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"How the allocation of resources in biomedical science influences researchers' career management and science output"

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Abstract

Scientific research is a driving force of contemporary economy; yet, the determinants driving how science is made, the topics pursued by science, not to mention the underlying incentives moving the behavior of scientists, have remained only poorly investigated. This research has the aim to understand how the allocation of resources – job positions and funding – in the field of biomedical research influences scientists' behavior in their career management, and in deciding which research lines to pursue. The present thesis work is conducted adopting a qualitative method, interviewing a pool of researchers at different stages of their career. Combining insights obtained through the interviews, the existing literature, and adopting the tools of managerial disciplines, some suggestions will be provided on how to rethink funding and career management processes.

Abstract in Italiano

La ricerca scientifica è universalmente considerata una colonna portante dello sviluppo economico. Tuttavia, poco è ancora stato scoperto riguardo ai fattori che determinano le motivazioni e gli incentivi che influenzano il comportamento organizzativo dei ricercatori, e gli ambiti di ricerca privilegiati dagli scienziati.

Questa tesi analizza il sistema di allocazione delle risorse con cui è finanziata la ricerca biomedica, sia in termini di finanziamenti, sia in termini di posti di lavoro. L'obiettivo è quello di comprendere come tale allocazione delle risorse influenzi il comportamento degli scienziati nella pianificazione della loro carriera, e nelle decisioni in merito a quali progetti di ricerca intraprendere.

La ricerca primaria presentata in questo lavoro è stata condotta adottando un metodo qualitativo, cioè intervistando in campione di ricercatori a diversi stadi della loro carriera. Verranno inoltre proposti alcuni suggerimenti in merito a come ripensare il finanziamento della ricerca biomedica e il career management degli scienziati, basati sullo studio della letteratura in campo manageriale e sui risultati ottenuti dalla ricerca primaria.

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Introduction

When we think about the winners of World War II, there is one that we tend to forget: the importance of the human scientific endeavor. Science emerged triumphant from that period of history. The creation of the radar, the implementation of nuclear physics, the invention of penicillin, the dawn of computing are just a few of the discoveries and technological advancements that were encouraged, impelled and implemented during the war period; their contribution was essential to shape our present. As Dr. Frederick Stone (Director in the 50's of the National Institute of General Medical Science) insightfully said, “it is from the end of the War that science was spelled with a capital ‘S’ and research with a capital ‘R’ ”. For example, the death rate for all diseases in army, which was around 14/1000 during World War I, dramatically decreased to 0.6/1000 in World War II (Stephan, 2014).

Today, it is universally acknowledged that scientific and technological advancement, the result of basic and applied research, is the booster of economic development and prosperity. As noted by Bifulco (2018), the present economic situation of the world has more than ever confirmed that the competitive capacity of a country is intimately and inextricably linked to investments in scientific and technological research. For example, for every dollar spent by the US administration for the NASA-Apollo project, there has been an estimated return of 7-14 dollars (Nasa, 2008); and every dollar used by the Human Genome project generated more than 50 dollars in economic revenues according to 2013 estimates (Battelle Technology partnership practice, 2013).

Unfortunately, too often governments tend to look at research just as an option, a cost that weighs on tight public budgets, a long-term investment with uncertain political returns. This view forgets that Science is not only one of the finest manifest of human kind, a celebration of its intellect, curiosity and endless interrogation of his role in nature. Science, from an economic perspective, is an essential means towards a more prosperous economic future, a hinge for a country international competitiveness, a link between Universities, industries and the overall society ultimately bringing advantage to the whole economic system, and the only able to create new job opportunities in the long run.

Taking all this into consideration, it is evident that there is an imperative need to use at best the scarce resources dedicated to science in order to maximize their impact. To be clear, demanding efficiency from research is nonsense: research is a trial and error process in which more risky projects are those with potentially the highest-gain. Yet, Economics may also be defined as the study of limited resources that may have many alternative uses; it is thus important to evaluate the current procedures in the way the scientific research is funded in the western world from an economic standpoint, to identify pitfalls, weaknesses and, ideally, to develop reasonable solutions.

But the theme of resource allocation isn't just limited to money and funding: speaking about the allocation of resources in life sciences, it is impossible to forget the importance of the management of human resources and human capital inside the field. As my primary research will demonstrate, this issue is intimately connected to the way scientists live day-to-day their profession, what are their motives, drivers, in turn related to how do they relate to funding bodies and to academic mechanisms for their own career management.

For all those reasons, I conducted my research keeping in mind the following overarching questions: **how does the allocation of resources in biomedical science influence researchers' career management and science output?** And consequently, how to rethink funding procedures to encourage the best results in science?

It would have been impossible to build considerations relevant for all branches of science. For this reason, I decided to concentrate on life sciences, the world of biology and medicine, that, according to the USA National Science Foundation's *2018 Science and Engineering Indicators*, is the research field that, by itself, accounts more than 50% of the R&D expenditures in the United States. Yet, the field presents two intriguing paradoxes: on the one hand, despite the amount investment, the way biomedical science is currently conducted has been defined by several commentators as "broke" (Brennan, 2017); on the other, economists have highlighted how biomedical science, unlike other profession's job market, does not respond to classic demand and supply system, as the number of trainees at PhD level is constantly increasing in a market in which job opportunities are lower and lower (Alberts et al., 2014).

Plan of the thesis

To be able to answer my research question ("how does the allocation of resources in biomedical science influence researchers' career management and science output?") in this thesis I start from a review of the existing literature, in order to first obtain a definition of the problems and the theoretical tools to understand the topic.

As explained in the Methods chapter, for conducting my primary research I chose to use a qualitative method, namely, to interview a pull of university professors and researchers with the aim to deepen my understanding of what obstacles they encounter, what changes they perceive as needed to solve life science's research weaknesses, while allowing to take advantage of its many strengths.

In the Results chapter, I will deepen the themes surfaced in my interviews in light of the existing literature, making particular reference to science economics and administration. In the Discussion chapter I have also highlighted the implications and links to managerial disciplines, who appear beneficial to solve many of the issues encountered in the analysis of the field. Finally, I will conclude my work presenting some suggestions on how to rethink funding and career management processes, building from the findings of my primary and secondary research.

1. Literature

Science is the product of scientific research and is arguably one of the noblest human endeavor. That said, scientific research is a main determinant of economy given the staggering amount of public and private money involved in the process and the fact that science is the ultimate driver of growth, wealth, economic power and societal advancement. In spite this, the macroeconomics forces driving how science is made, the topics pursued by science and those abandoned, not to mention the underlying incentives moving the behavior of scientists, have remained only poorly investigated. This indeed connects to other open issues, such as the role of policymakers in shaping research priorities into directions that, in principle, are more likely to be more valuable to society, and that might affect how scientists are trained and allocated in the job market. I have here decided to focus on the largest scientific enterprise on the global scale that affects the life of billions, that is, biomedical research.

Clearly, there is an issue of resource allocation efficiency in biomedical research that is only going to increase over time. As detailed in this thesis, economists and scientists-alike have warned on the existence of a crisis in the current system, whereby systemic flaws are threating its future, and in which competition for scarce resources results in sterile behaviors and poorly productive discovery processes; others have even called for the existence of a "biomedical bubble" (Jones and Wilsdon, 2018) whereby the directions of scientific commitment and investment can't be "rationalized through a cost-benefit analysis".

1.1. Research job market: rigidities and psychological contracts

From an analysis of the literature, I have enucleated many sources of frictions in the management and allocation of resources in biomedical science.

The first friction is imbalance between resources available and those needed to sustain biomedical research growth. Those imbalances do not concern only the scarcity of financial resources available for funding research, but also the reduction of job posts available for employing all the trainees produced by the biomedical research training system. In fact, the system is plagued by a strong gap between demand and supply in the research workforce (Blank and Stigler, 1957), partially due to its poor flexibility and adaptability to changes in research direction and needs of policymakers. Indeed, it has been noted that universities produce an ever-increasing number of trainees, such as PhD and postdocs (Alberts et al., 2014), while the job opportunities inside academia appear to reduce. The long training necessary to become a scientist (5-10 years after graduation) is a cause of rigidity because individuals take career choices years ahead and can hardly move outside their sector (Jones, 2009).

