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Innovation in the biotechnology industry: The role of university-generated intellectual property rights, knowledge base investments and funding mechanisms

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Abstract

The purpose of this paper is to analyze determinants of innovation process effectiveness in the health care biotechnology industry. We use empirical data to highlight specific differences between Europe and USA. We build from a body of literature investigating the historical development of the industry, expansion of intellectual property rights to new entities and new scientific fields as well as the role of different sources of funding of biomedical commercialization process in the development of companies innovative capabilities and new value creation. The theory of innovative enterprise with its focus on strategic control, financial commitment, and organizational integration is compared with the maximizing shareholder value concept in assessing the determinants of biotechnology innovation effectiveness. Our findings point to the weaknesses of the highly monetized US business model given the tendencies of the European biotechnology industry to emulate this model. Based on our findings we propose recommendations that should facilitate

sustainable growth of the sector.

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INNOVATION IN THE BIOTECHNOLOGY INDUSTRY: THE ROLE OF UNIVERSITY-GENERATED INTELLECTUAL PROPERTY RIGHTS, KNOWLEDGE BASE INVESTMENTS AND FUNDING MECHANISMS

1. INTRODUCTION

In recent years, there has been a growing interest in the healthcare biotechnology industry as a driver of economic growth. Here, new value is created through a lengthy, costly and risky process of research and development (R&D), clinical trials, regulatory approvals and finally, commercialization. The success depends on valuable inputs provided by multiple parties, including universities, venture capitalists, pharmaceutical firms, governments and emerging firms (Ebers and Powell, 2007). Previous studies of the determinants of the biotechnology innovation effectiveness, although substantial, have mostly been devoted to investigating collaborative networks and spatial dimensions of innovation (Shan, Walker and Kogut, 1994; Deeds and Hill, 1996; Powell, Koput and Smith-Doerr, 1996; George, Zahra and Wood, 2002; Owen-Smith, et al., 2002; Owen-Smith and Powell, 2004; Faems, Van Looy and Debackere, 2005; Phene, Fladmoe-Lindquist and Marsh, 2006). In this paper, we extend the existing research by focusing on three groups of influencing factors: university-derived intellectual property rights, public investments into knowledge base and commercialization funding mechanisms.

Based on the in-depth review of literature on driving forces of innovation in the healthcare biotechnology industry we identified three gaps. Little is known about how intellectual property rights system facilitates innovation (Orsenigo, Dosi and Mazzucato, 2006). Intellectual property rights (in what follows IPRs) have gained particular attention in the literature on biotechnology innovation after they have been widely used in new areas of scientific discoveries - life forms and new actors (non-profit research institutions). However, studies that explore how patenting activities at academic institutions produce innovations yield mixed findings. Most of the studies implicate that “locking up” of an increasing number of upstream life science inventions in patents negatively affects scientific progress and innovation (Dasgupta and David, 1994; Heller and Eisenberg, 1998; Henderson, Jaffe and Trajtenberg, 1998; Nightingale and Martin, 2004; Orsenigo, et al., 2006; Murray and Stern, 2007). These findings allude to potential deficiencies in the present IPR system as an innovation-driving force.

Next, although it is believed that innovation in biotechnology is facilitated through public investments into knowledge base, there is only limited evidence in support of this assumption (McMillan, Narin and Deeds, 2000; Autant-Bernard, 2001; Gittelman and Kogut, 2003; Angell, 2004). Toole (2012) points to the scant empirical verifications and finds that

basic research funded by the US National Institutes of Health (NIH) has a significant effect on the pharmaceutical innovation in the form of market entry of new therapeutics.

Finally, only few studies capture the relationship between funding mechanisms and innovation output in this industry (Coriat and Orsi, 2002; Dushnitsky and Lenox, 2005; Andersson, et al., 2010; Lazonick and Tulum, 2011). Most of them build on the fact that biotechnology companies have been characterized by the overall lack of innovations entering the market and subsequent profitability, and at the same time "bubbling" capital injections, predominantly in the USA over the past decade (Pisano, 2006).

There are two main contributions of our study. First, in order to develop an overview of driving forces of innovation process in healthcare biotechnology, we compare the dynamics in the US and European biotechnology sectors. Our comparative analysis is conceptually grounded in neoclassical financial theory and theory of innovative enterprise (Lazonick and O'Sullivan, 2000; O'Sullivan, 2000; Lazonick, 2003). The neoclassical financial theory assumes shareholder value maximization as a guiding principle in doing business while technologies and market conditions are given constraints in the system. The newer theory of innovative enterprise builds on the resource-based view foundations to propose that enterprises actively use R&D investment strategy and organizational structure to transform technological, market and other conditions to generate performance outcomes, such as innovations. The rationale for choosing these two divergent theories in the comparative analysis is that each highlights a specific aspect of the biotechnology business development, while applied together they contribute to a better understanding of the whole process. We thus acknowledge that the neoclassical financial theory represents a wide-ranging operating framework as shareholders seek short-term gains in an industry characterized by long terms and high risks, and enterprises maximize shareholder value typically by becoming acquired by pharmaceutical companies, instead of pursuing high-risk R&D (Ernst&Young, 2011). At the same time, we argue that this theory does not consider the role of different internal and external conditions that have historically shaped the innovation process in biotechnology. The theory of innovative enterprise offers a critical view on innovation creation, by investigating how the capital markets have profiled strategic priorities of biotech companies (Andersson, et al., 2010). We make our contribution by using the two theories as complementary views in assessing how university-generated intellectual property rights, public investments into knowledge base and business funding mechanisms affect biotechnology innovation output.

As to our second contribution, we combine theoretical discussions with statistical data in comparing the US and the European biotechnology industries. Although the widely accepted US biotechnology business model was questioned after the collapse of speculative markets in the financial crises of 2001 and 2008-2009, there have been clear tendencies to emulate the US model in Europe. By identifying key determinants that drive and motivate the production of biotechnology innovation output, we develop specific managerial implications regarding success factors of companies that compete in European environments.

2. THE ROLE OF UNIVERSITY-ASSIGNED INTELLECTUAL PROPERTY RIGHTS IN BIOTECHNOLOGY INNOVATION

In order to assess the role of university-generated IPRs in stimulating innovation effectiveness in biotechnology, we first briefly describe how they gained importance in the US and European university settings. Next, we discuss the benefits and challenges resulting

from the changes in the IPR regime in these settings, particularly with respect to the effects on innovation output.

