 2f^2 g_x^2 \leq 0$$

Equation (3) defines implicitly $x^* = x^*(fa, z, \rho, V)$. For a firm that assumes that the instantaneous probability of rival introduction is induced by a, x^* is its expected profit maximizing investment in R&D.

From this solution, we get the expected effects of ρ, and V on x^*. That is, investment per firm in R&D is decreasing in the discount rate and it is increasing in the reward.

An important result is the following:

Result 1: The private investment in R&D is increasing in the government's investment in basic research.
Proof: From the first- and second-order conditions above, we get the following:

$$\frac{dx^*}{dz} = \frac{\rho(fg - \rho - fa)f_z g_x}{(fa+\rho)\{(fa+\rho+fg)fg_{xx} - 2f^2 g_x^2\}} \geq 0$$

♦

Therefore, there is a positive effect from the knowledge produced by the government's investment in basic research, which is available to all firms in the industry. By having more knowledge available for free, all firms have a greater probability of finding new drugs and, as a consequence, each single firm might introduce the new drug sooner. That is, all firms are free loaders on the government's investment. Thus, they have incentives to invest more resources in R&D.

Now, we are interested in knowing how investment in R&D is affected by the degree of rivalry.

Result 2:[6] Investment in R&D per firm is decreasing in the degree of rivalry, a_i.
Proof: From the first- and second-order conditions above, we have the following:

$$\frac{dx^*}{da} = \frac{(fa+\rho-fg)f^2 g_x}{(fa+\rho)\{(fa+\rho+fg)fg_{xx} - 2f^2 g_x^2\}} \leq 0$$

♦

Thus, an increase in the degree of rivalry, a_i, which implies that the probability of introduction by any rival is bigger than the probability of introduction by firm i, induces a decrease in the investment of that particular firm.

Now, we turn to the general equilibrium analysis. Given that the firms are identical, we have that $x_i = x^*$ for all $i = 1,...,N$. Since firms' expectations are rational, we have that $a_i = a = (N-1)g(x^*)$. Therefore, from Result 2 we conclude that investments in R&D are always decreasing in the degree of rivalry.

Given the optimal value $a = (N-1)g(x^*)$, equation (3) defines implicitly

$$x_N = x^*((N-1)f(z)g(x_N), z, \rho, V) \tag{4}$$

Thus, x_N is the Cournot-Nash equilibrium level of R&D chosen by the firms. We should note that these optimal values depend on the number of firms in the industry.

[6] We should note that this is a partial equilibrium analysis because we still need to determine the optimal value of a_i.

Now, we want to know how the number of firms, N, affects this equilibrium.

Result 3: The optimal investment in R&D, x_N, is decreasing in the number of firms in the industry.

Proof:[7] By totally differentiating equation (4), we get

$$\frac{dx_N}{dN} = \frac{\frac{dx^*}{da} fg}{1-(N-1)f\frac{dx^*}{da}g_x} \leq 0$$

♦

Therefore, we expect to see lower investment per firm in research and development in those industries where more firms are engaged in the innovative race. Hence, increasing competition reduces the investments in R&D.

From Proposition 3 we get a reduction in investment per firm if there is an increase in the number of firms in the industry. This raises two interesting questions. First, what happens to the total investment in the industry? Second, what happens to the expected date of introduction of the new drug?

Let us analyze the first question. Define $X = Nx_N$ as the total industry investment in R&D.

Result 4: Suppose that $\frac{x_N}{N} \geq -\frac{dx_N}{dN}$ (that is, the elasticity is smaller than one). Then total industry investment in R&D, X, is increasing in the number of firms in the industry.

Proof: By totally differentiating X, we get

$$\frac{dX}{dN} = x_N + N\frac{dx_N}{dN} \geq 0$$

♦

Therefore, if the elasticity is smaller than one, we conclude that the total investment in R&D is larger in industries with more firms than in more concentrated ones.