Rigidities in training and career paths endanger the fruitful exploitation of the human capital, defined as the collective skills, knowledge and intangible assets of individuals that should in fact put at service of individuals and society at large.

In the journal Human Relations, Alice Lam and André de Campos (2015) explain how the declining of job opportunities in the research field facing an increased supply of workers has modified the psychological contract of young scientists. In his 1995 book "*Psychological Contracts in Organizations: Understanding Written and Unwritten Agreements*", Rousseau defines the psychological contract as "an individual's belief regarding the terms and conditions of exchange between themselves and the employer": in other words, what an employee expects from his employer in exchange of her/his contribution to the organization and its endeavor. Lam and De Campos explain that in traditional scientific careers young scientists are involved in a 'master–apprentice' psychological contract with professors: young researchers provide research assistance in return of training, mentoring and career support. Moreover, the majority of postdocs expect, through this career path, to obtain permanent posts after some temporary contracts. This system has substantially worked until recently. Nowadays, instead, the higher pressure on young scientists for funding and shrinkage of (or increased competitiveness for) job positions has contributed to change the balance of the old psychological contract. Professors find increasing difficulties to reward the efforts of young scientists by offering them long-term academic posts (Lam and De Campos, 2015). Furthermore, the responsibility for career management rests more and more on the shoulders of young scientists themselves: currently, a stronger reliance on individual initiative is required to have a successful career this field. In other words, working in the biomedical field is becoming more and more similar to the current job market in industry, where companies don't have the possibility to offer employees careers for life as it was in the past (Bridges, 1995; Kanter, 1989), thus individuals need to take the responsibility for their own career management (Arnolds, 1997).

1.2. Risk aversion and the innovator’s dilemma

The consequences of imbalances between the needs and the availability of investments in research and job positions had lead to a hypercompetitive atmosphere in the field, poor of career perspectives and other incentives particularly for more brilliant and ambitious minds, and adverse to real breakthrough discoveries.

In a consensus study report realized by USA’s National Academy of Sciences and National Academy of Engineering in 2007, the two institutions admit that processes for awarding research grants are too risk-averse: as it is observed in the report, “the current system can tend to drive award decisions toward conservative research that is based on precedent and is consensus-oriented”. Research support from government has become more conservative in the last decades, focusing on short-term, incremental, low risk goals: short-term profits are preferred, while it is difficult to accept the risks that come with investing in a long-term research project. As a result, public funding for research is gradually shifting from investments in transformational discoveries to much more incremental research; the danger is that innovative projects that could lead to future breakthroughs may never receive funding (National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, 2007).

The adversity to invest in high risk-high gain projects and research topics is one of the important areas of reflection in the field of innovation management. In fact, the issue of risk adversity of investment is not only confined to the field of biomedical research: on the contrary, it is a strong theme of debate also inside industries and companies when innovation is taken into account.

In the famous book “*The innovator dilemma*”, published in 1997 by Harvard Business School, professor Clayton Christensen insightfully described successful companies that dominated their industries up to a given time until they fail in the face of disruptive innovation, defined as “a breakthrough that changes an industry’s competitive patterns” (Christensen et al., 2015). Christensen illustrates that big companies often fail to recognize and invest in disruptive innovations, because they are too focused on short term rewards for their investors and feel overconfident about their dominant position in the market. Big companies usually prefer to follow the path of "sustaining innovation", which involves improvements in the performance of already existing products and processes, a choice that is effective in increasing financial performance in the short term. On the other hand, the performance of disruptive innovations may be initially below the standards, and dedicating valuable resources to risky and uncertain opportunities doesn't seem logical for a dominant player. Christensen defines “the innovator dilemma” as the struggle between the need to pursue sustaining innovation, which satisfies customers' current needs, and the necessity to be open to embrace disruptive technologies to meet customers' future needs.

1.3. Research evaluation system

The issue of risk aversion in biomedical research investments has its roots on a key feature of the life science field, hinging around the following questions: how is research evaluated? According to what principles are research funds allocated and individuals rewarded? Who is ultimately responsible of choosing which project to pursue, and which researchers to promote?

Typically, research funds for academic research are allocated according to a peer-review system: here, individual scientists respond to a call issued by public or private (e.g., charities) funding organizations by submitting a research project to be then scrutinized by fellow scientists, chosen by the organization as anonymous reviewers. Interesting, a similar peer-review system is what decides publication of the end-product of research, that is the factual results and their implications for the next round of investigation. Policymakers overseeing funding institutions have only relative space to manoeuvre, being able to change only the incentives or administrative caps (setting maximal funding thresholds or administrative constraints) but otherwise relying heavily on the scientists themselves for the core evaluation process. In spite of its seemingly rational and democratic outlook, this process is however plagued by the risk of several biases. Scientists may be (negatively or positively) biased toward certain types of new research (Boudreau et al., 2016), raising questions on their ability to judge outside their direct field of expertise; secondly, the scientist-applicant is encouraged to propose research plans that are more likely to be favorably received by his/her own community. At the other end of the table, when the same scientist serve as reviewer, s/he tends to accept more favorably proposals that are more likely to be successful, closer to her/his own expertise (while becoming territorial for those too close to his/her own research lines), and grants with preliminary results that are more likely to be published (Boudreau et al., 2016). This short-circuit risks to make research fields more and more parochial, with establishment of conscious or unconscious reinforcing networks, lobbies that leads astray and rejects newcomers, even when the field has already matured or have already demonstrated its limits (Ioannidis, 2018). In other words, research fields seem to adopt the same behavior of dominant industries who prefer to follow the path of sustaining innovation, as described in Christensen's work.

1.4. Knowledge sharing and knowledge management

Surprisingly, the above issue also applies to the Pharmaceutical sector, where research funds for internal drug-discovery projects and clinical trials are decided top-down, without peer-review, and depending on an integration of science state-of-the-art (and thus largely on prior academic discoveries) and business considerations. Pharmaceutical companies spend >70 billions of dollars each year on developing new medicines. As recognized by Bekelman et al., (2003) reviewing 1140 published studies, in spite of their wealth even big pharmaceutical companies struggle with limited resources, leaning them toward studies and clinical trials design that are more likely to give positive results. And yet, even this model is in trouble. The cost of a single approved new drug is over $1 billion (Herper, 2013), and clinical trials account for much of that expenditure. Fewer and fewer new drugs have emerged from internal research conducted by pharmaceutical companies, because of its extreme inefficiency and levitating costs (with most drugs being stopped at advanced stages of development). This is in fact transforming the Big Pharma business model, tending to reduce internal research and development expenditures in favor of external merges and acquisitions with smaller biotech and start-ups that ultimately (with their venture capitalists) take all the risks (Ioannidis, 2018).

Limits of internal research raise questions on the existence of other ways to pursue innovation. Indeed, the complexity of today's biomedical research and its multidisciplinary nature should greatly benefit from solutions that would favor open innovation models, in turn connected to transparency and knowledge sharing good practices (Worthy and Yestrebsky, 2018).

In managerial field, a lot have been written about knowledge management. This discipline, initiated by the Japanese organizational theorist Ikujiro Nonaka, investigates the ways to improve the better sharing of knowledge within a company. Knowledge management practices are essential to overcome the natural barriers that individuals have when it comes to sharing their knowledge; such barriers are often worsen by the organizational structure and corporate culture. Individuals are often reluctant to share their knowledge for various reasons (Bureš, 2003). Some fear the loss of power, as exclusivity of knowledge means irreplaceability and respect, which may be reduced if knowledge is shared. Others don't share what they know because of illusion of reward deprivation: these individuals often see knowledge sharing as a risk to lose their work rewards, as someone else may gain from their knowledge and get rewarded in their place (Bureš, 2003).