The adoption of the Patent and Trademark Amendments of 1980 in the USA, known as the Bayh-Dole Act, is historically viewed as an event that marked the beginning of the global upsurge of knowledge transfer activities from non-profit research institutions to the business sector. The Bayh-Dole Act gave non-profit institutions and small businesses the privilege to retain the property rights to inventions deriving from the state-funded research (Mowery and Ziedonis, 2002) and hence relaxed government control over the commercial use of the results of publicly-funded research (Lazonick and Tulum, 2011). This new legislation was later adopted in most countries in Europe (Geuna and Nesta, 2006; Hall, 2007), although not with the same clarity: whereas in the USA ownership of university-generated IPRs obviously belongs to the university, some countries in Europe traditionally had the so-called professor privilege, which gives university employees the IPRs to their inventions. Even though most of these countries in the 1990s and 2000s changed their legislation by assigning ownership to the university, university ownership has usually been weakly enforced, thus in reality leaving the decision on ownership to be negotiated (Crespi, et al., 2010).

The expansion of commercial considerations to new actors and new scientific fields has been evaluated as desirable for both the academic (Colyvas and Powell, 2006) and the industrial partners. The benefits include the expansion of basic research funding sources, less strict borders between basic and applied research (Czarnitzki, Glänzel and Hussinger, 2009) and facilitated transfer of knowledge that supports the creation and growth of new technology firms (Mowery and Ziedonis, 2002). It was argued that many state-funded inventions would be left unexploited unless the conditions for the transfer of IPRs were made less restrictive (Lazonick and Tulum, 2011).

The most important challenge associated with the current IPR regime relates to patenting and exclusive licensing of fundamental technologies with broad application in life sciences. Dasgupta and David (1994), Rai and Eisenberg (2003) and Murray and Stern (2007) argue that such practices can restrict, and not stimulate future innovation, measured by the number of new useful products for health. With an increasing body of upstream knowledge covered by patents, they claim, the costs of research increase, access to technologies is hindered and free flow of scientific knowledge needed for subsequent research becomes compromised. This concern has been captured in the phrase "*the tragedy of the anti-commons*", which has been used extensively to point to the problem of existence of multiple holders of rights to separately patentable inputs which combined form one product or resource (Heller and Eisenberg, 1998). Exclusive licensing of broadly useful research tools seems to be particularly problematic from the social welfare perspective. If a single patent holder exploits the invention exclusively, it limits new entrants who would compete to produce more efficient and cheaper medicines (Lazonick and Tulum, 2011), leaving the research and commercial potential of an upstream discovery in subsequent research largely unexploited. Alternatively, society benefits more if such discoveries are made broadly available (Walsh, Arora and Cohen, 2003).

Other challenges related to the expansion of IPRs and commercial activities at academic institutions are discussed by Henderson and colleagues (1998), Jensen, J. G. Thursby and M. C. Thursby (2003), Hall (2007), Kenney and Patton (2009) and others. These authors argue that legal systems introduced to encourage academia-industry knowledge transfer indeed increased the number of university-assigned patents in the USA. However, one of the consequences of the increased demands for patenting is a growing number of commercially irrelevant patents. This is accompanied by the constant friction between academic institutions that desire publication and the establishment of priority, and industry

research sponsors that wish to defer disclosure until the patents can be employed to protect the future monopoly rents (Barbosa and Faria, 2011). Thus, the rules of market competition may not be compatible with the social norms of priority and free circulation of knowledge within the scientific community (Calderini, Franzoni and Vezzulli, 2007).

Based on the above described findings, we contend that the change in the IPR regime towards patenting of life forms and university-assigned patenting has facilitated technology transfer from universities to industry, mostly through the creation of new biotechnology companies. What is more, the strong dependence of the biotechnology sector on science base, manifested primarily through monetization of IPRs (Pisano, 2006; Andersson, et al., 2010), has increased its attractiveness to private equity investors. Since the development of new products is a lengthy and unpredictable process, the biotechnology sector has usually been marked as critically dependent on the enforcement of patents as a means of protecting the future economic returns of inventions.

Yet, we argue that, although the new IPR regime has facilitated the development of the biotechnology industry, it does not necessarily positively affect innovative output (see Table 1 for the summary of key findings). In this sector, IPRs are used by new companies to attract established companies, which in return enter into alliances with them or acquire them. IPRs thus enable young companies to send positive signals to investors, essential to obtain funding or quickly exit to capital markets through IPOs, despite the fact that they typically lack products close to the market. This widely accepted operating principle may not go along with increased innovation effectiveness. In fact, recent studies show that strong IP protection is a weaker determinant of successful development of innovative products than innovative capabilities of biotechnology firms to translate new technologies into innovative products (Orsenigo, et al., 2006). In accordance with this, the critical importance of patents as a means of providing market advantage declines with the longer product development timelines, due to their limited term. This poses the need for development of capabilities of companies to transform new technologies into innovative products and processes.

Table 1
Overview of key studies on university-generated IPRs and innovation in biotechnology

Setting	Important authors	Key findings	Dependent variable(s)
USA	Dasgupta and David (1994)	Growing "privatization of the scientific commons" may endanger scientific and technological progress, particularly by restricting access to upstream discoveries essential for subsequent research.	
USA	Heller and Eisenberg (1998)	Commercialization of biomedical research can stimulate private investments in science, but it can also produce a "tragedy of the anti-commons", through a rise of fragmented and overlapping IPRs. This is due to the high transaction costs of bargaining, heterogeneous interests among owners, and cognitive biases of life science researchers.	
USA	Henderson, Jaffe and Trajtenberg (1998)	Explosion in US university patenting in the period from 1965 to 1992 has been accompanied by a decrease in their importance, measured by patent citations.	- patent importance - patent generality
17 OECD countries	Furman, Porter and Stern (2002)	Variation in innovativeness across countries is due to differences in the level of R&D personnel and spending, extent of IP protection and openness to international trade; share of research performed by academia and funded by the private sector.	- number of "international patents"
USA	Nightingale and Martin (2004)	The "biotechnology revolution" model of technological change along the innovation path from basic research to clinical development is not supported by the empirical evidence: R&D expenditures increased tenfold, while patenting output increased	

		only sevenfold, and only a handful of new chemical entities were approved by the FDA over the period 1983–2003. The slowdown in innovation is explained by difficulties in keeping pace with the increasingly complicated new scientific-technological base.	
USA, Europe, Japan, India	Orsenigo, Dosi and Mazzucato (2006)	A tighter IPR regime does not automatically lead to an increase in innovative activities in the countries which introduced substantial institutional changes in IPR systems.	
Nat Biotech articles and USPTO patents	Murray and Stern (2007)	Patenting has a modest negative effect on free flow of scientific knowledge; citation rate for a scientific publication falls after formal IP rights associated with that publication are granted.	- number of forward citations

The described findings suggest some deficiencies in the present IPR system as a biotech innovation-driving force in the USA and Europe. In Section 6 we propose several solutions that, we argue, might overcome the problems related to misaligned interests of different actors involved in biotechnology commercialization process.

