Modeling Change in Equilibrium Scientific Investment with Respect to Economic Return

Aaron J. Cutts
March 2013

Senior thesis submitted in partial fulfillment
of the requirements for a
Bachelor of Sciences degree in Economics
at the University of Puget Sound

Introduction

The scientific research industry is of great importance, spawning technological innovation and more effective goods and services. Academic organizations and universities that typically identify as non-profit have traditionally performed the majority of scientific research. However, there has been a recent emergence of for-profit basic research firms, particularly in the pharmaceutical and biotechnology sectors. This paper will employ a mathematical economic model in order to compare the equilibrium amount of scientific investment that will be engaged in by a for-profit and non-profit firm. For-profit and non-profit firms have very different operating conditions that will result in different investment behavior. While a for-profit firm will operate at maximum profit, a non-profit firm will operate a zero profit, or where total revenue equals total cost. Both of these behaviors can be modeled mathematically and a comparative statics result can be obtained. This comparative statics result will offer insight into the investment decisions of each type of firm by determining how the equilibrium amount of investment in scientific research will change with respect to the economic return associated with this research. By comparing the equilibrium investment decisions of each type of firm, this paper will aim to identify which industries will lean toward to the promotion of for-profit research, and which will be dominated by non-profit firms.

Background

Traditional Scientific Research Norms

In order to properly evaluate the production of scientific research as an industry, it is first necessary to recognize the difference in the production of scientific research from the majority of other economic industries. Scientific research is unique in that behavior of individuals and firms within the industry is guided more by societal norms, and not necessarily the economic factors that influence the traditional firm. Historically, the nature of science has lent itself to the formation of a tight-knit community. Scientists consider themselves to be discovering fundamental truths about the universe that are applicable to all beings and objects in the universe, regardless of nationality or religion (Barber, B 1968). In order to acquire more, different, or new information, scientists were motivated to breach and often challenge cultural boundaries. By doing so, scientists were ostracized from their original society, finding solace in the company of their peers (Barber, B 1968). Additionally, the mere desire for adequate intellectual stimulation will encourage societal formation among researchers (Hagstrom, W 1964). As a result, the scientific community is heavily influenced by traditional scientific norms that have been developed over time.

Societal norms within the scientific community have been both well studied and documented by a number of sociologists of science, the findings of which are all remarkably congruent with one another. The three primary principles that are well grounded throughout the industry are the promotion of accessible scientific information, freedom to choose the topic of scientific inquiry, and unrestrained invention (Hagstrom, W 1965; Rai, A 1999).

One cornerstone belief held by the majority of the scientific community is that scientific knowledge is a common resource and all scientific findings are to be freely accessible. This idea has been referred to as "communism" or "communalism" by renowned sociologists in the field, Robert Merton and Bernard Barber. Communalism describes substantial scientific findings as "common heritage," that cannot be possessed by the individual that produced it, and that his claim over this knowledge is "limited to that of recognition and esteem" (Merton, R 1973). By encouraging not only access but also distribution of scientific findings throughout the community, scientists are able to validate each other's results and avoid needless repetition of experimentation or proof (Rai, A 1999). Communalism is an integral and widely accepted norm in the scientific community.

Another important norm recognized in the scientific community is the freedom of choice with respect to research decisions and critiques. Scientific independence is the ability for scientists to establish their own research agenda, including which problems and when, where, and in what manner a particular problem should be tackled (Barber, B 1968). Independence in this context also includes the freedom to critique peers as well as predecessors without fear of persecution within the community (Barber, B 1968).

The final, and perhaps most important norm upheld by the scientific community is the uninhibited right to invention. This is widely considered the most important norm recognized by science because it is invention that will earn the greatest prowess (Hagstrom, W 1964; Rai, A 1999). In the scientific community, making pioneering strides in one's field will earn the highest recognition and praise. Furthermore, the recognition that this scientist will receive is correlated to the significance of his contribution (Hagstrom , W 1965). The result of this societal norm is furious competition within the industry to be the first to publish his findings (Hagstrom, W 1965). This competition motivates scientists to find flaws in the work of their peers, leading to the further validation of each finding. The competitive nature of the industry also ensures the production of new findings.