The root of all this individual hurdles to knowledge sharing can be resumed in one single assumption, which has been highlighted by Vladimír Bureš in his paper *Cultural barriers in knowledge sharing* (2003). As Bureš said, “by providing knowledge, we show that this knowledge has a value”: without an appropriate incentive, individuals won’t deprive themselves of this value. Knowledge management practices in business aim to overcome these obstacles, designing specific rewards to sharing (for example, building a company’s culture where knowledge sharing is perceived as a means for increase value for everyone, or through targeted individual incentives) and making easier the communication of tacit knowledge through proper information systems.

Good practice of knowledge sharing could be beneficial to biomedical scientists tackling extremely complex facets of human biology (where knowledge constantly grows), where the need for an increased *depth* of knowledge is compensated by necessarily reducing the *scope* of their training (Jones, 2009); in these endeavors, fostering a fully open, multisciplinary and inter-group collaborative approach could help researchers to acquire a broader vision of the complex phenomenon they are called studying. This is in itself an important reward for all scientists involved, improving their unique multidisciplinary training, the ability to see and tackle old so-far-"impossible" problems from entirely fresh perspectives and new solutions at hand, and, as such improving their originality in grant competitions and in the job market.

Furthermore, knowledge sharing good practices would represent also a relief to another bane in biomedical research, the fact that several studies do not appear to be broadly reproducible (Nosek, 2015). A recent study showed how failures to replicate pre-clinical research costs almost 30 billion dollars every year in the sole US (Palus, 2018). In other words, we are witnessing to a reliability problem in biomedical research that, in the long run may undermine its public support. Better sharing in this case would translate in increased reproducibility and peer-recognition on the world stage.

1.5. Compensation and motivation

Another friction in the biomedical research field is represented by the incentive of research. Analyzing the relevance of researchers' motivators is pivotal to understand their behavior in their own career management, and the reasons under the research lines they choose to pursue.

Scientists are of course deeply human, and their motives are no different than any other economic actor. As exposed by Maslow, the father of the theory of motivation in Human Resource Management (1943), human needs can be classified in 5 categories, presented in a hierarchical order usually described as "Maslow's pyramid of needs". Needs in the lower levels of the hierarchy must be satisfied before individuals feel needs in higher levels of the pyramid. From the bottom of the hierarchy upwards, the needs are: physiological, safety, belonging, esteem and self-actualization. Biomedical scientists tend to display needs belonging to Maslow's categories of esteem and self-actualization: raised in a hypercompetitive environment, researchers tend to show higher than normal egos and need of peer-recognition and notoriety as a driver, even more than salary compensation. Dasgupta and David (1994) well framed the tension produced by the fact that "society does not care who is successful in solving a given scientific problem, it cares that the problem is solved", while on the other hand, for the individual scientists (or team) who is making the discovery, the temporal priority of the first discovery (public announcements through publication) is of the utmost importance, given their priority-based reward system (inconsequential from the societal standpoint). This raises questions on the efficacy of scientists as unbiased judges of what research to pursue and how (as individual or as part of a team, or adhering to an open vs. closed innovation models, etc.). An explicative example is offered by Brian and Lemus (2017) on the response to a major prize (e.g., the Nobel prize) as incentive: if it is known that the Nobel prize for Medicine would be awarded for investigation on two diseases, the scientist will invest much more effort into the "easier" problem, even if curing the more "difficult" diseases would ensure broader benefits for a larger number of patients.

1.6. Push and pull funding programs

Prizes, as in the above example, belong to a category of research incentives known with the name “pull programs”. Funding schemes designed by funding bodies can be conceived to support science in other ways. Research grants, for example, are classified as “push programs”: in this kind of financing scheme, the funder decides to support the research before the beginning of the study, and his contribution is not linked to the future results of the funded project (in other words, funding subsidizes inputs). Instead, sometimes funding organizations can decide to contribute to scientific project via “pull programs”, that tie rewards to output: the scientist receives economic support at the end of the project, when it has already produced results. Prizes, or “mixed” research award that include in part a personal cash award and research support yet largely based on past achievements, as well as patent buyouts, can be considered examples of pull incentives (Rietzke and Chen, 2018).

The way funding bodies outline funding schemes to provide economic support to biomedical research is at the center of a strong debate, where funding institutions wonder about whether incentives for research should be linked or not to the outcomes of the financed project, and which between “push” and “pull” models are more effective in stimulating research.

The literature regarding this theme is linked to studies in labor economics which investigate to what extent incentives should be linked to performance, not only in terms of salary and compensation for workers, but also in terms of budget allocation between different projects or departments in a corporation.

The idea to link incentives to performance is not new, and it is broadly considered the main solution in solving the inefficiencies posed by the agency problem. Jensen and Meckling (1976) define an agency relationship as “a contract under which one or more persons (the principal(s)) engage another person (the agent) to perform some service on their behalf which involves delegating some decision-making authority to the agent". The relationship between employer and employee, between stockholders and top management, but also between the funder and the scientists, might all be considered agency relationships. The peculiarity of agency relationships is the existence of information asymmetries: a situation in which the agent has more information about the principal about the task to perform, and the principal can't fully monitor the agent's behavior. Information asymmetries can be the source of opportunism, such in the case of adverse selection (opportunist behavior held by the agent in the phase of contract stipulation: the agent hides information that are essential to the principal to correctly set the contract) or moral hazard (when the agent doesn't respect of the rules established in the contract, taking advantage on the impossibility for the principal to control her/him).

In the case of science funding, pull programs, that reward only those projects judged to be worthy *after* the achievement of the results, may only in part protect funding organizations from opportunist behaviors of scientists attracted by push programs (Kremer, 2002); however this advantage may be only apparent and counterproductive, favoring bad practices such as publication of results that are too preliminary (if not fraudulent) in predatory journals (those publishing results after payment of fees from the submitting scientist), undermining the whole research enterprise (Aguzzi, 2019).

Grace and Kyle (2009) also contend that pull programs may be preferred by funding bodies when they have a specific research outcome in mind that they want to be reached (for example, the discovery of a cure against a particular disease): in this case, a pull model financing research *ex-post* as a prize could be effective in drawing the scientific community's attention and speed innovation on that desired research topic. However, it is also evident that, if the ultimate goal is to augment the number of teams working on a particular research area (i.e., a specific rare genetic disorder), pull programs must be accompanied by larger push programs, since new post-docs, PhD and research costs must be hired and sustained for years before newcomers reach meaningful results in that specific area. In other words: pull schemes serve as "shining examples", inspiration and incentives, but only push schemes really advance the field forward.

Pull programs, at the same time, might be important where experts on that topic are hard to identify: "a key advantage of pull mechanisms is that the funder can draw on the expertise of a large and diffuse set of researchers, rather than identifying and funding a handful of scientists with the greatest potential" (Grace and Kyle, 2009). On the other hand, the paper warns about the risk of racing for the prize, that may have negative consequences, such as wasteful duplication of resources and effort, and to harsh the already existing barriers to knowledge sharing. It is true that pull programs are very effective in protecting funding organization in "wasting" their investment in research that may not bring to the desired outcome; but again, the risk is that the preference of this kind of funding schemes may bring funding organizations to the already described vicious cycle of risk aversion, that penalizes basic research and cutting-edge innovative projects.

It should be also reminded that a part of pull incentive is anyway present in all the push granting schemes in the biomedical arena: it is very rare these days to award a grant proposal without key, and often hefty, preliminary results that ensure feasibility, scientist's commitment and likelihood of success.

All in all, in the majority of cases it is nearly impossible to predict the outcomes of a research project, its timing and even the specific area in which results could find an application (Tripsas et al., 1995). Push schemes, therefore, result to be an essential pillar to the development of innovative, disruptive and sometimes and unexpected outcomes. Funding institutions must always remember that, as Nelson and Winter insightfully said, "innovation involves uncertainty in an essential way" (Nelson and Winter, 1977).

1.7. Career management in Biomedical research

Intimately connected to the reward and incentive system, it is worth mentioning how research career is rewarded at least in academia.