In order to answer the second question, we need to know the expected date at which the new drug will be ready to be introduced into the market. At this point it

[7] We are treating N as a continuous variable in this analysis.

does not matter from the society's point of view which firm actually finds the new drug.

Let this random variable be defined as

$$\tau_N = \min_{1 \le i \le N} \{\tau_i(x_N)\}$$

Thus, the probability of introduction of the new drug into the market before certain date t, is given by

$$pr\{\tau_N \le t\} = 1 - e^{-Nf(z)g(x_N)t}$$

Hence, in equilibrium, the expected date of introduction of the innovation is given by

$$E[\tau_N] = \frac{1}{Nf(z)g(x_N)}$$

Result 5: Suppose that the industry is in equilibrium. Suppose that $1 \ge -f\left\{\frac{dx^*}{da} g_x\right\}$. Then the expected date of introduction of the new drug is a decreasing function of the number of firms in the industry.

Proof: In equilibrium, we have the following expression

$$\frac{d}{dN}\{Nfg(x_N)\} = fg\left\{\frac{1 + f\frac{dx^*}{da}g_x}{1-(N-1)f\frac{dx^*}{da}g_x}\right\} \ge 0$$

Therefore, $\frac{d}{dN}E[\tau_N] \le 0$

♦

Thus, suppose that marginal increases in investment in R&D by any single firm induce the respective investments of all other firms to fall by a smaller amount. Then, from this Result we conclude that the expected date of introduction of the new drug is decreasing in the number of firms in the industry.

Result 6: The expected date of introduction of a new drug is decreasing in the investment in basic research made by the government.

Proof: In equilibrium, we have the following expression

$$\frac{d}{dz}\{Nfg(x_N)\} = Nfg_x(x_N)\frac{dx_N}{dz} + Nf_z g(x_N) \ge 0$$

Therefore, $\frac{d}{dz}E[\tau_N] \le 0$

Therefore, if the government puts more money in basic research, we expect to get the new drug sooner.

II. Welfare Analysis

If we compare the results of the previous Section with the socially efficient equilibrium, we find that the private equilibrium is not efficient. In this model, all firms are investing too much in R&D.

In the context of innovation, it is hard to argue whether the private returns are smaller, equal, or bigger than the social returns. We can find examples that go either way. The gap between the private and the social returns depends on three factors. First, the market structure of the innovator's industry. Second, whether the innovation is minor or major. Third, whether the innovation is a new product or a new process of production (Mansfield, et. al., 1977).

For these reasons, in what follows we assume that the private returns are equal to the social returns from an innovation. This assumption allows us to make comparisons between the private and the social outcomes.

We know that in the Cournot-Nash symmetric equilibrium of Section I, the optimal value of a is determined by $a = (N-1)g(x)$.

Given our assumption that the private and social returns coincide, the expected present value of the social (and private) returns in equilibrium is given by

$$V = V_P = V_S = N\Pi(x_N, (N-1)f(z)g(x_N))$$

However, when any single firm is maximizing its profits by choosing the optimal level of investment in R&D, it takes the value of a as given

Since firms take a as given, it is clear that they overinvest in R&D. We show this in the next Proposition. Let x_N^* denote the socially optimal investment in R&D, for a fixed number of firms.

Result 7: Let N be the fixed number of firms in the industry. In equilibrium, the investment in R&D is higher than the socially optimal investment.

Proof: Let N be fixed. The socially optimal level of investment in R&D, x_N^*, is the solution to the following problem

$$\max_x \left\{ N\Pi(x, (N-1)fg(x)) \right\}$$

Thus, x_N^* satisfies the following first-order condition

$$\frac{d\Pi(x_N^*, (N-1)fg(x_N^*))}{dx} + \frac{d\Pi(x_N^*, (N-1)fg(x_N^*))}{dfa}(N-1)fg_x(x_N^*) = 0$$

On the other hand, the private equilibrium value, x_N, is given by

$$\frac{d\Pi(x_N,(N-1)fg(x_N))}{dx} = 0$$

We know that $\frac{d\Pi(.)}{dfa} = -\frac{fg^2}{(fa+\rho)^2 g_x} < 0$.

