Patents and the experimental space: social, legal, and geographical dimensions of 3D bioprinting

Article (Accepted Version)

Patents and the experimental space:
social, legal, and geographical dimensions of 3D bioprinting

Abstract

The entanglements between social creativity, legal instruments, and global policies becomes particularly clear in emerging technological fields where such relations are being established or improvised. In this paper, an analysis of such entanglements is delivered, focusing on 3D bioprinting. This technique amounts to the use of robotic, computer-controlled devices called bioprinters, with which bioactive structures are manufactured, with potential medical applications.

Bioprinting has triggered manifold relations and processes, here grasped with the concept of experimental space. It is claimed that the experimental space has several dimensions, three of which are analysed here. First, there is a legal dimension formed by a multiplication of patent documents making reference to each other and forming a discursive network. Second, there is a social dimension, as the experimental space is populated by innovative companies and universities involved with bioprinting. Finally, the geographical dimension derives from the spatial processes and global geography of bioprinting.

The study of these three dimensions is underpinned by a quantitative analysis of bioprinting patents filed from 2001 to 2019 and found on two specialized websites (The Lens and Google Patents). Furthermore, fieldwork was conducted in three countries (the UK, Brazil, and Italy), involving interviews with academics and entrepreneurs exploring bioprinting.

Keywords: bioprinting; patents; experimental space

1. Bioprinting, innovation, and patents

What kinds of social actors, regulatory tools, and geographical processes have shaped the biomedical technologies that are nowadays considered as scientifically, technically, and clinically promising? In order to answer this question, an explicative framework is needed which would make it possible, on the one hand, to disentangle the different aspects of technological evolution and, on the other hand, to clarify the

ways in which these aspects mingle and reinforce one another. In the present paper, the concept of experimental space is invoked as a tool to enable such kind of understanding. For so doing, we focus on the empirical example of 3D bioprinting and, more specifically, the patenting of bioprinting techniques.

In the study of patents, analysts often seek to understand whether intellectual property rights are conducive to innovations or not. Classically, patents are said to induce innovation (Arrow, 1962, Nordhaus, 1969, Scherer, 1972). In the biomedical domain, the production of pharmaceuticals was a recurrent example for those willing to make a case for patents and intellectual property rights (IPRs), especially in the 1970s and 80s (Levin et al., 1987, Taylor and Silberston, 1973, Mansfield, 1986) but also more recently (Graboswki, 2002).

This claim has been challenged by recent empirical studies. For some analysts, the patent system is helpful but fraught with imperfections, in such a way that adjustments are in need towards 'revitalizing the patent system to incentivize pharmaceutical innovation' (Tang, 2013). For other analysts, patents prevent the sharing of resources and knowledge, thus blocking innovations (Nicol, 2009, Heller and Eisenberg, 1998). For the 2010s, one can even speak of '[…] an emerging consensus that, in many circumstances, IPR rights may be an inhibitor of innovation' (Bouchard, 2012, p. 131). In terms of pharmaceutical innovation, this claim is often coupled with warnings against the scientific 'tricks' deployed by large pharma corporations in order to appear as innovative players (Davis and Abraham, 2013, Busfield, 2006, Petryna, 2009, Shah, 2006), including the analysis of the dubious relations between companies and regulatory agencies (Abraham, 2009), which might suggest the phenomenon of regulatory capture (Laffont and Tirole, 1991, Levine and Forrence, 1990, Peltzman, 1976, Stigler, 1971).

However, this paper is not part of this debate around the efficiency or inefficiency of the patent system. Instead of focusing on stimuli to innovation, we analyse the legal and social contexts in which technologies evolve. In this sense, the idea of innovation (the production of technological novelties) is here less important than that of experimentation (the socio-political processes underpinning the production of so-called novelties). This is why we have recourse to the concept of experimental space.

As shall be argued, the experimental space is multi-dimensional. Three dimensions will be discussed here: its legal, social, and spatial dimensions. Patent

documents are pivotal instruments in the realization of such dimensions. As documents, they impart a legal nature to the techno-scientific inventions, covering them with the seal of intellectual property. Because they are held by particular players, whose inventions derive from specific attributes and capacities, patents are imbued with social content. Finally, the spatial side of patents is revealed by the simple fact that each of these documents is valid within a certain jurisdiction. Therefore, it will be claimed here that patents are fundamental in shaping the experimental space described below.

This paper is organized in six parts. Initially, the concept of experimental space is discussed. This is followed by a description of the methods used in this study. We then analyse the legal network formed by the increasing number of bioprinting patent applications. We move on to scrutinize the social aspect of the experimental space, identifying the main promoters of today's bioprinting techniques. The following part analyses the global geography of bioprinting patents, as well as the spatial strategies mobilized by different players. The final part reviews key findings and presents some closing remarks.