3. THE ROLE OF PUBLIC INVESTMENTS INTO KNOWLEDGE BASE IN BIOTECHNOLOGY INNOVATION

Public investments into science base are a prerequisite for development of biotech inventions. We provide an overview of the literature investigating the impact of public funding of basic research on biotechnology innovation. Then, we draw from statistical data to illustrate the extent of public investments into knowledge base in the USA and Europe. Finally, we discuss the implications of the findings for the biotechnology new value creation process.

Despite the fact that many scholars acknowledge the importance of public investments into science base for biotech innovation (O'Sullivan, 2000; Chandler, 2005b; Chandler, 2005a), very few have shown empirical evidence in support of this claim (Toole, 2012). An overview of the key studies investigating this relationship is provided in Table 2. The results generally indicate a high reliance of the biotechnology industry on public science. A particularly challenging discussion is presented by Angell (2004), who finds that "those few therapeutics that are truly innovative are usually based on taxpayer-supported research done in non-profit academic medical centers or at the National Institutes of Health". Furthermore, Stevens and colleagues (2011) find that 9,3% of medicines approved by the US Food and Drug Administration (FDA) in the last 40 years were discovered by public sector research institutions. According to this view, the bearers of innovative activities in healthcare biotechnology are government-funded institutions. This implies that biopharmaceutical companies overstate the development costs of new medicines, and consequently, product prices. Still, one must not neglect the fact that a substantial part of experiments required to develop the efficient medicine, including the clinical trials, is done by the private sector.

Table 2
Overview of key studies on public investments into knowledge base and innovation in biotechnology

Setting	Important authors	Key findings	Dependent variable(s)
USA; top 10 "biotech" countries	Zucker and Darby (1996)	The larger the extent of collaboration of a company with star scientists, the bigger its success, particularly in the USA.	- products in development - products on the market - employment growth
USA	McMillan, Narin and Deeds (2000)	Biotechnology industry relies on public science much more heavily than other industries, including pharmaceutical, for very basic scientific research.	- non-patent references (NPRs) on patents
France	Autant-Bernard (2001)	Public research produces positive effects in increasing innovation level; however, the positive externalities are limited to geographic space.	- patents
USA	Gittelman and Kogut (2003)	Publication, collaboration, and science intensity are correlated with patented innovations; there is a negative relationship between important scientific papers and high-impact innovations.	- cumulative forward citation frequencies to an individual patent assigned to firms
USA	Angell (2004)	A large part of the upfront search and innovation costs are borne by the public sector. Truly innovative therapeutics almost always originate from publicly funded laboratories.	
USA	Toole (2012)	NIH-funded basic research and market size have an economically and statistically significant effect on pharmaceutical innovation in the form of entry of new medicines.	- number of new medicines (new molecular entities) applications

In analyzing the extent of public investments into life science base we compare the US and the European situation. The US National Institutes of Health (NIH) have been the major and stable provider of funding for basic biomedical research at academic research laboratories, government research institutes and small businesses worldwide. Unlike venture capital and stock market investments, which have fluctuated widely, NIH funding increased in nominal terms in every year from 1970 to 2009, except for a small decline in 2006 (Lazonick and Tulum, 2011). In 2007, the NIH investments represented 27% of the total biomedical research expenditures in the USA, making it the second largest contributor to biomedical research, next to industry (Dorsey, et al., 2010). These investments are indispensable for the development of biotech industry knowledge base and consequently, responsible for private investment flows into the sector (McMillan, et al., 2000; Lazonick and Tulum, 2011).

Unlike in the USA, in the European Union (EU) there is no single major public provider of funding of biomedical research. The majority (85%) of public funding is provided by various national funding organizations, while the remaining 15% is funded at the supranational level. The European Commission complements national policies primarily through its Framework Programmes (FP) and the European Research Council (ERC). Moreover, the major part of R&D funding in Europe is for "top-down" activities, whereas the USA favours "bottom-up" investigator-initiated research (Philipson, 2005). In Table 3 we compare Europe and the USA with respect to public investments in biomedical research. The figures show the lead of the USA over Europe. Looking at the time trends, the investments in Europe have mostly steadily grown between 1995 and 2007; however, an overall increase of 170% over that period was not sufficient to match a much stronger growth in the USA (Berghmans, et al., 2011).

Table 3

Public investments in biomedical research in the USA and Europe

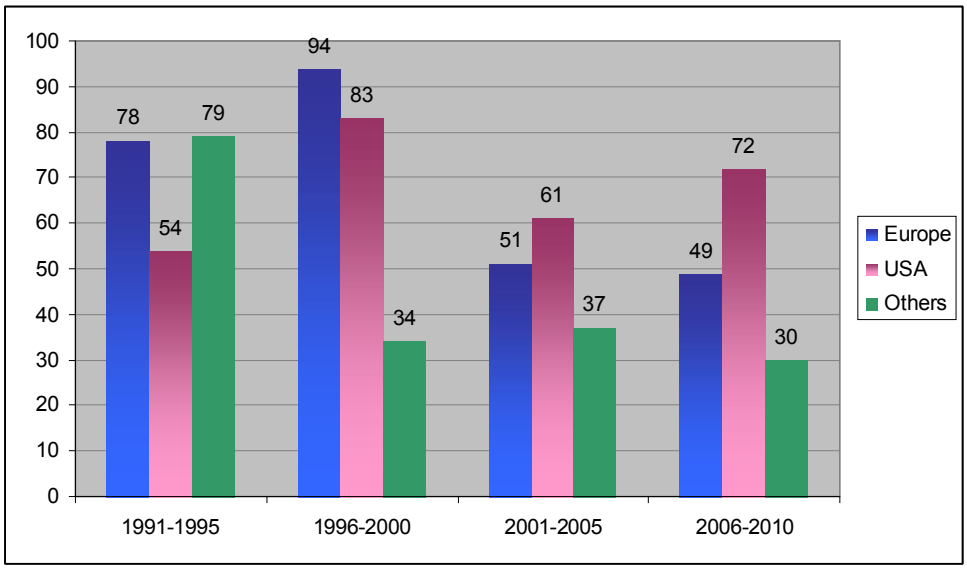
	USA	EU
Major public provider of funding	National Institutes of Health (NIH)	No single major provider: - national organisations (85%) - EU (15%)
Health R&D expenditures in the non-profit sectors, PPP US$b (2007)	32,0	20,3
Budget for health of the major public provider of funding, US$b (2011)	30,7 (NIH)	0,86 (European Commission)
% of public funding going to biomedical research (2011)	50%	30%
% of GDP committed to public funding of health research (2008)	0,222%	0,054%