Hence

$$\frac{d\Pi(x_N^*,(N-1)fg(x_N^*))}{dx} > \frac{d\Pi(x_N,(N-1)fg(x_N))}{dx}$$

Finally, from the second-order condition, we know that $\frac{d^2\Pi(.)}{dx^2} \leq 0$. Therefore, $x_N^* < x_N$.

♦

III. Application to the Pharmaceutical Industry

We will try to see if this model supports the statement made by members of the pharmaceutical industry about the role of the investment in basic research made by government. We use data for the pharmaceutical and biotechnological firms that are members of the Pharmaceutical Research and Manufacturers of America (PhRMA). The membership of the PhRMA accounts for about 100 pharmaceutical and biotechnological firms that have a primary commitment to pharmaceutical research. Some of these firms are foreign firms. Also, some American firms are not members of this association. However, this is a good proxy for the total investment of this industry because the members of this association make more that 80% of the investment in the industry

These firms discover, develop and bring to market drugs that improve people's health and quality of life –as well as reduce the overall cost of health care.

On the other hand, the government's investment is done via the National Institutes of Health (NIH) and is allocated mainly to basic research.

Figure 1 shows the total industry's investment in research and development (in current dollars and in dollars of 1997) made by the members of the PhRMA.

Figure 2 shows the investment made by the National Institutes of Health (in current dollars and in dollars of 1997). This investment is allocated mainly to basic research. Part of this investment is allocated to the different National Institutes of Health and part goes to some Universities via grants and to sponsor some research on private companies. Pharmaceutical companies make use of this knowledge to find new drugs. This new knowledge helps private companies to better understand some diseases. The PhRMA argues that the government's investment is vital and that government should increase the money allocated to basic research in the industry.