2. The experimental space

Experimental space can be defined as a fluid technological and social context in which certain technologies emerge, develop, and decline or thrive. The concept differs from that of national innovation system (NIS). In the NIS approach, a central assumption, which is nevertheless not always made explicit, is the beneficial and desirable nature of innovations. 'The concept of *national innovation systems* rests on the premise that understanding the linkages among the actors involved in innovation is key to improving technology performance' (Organisation for Economic Cooperation and Development (OECD), 1997, p. 9). Such improvement and such performance are framed as a sort of national targets. Irrespective of the interpretive differences between the different analysts subscribing to the NIS approach (Freeman, 1987, Nelson, 1993, Patel and Pavitt, 1994, Fromhold-Eisebith, 2007), the notion of innovation as a target can always be noticed.

In the approach proposed here, innovation is not considered as a target but as a process through which a set of legal and political relations occur. Striking a good balance in those relations (that is modelling contexts in which no actor becomes

powerful to the point of hoarding technologies, excluding other actors or creating social conflicts) could be described as a goal of governance in a given domain.

Furthermore, in the NIS approach the space is generally considered as a neutral and passive element where innovations occur. In the approach proposed here, the space is considered as a key and active element. In this sense, there are some similarities between the approach proposed here and that adopted by Schwarte (2005). However, in his analysis of the anatomical theatres of the seventeenth century, Schwarte thought of experimental spaces as closed, well-defined, and tightly regulated premises where a certain kind of anatomical epistemology could be produced. 'The experimental space demarcates body, perception, and processes from one another in such a way that the differentiation between a thing and its circumstances is possible from a particular perspective' (Schwarte, 2005, p. 97). In this paper, the experimental space is far from being subjected to these epistemological architectures, because it is shaped by varied, and sometimes messy, forms of interests and rationales, which can be economic, administrative, legal, and so on.

In this sense, the concept, as proposed here, takes us away from philosophical thought and make us approach the realm of legal reasoning and political economy. It bears similarities with 'the legal landscape governing biomedical innovation' described by Bouchard (2012, p. 132), because this landscape '[…] functions as a strongly networked *innovation ecology*' (p. 132). As our approach focuses much less on economic and technological than regulatory and governance ones, it also bears some similarities to the "sectoral systems of innovation and production" approach (Malerba, 2002).

In order to properly comprehend the nature of the experimental space, it is important to consider its various component dimensions. This paper aims to explain the ways in which its legal, social, and geographical dimensions come to overlap and combine. For so doing, we focus on the field of 3D bioprinting and, more specifically, on patents filed for different areas of bioprinting.

Bioprinting can be defined as the production of tissues and biological constructs through the use of 3D bioprinters. The latter are robotic devices that receive instructions from computer software and deposit biological material to form 3D-organized structures (Abudayyeh et al., 2018, Ahadian and Khademhosseini, 2018, Castro et al., 2018, Kelly, 2018, Ma et al., 2018). Now in early stages of development,

the technology has allowed the production of simple tissues and cell structures, but it is hoped that in the future, it will be possible to bioprint more complex structures and even whole organs. This is why, in the beginning of the 21st century, some bioprinting pioneers, like Mironow and colleagues (2008), preferred to use the expression 'organ printing.' Nowadays, it is often assumed that bioprinting is becoming a key technique in the fields of regenerative medicine and tissue engineering. 'It is one of the most promising technologies for addressing diverse health problems, and therefore, numerous research efforts have focused on further developing this technique' (Garcia-Garcia and Rodriguez-Salvador, 2018, p. 1).

Basically, the bioprinting process requires some implements, in addition to the bioprinter itself. Bioinks are gels deposited by the bioprinter, containing the cells that constitute the biologically-active part of the bioprinted construct. 'Scaffolds' are inorganic structures that can be used to hold the organic components, giving shape and support to the printed structure; often, they are supposed to disintegrate after the living part has gained biological and physical stability. Both bioinks and scaffolds have been the object of patents, and so too some final products (such as cell constructs or cornea) resulting from bioprinting processes.

This range of patentable products is another feature that makes bioprinting an interesting topic for the analysis proposed here. Some biomedical domains have key technological components protected by patents. This is what happens, for example, with Crispr-Cas9, a cutting-edge technique for gene editing that enables to modify genetic information. The core of this technology has been patented, which is currently provoking a legal dispute between the University of California and the Massachusetts Institute of Technology, holders of foundational patents on Crispr-Cas9 (Harrison, 2019, Lim, 2018). In bioprinting, such legal fences are absent, as the technology basic components (such as the extrusion system making it possible to deposit cells or the system enabling to accurately position printer heads) derive from relatively old 3D printing techniques which are free from patent protection.

In this way, much space can be found by promoters of innovations in bioprinting. In their analysis of bioprinting patents, Hornick and Rajan (2016) concluded: "[…] innovations in the field are originating from many different parts of the world and from companies both big and small." This is possible because bioprinting researchers and companies have considerable leeway for operating in a

non-proprietary space while trying to appropriate some areas of this technological field.