The innovative norm is so powerful in the scientific community, that other norms in the community may be violated for the sake of original invention. For example, secretive behavior that may violate communalism may be tolerated for the sake of invention (Rai , A 1999).

When applying economic analysis to the production of scientific research, it is first necessary to recognize that many research firms will react according to the established norms within the scientific community, as well as economic factors that may contribute to traditional production. Many of these norms are congruent with the standards established within the academic community. In fact, this overlap in traditional thinking contributed to the introduction of basic scientific research into the university setting hundreds of years ago (Rai, A 1999). For this reason, universities in the non-profit research setting have traditionally performed scientific research. This paper will offer an explanation for why the for-profit scientific research sector has grown, and in what areas of research it should be expected to thrive.

Optimal Operating Conditions of For-Profit vs. Non-Profit Firms

In order to compare the investment decisions of for-profit and non-profit firms, a standard model based on optimal operating conditions will be employed. In this model, investment in scientific research will be considered a stock variable of knowledge that can be used to produce both social and private benefit. Both for-profit and non-profit firms produce scientific research and will be able to earn an economic return on this research through the sale of intellectual property rights or direct production of a good or service.

This model is to be distinguished from previous literature involving investment in scientific research, in that it will focus on how the optimal level of investment will change with respect to a change in the potential economic return. This is in contrast to describing the optimal investment behavior of the firm each term over time. In order to obtain the comparative statics result desired, a simple model describing the optimal operating conditions will be employed. However, the optimal operating conditions for a for-profit firm are distinct from those for a non-profit firm. It is therefore necessary to use two separate models to describe the behavior of each type of firm, and a comparison between the two can then be drawn.

For-Profit

The behavior of a for-profit firm that engages in the investment of scientific research can be described by a standard profit maximization problem. Profit, π, can be represented by the difference between total revenue derived from investing in scientific research and the cost of producing that research. Let total revenue be $rS(I)$, where r is the return associated with the investment, and $S(I)$ is total stock of research. $S(I)$ is to be assumed finite, continuous, and twice differentiable across all I, and dS/dI (S_I) is positive across all I. Let total cost be $C(I)$, where $C(I)$ is also to be assumed finite, continuous, and twice differentiable across all I, and dC/dI (C_I) is positive across all I.

The general profit maximization problem can then be represented in the following form:

$$\max \pi(I) = rS(I) - C(I)$$

This equation assumes the firm has no control over the return associated with the investment in scientific research and therefore will be treated as a parameter.

The first order condition associated with this problem would then represent the optimal level of investment in scientific research for the for-profit firm and can be represented as a function of the parameter, r. The first and second order conditions would therefore be as follows:

$$0 = rS_I[I^*(r)] - C_I[I^*(r)]$$

$$S_{II} < 0 \; C_{II} < 0$$

From the first and second order conditions, the change in the equilibrium amount of investment with respect to a change in the economic return can both be identified and signed. The comparative statics is given as:

$$\frac{dI^*}{dr} = \frac{-S_I}{rS_{II} - C_{II}}$$

Assuming that the second order conditions hold, this term is found to be positive across all I.

This is not an exceptional result, as it follows logically that a for-profit firm would increase equilibrium investment if the potential return has increased. However, it can be used as a good measure of comparison with non-profit optimal behavior.

Non-Profit

The behavior of a non-profit firm is entirely distinct from that of a for-profit firm in that it is not a maximization problem at all. This means first and second order conditions cannot be derived or drawn upon when considering comparative statics. While the non-profit firm does not operate at the level of profit maximization, it does have a level of optimal output, where profit is equal to zero.

Again profit, π, will be represented by the difference between total revenue and total cost. However, a non-profit firm is again distinct from its for-profit counterpart, in that it can receive grants and donations from foundations, governments, and consumers. To incorporate this into the model, total revenue will be represented not only by $rS(I)$, the return and stock of scientific research, but also $G(I)$, or the grants and donations received by the non-profit firm. In this model, grants will be thought of as a function of investment in scientific research, or the amount of money that the non-profit firm receives in grants depends on the amount of research in which the firm engages. Both $S(I)$ and $G(I)$ are assumed to be finite, continuous, and differentiable functions across all I, and S_I and G_I are both positive. The total cost will be represented by a single cost function $C(I)$ where again, $C(I)$ is assumed to be finite, continuous, and differentiable across all I, and C_I is also positive.