Source: Adapted and compiled from Wiecek (2011), Berghmans, et al. (2011), BBC (2011), and the European Public Health Association (2011)

Since the private sector needs a rapid return on investment, it cannot afford to support basic research. Governments' agencies worldwide thus produce a broad portfolio of fundamental discoveries which provide biopharmaceutical companies with opportunities to transform these into diagnostic and therapeutic products. We have also discussed how very few studies have empirically assessed the actual impact of public investments into science base on biotechnology innovation output. The most often used indicator of innovation output is the number of approvals of new molecular entities (NMEs). Until the end of 1990s, the European biopharmaceutical industry was the major global developer of NMEs. As shown on Figure 1, the USA has taken the lead in the past decade, with 47,68% of all NME approvals in the period from 2006-2010 as compared to Europe's 32,45% (Berghmans, et al., 2011).

Figure 1

Overview of NME approvals in the USA and Europe, 1991-2010



Source: Adapted from Berghmans (2011)

Another interesting trend that can be observed from Figure 1 is the decreasing number of total NME approvals over the past 15 years. Thus, the increase in funding levels was not accompanied by an increase in approvals of molecular entities, including medicines (Dorsey, et al., 2010). One explanation for this trend is the increasing cost and complexity of research, accompanied by increased regulatory requirements (Berghmans, et al., 2011; Ernst&Young, 2011). Others find that research productivity should not be measured solely by the number of NME approvals, since broader factors, such as lower death rates, longer life expectancy and improved quality of life, are also relevant consequences of biomedical research investments (Dorsey, et al., 2010). In the next section we seek to provide a more detailed analysis of this problem, focusing on the role of commercialization funding mechanisms in fostering biotechnology innovation.

4. THE ROLE OF COMMERCIALIZATION FUNDING MECHANISMS IN BIOTECHNOLOGY INNOVATION

The aim of this section is to investigate the impact of funding mechanisms deployed by the US and the European healthcare biotechnology companies on innovation effectiveness in the sector. We build our analysis around two historically relevant periods: first, the phase of dramatic increases in investments in the biotechnology industry and then, the phase of rapid loss of trust of investors in this sector. We rely on a set of empirical studies and industry reports in determining the causes of these occurrences and their consequences for the biotechnology new value creation. As a first step, in Table 4 we compare the core financial figures of the US and the European biotechnology industry.

Table 4
Overview of the US and European healthcare biotechnology in figures, 2009-10

	USA (US$b)			Europe (US$b)		
	2010	2009	% change	2010	2009	% change
Public company data						
Product sales	52,6	48,1	9%	n/a	n/a	n/a
Revenues	61,6	56,2	10%	17,26	15,40	12%
R&D expense	17,6	17,1	3%	4,51	4,29	5%
Net income (loss)	4,9	3,7	33%	(0,61)	(0,62)	-2%
Market capitalization	292,0	271,6	8%	78,89	62,94	25%
Number of employees	112.200	106.600	5%	49.060	48.660	1%
Financings						
Capital raised by public companies	16,3	13,5	21%	2,47	2,78	-11%
Number of IPOs	15	3	400%	10	3	233%
Capital raised by private companies	4,4	4,6	-3,2%	1,36	1,05	29%
Number of companies						
Public companies	315	314	0,3%	172	167	2%
Private companies	1.411	1.389	2%	1.662	1.675	-1%
Public and private companies	1.726	1.703	1%	1.834	1.842	-0,5%

Source: Adapted from Ernst & Young (2011)

As shown, in 2010 Europe had more biotechnology companies than the United States. However, the United States had almost as twice as many publicly listed companies; more than

twice as many employees, spent more than three times more on R&D and generated three times as much revenue in total (Ernst&Young, 2011). According to the same report, industrial leaders in the USA had lower growth rates (9%) when compared to other companies (13%). A challenging fact for our analysis is that the former increased R&D spending by 7% in the respective period, while the other companies reduced R&D by 1%. Thus, emerging companies, which have historically been a vital source of innovation, started decreasing their R&D expenditures. In Europe, both commercial leaders' and other companies' growth was 12%; however, both groups increased R&D expenditures.

4.1 On the causes of the biotechnology "boom" and relations to innovation

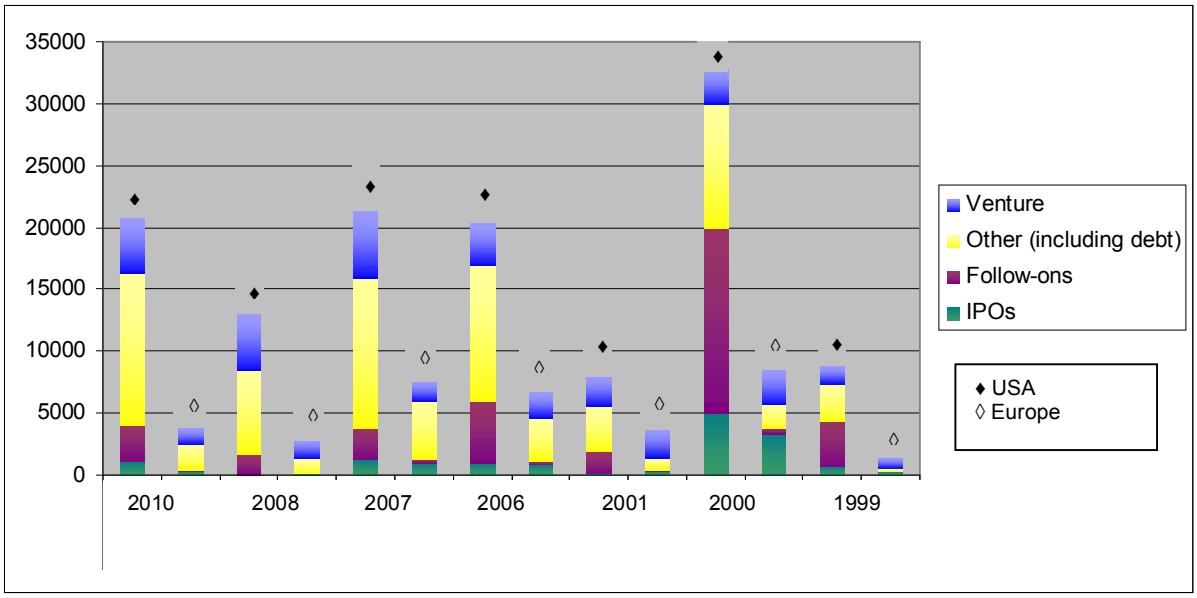
Before and during 2000s, biotechnology industry in both the USA and Europe was characterized by a "boom" in investments, primarily from venture capital (VC) firms and R&D alliances with established pharmaceutical companies. The largest jump in the level of investment occurred in 2000 in relation to 1999, amounting to 273% in the USA and 525% in Europe (Ernst&Young, 2011). These substantial investments were present despite the fact that the industry mostly lacked market-ready products and profitability (Pisano, 2006). Following the literature review we identify two major explanations for this phenomenon: existence of initial public offerings (IPOs) and use of stock-based executive compensations. Both are manifestations of alliances between the financial markets and new biotechnology firms (Coriat and Orsi, 2002).