3. Research methods

An analysis of bioprinting patents is one of the components of this paper. Data was collected on two websites: The Lens (https://www.lens.org/) and Google Patents (https://patents.google.com/). In June 2020, the following search strategy was used on The Lens website:

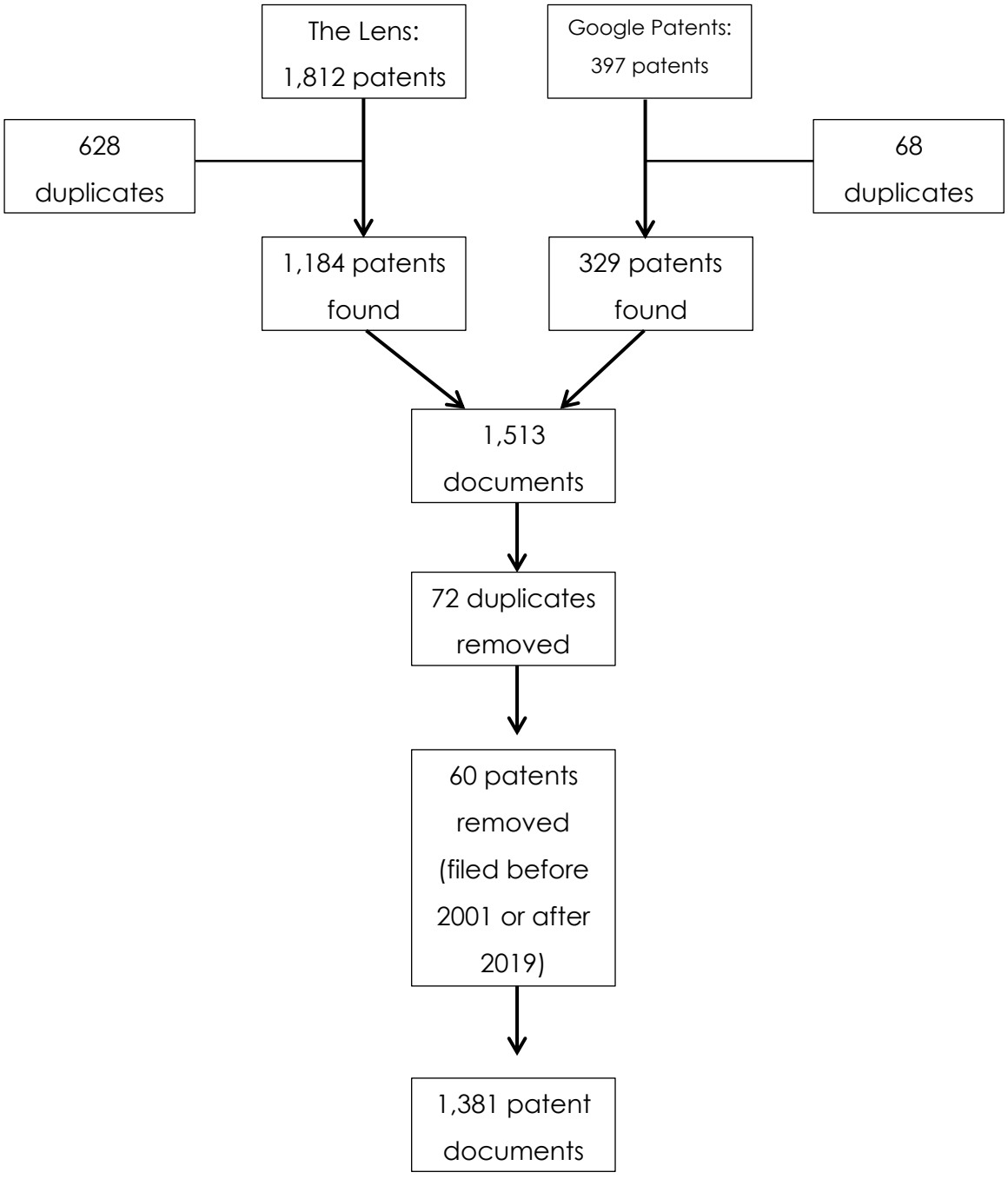
(title:((bioprint OR bioink OR "bio-ink" OR biofabrication OR biomanufacturing OR bioassembly OR bioadditive OR bioprinter OR bioplotting) NOT (animal OR cow OR bovine OR insect OR rabbit OR mammal OR monkey OR baboon OR chimpanzee OR primate OR cat OR feline OR dog OR canine OR ferret OR shrew OR gerbil OR "guinea pig" OR "guinea pigs" OR pig OR rat OR mouse OR mice OR opossum OR bird OR reptile OR frog OR amphibian OR fish OR shark OR plant OR vegetal OR yeast)) OR abstract:((bioprint OR bioink OR "bio-ink" OR biofabrication OR biomanufacturing OR bioassembly OR bioadditive OR bioprinter OR bioplotting) NOT (animal OR cow OR bovine OR insect OR rabbit OR mammal OR monkey OR baboon OR chimpanzee OR primate OR cat OR feline OR dog OR canine OR ferret OR shrew OR gerbil OR "guinea pig" OR "guinea pigs" OR pig OR rat OR mouse OR mice OR opossum OR bird OR reptile OR frog OR amphibian OR fish OR shark OR plant OR vegetal OR yeast)) OR claims:((bioprint OR bioink OR "bio-ink" OR biofabrication OR biomanufacturing OR bioassembly OR bioadditive OR bioprinter OR bioplotting) NOT (animal OR cow OR bovine OR insect OR rabbit OR mammal OR monkey OR baboon OR chimpanzee OR primate OR cat OR feline OR dog OR canine OR ferret OR shrew OR gerbil OR "guinea pig" OR "guinea pigs" OR pig OR rat OR mouse OR mice OR opossum OR bird OR reptile OR frog OR amphibian OR fish OR shark OR plant OR vegetal OR yeast)))