Career management is defined as the conscious planning of employee's activities and engagements in the jobs undertaken in the course of one's life for better fulfilment, growth and financial stability. It is the set of activities aimed at fostering an employee's career both within the organization and in the external job environment (Sturges et al., 2005). Scholars in Human resources Management usually define career development path as vertical, when it involves successive linear movement up the career ladder of the organization, gaining along the way additional increments in formal authority, and intrinsic or extrinsic rewards. Horizontal or lateral career development involve mobility at the same level of the organization's hierarchy, acquiring along the necessary broad experience to move from a specialist to a more generalist management position (Garavan and Coolahan, 1996).

Academic careers in the biomedical field usually display vertical career development paths; Universities display a typical ladder, whereby new investigators are hired as tenure-track assistant professor that, after peer-to-peer evaluation may or not get promoted to tenured and higher positions (associate and then full professors sitting at the top of the hierarchy). In addition to the above academic positions, lab members in a typical biomedical research laboratory include undergraduates, PhD students, technicians and post-docs (typically those entering in the job market for professor positions). The head of the laboratory (at any stage of career) is called the Principal Investigator of the research awards s/he could secure.

Each of these steps of the latter is directly connected to the individual research output, which is the main decisional criteria in the peer review system which has to choose which scientist is the most worthy to promote to a higher position in the hierarchy. Consequently, this impacts on the same problems of science evaluation and their (often negative) influence on science choices mentioned above.

1.8. Patenting and commercialization of research

It is here worth introducing, in the context of incentives and rewards, the possibility of exploiting the commercialization of research discoveries. Policymakers and funding organizations have long shown a primary interest for those studies which claimed the possibility to develop practical applications, “and the term translational research has been widely, if unofficially, used as a criterion of evaluation” (Alberts et al., 2014). Many studies also provided econometrical evidence of the existence of a positive correlation between a scientist’s commercial activities (specifically patenting) and quantity and quality of a his/her scientific production (Azoulay et al. 2009). However, also in this context some frictions have been discovered. On the one hand emphasis on translational research and number of patents as means to gauge scientific output is frustrating for scientists, particularly those working in frontier fields or in fundamental research. Their argument is well taken and macroscopically exemplified by the recent discovery of CRISPR, a new technology for gene manipulation (also called gene editing) that is revolutionizing not only biomedical research but also crops and livestock; the discovery came from pure and apparently "application-free" research on how bacteria resist to their infective agents (phages, that are the bacterial viruses). On the other hand, Stern et al. (2004) showed that new PhDs in biology are willing to take a consistent (25%) salary cut in exchange of the possibility to get publication, and that scientists are not prone to the commercialization process of their discovery (Gans and Stern, 2010). Intriguingly, this trend occurs in both Universities and in the private sector. Clearly, this represents an important limitation to an effective circulation and exploitation of research output, in turn limiting investments from companies and venture capitals in academic institutions worldwide. The reasons of this lack of propensity to commercialization is unclear but most likely, as discussed in this thesis, may be merely part of lack of paradigm examples, of success stories and lack of appropriate training or knowledge of such opportunities.

1.9. Economical benefices of science

Today more than ever there is the need to reinforce science against all movements currently threatening the science-based thinking that has shaped our society. There has been many voices refusing to listen to the scientific evidences regarding global warming, calling it “a hoax”; and many countries have banned the cultivation of OGM food, ignoring all the data demonstrating that they are just as safe as the traditionally breed crops. At the same time, in Europe the debate about the side effects of vaccines is still fierce. These are just a few examples of how the anti-science way of thinking is potentially diffused. The most essential cure to reinforce science is to tackle research’s own problems. This work, far from having the ambition to provide real solutions, is just an attempt to observe the system from its inside, to discover its flaws and hypothetical ways to fix them. Defending science from science skeptics, ensuring the widest public support, is critical for moving forward science, and with it, economy.

An analysis of science’s economical benefices, so prominent in the biomedical world is also necessary. New technologies, made possible by research advancements, are transforming numerous clinical procedures, affecting positively not only the welfare of millions of patients, but also the cost of the national health systems. New treatments, developed thanks to the understanding of the molecular basis of diseases and by the blending of medicine with disciplines considered totally unrelated until yesterday, are already making far less necessary many costly and often clinically inadequate interventions such as invasive surgery, intensive care units and long-term nursing (Pardes et al., 1999), improving both cost savings and life quality. But the benefices of the introduction of these innovations in medicine on the economic system are much greater. One example of the “multiplier effect” that biomedical research has on economical welfare is the impact of investments in health technologies on labor productivity. Improved health would allow a reduction on lost work time for patients and their families, affecting also the number of year a worker can be producing and consuming, with positive consequences on many different economic sectors (Pardes et al., 1999).

1.10. Formulation of the Research question

During the 67th Lindau Nobel Laureate Meeting in 2017, the Nobel laureate in Chemistry William E. Moerner said: “Science is not an alternative fact or a belief system. It is something we have to use if we want to push our future forward”. Not only there is the necessity to invest on science: it is crucial to invest in the most effective way, solving inefficiencies of research mechanisms and pushing scientists towards the best discoveries. The research I conducted while writing this thesis is therefore centered in the aim of understanding **how researchers’ career management and science**

output are influenced by the allocation of resources in biomedical science, with the purpose of providing contributions arising from the study of managerial disciplines.

2. Methods

2.1. Research Design

For this dissertation, I chose to formulate my research using the qualitative method format.
Qualitative research method has the objective to understand a phenomenon from the perspectives of the population it involves, providing complex descriptions of the way in which the population perceives it (Mack at al., 2005). Qualitative research, in fact, is particularly effective in getting culturally specific information concerning the values, opinions, behaviors, and social contexts and in obtaining deep insights about intangible factors, such as social roles, rules and ethics that may have an influence on the research topic (Mack et al., 2005).
Qualitative research is commonly used to understand a phenomenon when the researcher doesn't have preconceived hypothesis or theories (Taylor et al., 2015). Glazer and Strauss (1967) define "grounded theories" those theories built from the process of induction from the data obtained though qualitative research.

One of the usual qualitative methods is interviews, which are conducted as normal conversations rather that formal question-and answer exchanges (Taylor et al., 2015). This method may present some limitations – for example the influence of the researcher on the people s/he is studying (Taylor et al., 2015), and often findings from qualitative data can't be generalized (Mack at al., 2005). However, it is one of the most effective techniques to collect data on individuals' personal perspectives and experiences.

I pondered that speaking with people actually working in the field of biomedical science would allow me to better understand its strengths and pitfalls form the point of view of professional figures, aiming to get bottom-up opinions and perspectives from the insiders of that field. For this reason, I decided to base my work on interviews collected within a small group of professors, trainees and other figures within an academic research Department.

2.2. Context presentation

The scientists I picked for my interviews are working, or have worked in the past, as researchers in the Department of Molecular Medicine in University of Padova, Italy. The Department of Molecular Medicine (DMM) has been ranked among the top research institution in Italy (according to the last two national research assessments, or "*VQR - Valutazione della qualità della Ricerca*"). The mission of the Department is to study mechanisms of diseases through a "vertical" integration of medicine and basic biology. In fact, the investigation fields studied in the DMM laboratories range over Biochemistry, Biophysics, Molecular, Cell and Developmental Biology, Physiology, Microbiology, Virology, Pharmacology, Gene Therapy and Bioethics. Most these different disciplines are investigated through shared technology platforms, heavily relying on some of the cutting-edge methodologies in the biomedical field, from the use of transgenic animals, genome editing, stem cells, genomics and advanced bioinformatics. The DMM, therefore, summarizes consistent competences of basic sciences and biomedical, clinical and public health, where basic research, applied technologies and clinic studies are interwoven.