The optimal operating conditions will then describe the equilibrium amount of investment in scientific research as a function of the parameter, r, and can be described as follows:

$$0 = rS[I^*(r)] + G[I^*(r)] - C[I^*(r)]$$

From this equation, the comparative statics result relating the change in the equilibrium amount of investment in scientific research to the change in potential economic return can be obtained and is given by:

$$\frac{dI^*}{dr} = \frac{-S}{rS_I + G_I - C_I}$$

This comparative statics result implies that (dI^*/dr) is positive when $C_I > rS_I + G_I$ and negative when $rS_I + G_I > C_I$ and zero when $rS_I + G_I = C_I$. This is a more interesting result than the for-profit comparative statics result because it implies that equilibrium output of non-profit investment in scientific research can both increase, decrease, and remain the same as economic return changes depending on a variety of factors.

Results

In order to analyze the comparatives statics result found from the non-profit model, it is first necessary to understand the factors that contribute to whether or not a non-profit firm decides to increase, decrease, or maintain the level of investment in scientific research when the return associated with that research changes. According to the comparative statics result, these factors include rS_I, G_I, and C_I. S_I will be interpreted as the marginal productivity of the research, that is it represents how the total stock of research changes with respect to investment. Therefore, rS_I should be considered as the marginal private benefit of investing in scientific research. G_I represents the change in grants and donations received by the firm with respect to the change in investment undertaken by the firm. For this analysis, G_I will be called the firm's availability of funding. If G_I is large, the amount of funding that is received by the firm will be large even if the firm is only engaging in a small amount of research. In this case, it would be said that the firm has a high availability of funding. C_I is simply how cost changes with investment in research, or the marginal cost of undergoing that research.

Based on the comparative statics result from the non-profit model, (dI^*/dr) will be positive when $C_I > rS_I + G_I$ and negative when $rS_I + G_I > C_I$. This means that if the private marginal benefit of engaging in the investment or the availability of funding exceeds that of the marginal cost, a non-profit firm will increase equilibrium investment when the economic return associated with that investment is falling.

This result is in stark contrast to the comparative statics result found for the for-profit firm. While the for-profit firm will always act in a predictable manner, increasing equilibrium investment as the economic return associated with that investment increases, the non-profit firm may not always react in the same way. If funding for the research is highly available, or the marginal private benefit of the research is great enough, the non-profit firm will act in the opposite way as the for-profit firm.

The result of this model suggests contradictory scientific investment decision-making behavior among for-profit and non-profit firms. It predicts a polarization within the industry of scientific research. For-profit firms will dominate industries that have high returns, while non-profit firms will engage in research with high returns only if the associated marginal cost of that investment is greater than the availability of funding and the total economic return. Non-profit firms will engage in scientific research that has high marginal private benefit, high availability of funding, and a low rate of return.

Evidence

Pharmaceuticals

The pharmaceutical industry is dominated by for-profit incentives. Research and development in this industry has typically been viewed as a very high cost, high-risk investment. This is often the justification for the high price of newly developed drugs and the lack of research and drug development aimed at diseases of the poor (Trouiller, P *etal.* 2002). Unsurprisingly, drug development within the industry is dedicated to diseases for which there are viable markets. From the years 1975 to 1999, infectious and parasitic diseases accounted for one-third of the world's disease burden but only 5% of the disease burden in developed countries (Trouiller, P *etal* 2002). While infectious and parasitic diseases dominated the world's disease burden, two to three times more funding was dedicated to fighting diseases prevalent in high-income countries (Trouiller, P *etal.* 2002). Drugs that target cardiovascular and central nervous system disease, diseases most prevalent in the United States and other high-income countries, accounted for 35% of total worldwide pharmaceutical sales and constituted 28% of the 1393 new drugs approved for market sale from 1975-1999 (Trouiller, P *etal.* 2002). These numbers do not reflect the total worldwide disease burden of cardiovascular and central nervous system disease, but instead reflect the focus of the pharmaceutical industry on high economic returns. In fact, in the United States, the primary reason for research abandonment in the pharmaceutical industry four years after filing the investigational new drug application, was poor prospective economic return and not for reasons of safety or efficacy (DiMasi, J 2001).