The search was filtered to include only papers from 2001 to 2018. It is hard to precisely indicate the beginning of bioprinting. As explained by Bauer and colleagues (2016, p. 294), even though 'The origins of modern three-dimensional (3D) printing can be traced back to as early as 1984 […],' it was only in the late 1980s that early forms of bioprinting could be identified, with the use of bioinks. However, it was only in the

late 1990s that scientists bioprinting organoids and structures that could mimic organs. Furthermore, the vast majority of bioprinting companies would only be created in the 21st century. For these reasons, our search considered patents filed after 2000, which is similar to the temporal delimitation of the bioprinting patent analysis carried out by Rodríguez-Salvador and colleagues (2017). Excluded from our search were also the patents whose jurisdiction was indicated as World Intellectual Property Organization (WIPO). This is because patent applications dealt with by WIPO still have to be filed in individual member countries. Eventually, 1,184 patent documents were found on The Lens website.

On Google Patents, a similar search strategy was used, yielding a total of 329 patent documents. The two sets of patents (The Lens and Google Patents) were combined and duplicates removed. Two patent documents were considered as duplicates when they had the same title, the same jurisdiction, and the same date of priority. Eventually, a total of 1,381 patents were obtained. The following figure summarizes the process of patent identification.

Figure 1. Patent search on The Lens and Google Patents



For data processing and data visualization, the R programming environment was used. More specifically, the following libraries were used: dplyr, stringr, readr, reshape2, and ggplot2.

However, this is not an exercise of patent metrics, for two reasons. First, as claimed before, quantitative patent analyses tend to consider the multiplication of patents as a positive phenomenon, an assumption that might downplay the political and legal considerations which are key in our analysis. Second, Adelman and DeAngelis (2007) are right to claim that exercises of patent metrics often constitute 'mismeasure of innovation,' as they tend to ignore that patents are filed within a geographic space containing a plethora of actors and resources, including scientific commons. A quantitative analysis of patents is undertaken here because such approach helps unravel three key dimensions of the experimental space, as explained above. Thus even though some quantitative data will be taken into account here, they will be interpreted in the light of qualitative and social processes.

In addition to the patent analysis described above, information from qualitative interviews with bioprinting researchers and entrepreneurs will also be considered. With approval from the Research Ethics Committee of King's College London, we conducted six interviews in Brazil (three academics and three people based bioprinting companies). With approval from the Central University Research Ethics Committee of the University of Oxford, interviews were conducted in two countries: the UK (eleven academics and two entrepreneurs) and Italy (three surgeons, three researchers, and one entrepreneur). These three countries were selected because they represent different contexts in terms of biomedical innovation and, more specifically, bioprinting. Brazil is the economic and scientific leader of a region where biomedical innovations and patent applications take place in modest numbers (South America). The UK and Italy are located in a region holding much biomedical innovation and receiving many patent applications (the European Union), but in the UK investments have been more substantial, including the creation of a bigger number of bioprinting companies. In this way, our interviews enabled us to analyse the particularities of different world contexts.

This study is part of a research project called *Biomodifying technologies: governing converging research in the life sciences,* with funding from the Leverhulme Trust[1]. It is collaborative work involving the universities of Sussex, Oxford, and York. In addition to focusing on bioprinting, the project analysis the social and regulatory aspects of gene editing, and induced pluripotent stem cells.

[1] Grant number 68387.

4. Patent networks: the segmentation of the experimental space

From a legal perspective, the experimental space is not a uniform space. Moreover, it can only exist insofar as it is segmented into fragments, each of which is to be appropriated by different players. Patents are key tools because they render this appropriation possible. Furthermore, they help stabilize social expectations.

Sociologist Niklas Luhmann (1972) characterized human behaviour on the basis of the expectations informing it. When behaviour is informed by practical experience (in a learning process), we have cognitive expectations. If behaviour is informed by lasting rules endowed with a sense of duty, we are dealing with normative expectations. In this second case, we are in the sphere of regulation and law, which posit and institutionalize social expectations. From this viewpoint, law is defined

> '[…] not by the existential similarity to the given original quality of the 'ought', and not by a specific factual mechanism, e.g. 'state sanction'. These normal characteristics of definition are not […] excluded or evaluated as irrelevant, but neither are they interpreted as defining characteristics of the essence of law. Law is in no way primarily a coercive order, but rather a facilitation of expectation' (Luhmann, 1972, p. 77-78).