Figure 1: Investment in R&D by the Pharmaceutical Industry

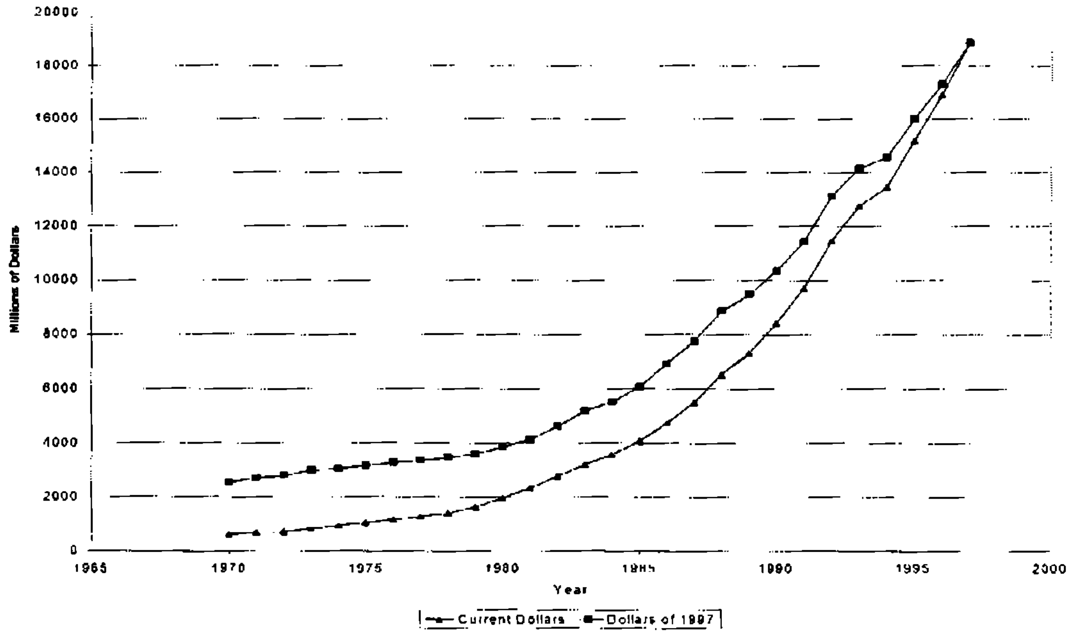
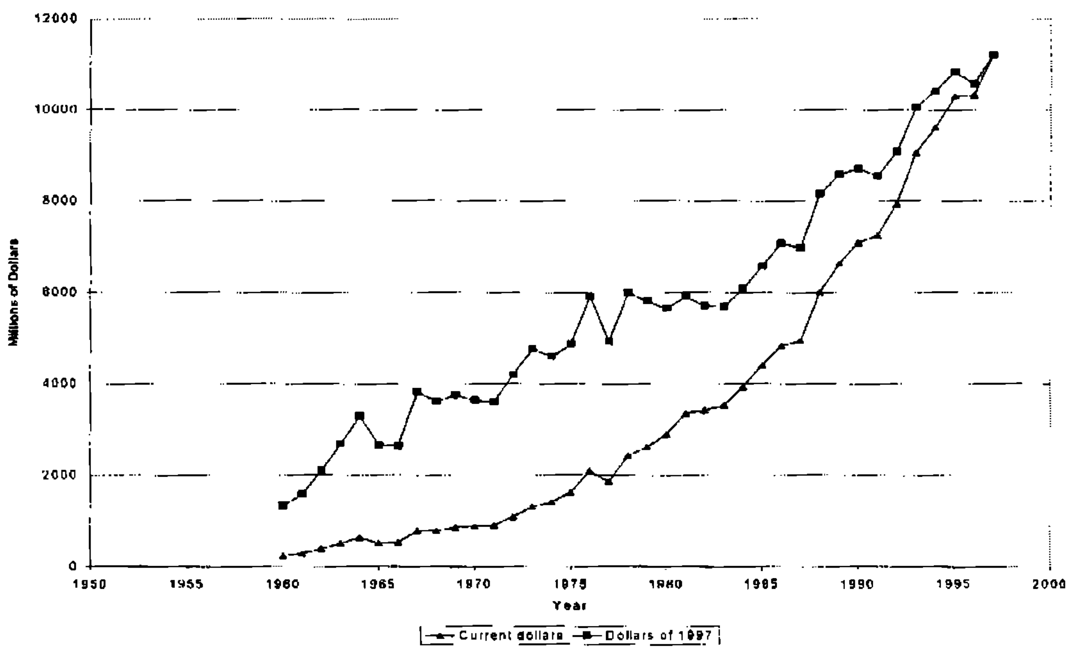


Figure 2: Investment in R&D by the National Institutes of Health in USA



We will try to see if in fact the NIH's investment is affecting the investment made by the members of the PhRMA. We perform a lagged analysis to analyze such a relationship. Given the available data we use the aggregate investment in research and development made by the pharmaceutical industry. On the other hand, the investment by the government is given by the NIH's investment. Thus, in terms of our model, we denote $NIH = z$.

Therefore, we want to fit the following econometric model

$$x_t = \alpha + \sum_{i=0}^{q} \beta_{t-i} NIH_{t-i} + \varepsilon_t$$

where the dependent variable is the total investment in R&D made by the members of the PhRMA, denoted by x; the explanatory variable is the government's investment, via the National Institutes of Health, denoted by NIH; and $\beta = \alpha_0 + \alpha_1 i + \cdots + \alpha_p i^p$ for $p < q$.

We set $p = 3$ whenever $q > 3$ and $p = q - 1$ otherwise. The optimal q is the one that minimizes the following expression

$$AIC(q) = \ln \frac{e'e}{T} + \frac{2q}{T}$$

where $e'e$ denotes the sum of squared residuals, q the number of lags, and T the number of observations.

Our empirical analysis shows two facts. First, it shows a positive effect of the NIH's investment on the industry investment in research and development. Second, it strongly points out lagged effects of the NIH's investment on the industry's investment. Table 1 shows these results. By analyzing the original series, we find effects lasting for 14 years. That is, investment made by the NIH 14 years ago is affecting the current investment by the firms in this industry.