During years of fruitful research, the Department has a yearly multimillion budget (in grant only) and has built strong ties with Italian and European private pharmaceutical enterprises, world-class academic Institutions and important funding organizations; many research teams and individual investigators within the Department have been awarded with some of the most prestigious international scholarships and grants provided by the European Union (Horizon 2020), the European Research Council (ERC), The Melinda and Bill Gates Foundation, Human Frontiers Science Program, Italian Ministry of Education University and Research (MIUR), Italian National Research Council (CNR) and many other prestigious private enterprises and foundations. The Department is a challenging environment, attracting talented students and researchers from the best academic research institution. Researchers in the department can benefit from a well-equipped and modern infrastructure, and from the mentorship of some very established investigators. The Department faculties are also engaged in teaching in a considerable number of university courses for Medicine and Health professions graduate programs, and for the Molecular Medicine PhD Program.

Beside the traditional missions of teaching and research, DMM is also involved in technology transfer activities and spin-offs in fields such as biotechnology, genome editing, and nanomedicine. Furthermore, DMM participates in the University so called "third-mission", that is dissemination of knowledge, managing communication on issues of biomedical, social and bioethical relevance (source: DMM website).

I choose this organization as a context for my interviews because of its good reputation in the life sciences. The commitment of several DMM investigators to promote interdisciplinarity and to carry out competitive research on very advanced topics was important for me to collect testimonies from people specialized in various disciplines within biomedical field. Moreover, I could have the possibility to meet professors at different stages of careers, and young researchers.

2.3. Data collection

To obtain a broad vision of the research environment and to obtain the maximum amount of insights about the phenomenon of research funding, I decided to interview people with different backgrounds and different positions within the Department organizational structure. Indeed, I wanted to analyze the problem from many different perspectives, see this issue. I also included in my observation the interviews of two people who are now outside of the Department's activity: a retired professor, and a former post-doc who now works in high-school teaching.

Here I present a small profile of the interviewees, and the reasons to include their testimony in my work. For privacy issues, I omitted the real name of these scientists.

Interviewee n. 1

55 years old, Full Professor. Successful academic career and an authoritative expert in his field. He is leading an established laboratory, whose staff counts 12 people including tenured researchers, postdocs, PhD students and staff scientists. I decided to interview him because I wanted to know which is the perspective of an accomplished scientist, who has acquired a considerable experience and reputation.

Interviewee n. 2

40 years old, Associate Professor. He started his independent research enterprise 5 years ago and currently he is the Principal Investigator of his own laboratory, where he works with 7 other collaborators. His point of view is important to understand the challenges of a young scientist who is building his own research venue and trying to establish his own reputation in the biomedical world. I was interested to compare his vision to elder interviewees' opinions.

Interviewee n. 3

28 years old, postdoc. After his PhD, he was hired as postdoc in one of the laboratories in the department. His words are useful to understand what does motivate young scientists to start a career in biomedical research, and which obstacles they might encounter in starting this profession.

Interviewee n. 4

74 years old, former Full Professor. He has been the head of one of the Department's labs for several years. Even if he's now retired, he never stopped his activity as a mentor: he keeps frequenting the laboratories and I understood that he's a reference point for many fellow scientists of the DMM, providing an "historical memory" in many discussions. Interviewing him I wanted to understand the perspective of someone who have witnessed the evolution of the field and who could make interesting comparisons between the contemporary way in which research works and how it was is the past.

Interviewee n. 5

35 years old. He has worked as a researcher in the department some years ago. After his PhD he was not able to find a position in the academia, and spent a few years doing temporary jobs at universities, both in Italy and abroad. Now he is working as a biology professor in high school. He could describe me the transition from a research career within university to the external labor market.

Interviewee n. 6

34 years old. She is a junior Assistant Professor in the Department, hired two years ago. She is a project leader within the lab of Interviewee n.1. She has the responsibility of a small group of Undergraduate and PhD students who work together to follow a specific project. I thought about to enquire, in a field mainly dominated by males, on possible gender issues in the field.

Here I attach a scheme resuming some details about the interviews. All interviews were recorded.

Interviewee	Position of the interviewee	Date of the interview		Duration
n. 1	Full professor – head of laboratory	12/18/2018	Face to face	00 h 45 m
n. 2	Associate professor – Principal Investigator	01/04/2019	Face to face	1 h 05 m
n. 3	Postdoc	03/22/2019	Via Skype	00 h 40 m
n. 4	Former full professor - Retired	02/13/2019	Face to face	1 h 10 m
n. 5	Former researcher – no more in academia	04/15/2019	By phone	00 h 25 m
n. 6	Assistant professor –	04/19/2019	Face to face	00 h 40 m

	project leader			
Total duration of interviews:			4 h 45 m	

2.4. Data treatment

As for the structure of my interviews, I chose to divide my interviews in two parts: in the first part, I interrogated the interviewees following the "directive interview" structure – asking them details about their career as their age, position and activities inside the department (see Appendix). These questions were the same for each interviewer, and they helped me to frame the role and the point of view of each interviewee. For the second part, I preferred a semi-structured interview style, to allow more flexibility in the conversation and to be able to deepen some interesting themes arising from the interviewee. I also asked the meaning of jargon expressions used by the interviewees.

For the analysis of the data collected through my interviews, I adopted a thematic analysis method. I classified the answers on the base of the themes they contained, in order to highlight similarities and assonances between the interviewees' point of view. In this way, I was able to enucleate 4 main answers to my research question, which are presented in the Results section.

3. Results

The interviews I conducted were useful to highlight some important answers to my main research question: **how does the allocation of resources in biomedical science influence researchers' career management and science output**? Which are the drawbacks in the current system of resource allocation in the field of biomedical research? And which are the consequences of this pitfalls in the outputs of science?

Result n. 1: The current resource-allocation system creates hypercompetition

Many of the experts I interviewed for this thesis seem to agree that one of the main sources of inefficiency in the system is the strong competition that is characterizing the field in the last decades.

Interviewer n. 1 attributes the origin of this competitive pressure for job posts and financing to the increasing gap between the investments in science and the growing needs of the biomedical research system itself: too many trainees compete for too few academic positions, and available financing allocated to research is reducing while demand for funding is growing. Interviewee n. 1

attributes the cause of this imbalance to "*the common belief that biomedical research system will expand forever, and at a sizable rate*", which has brought the sector to an "*unsustainable path*". He believes that nowadays academia, government, and the private sector are no more capable of absorbing the growing number of junior scientists produced by the training pipeline. Another problem highlighted by the interviewee is that successful researchers train far more scientists than are needed to replace themselves, and this brings chaos and hyper-competition. As a consequence, scientists' careers and the way they design research is too often corrupted by perverse incentives: the necessity to compete for funding and positions force them to prioritize self-preservation over asking the best questions and discovering meaningful truths. "*Over time, it is unclear to me whether we are entering into a system in which we are rewarding more those people that "know their way" in navigating the system more than just the best scientists [...] Research system has to take better advantage of its ever-increasing human capital toward innovative, "out of the box" thinking, rather than push researchers to "me-too" science which allows them to survive*".

The same view is shared by interview n. 2, which puts the accent on scientists' tendency to prefer low risk research path that can bring to more "certain" and positive results than true disruptive or innovative research questions. He believes that hypercompetition brings to "*the death of creativity*". He explained me that break-through discoveries require collaboration with other research teams, time (i.e., few distractions, less teaching, less university politics/administrative blocks etc.) and of course risk-taking; however, "*this has almost become a chimera*" for researchers. This interviewer seems to be ever more critical against the competitive atmosphere to which young scientist are subjected in the field: far from helping the "natural selection" of the best ideas and projects, often it has the result to push researchers to "inflate" results, overemphasizing the implications of their work. "*Consequently, published discoveries become less and less accountable... The public risks to become addicted to big claims with no follow up. The current parameters used for the evaluation of researchers are actually mining the bases of our working environment and science credibility. We live in our field in an experiment replication crisis, that has of course other roots but becomes part of the trouble.*"

Result n. 2: The current resource allocation system has created inefficiencies in the way research is evaluated.