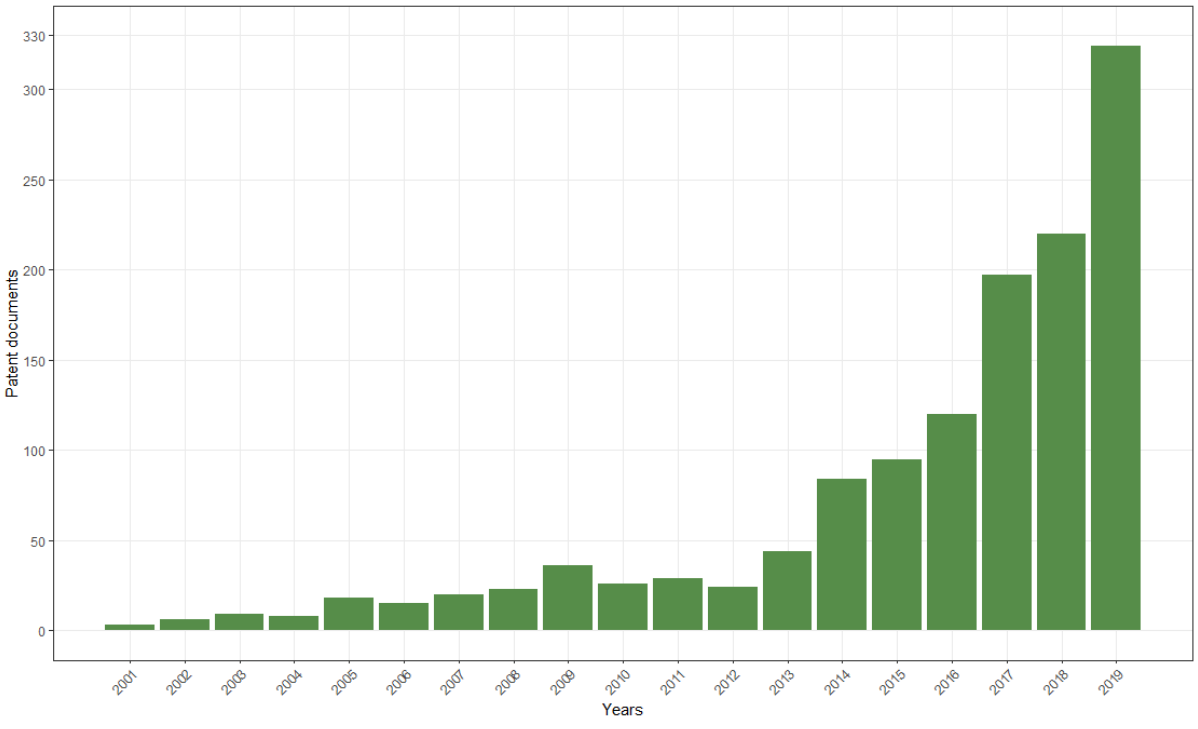
Previous studies have highlighted the key role played by potentially normative expectations in the development and use of biomedical technologies, forming a field that came to be known as sociology of expectations (Gardner et al., 2015, van Lente, 2012, Brown and Michael, 2003). However, the relevance of legal tools for the formation and stabilization of expectations has yet to be properly described, making it clear that: 'Legislative texts are one, particularly salient vehicle bearing social actors' expectations […] about an emerging technoscientific field' (Faulkner, 2012, p. 755). In bioprinting, such circumstance manifests itself in at least four ways.

First, there is the obvious expectation, stressed in classical economic explanations, that by filing patents, some actors will glean economic benefits. Second, whenever a patent is granted, their grantees secure technical and scientific prestige, in such a way that they are expected to come up with new innovations in the future. Third, because patents are filed by actors based in specific cities and countries, those places are expected to become the cradle of further innovations in

the future. Finally, every technological domain can be subjected to a technical differentiation whereby patents can be filed in different subfields. In bioprinting, this has led to the possibility of filing patents for bioprinters, bioinks, scaffolds, and so on. For example, an interviewee based in a Brazilian company declared: '[...] the bioprinter, the whole device, that wouldn't be possible [to patent]. But it's possible [to file patents] when we think of specific applications, like the UV light system or a technology developed as a specific component of the device.' In this way, there emerges some expectations of new technical segments being discovered which would be the object of new patents in the future. For example, Yoo (2015) lists potential areas of development for bioprinting, which can lead to both medical applications and technical discoveries to be protected with patents.

Because bioprinting is a relatively recent technology, the filing of patents, as well as the multiplication of such expectations, is also recent. The following chart displays the number of patents identified in this study across the years 2001 to 2019.

Chart 1. Number of patents published per year (The Lens + Google Patents): 2001-2019