IPOs have had two primary roles in the biotechnology industry: to quickly and lucratively attract funds for further therapeutic development (Lazonick, 2007), and to provide venture capitalists and pharmaceutical companies with the opportunity to exit from their investments, often with a considerable return, without having to wait for product regulatory approvals and market entry (Lazonick and Tulum, 2011). It is known that the development of new medicines requires a highly risky process that can take up to 20 years. In contrast to the direct private investment in innovation, which involves facing technological, market and competitive uncertainty, and where "patient capital" is needed from investors, public shareholders' investments have been characterized by "short-termness". The operating principle becomes speculation, which produces gains for investors based on their assumption of existence of "greater fools", ready to buy the over-priced shares on the market. The buildup of innovative capabilities is here set aside since more effort is often devoted to reaching an IPO than to commercialization (Lazonick, 2007).

In the USA, stock markets for new technologies have had longer tradition and higher relevance than in Europe. Only minorities of European companies have managed to access stock markets, and if so, primarily through IPOs (Critical I 2006). Even though the share of IPOs in the total European biotechnology financing rarely exceeded 15%, in 2000 it was almost 40%, compared with the US 15% in the same period (Ernst&Young, 2011). Thus, we must not neglect the role of IPOs in the European financing picture. Figure 2 shows the extent and distribution of biotechnology financings in the USA and Europe, in selected years over the period between 1999 and 2010. In addition to the significant difference in the level of financing, the USA and Europe differed in the relative importance of funding mechanisms. While "other" sources, mostly debt, dominated in the USA in most of the years observed, in Europe venture capital generally had the highest relative importance. Moreover, secondary stock offerings on the public markets were common in the USA and rare in Europe.

Figure 2

Overview of biotechnology industry financings in selected years, USA and Europe



Source: Adapted from Ernst&Young (2011)

Although underdeveloped, fragmented, illiquid and without the necessary support structures (EC 2009), stock markets were a playground for speculations in Europe, similarly to the USA. In his analysis of the top European biotechnology companies, Cooke (2001) noticed the difference between their valuation, in terms of market capitalization, and their much lower turnover, and discussed the speculative confidence of stock market investors in the industry characterized by general non-profitability. The result of such an approach are loss-making companies on the stock market, with strong research results, alliances with large pharmaceutical firms, or products going through clinical trials, using stock market valuations to ensure the expansion of firm activities (Casper and Kettler, 2001). Both in Europe and in the USA, speculative stock markets have been highly sensitive to media news and expectations at every stage of the product development process, and particularly concerning the results of the clinical trials of therapeutics (McNamara and Baden-Fuller, 2007; Andersson, et al., 2010).

The second explanation for the occurrence of substantial investment capital in the biotechnology industry can be related to executives' stock-based compensations. This practice stems from the USA and was gradually expanded to non-executive employees, as an instrument to attract skilled personnel to high-tech start-up companies (Lazonick, 2007). The European legal and tax systems discouraged stock options until the beginning of the 21st century (Cooke, 2001). However, empirical evidence shows that stock-based compensations to executives and employees are at present regularly exercised also in Europe (Lazonick and Sakinç, 2010). As discussed by Casper, and Kettler (2001), the legalization of stock options as performance incentives in the UK has been as dangerous as stimulating, since they are highly dependent on public companies' stock price - its lowering may motivate scientists to seek performance rewards in established pharmaceutical companies, rather than in biotech companies. Moreover, Lazonick and colleagues (Lazonick, 2007; Lazonick and Sakinç, 2010; Lazonick and Tulum, 2011) argue that stock-based compensations can stimulate stock manipulation through buybacks due to their short-term orientation, and in that way challenge the extent of investments of biotechnology companies in generation of innovative products.

Specifically, by making resource allocation decisions in a way that productive resources are not developed or utilized, but deployed to make primarily personal gains, top managers jeopardize new value creation and long-term growth of their companies (Lazonick, 2011). The observations we put forward are relevant because they raise the question of sustainability of the "short-term" oriented business approach in the industry characterized by "long-termness".

4.2 On the causes and consequences of the burst of the "biotechnology bubble"

In this section we analyze the causes and consequences of the loss of trust of investors in the biotechnology industry, which occurred in 2001 and 2008, following the periods of the biotechnology "boom". We identify two major origins of the burst of the "biotechnology bubble": dependence on speculative stock markets and inadequate expertise of investors.