Another interesting element emerging from interview n. 2 is the critic against the research evaluation system, which is accused to be "*allergic to risky ideas*", more and more conservative, trapped in short-term thinking; the reason is that risky projects have weaker guarantees of success, so they tend to be rejected, while incremental discoveries, which promise more certain results, are usually preferred. "*This is a deterrent to innovation*" said Interviewee n. 2 "*In a hypercompetitive rush for jobs and funding, researchers can't do anything rather than adapt to the system. It's a domino: we need to be evaluated for what we do, of course: still, we are evaluated on research papers or patent output, and on a short time frame* [ed. sometimes as less as 5 years, as in the current abilitation system to be a professor]. *Then my post-docs need to find jobs based on similar criteria, which also brings them to prefer "secure" projects... a vicious cycle for a system operating to justify its own existence*".

The critic against the evaluation system, which is at the base of publishing, funding decisions and career progression for scientists, is common also to interview n. 3 and 5. The young researcher surveyed in interview n. 3 complains on the fact that funding system is constructed to favor the scientists with prestige and numerous publications: elder scientists are thus placed in advantage over younger scientists, who often don't have the possibility nor the means to bring original and independent contributes to research. "*This is a shame, because the years between 20 and 30 are the most fertile regarding creativity, originality and mind openness... It is the age in which we can contribute the most*", he added. The same fact is put in evidence in interview n. 5, where the interviewee blames the impossibility for a young scientist to take personally credit for the research accomplishments achieved and the ideas developed while working in someone else's laboratory. "*This lack of sense of ownership of the work I had done for many years was very difficult to accept for me*", he said.

Another weak element of the research evaluation system is emphasized by interviewee n. 4, who testimonies that all the tasks required to perform research in accordance to the current regulations and requirements are reducing time scientists need to dedicate to review their peer's research, ultimately damaging the quality of peer review. The interviewee blames that for this reason researchers are often replaced by professional editors or more inexperienced collaborators, who often don't have the competences or the expertise to recognize scientific quality and understand the effective implications of a discovery.

Result n. 3: The current resource allocation system does not favor knowledge sharing.

An important takeaway from interview n. 4 is that the increasing complexity of today's science requires multisciplinarity: only the teams able to combine different branches of science and research techniques will be able to stay at the forefront of innovation in the current biomedical landscape. "*You almost need to be a renaissance man, with broad knowledge across all possible disciplines.*" he explained, "*But this is obviously impossible. Of course there is always going to be the individual with a brilliant idea. But this is not how biomedicine, in bulk, is at present, and even more the* *future. I predict that large teams with expertise ranging from cell biology to artificial intelligence will be those bringing more and more advancements*." This opinion is shared also by interviewee n. 6, who strongly supports the belief that more "diverse" research teams (in terms of scientific background, nationality and gender) are the best performers in creativity and problem solving. However, again scientists' personal incentives seem to represent an obstacle to collaboration and knowledge sharing. As stated in interview n. 3, peer recognition and temporal priority of a discovery are the main motivators for scientists: "*There is pride and sense of accomplishment to be the first owner of a discovery, the first person in the world, in history, to have understood a new piece of knowledge… "To be where no man has gone before*"". But the stronger motivation for scientists raises from "*peer recognition, the prestige coming from the fact that others give you credit and credibility. It is a big boost to your ego. That's why the fear of being "scooped" is the most worrying and well spread fear in the scientists' world*". To be scooped means to lose the exclusivity of an idea, because someone is able to publish it faster. A scooped scientist does not only loose the novelty of the discovery, but also feels to be deprived of the authorship of an idea that he had being developing with hard work. "*A scooped discovery means years of work thrown away, and the loose of the peer recognition to be the father of that idea. That's the principal reason why scientist want to avoid this risk with all means*". On the other hand, the interviewee also recognizes that this fear transforms colleagues into competitors, and so it is a strong barrier to collaboration between different research groups.

Result n. 4: The current allocation of job posts and the career management system are not able to ensure an efficient exploitation of human capital in biomedical research.

The last big theme arisen from the interviews as a big issue in the biomedical research field is the obstacles encountered by scientists in their career management. The shortage of funding and career positions make young scientists' future unstable and uncertain "*It requires a lot of effort to manage family, moving across countries to seek for academic programs and job opportunities… many fellow colleagues complain also that salary compensation is not always linked with the level of work and training*" declared the interviewee n. 3. Furthermore, family issues may hinder a young researcher career in the research field; this issue is particularly felt by women, and demonstrated by the lower percentage of female researchers occupying leadership positions in the biomedical field (Plank-Bazinet, 2017), also confirmed in interview n. 6: "*I see that in many of my friends and colleagues: a lot of couples in this field are formed by fellow scientists, and the shortage of long term jobs in universities makes difficult to find a stable academic position in the same time and place for both. Almost always, a wife's career is subordinated to her husband's. Women get* *pregnant, their projects are delayed… Moreover, PhD and postdoc are demanding jobs which may be challenging when it comes to start a family… it also helps contribute to gender inequalities in research*".

The strongest critics against the current career management for researchers are moved by interviewee n. 5, who believes that the training acquired through the PhD does not prepare a scientist to face the job market outside academia. He denounces the existence of a gap between the preparation students acquire during PhD and postdoc and what non-academic employers are looking for. "*The expertise you gain at Universities is mainly theoretical and the only applications you learn concern to your own work in a lab… but all this are completely useless if you wish to change your path. All in all, postdoc didn't help me to find my way into the scientific career I was hoping for, neither in academia, neither in other fields*". Furthermore, neither the trainees neither their mentors inside academia know which are the opportunities for careers beyond academia, and lack of training to recognize and be prepared to face similar opportunities. "*Of course, it is not that Professors deliberately want to obstruct postdocs' career outside science, but, more simply, they may not be right person to whom ask for some advice, because they may not be familiar with alternative jobs opportunities beyond their own world*" added interviewee n. 5. The lack of their mentor's guidance while orientating towards a new profession outside Academia represents a big obstacle for students, who rely on their supervisors for letters of reference, but also on networks for collaboration and career progression.

At the same time, interviewee n. 4 highlights that, while job posts for researchers are scarce, nowadays the workload of each researcher has increased, since new tasks and responsibilities (i.e. be compliant to security and regulatory requirement on issues such as the treatment of hazardous waste, the welfare of lab animals, human resource management...) have become essential to run a safe and efficient lab. "*All these administrative tasks take away time for thinking, studying, and talking with peers, which are the quintessence of doing science. Time has become a luxury*". In other words, the increasing complexity of the scientist's job described in interview n. 4 makes understand the need for a new and more efficient allocation of human resources and human capital in the field.

4. Discussion and managerial implications

4.1. Theoretical Implications

There is one element that results clear from both literature review and interviews: in the last decades, the gap between demand and supply in biomedical research job market has undoubtedly deepened. The consequences of this take different shapes, denounced in different ways by my interviewees and my references. The immediate answer to the research question (how does the allocation of resources in biomedical science influence researchers' career management and science output?) is that resource allocation and its inefficiencies have often distorted scientists incentives (Dasgupta and David, 1994; Brian and Lemus, 2017; interviews n. 1 and 2) and the whole evaluation system (Boudreau et al., 2016; Ioannidis, 2018; interviews 2, 3, 4), resulting in a difficult career management especially for the young (Lam and De Campos, 2015; interviews 3, 5, 6).

According to the classic demand and supply system, it should be reasonable to expect that in such a context the number of the applicants for academic positions should decline; however, this is not the case for biomedicine. Economists have highlighted how biomedical science, unlike other profession's job market, does not respond to classic market forces. The reason is accurately explained by interviewer n. 3: despite researchers' career path is marked by uncertainty, this job doesn't lose its appeal for young brilliant minds, because it gives the possibility to add new discoveries to our understanding of biology, and advance the application of those insights into improved health for all. The values and motivation of aspiring scientists is what push so many individuals to try to find their way in this fascinating world.

The existence of such a mismatch between job demand and supply stands out from interview n. 1 and from the work of many authors cited in the review of Literature (Blank and Stigler, 1957; Alberts et al., 2014; Lam and De Campos, 2015). This idea has some assonances with the theories of the XVIII century economist Thomas Malthus (1766-1834). In 1798 Malthus published "*An essay of the principle of the population as it affects the future improvement of society*", a study in which he argued that the increase of population would be the cause of the arrest of economic development. According to Malthus's argument, the increase of population would have pushed to cultivate less fertile lands, with consequent scarcity of food; Malthus believed that people would grow faster than food availability, because population would tend to grow in geometric progression while crops grow in arithmetic progression, and that would cause human impoverishment.