As of the year 2000, the total amount of spending on "neglected diseases," such as malaria, tuberculosis, leishmaniasis, and African trypanosomiasis was estimated to be less than $70 million yearly (Trouiller, P *etal.* 2002). All of these diseases contribute significantly to the worldwide disease burden, but do not have viable market returns. The Gates Foundation, however, has focused its resources on eliminating malaria, boosting total spending on malaria drug development to around $240 million annually (McCoy, D *etal.* 2009). In 2007, the Gates Foundation provided $1.22 billion dollars of funding to the non-profit sector dedicated to global health (McCoy, D *etal.* 2009). This was almost equivalent to the total World Health Organization budget of $1.65 billion (McCoy, D *etal.* 2009). These kinds of contributions hold considerable influence in the non-profit sector and represent the majority of non-profit spending on drug development. The Gates foundation focuses most of this funding on malaria and tuberculosis, diseases that have low economic return and therefore tend to be ignored by the for-profit sector. The result of this high availability to funding is high levels of non-profit investment despite the relatively low rate of return.

The Molecular Biology Revolution

Molecular biology began in the 1930s when Warren Weaver, a mathematical physicist and director of the Rockefeller Foundation's Division of Natural Sciences, began providing funding to physicists and chemists at elite universities to study biological molecules (Rai, A 1999). As little was known about how these new analytical methods in chemistry and physics could be applied to macro-sized biological molecules, early research in molecular biology was carried out strictly by non-profit and university organizations. The nature of such research was far from commercially viable when it was being developed. Research in molecular biology was therefore ignored by the for-profit sector, which flourished in the pharmaceutical industry due to the high rate of returns (Rai, A 1999). Given the highly theoretical manner and academic setting in which research on molecular biology was conducted, it follows that such research was guided by the traditional scientific norms, namely communalism and invention.

Early in molecular biology, communalism was an essential cornerstone for the development of the industry. The freedom of information helped motivate future research in the field by providing key insights and avoiding needless duplication of effort (Rai , A 1999). However, as the commercialization of molecular biology became not only feasible, but also profitable, communalism has become increasingly less respected. Throughout the 1970s, economic opinion within the molecular biology community began to shift towards strong intellectual property rights (Rai, A 1999). This opinion was in contrast to the traditional norm of communalism, but increasing pressure from the community led to the passage of the Bayh-Dole Act in 1980.

The Bayh-Dole Act ensured that universities could patent their findings and assign ownership of the intellectual property rights associated with that research, even if it was funded publically (Argyres, N & Liebeskind, J 1997). Since its passage, the number of patents taken out by universities has increased substantially and has blurred the line between for-profit and non-profit research. Many universities have established "technology-transfer" offices that license these patents to start up for-profit firms in exchange for a stake in equity (Pisano, G 2006). These for-profit firms then use this knowledge for not only direct commercialization but also follow up research (Pisano, G 2006). As the economic returns and commercial viability associated with research on molecular biology have increased, universities have also began partnering with for-profit venture capital firms to create for-profit firms that engage in the commercialization of and follow up on academic research (Argyres, N & Liebeskind, J 1997). Harvard University pioneered this effort in 1980 when they proposed to acquire equity in a for-profit start-up firm founded by a Harvard staff member and molecular biologist who himself would be a primary stockholder in the firm (Argyres, N & Liebeskind, J 1997).

As economic returns in the biotechnology industry have increased, a number of for-profit firms have emerged. The two that are perhaps the most successful, Genentech and Amgen, have enjoyed great success as for-profit research firms in the biotechnology sector. Genentech, widely considered the father of biotechnology, was the first for-profit technology firm to exploit the exciting new findings of molecular biology (Pisano, G 2006). Genentech created a model for monetizing research within the biotechnology industry, teaming up with both academic institutions and pharmaceutical firms to become one of the most successful medical research firms in history (Pisano, G 2006). However, it was not until high economic returns on biotechnology research became feasible that for-profit firms emerged in the industry and became successful.