The first cause of sharp decreases in investments is the dependence of companies on stock markets for funding commercialization-related activities. The finance-driven innovation model (Coriat and Orsi, 2002) mostly disregards the need for "patient" capital as the main motivation of investors remains to quickly exit from their investments through speculations and securing of gains in the short term. The outcome of this principle is the discrepancy between the companies' value on the stock markets and actual performance, which disrupts the long-term sustainability of the industry. Although specific for the USA, the reliance on speculative stock markets has been present in Europe as well. One illustrative example is British Biotechnology, formerly Europe's largest biotechnology company in terms of market capitalization and R&D costs, which experienced a stock market decline of $2 million in 1997 because of delays in gaining approval for its two leading products. This event highly affected the level of confidence of the European investors in the sector (Cooke, 2001). Europe attempted to emulate the US National Association of Securities Dealers Automated Quotations (NASDAQ) by establishing its own stock markets for high technologies. Following the crash of NASDAQ at the beginning of the 21st century, many European stock markets collapsed (Howell, Trull and Dibner, 2003; Lazonick and Sakinç, 2010). The facilitated access to stock markets is therefore estimated as positive with respect to necessary fund raising, but it can also be problematic for companies without capacity to meet expectations and cause dissatisfaction on the stock market, which easily spills over to other biotechnology firms, as it occurred in 2001 and 2008 (see Table 5). Investors in the industry were then no longer motivated to invest because of weaker exit opportunities and IPOs seriously decreased (Dibner, et al., 2003; Lazonick and Tulum, 2011).

Table 5
Capital raised in the biotechnology industry in USA, Canada and Europe, 2000-10 (US$m)

	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000
IPOs	1.316	823	116	2.253	1.809	1.785	2.157	484	602	438	7.393
Follow-ons	3.454	6.579	1.840	3.345	6.303	4.600	3.398	4.046	1.070	2.431	15.675
Other	14.402	10.044	8.402	17.185	14.883	8.430	11.149	10.178	5.542	4.403	11.625
Venture	5.849	5.765	6.168	7.476	5.404	5.417	5.713	4.077	3.622	4.298	5.177
TOTAL	**25.021**	**23.211**	**16.527**	**30.258**	**28.399**	**20.232**	**22.417**	**18.785**	**10.836**	**11.571**	**39.870**

Source: Ernst&Young (2011)

The second explanation for the loss of trust in the sector is characteristic for Europe and refers to the lack of expertise of investors. The Critical I study (2006) discusses Europe's "localized and inward-looking" investors and not sufficiently mature industry to attract debt finance for growth-by-acquisition strategy of the US biotechnology industry. Moreover, venture capitalists are evaluated as investors that inhibit innovation, because of their weak specialization, or support of too many companies with insufficient funding. This is closely related to the fragmentation of the European venture capital industry (EC 2009), not only in countries with no tradition in biotechnology entrepreneurship, such as Portugal, Spain and Italy (Arantes-Oliveira, 2007), but also in mature ones, like Germany (Casper and Kettler, 2001).

We further identify several effects of the funding crises: increased concentration of funding, change in investment targets, more prominent role of the public sector, increasing share of debt financing, and cost-cutting.

Increased concentration of funding in a smaller number of companies is observed both in the USA and in Europe. In 2010 in the USA, top 20% companies in raising funds received 82.6% of capital (compared to 78.5% in 2009 and 68.7% in 2005), whereas the bottom 20% of companies raised only 0.4% of funds (compared to 0.6% in 2009). Moreover, funding often represented reinvestments in existing portfolio companies rather than in new ones (Ernst&Young, 2011). The rising unevenness in funding allocation distribution is expected to result in the return to quality, at the expense of the number of IPOs, but with larger amounts of funds on average raised than had been the case in the period of a "boom" (Lazonick, 2007). Thus, restrictions in the access to funding forces companies to focus their resources on a more narrow set of technologies. They are required to concentrate on achieving short-term milestones to satisfy their investors, which have become more careful in assessing regulatory and commercial risks earlier in a product's development cycle. Short-term milestones enable the VC investors exiting earlier even in the period of higher selectivity of IPO investors, preferably through mergers and acquisitions (M&As), which may not always be in the interest of a company (Ernst&Young, 2011).

The second effect of the burst of the "bubble" is refocusing of investors' preferences towards investments of lower risk. An example is their preference for late-stage clinical trials rather than for therapeutics' discovery. According to Dorsey and colleagues (2010), such practice is accompanied by a more frequent purchasing of small firms by large pharmaceutical companies, rather than investing in early stage research themselves. This trend is problematic because higher risk investments are essential to fill the gap between government-sponsored research and commercial research.

Another effect of capital raising limitations is a bigger role of the public sector in industry financing, particularly in Europe. By launching new national and supranational funding and fiscal initiatives (EC 2009), the governments aim to bridge financing gaps. Also, in Europe, non-traditional funding sources, such as corporate venture capital and family-controlled pools of capital, have become much more relevant (Ernst&Young, 2011).

Fourth, there is an increasing importance of debt financing, specifically in the USA. Even though the most recent industry reports show that biotechnology companies managed to attract amounts of funding similar to those raised during the "boom" preceding the second crisis (Ernst&Young, 2011), this recovery mostly came from debt funding of mature profitable companies, to refinance existing debt and for stock buybacks and acquisitions. If these funding sources are excluded, "innovation capital" raised by US companies was in fact in decline by 21% in 2010.

Finally, a very frequent effect of the crisis, both in the USA and in Europe, is cost-cutting, primarily in R&D expenditures. In 2009, 64% of US companies and 55% of

European companies decreased their R&D spending. With this step, restructuring of the companies with a negative impact on employment becomes apparent and future innovation in the form of new products in the pipeline becomes compromised (EC 2009). According to Nature Biotechnology report (2011), those companies that increase their R&D expenditures explain their strategy of constant innovation as indispensable to survive, in particular in a time when a significant number of marketed products are losing patent protection.

The presented evidence indicates that some mechanisms of funding of commercialization do not necessarily foster innovation in the healthcare biotechnology sector. This primarily refers to stock-market-related practices that promote short-term gains and thus disregard the need of the biotechnology industry for "patient" capital.

5. INNOVATION IN THE US AND THE EUROPEAN BIOTECHNOLOGY INDUSTRY: A COMPARISON THROUGH THE LENS OF TWO THEORIES

In this section we compare the US and the European industries using two theories as a conceptual framework: the neoclassical financial theory and the theory of innovative enterprise. While the neoclassical financial theory takes market price signals and shareholder value maximization as guiding principles, it treats technology and market conditions as exogenous factors. The theory of innovative enterprise builds on the resource-based view and treats technology, market and other conditions as dynamic, transformable, endogenous factors. It further argues that innovative capacity to create new products and processes is what drives innovations and economic growth (Lazonick and O'Sullivan, 2000; O'Sullivan, 2000; Lazonick, 2003). The innovative performance depends on "organizational integration" of participants in a specialized division of labor toward achievement of common goals, "strategic control" in executive-made resource allocation decisions, and "financial commitment" of resources to sustain the innovation process until it can generate products that can make financial returns (Lazonick, 2003).