From Figures 1 and 2, we see that both series present a trend. Then we remove the trend in both series and then perform the same analysis with our transformed series. The results are presented in the third column of Table 1. Even thought the number of lags has decreased, we still see that the lagged effects are strong. In this case, the investment made by the NIH 12 years ago is affecting the current behavior of the pharmaceutical firms.

Finally, we make the same analysis by taking the first difference in both series. The results are presented in the last column of Table 1. We can see that the number of significant lags decreases substantially but we still see a lagged effect of 4 years.

Therefore, from our results, we get that an increase in the current investment by the NIH will have effects on the investments made by the pharmaceutical firm during the following 12-14 years. However, if we take the first difference to both series, these effects will last only during the following 4 years.

Table 1. Lagged Effects for Different Data Transformations

	Original Series	*Detrended Series*	*First Difference*
R^2	0.9995	0.9792	0.9478
Adjusted R^2	0.99775	0.948	0.938722
t-0	-1.08104 (-9.48918) *	0.279378 (1.040118)	0.159958 (1.159773)
t-1	-0.50654 (-11.7936) *	0.672126 (8.402486) *	0.02504 (0.219052)
t-2	-0.12139 (-2.02291)	0.805966 (6.911039) *	0.467403 (5.920906) *
t-3	0.109833 (1.377657)	0.739923 (4.709234) *	0.882892 (7.449986) *
t-4	0.22255 (2.766561) **	0.533021 (3.582564) *	0.667352 (4.364248) *
t-5	0.252189 (3.683081) *	0.244284 (2.167157) **	
t-6	0.234173 (4.135941) *	-0.06726 (-0.75001)	
t-7	0.203926 (3.354734) *	-0.3426 (-2.98795) *	
t-8	0.196875 (2.486699) **	-0.52269 (-3.46929) *	
t-9	0.248442 (2.564641) **	-0.54853 (-3.45149) *	
t-10	0.394053 (3.808361) *	-0.36108 (-2.91863) *	

Table 1. - Continued

	Original Series	*Detrended Series*	*First Difference*
t-11	0.669133 (7.093222) *	0.098685 (0.859781)	
t-12	1.109106 (13.89155) *	0.889781 (2.920549) *	
t-13	1.749396 (15.35422) *		
t-14	2.625429 (11.6669) *		

* Significant at the 5%
** Significant at the 10%

IV. Conclusions

We have set up a model of product innovation to support the statement by members of the Pharmaceutical Research and Manufacturers of America. The statement is that the government's investment in basic research has a positive effect on the pharmaceutical industry's investment in research and development. For this reason, government should increase such an investment. In our model, we find that the optimal investment in R&D per firm is increasing in the reward available to the first firm that introduces the new drug into the market. Also, this investment is inversely related to the discount rate. Finally, investment in R&D is increasing in the government's investment in basic research.

Given that a certain stability condition is satisfied we are able to show that an increase in competition reduces the investments in R&D. However, total industry investment in research and development is increasing in the number of firms in the industry. Even though the optimal investment can be decreasing in the number of firms, we show that the expected date of introduction of the new drug is an increasing function of the number of firms in the industry. Also, we find that each firm is investing too much in R&D.

Finally, we make an empirical analysis to test our results. We find that the effect of government's investment in R&D on the industry's investment in research and development is positive. Moreover, we have also shown that there is a lagged effect from a minimum of 4 years to a maximum of 12-14 years of the government's investment on the industry's investment.

There are some extensions that are worth to be analyzed. First, if we could break the investments of the government and the investment of the firms by disease or by some broader category, we could test the result that the time of introduction of the new drug is shorter the more money is invested by government. Second, we can make the reward variable over time to account for the introduction of generics. Third, we can try to make this model a dynamic one to see the behavior of the firms over time and to know what is to be the more likely final market structure of the industry.

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