Malthus's demographic theory has certainly encountered various criticisms, exemplified by the American writer Ralph Waldo Emerson, who said: "Malthus, stating that the mouths multiply geometrically and the food only arithmetically, forgot that human mind is also a factor in political economy, and that the growing needs of society would be met by a growing power of invention."

Emerson's statement contains a hint to find a solution for biomedical science's crisis. From the point of view to research field, Emerson's words seem to propose a brighter perspective of the future of biomedical research: science will not stop its expansion, because new discoveries will lead to the creation of new worlds and new job opportunities. Creating innovation, science is the only driving force capable to generate new fields and professions: the flaws in research training pipeline will be absorbed by these innovative areas.

4.2. Managerial Implications

How to translate all this in reality? Here I develop some suggestions to improve biomedical research funding and career management based on the review of the literature and on my primary research insights.

4.2.1. Managerial solutions to reduce risk aversion of investments in biomedical research

Without the implementation of solutions to award originality and risk taking of research, it is hard to expect the achievement of scientific progress that ensure long-term benefits to society. Both in scientific research and in the industrial environment, there is the need to invest in high risk-high gain ideas, that have the potential to become breakthrough innovations that will disrupt the contemporary landscape (Christensen et al., 2015).

One possible solution to encourage risk taking of the investments in the biomedical field is to provide financial support to people rather than projects, with a long-term vision, focusing on the overall quality of a researcher's contribution. It is necessary to give to outstanding scientists more stable resources: this will allow more freedom to deepen new areas of science, and to follow visionary ideas that may be too risky to be funded as a single project. As suggested by interviewees n. 2 and 3, this would ensure job security especially for young investigators, giving them the opportunity to develop their own skills and ideas.

Luckily, funding organizations are becoming aware of this issue, and some solutions are already starting to be implemented. Some funding organizations have already adopted successfully different models of funding. Among them, it is important to remember Howard Hughes Medical Institute; rather than investing on a project, this organization provides funding for excellent scientists who propose visionary research. Funding the individual rather than the project allows the researchers to pursue freely their ideas, that might have the potential for high impact, but may be too risky to obtain the necessary financial support. Other grants focus in particular on young researchers, for example NIH Director's New Innovator Award, ERC starting grant, and HSFPO Young Investigators' Grant. All the tree grants here cited are dedicated to researchers in the first stage of their independent research experience (up to 7/10 years after the end of their PhD;

sometimes a number of publications without the support of the PhD supervisor is required to apply). As declared in the NIH Director's New Innovator Award website, this kind of programs "seek to identify scientists with high-impact ideas that may be risky or at a stage too early to fare well in the traditional peer review process. The program encourages creative, outside-the-box thinkers to pursue exciting and innovative ideas in any area of biomedical research".

4.2.2. Managerial solutions to improve biomedical science evaluation system

One of the issues regarding research evaluation is that, as showed by interviewee n. 4, scientists lack time to accurately review peers' papers and applications, assigning this key task to less experienced collaborators. Paying the referees (i.e.: the scientists whom is assigned the task to evaluate their peers' work) could be the answer to this problem: it is right to assign to reviewers a compensation for such a critical task.

Currently, scientists consent to review their peer's research because they understand that their contribution is useful to the functioning of the research evaluation system: in other words, they are motivated by an intrinsic reward, which managerial disciplines define as the psychological or internal reward that actors get directly from performing the task itself. In this case, the intrinsic reward for reviewers is the feeling to give a contribution to the evaluation of research and to biomedical science itself. Nevertheless, the current issues highlighted in the literature review and the interviews (bias and risk aversion – Boudreau et al., 2016; saturation of some research fields – Ioannidis, 2018; lack of time and skilled personnel dedicated to peer review – interview n. 4), highlight the fact that this intrinsic reward is not sufficient anymore to motivate scientists to dedicate the necessary effort, time and commitment in the evaluation. There is the need to assign extrinsic rewards connected with the expertise and skills required to assess quality of peer's works, and that scientists will consider proportional to the responsibility related to this task.

Other journals, as Elife and Development, have successfully adopted a new way for peer review called "cross reference": the author of the article under revision doesn't know the identity of the referees, while the reviewers know who each other is. As James Briscoe and Katherine Brown wrote in January 2019 editorial of Development, "we introduced cross-referee commenting to the peer review process. This allows reviewers to see and comment on each other's reviews to provide extra feedback to help the editor decide on the appropriate course of action [...] it helps to generate more consensual outcomes and clarify uncertainties [...] and to improve the transparency and quality of peer review" (Briscoe and Brown, 2019).

4.2.3. Managerial solutions to encourage knowledge sharing

The Resource Based View, one of the pivotal theories in management field, has highlighted the importance of a firm's internal resources as a mean to the building of strategic advantage (Barney, 1991; Nelson and Winter, 1995). In specific, knowledge is defined as a key source of competitive advantage for a firm, and a critical element of differentiation (Penrose, 1995). For this reason, firms encounter the same barriers to knowledge sharing described by interviewer n. 3 in the biomedical field. Furthermore, management scholars (Loebbeke et al., 2016) have highlighted the existence of a paradox in the intra organizational knowledge sharing practices for firms: knowledge sharing could allow a company to get access to its partners' information and thus new business opportunities, but could also affect the uniqueness of internal knowledge, exposing the firm to the risk of losing one of its sources of competitive advantage.

Its seems clear that the issues encountered by researchers and firms involved in intra organizational knowledge sharing relations are similar; for this reason, research labs should take inspiration from managerial solutions developed by scholars in the management field to find new ways to take advantage from knowledge sharing in order to exploit the benefits of cooperation without "offering ammunition to competitors" (Ioannidis, 2018) and losing one's own advantage (Loebbeke et al., 2016). Some of these solutions propose the setting of contractual relationships between different organizations, that include control and coordination mechanisms to ensure the reciprocal benefits and protect against free-riding. This kind of partnerships between research organizations could enable scientists to get access to their colleagues' results, and to start building new science on the findings of others (Palus, 2018).

Another solution to enable an easier dissemination of scientific results is to increase free accessibility to publications, currently limited by subscription-based journals and databases, as such costly and difficult to accede. A radical step proposed by Belluz et al. (2016) is "to abolish for-profit publishers altogether and move toward a nonprofit model*";* that on the other hand would represent a challenging revolution for the scientific press industry.

But first of all, there is the necessity to rethink research funding to make it the means to create better mechanisms for enabling transparency, openness and sharing. For example, transparency should be a prerequisite for funding, and Universities and research institutes should encourage sharing by hiring and rewarding those scientists who are promoters of transparency (Ioannidis, 2018).

4.2.4. Managerial solutions to ensure a more efficient exploitation of human capital in biomedical research

A possible solution to ensure a more efficient exploitation of human capital in biomedical research is to rethink research's organizational model, reconsidering the role and the importance of staff scientists inside laboratories. As denounced by interviewee n. 4, while researcher posts are scarce, each scientist holds a heavier burden of work trying to perform all the task required from his position – managing lab personnel, following bureaucratic and administrative duties, writing grant applications... tasks that steal time for thinking, experimenting, and producing results. Scientist must be supported by a competent and efficient staff of specialized figures, that may be called "science managers", whose responsibilities should cover all the necessary task to support researchers' core activities and interests. "We need people management, so that merit is identified and employees play to their strengths. Simply put, we need to run ourselves like a company" state Alberts et al. (2014). Research labs, in other words, should imitate the organizational structure proposed by Minzberg (1992): an "operative core", represented by researchers in charge of carrying out experiments, producing and interpreting results, assisted by a "technostructure" composed by employees filling heterogeneous types of positions, ranging from lab managers complying all the administrative, regulatory and safety duties, down to those carrying out the most routine jobs needed to support and assist scientist in their tasks.