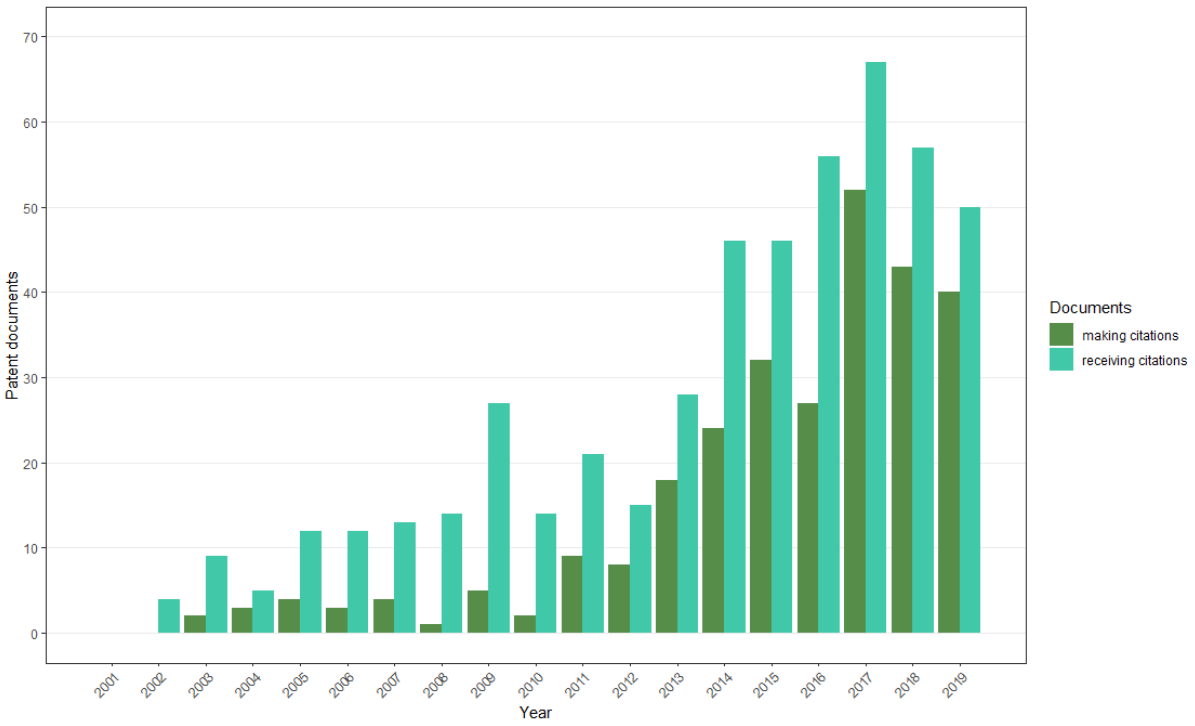


Of the 1,381 documents found on The Lens and Google Patents, 319 were granted patents and 1,062 were patent applications. Considering only applications, there was, from 2001 to 2019, an average of 55.89 applications per year. To have an idea of how modest this number is, let us compare it with the average of the pharmaceutical sector. Kumazawa (2017) analysed pharmaceutical patents submitted in three jurisdictions (the United States, Europe, and Japan) from 1999 to 2012, obtaining an average of 6,119.63 applications per year[2]. The filing of bioprinting patents, in spite of such low relative performance, displayed, in the period comprised in Chart 1, a steady growth.

As a consequence of the expansion in the number of bioprinting patents, legal pillars have been built up for the submission of new patent applications. This is so because patent applications, as legal documents, can, and often do, cite previous patent documents on which they rely to make a case for gaining property rights. In other words, a bioprinting patent submission can make reference to previous patent documents (whether they are bioprinting documents or not) and can also be cited by future applications. The following Chart 2 summarizes the occurrence of such documents making and receiving citations.

[2] However, it is important to consider that "[…] there could be many unpublished applications that will eventually reveal a new 3D bioprinting IP powerhouse. Normally, patent applications are published 18 months after they are filed, and are secret until then" (Hornik and Rajan, 2016).

Chart 2. Number of patent documents making and receiving at least one citation: 2001-2019



Until 2004, the number of documents making citations (referring to at least one other patent) or receiving citations (being cited by at least one other patent) did not exceed ten. In 2017, both numbers were over 50. Since 2013, there was a remarkable growth in the number of both documents citing and receiving citations, with figures reaching a peak in 2017. Even though numbers have displayed a decrease thereafter, they are clearly at a higher level compared to the figures of the beginning of the century.

As an example, let us take the patents of two bioprinting companies, Cellink (Sweden) and Organovo (United States). In a patent filed in the United States in 2015, Cellink cites other four patents. This document was subsequently cited in 6 other applications[3]. In a patent granted to Organovo in 2016, valid in the United States, the company cites 114 other patents, eight of which had been submitted by itself while

[3] https://patents.google.com/patent/US20170368225A1/en

the other patents had been submitted by several other companies, universities, and people. This document was subsequently cited in 39 patent applications[4].

In the bioprinting domain, the 'legal corpus' has become thick, so to say, in the sense that there is a proliferation of patent documents that can, and do, refer to other patents. From this point of view of legal documentation, the bioprinting domain is configured by a series of utterances which reinforce each other while referring to each other. This discursive chain has some similarity to the logical articulations described by young Wittgenstein (1922) whereby basic (or 'elementary') utterances (or 'propositions') support the expression of more complex propositions. In this construction, '[…] the comprehension of the general propositions depends *palpably* on that of the elementary propositions' (Wittgenstein, 1922, p. 51).

The discursive dimensions of law have been pointed out by theorists who showed the connections between law and communication (Habermas, 1996), law and ideology (Hirst, 1977), law and power relations (Humphreys, 1985). From the viewpoint of the experimental space, this discursive dimension of law and patents has two consequences.

On the one hand, a network of techno-legal discourses comes to be formed, underpinning the segmentation of the experimental space, as well as the appropriation of its various segments. A similar phenomenon has been noticed before by analysts who showed that mutually reinforcing discourses can be voiced in the field of scientific publications (Latour, 1987), regulatory documents (Faulkner, 2012), and ethics committee letters (Dixon-Woods et al., 2007).