We recognize that although the neoclassical financial theory is generally accepted in modern theory and practice, it mostly does not consider the role of different conditions that have been shaping the innovation process in the healthcare biotechnology industry. The theory of innovative enterprise is relevant because it combines theory and history in investigating how conditions such as financial markets or government investments impact strategic priorities of biotechnology companies (Andersson, et al., 2010). The results of our critical comparison are summarized in Table 6. We here acknowledge that commercial success is boosted by opportunities for accessing high-risk finance and attracting scientists and managers (Casper and Kettler, 2001; Lemarié, Mangematin and Torre, 2001). The US companies have been more successful in translating research into end products than EU companies (Jonsson, 2007). However, both in the USA and in Europe there has been a dominant stance on the side of investors that the most favorable way to maximize the shareholder value in the short-run is "selling to revenue-hungry pharmaceutical companies that have to complement their internal R&D efforts by looking externally for breakthrough innovations, rather than by pursuing high risk R&D" (Ernst&Young, 2011). The consequence of this strategy is an increasing gap between the high values announced and the funds actually deployed to fund innovation.

Table 6
Innovation-influencing factors: a comparison of the US and the European biotechnology industries
**NFT stands for neoclassical financial theory, while TIE stands for the theory of innovative enterprise*

Innovation-influencing factor	USA	Europe	Theoretical framework
University-generated IPRs	Regulatory changes associated with IPRs encouraged commercialization of federally funded research at universities and establishment of biotech start-ups (Lazonick and Tulum, 2011). Although university patenting increased, its importance, measured by patent citations, decreased (Henderson, et al., 1998; Nightingale and Martin, 2004).	Most countries emulate the US Bayh-Dole Act (Geuna and Nesta, 2006; Hall, 2007). However, high cost and heavy administration related to patents are identified as factors that impede innovation (Jonsson, 2007). Most countries introduced patent protection in pharmaceuticals later than the USA, which has been characterized by strong IP protection in this sector (Orsenigo, et al., 2006).	**NFT:** Patents on publicly funded research serve the purpose of creating markets for knowledge (Orsenigo, et al., 2006). IPRs are incentive to invest based on excluding access to information. Without IPRs, the innovative output will be suboptimal and innovators will be under-rewarded, because markets are highly competitive and information is perfectly appropriable - easily transmitted to those not paying for its use. Broadening the scope of patents is desirable, as it is imposing higher penalties for infringement and if successfully marketed, maximizes the reward to investors (Dempsey, 1999). **TIE**: In the case of public research, the incentive in the form of IPR laws is not needed because invention has already been paid for, by the public (Orsenigo, et al., 2006). Information is a resource; innovation is not a bounded process, but involves many participants that interact in a learning process and that have limited knowledge and abilities (Dempsey, 1999). IPRs are used by new biotech companies to attract acquisitions by established companies, which enables them to quickly exit to capital markets, despite the lack of market-close products (Lazonick and Tulum, 2011). Innovative capabilities to translate new technologies into innovative products are a stronger determinant of successful new value creation than IPRs (Orsenigo, et al., 2006). In the case of upstream discoveries, exclusive exploitation of a patent limits new entrants who would compete to produce more efficient and cheaper medicines from subsequent discoveries (Lazonick and Tulum, 2011).
Public investments into knowledge base	Continuous and substantial government investment in knowledge base and subsidies have financed US biotechnology and motivated equity investors throughout the industry's history (Angell, 2004; Lazonick and Tulum, 2011).	Biotechnology development is boosted through government-initiated technology transfer initiatives, seed funding schemes, and taxation schemes (EuropaBio 2006).	**NFT:** A purely market relation produces the optimal situation and government policy should be limited to situations where market failures have developed. One such market failure demands government funding of basic research, which overcomes the reluctance of firms to fund their own research because of their inability to appropriate all the benefits (Salter and Martin, 2001). **TIE**: Governments have a critical role in developing knowledge base indispensable for international competitiveness of the biotechnology industries, through infrastructural investments that are of far too broad scope to be done by companies, and different incentives to companies for investment in innovation (Lazonick, 2007).

Table 6 Cont.

Innovation-influencing factor	USA	Europe	Theoretical framework
Funding mechanisms *The role of speculative stock markets* - *IPOs*	Industry funding mechanisms have been characterized by stock market investors investing in IPOs of not-yet-commercially-present companies (Lazonick and Tulum, 2011).	Similar to the USA, although to a lesser extent, equity investors are motivated by speculative gains, especially after the IPO, even though the products are mostly not yet close to the market (Lazonick and Sakinç, 2010).	**NFT:** The healthcare biotechnology business model is financialized, shareholder distribution-oriented; companies are investment portfolios of innovations where products in pipeline and firms trade for shareholder value in speculative processes (Andersson, et al., 2010). **TIE**: The extent of financial commitment required to sustain an investment strategy depends on the size of the investments in productive resources and duration of time required for those investments to generate financial returns (Lazonick, 2011).
- *Stock buybacks*	Stock-based compensations to executives and employees are regularly exercised (Lazonick and Sakinç, 2010).		**NFT:** Short-term earnings per share and share price are the most important measures of corporate performance. Only shareholders are "residual claimants" as they receive returns only after all other stakeholders have received their "guaranteed contractual stakes" (Lazonick, 2007). By giving managers stock-based compensation, shareholders mitigate the principal-agent problem – they ensure that managers have aligned interests with them and allocate resources efficiently (Jensen and Meckling, 1976). **TIE**: Shareholders are not the only "residual claimants". State is one example of a "residual claimant" without guaranteed return on investment to taxpayers (Lazonick, 2007). Strategic decision-makers allocate resources to financial interests using speculation and stock-based compensation, to increase stock price regardless of the effect on organizational learning that can result in commercial products (Lazonick and Tulum, 2011).
Other sources of funding: debt and venture capital	Companies are supported by public capital markets and financial institutions lending money secured only by stock (Ernst&Young, 2011). Debt funding dominates the sector.	The industry is not mature enough to attract debt finance for growth-by-acquisition strategy of the US industry (EuropaBio 2006). Venture capital industry is fragmented, with weak specialization (EC 2009).	**TIE**: Productivity problems of the US biotechnology industry were not due to a shortage of funding, but due to the highly financialized business model which undermines innovation (Lazonick and Tulum, 2011), as managers extract value; they don't create value by allocating resources to developing and utilizing productive resources (Lazonick, 2011).
Other sources of funding: pharma companies	In order to maximize shareholder value, companies typically become acquired by pharmaceutical companies, instead of pursuing high-risk R&D (Ernst&Young, 2011).	Mature companies mostly license out their inventions to pharmaceutical companies, get acquired by US companies or move to the USA to access their product and financial markets and thus export value-creating R&D (EuropaBio 2006).	**TIE**: Pursuing acquisitions of small biotech companies by established pharmaceutical companies as a dominant strategy prevents Europe from developing self-sustainable, larger companies and endangers the extent of future innovation (Jonsson, 2007). In both Europe and the USA, this trend negatively affects the investments in early stage research by pharma companies (Dorsey, et al., 2010).