Conclusion

For-profit scientific research firms will emerge and be successful in industries that demonstrate high rates of return. Non-profit firms will dominate industries that have low rate of returns, but high availability to funding. Due to the nature of scientific research, infant industries will most likely be dominated by non-profit firms that adhere to the scientific norms established within the scientific community. However, as the economic return associated with this research becomes more feasible or more profitable, the industry will witness the growth of for-profit research firms.

If the economic return associated with the scientific research is not great enough, non-profit firms will still engage in high levels of investment in this research if available funding is great enough. Funding is a driving determinant with respect to the equilibrium amount of investment in scientific research produced by a non-profit firm. Government and large non-profit foundations, such as the Gates foundation, are effectively deciding which health concerns take priority and will receive attention by the research community. This conclusion is congruent with associated economic literature that defines "research opportunities" as a defining determinant in scientific investment (Bhattacharya, J & Packalen, M 2010).

While the intention of public and non-profit funding is admirable, and the research produced by the firms that receive the funding important, a question of efficient use of resources is raised. The Gates foundation, for example, spends $1.22 billion dollars on funding for global health, but primarily focuses on only a few of the "neglected diseases," and the foundation does not appropriate funds according to the worldwide disease burden. The for-profit sector will only respond to markets in which a viable economic return is feasible, meaning it will respond to the demand of those willing and *able* to pay for the resulting good or service. The lack of response of the for-profit sector to those unable to pay for the resulting good or service of scientific research is what inspired governments and foundations to provide funding to the non-profit sector. However, the non-profit sector is primarily responding to the availability of funding, and not to the demands of those unable to pay for treatment. Is the most efficient use of $1.22 billion dollars on global health spending to devote it to only a narrow spectrum of diseases? Another important consideration is to recognize that a majority of funding from the Gates foundation is given in grants to United States firms. From the years between 1998 and 2007, 82% of total funding was given to firms within the United States (McCoy, D *etal.* 2009). Funding to non-profit firms by the Gates foundation is centralized in the United States, particularly in Seattle, Washington (McCoy, D *etal.* 2009). The incredible influence that large non-profit foundations such as the Gates and

Rockefeller foundations have over the research community has shaped the research industry into pawns, over which these foundations can exercise economic authority. While their work is admirable, it may not be the most efficient allocation of resources.

Bibliography

Argyres N.S, Lieveskind J.P. 1997. Privatizing the intellectual commons: Universities and the commercialization of biotechnology. *Journal of Economic Behavior & Organization* 35: 427-454.

Barber, B. 1968. The Sociology of Science. *International Encyclopedia of Social Sciences* 13: 92-100.

Cloutier L.M. Public Policy Timeliness to Disruptive Innovation in Biotechnology: Information Feedback and the Regulation of Balancing Loops. *System Dynamics Society* [online].

DiMasi J.A. 2001. Risks in new drug development: Approval success rates for investigational drugs. *Clin Pharmacol Ther* 69: 297-307.

Hagstrom, W.O. 1964. Anomy in Scientific Communities. *Social Problems* 12.2: 186-195.

Hagstrom, W.O. 1965. The Scientific Community. *American Sociological Review* 39.1: 1-18.

Hagstrom, W.O. 1974. Competition in Science, *American Sociological Review* 39.1: 18-28.

McCoy D, Kembhavi G, Patel J, Luintel A. 2009. The Bill & Melinda Gates Foundation's grant-making programme for global health. *The Lancet* 373: 1645-1653.

McMillan G.S., Francis N, Deeds D.L., 2000. An analysis of the critical role of public science in innovation: the case of biotechnology. *Research Policy* 29: 1-8

Merton R.K. 1973. The Normative Structure of Science. *Sociology of Science* 275-77.

Nathan C. 2004. Antibiotics at the crossroads. *Nature* 431 [online].

Pisano G.P. 2006. Can Science Be a Business? *Harvard Business Review* [online].

Rai, A.K. 1999. Regulating Scientific Research: Intellectual Property Rights and the Norms of Science. *Northwestern University Law Review* 94.1: 77-152.

Trouiller P, Olliaro P, Torreele E, Orbinski J, Laing R, Ford N. 2002. Drug Development for Neglected Diseases: a Deficient Market and a Public-Health Policy Failure. *The Lancet* 359: 2188-2194.