On the other hand, a variety of expectations can emerge, as this discursive background, which could also be considered as a pioneering legal discourse, provides the support for future bioprinting innovations. Even if the innovative pace of bioprinting slows down for some time, the current corpus of patent documents keep nurturing expectations, because '[…] normation gives a lasting quality to an expectation regardless of the fact that it is disappointed from time to time' (Luhmann, 1972, p. 74). Moreover, current patent documents create a background for more robust expansions in terms of both patent numbers and discursive strategies to be mobilized to enlarge the horizon of property rights in the bioprinting field.

[4] https://patents.google.com/patent/US9315043B2/en

5. Patent holders: the population of the experimental space

If, as claimed here, legal tools constitute a discursive network, then it is important to consider what was claimed by Humphreys (1985, p. 254): 'To characterise law as a discourse further implies […] that it is a combination of speech and action, of explicit claims and implicit messages. We have to ask who plays dominant and who subordinate roles in it […].' In terms of bioprinting innovations, we have to ask who the actors are who have appropriated segments of the experimental space the most successfully. From this perspective, the experimental space, in addition to being modelled by the presence of legal tools, is modelled by the presence of particular actors with particular rationales and interests.

To begin to analyse this issue, let us consider the following table.

Table 1. Number of patents per type of institution: 2001-2019

Institution	**Patents**
non-bioprinting company	644
university	259
bioprinting company	240
individuals	147
research institution	67
hospital	13
national agency	11
TOTAL	1381

In this paper, we will only analyse the role played by the three main groups of bioprinting patents applicants/holders: non-bioprinting companies, universities, and bioprinting companies.

Historically, the first group of actors to explore bioprinting were companies whose activities bore some relation with 3D printing, such as companies producing medical or electronic devices. The main reason why those companies got interested in 3D printing (and later on in bioprinting) is that the technology would help them streamline their main production activities. These companies have become key applicants/holders of bioprinting patents, as show in the following table.

Table 2. Main non-bioprinting companies with bioprinting patents (as either applicants or holders): 2001-2019

Company	Foundation	Headquarters	Country	Field	Patents
GE Healthcare	1994	Chicago	United States	Medical devices	24
Genzyme	1981	Cambridge	United States	Biomedical	21
Celgene	1986	Summit	United States	Pharmaceutical	20
Blue-Ray Biotech	2004	Taipei	Taiwan	Medical devices	11
Deka	1982	Manchester	United States	Medical devices	7
Ultra Inc	2014	Portland	United States	Biotech	7

Table 2 reveals the prominence of the United States, as well as the importance of medical device companies. For the latter, bioprinting is a sort of ancillary technology, which could provide them with some competitive advantages in the future.

To be sure, these companies, in order to submit their patents, had to rely on basic research previously conducted in universities. However, in terms of actual patents, they seem to have pioneered the field while universities waited some years before beginning to file their own patents. Nowadays, universities, taken as a group, are important players. The following table gives us an idea about the role they have gained.

Table 3. Main universities with bioprinting patents (as either applicants or holders): 2001-2019

University	City (main campus)	Country	Nature	Patents
Pohang University	Pohang	South Korea	Private	22
Univ Queensland	Brisbane	Australia	Public	16
Wake Forest Univ	Winston-Salem	United States	Private	12
Zhejiang Univ	Hangzhou	China	Public	11
Univ California	Berkeley	United States	Public	10
Univ Lousville	Louisville	United States	Public	9

Two factors can help us interpret Table 3. On the one hand, the academic dynamics of bioprinting seems to be heavily dependent on the strategic value accorded by the field in the whole country. The United States, South Korea, and Australia are countries with important investments in innovative sectors such as bioprinting. On the other hand, the performance of each particular university seems to depend on the institution's willingness to explore the clinical applications of bioprinting, instead of only using it as a tool for the generation of new knowledge. For example, the Institute for Regenerative Medicine of the Wake Forest University has developed a mobile bioprinter for the treatment of large wounds[5]. And a research team of the University of Queensland is using bioprinting for studying the perivascular niche and its interaction with stem cells[6]. Thriving universities, in terms of bioprinting patents, are those willing to combine research tasks with effective translational efforts. The relevance of strategic decisions taken within each university is reflected in the fact that, of the six universities of Table 3, two are private institutions.

As claimed by Kesselheim and Avorn (2009), patents filed by companies are generally in large numbers but are often less strategic than those generated by non-profit players. Indeed, because universities host fundamental research, they are likely to generate technologies which will subsequently be used by a wide range of actors. However, as recognised by some of our interviewees, universities and research centres often have less skills and resources, compared with companies, when it comes to securing patents. The process necessary to secure a patent may take many years and require much investment. Even larger investments are necessary for maintaining patents in the different jurisdictions, as explained by one of our Italian interviewees. Based in a research centre, this researcher claimed to face patent difficulties, '[…] but not for the positioning of the patent but to make it available in other countries and to maintain that. This is very expensive. We have to maintain the patent.'