Increasing the ratio of permanent staff positions to trainee positions, introducing managerial figures in the labs and acknowledging value and importance to these lateral but essential roles may be a solution both to offer job opportunities to motivated individuals, who may not have the possibility to find a post as a principal investigator, and at the same time allowing researchers to concentrate on the development of science.

At the same time, there is the need to remove the obstacles that prevent young scientist to eventually change their paths, finding new jobs in non-academic positions. As emerged from interview n. 5, there are many elements that may hinder the transition of a young researcher from academia to the outside job market: among them, the lack of the competences needed by industry, absence of support—and in some cases opposition—from their mentors, and poor knowledge of non-academic job opportunities. On the other hand, PhDs and postdocs follow a path that provides them broadly applicable skills in critical thinking and problem-solving, and their background could be extremely valuable in fields such as science policy and administration, the commerce of science, writing scientific papers, intellectual property law, and science education at all levels (Alberts et al., 2014). It is necessary to train young researchers into a variety of career opportunities (not only the academic one), that can benefit from their abilities and education; at the same time, postdoc and PhD should combine training in research with skills that match with industry needs such as leadership, project management, teamwork, and communication (Alberts et al., 2014).

Above this, it is essential to enhance the knowledge and information, both for trainees and for their supervisors, that these different paths exist. All in all, it is evident that a wiser career management could be the answer to many pitfalls in the biomedical research system.

Conclusions

This dissertation had the objective to analyze biomedical research's job market and funding system, with the aim to develop insights and suggestions towards a better distribution of resources in the field. The basic assumption was that a more efficient allocation of job posts and funding could be the answer to ensure a more stable progress in life sciences.

The interaction with professional figures working in the field gave me the priceless opportunity to observe the world of research from the inside, to better understand its strengths and deficiencies. The overall impression I acquired studying this context is that the strongest power of contemporary biomedical research is the extraordinary passion and motivation of people working in this field. By consequence, there is the absolute need to change the pitfalls of the current managing of resources to give scientist the possibility to express their potential, taking advantage of their outstanding determination toward fruitful results.

With regard to funding procedures and regulations, this work clearly puts in evidence the essential need to change funding's perverse incentives system who often lead to biased, risk-averse research, which is sometimes designed with the aim to help the researcher's career and funding goals more than towards scientific achievements. Funding systems should find ways to encourage originality and risk taking, following the example of virtuous institutions who are already experimenting with success alternative funding requirements.

Funding organizations should encourage and reward knowledge sharing, to favor a more collaborative and less competitive approach to science development; this would also help to ensure reproducibility of previous studies, which must be the firm foundations of further research. Furthermore, research evaluation system should be taken in higher consideration and used as a mean to enhance research quality. From my analysis, push programs, rewarding scientists before obtaining results should be preferred over pull programs, although the latters may be relevant to attract the attention of the scientific community on very specific and otherwise forgotten research topics (such as a rare genetic disorders).

The other big issue is to correct the failures of job market in academia, opening numerous and varied career paths for the growing number of trainees produced by academic pipeline. To give young researchers the means to express their potential, the system must ensure them a more stable future and a more certain employability both in University (increasing the ratio and the importance of staff scientists and managerial figures in labs), both in industry, coupling scientific with managerial training.

In conclusion, it seems clear that the importance of managerial skills and practices is becoming essential to tackle increasing complexity in this field. There is ample room to be optimistic about it. As remarked by Belluz et al. (2016), "science is conducted by fallible humans, and it hasn't been human proofed to protect against all our foibles. The scientific revolution began just 500 years ago. Only over the past 100 has science become professionalized. There is still room to figure out how best to remove biases and align incentives. But the gains humans have made so far using even imperfect scientific methods would have been unimaginable 500 years ago. The gains from improving the process could prove just as staggering, if not more so" (Belluz et al., 2016).

The interviews I conducted for this work certainly don't have the ambition to have scientific relevance; yet, I hope they may be useful to shed some light in main issues and themes in the field, as supported by work of respected alumni, as shown in Literature and Discussion chapters. What this work does highlight however, is the need further economic research in these themes, the need to propose more specific ways to put into practice the general suggestions here developed, and application of more long-term statistics and quantitative methods to test whether implementation of new approaches and policies to science funding and career management could offer useful improvements in the quality of research advancements in life sciences.

Appendix

Interview guide

Here I present the guide used for the first part of the interviews – these questions were asked to all the interviewees.

- How old are you?
- What is your current position in the department?
- In which biomedical field are you specialized?
- Which is your role in the lab you are working for?
- What is your job about?

Full transcription of one interview (verbatim)

Refers to the interview with Interviewee n. 6.

JP: How old are you?

I'm 34 years old.

JP: What is your current position in the department?

I have been an Assistant professor in University of Padova DMM for two years. I graduated from Master Degree in Biotechnologies and from PhD in this same University, while I spent my PhD in California.

JP: In which biomedical field are you specialized?

I have a Master Degree in Biotechnologies and a PhD in Molecular Medicine.

JP: Which is your role in the lab you are working for?

I am a Principal Investigator (PI). It means that I am responsible for my own research line, that I have ideated collaborating with the Professor who is head of the lab where I am working. I have the responsibility of a small group of Undergraduate and PhD students who work together to follow the project under my supervision.

JP: What is your job about?

In our laboratory we study how cells sense their environment and use this information to build and maintain tissues with specific form, size and function. We are also interested in how disruption of these homeostatic mechanisms leads to tumor formation, progression and metastasis.

JP: Women occupy nearly half of the posts in university research, and more than half of all university graduates are women. However, they are less likely to be promoted to senior

positions within universities, and encounter more difficulties to receive research funding (Plank-Bazinet, 2017). **Can you explain this phenomenon from your point of view?**

I believe that the difficulties in obtaining funding are largely correlated with the obstacles that a woman encounters in reaching a leadership position. Like many other professional areas, science has always been a male dominated field, and women in science have been discriminated for long. I think that part of the problem of scarce representation of women in senior positions is due to the fact that women seem to be less ambitious than men in their scientific careers, and at the same time they are less stimulated to be ambitious by their supervisors. I had the extreme privilege to work with mentors who have always supported and encouraged me towards high end objectives; I know that this is not the case for many of my female colleagues around the world.

JP: why do you think women show lower ambition in research?

I imagine that family issues contribute a lot in this. I see that in many of my friends and colleagues: a lot of couples in this field are formed by fellow scientists, and the shortage of long term jobs in universities makes difficult to find a stable academic position in the same time and place for both. Almost always, a wife's career is subordinated to her husband's. Women get pregnant, their projects are delayed... Moreover, PhD and postdoc are demanding jobs which may be challenging when it comes to start a family... it also helps contribute to gender inequalities in research. Furthermore, also the scarcity of women in senior leadership positions may be itself one of the factors which contributes discouraging women and repressing their ambition. Young researchers like me need to take inspiration from female role models who have successfully learnt how to communicate, progress and flourish, against all the integration issues of a male dominated field like ours. We need to think "If she succeeded, I can succeed to". Unfortunately, such models are difficult to find. This can be disheartening.

JP: how is it like to be a woman in science?

I'll answer to this question using the words of Donna Strickland, Noble prize in physics in 2018: "I don't see myself as a woman in science. I see myself as a scientist". Bringing my contribute in biology has always been my greater wish: realizing this dream every day with my work is sensational, and of course being a successful woman is empowering; but I think that the first step to improve equality and parity for women is stopping considering successful women as "mythological creatures". Everybody is becoming aware of the huge contribute that women can bring to science, with their creativity, hard work and problem solving capabilities. Moreover, is a matter of fact that more "diverse" groups, formed by people of both sexes and coming from different cultural backgrounds, are more creative, innovative and better decisions makers, thanks to the opportunity of bringing together many different points of views. At the same time, I see with delight the significant efforts that science institutions are making to improve equity, diversity and inclusivity in biomedicine and in science in general. I'm confident that we are all building a brighter future for female scientists.

Number of words in this document (from Introduction to Appendix included): 13 242.

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