6. CONCLUSION AND IMPLICATIONS

The aim of this paper was to analyze the role of university-generated intellectual property rights, public investments into knowledge base and commercialization funding mechanisms in stimulating innovation effectiveness in healthcare biotechnology. We focused our research on these three determinants of innovation output following the in-depth literature review, which pointed to limited knowledge on key determinants that drive the development of this sector. In our analysis we compared the US and the European biotechnology industries, relying on conceptualization extended by statistical data. Our conceptual frameworks were the neoclassical financial theory and the theory of innovative enterprise, which were contrasted assuming the theoretical and practical dominance of the former and historical perspective of the latter in evaluating innovation-influencing factors in the biotechnology industry. In this concluding section, we develop some implications for practitioners and future research avenues.

Although evaluated as beneficial for commercial exploitation of university-generated research results, venture creation and protection of the future economic returns of inventions, wide-scope patenting and exclusive licensing of upstream discoveries has also been discussed as harmful for future innovation. Even though the change in the IPR regime positively affected the extent of university patenting, it has also led to a lot of commercially irrelevant patents. We propose that academic institutions should reconsider their present policies: instead of "pushing" their technology transfer offices to patent as much as possible in a "monolithic way" (Barbosa and Faria, 2011), universities should invest in developing effective pipelines for critical evaluation of potentially patentable inventions. In that way, they will reduce irrelevant activities in technology transfer offices; reduce the pressure on basic academic research and decrease the costs of legal services associated with IP protection. On top of that, there have recently been attempts to propose alternative IPR regimes. These include the return to inventor ownership and compulsory non-exclusive licensing (Kenney and Patton, 2009; Dorsey, et al., 2010; Hoffenberg, 2010). Recently initiated in the USA and existing in Germany, compulsory licensing should enable innovative companies to receive a return on their investment. At the same time, users would have access to technology at reasonable prices.

The theory of innovative enterprise acknowledges that public investments into knowledge base are indispensible for the development of innovative activities in biotechnology, as companies lack resources to invest in basic infrastructure and projects aimed to reveal the fundamental mechanisms in molecular biology, which are in the background of discovery of any diagnostic or therapeutic product. For that reason, companies rely on investments by governments, and on knowledge available at non-profit institutions. The US National Institutes of Health are the major provider of funding for basic biomedical research, not only in the USA, but also globally, while in EU the majority of basic funding is provided at the level of member countries. Neoclassical theory also stipulates the importance of government investments into knowledge base; however, it argues that the rationale for government involvement is related to the existence of market failures, which discourage biotechnology firms from funding their own research due to high risks and long terms and their inability to appropriate all the benefits. Since very few studies have attempted to measure the actual impact of public funding of biomedical research on innovation effectiveness in this sector, we propose that future efforts should take this direction.

Finally, the analysis of mechanisms of funding of biotechnology commercialization process revealed that speculative stock markets attracted substantial investments into this sector in the USA, and less so in Europe, primarily through IPOs and exercise of stock-based

compensations. Substantial investments were present due to quick exit opportunities for investors, and regardless of the fact that most companies involved were principally R&D companies, lacking profitability and products on the market. This, in practice still dominant business model, highly relies on the neoclassical financial theory and its emphasis on short-term maximization of shareholder value in an industry characterized by long terms and high risks. However, it was questioned after the collapse of speculative markets in the financial crisis of 2008-2009, which largely affected the USA. The crisis affected European biotechnology industry as well, however, not only because of its attempts to emulate the US speculative stock markets, but also because of the generally weak expertise and fragmentation of investors, primarily venture capitalists.

We showed that the US biotechnology sector significantly outperforms the European in most of the performance indicators. However, we also provided evidence that the financial markets-driven US business sector impedes new value creation due to its focusing on short-term gains in the industry demanding "patient" capital. Thus, not all the features of the US business model should be imitated in Europe. We propose a few managerial implications and recommendations with respect to innovative products development at companies that compete in European environments.

The first refers to the need for strategic selection of fewer funding priorities and long-term focus on therapeutic and diagnostic products that have the potential for sustainable commercial success (Commission, 2007; Lazonick and Tulum, 2011).

Next, as Europe is evaluated as competitive mostly in healthcare applications and in industrial biotechnology, including the chemical industry, it should invest more efforts in these areas.

Third, an opportunity exists in the development of biosimilars (which assume an R&D-intensive activity, unlike the production of generic pharmaceuticals), due to the fact that the patent protection of many biotechnology medicines will expire in the forthcoming years.

Fourth, developing treatments for rare diseases represents an opportunity that has already been recognized on both sides of the Atlantic. To respond to the challenge of unsustainable "blockbusters" (traditional medicines), large companies have started focusing on personalized medicines, orphan drugs and vaccines for developing countries (Mittra, Tait and Wield, 2011; Montalban and Sakinç, 2011). Orphan drugs legislation provided pharmaceutical companies with incentives to invest in the development of drugs for rare diseases, in the form of tax credits and market exclusivity for several years from the time of drug approval (Lazonick and Tulum, 2011). The attractiveness of this sector is reflected in the data that the number of orphan drug designations by the FDA in the USA increased from 119 in 2007 to 175 in 2010 (Ernst&Young, 2011). In Europe, this regulation resulted in 724 designated products and 62 marketing approvals in the first 10 years (JustPharmaReports, 2011). Medicines for rare diseases have a different expected return of investment than traditional blockbuster medicines, however, technological developments suggest that the next generation of innovative medicines are exactly personalized medicines (EC 2009).

Fifth, an area where the European industry should emulate the US biotechnology is bigger interrelatedness of basic science and clinical development, as proposed already by Owen-Smith and colleagues (2002). They showed that the US research organizations and biotechnology companies conduct decentralized R&D across multiple areas and development stages, while Europe has regional specialization with a less diverse group of public organizations, with a considerably more centralized funding within nations. Europe thus needs to make changes in the division of labor in order to support innovation.

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