For all these requirements, companies are frequently more prepared than universities, even when these latter have in-built offices for patent application and technology transfer. This difference helps explain why large companies, not universities, are generally referred to for the strategy called 'patent thicket,' through

[5] https://www.3dnatives.com/en/mobile-3d-bio-printer-0503320195/

[6] https://aibn.uq.edu.au/project/developing-microfluidic-and-3d-bioprinting-platforms-model-and-study-human-perivascular-niche

which several related, and sometimes overlapping, patents are filed so as to protect a certain area from the actions of competitors (Roberts et al., 2014).

Moreover, in order to secure a patent, academic researchers have to delay publication of research results, which clashes with the academic need to publish results quickly. In this way, academics deal with a tension between delaying publication to secure a patent, on the one hand, and fulfilling the academic need for publication, on the other. In the case of one of our Brazilian interviewees, who is based in a company, the option will probably be the patenting of a bioprinted product under investigation. 'We'll try to patent it, yes. That's why, as soon as we begin to have some results, we won't publish them, to keep it secret, and we'll try to patent it.'

In spite of the importance of both companies and universities, the bioprinting patent scenario underwent an upheaval in 2012 when a new kind of actor entered the scene: dedicated bioprinting companies. The following chart illustrates this pivotal shift.

Chart 3. Number of bioprinting patents per year and per type of applicant/owner: 2001-2019

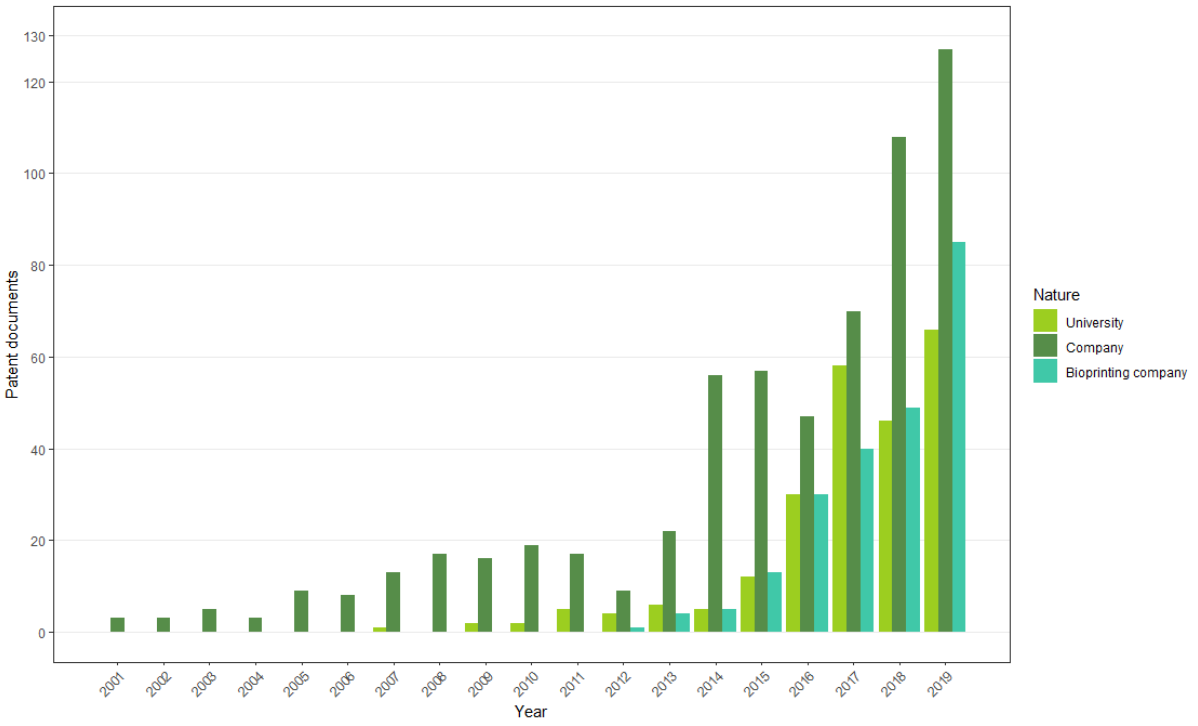


Chart 3 shows the impressive performance of bioprinting companies, which constituted the third group of patent applicants/holders in 2012 and became the second group in 2018, consolidating this position in 2019. The meaning of such performance is grasped by considering that the group of bioprinting companies (and particularly those holding patents) is quite small compared with the numerous universities and non-bioprinting companies. Looking at different sources, we have identified 86 bioprinting companies based in several countries. Only 15 of these companies appeared in our patent analysis.

These specialized companies have strategic partnerships with the academic world from which they frequently derive. For example, one of the companies visited in our fieldwork, based in the UK, has patented a technology initially developed as part of a PhD. According to the researcher responsible for that study: 'We had the patent […], the work I did in my PhD. Then we improved that thing and worked for four years as a postdoc in the same work. Then we opened the spinout company from the same work which I did in my PhD.' For these emerging companies, the ownership of patents becomes a strategic asset, as explained by the manager of a UK bioprinting company: 'Yes, that's an important consideration for a small company that has developed an innovative technology is that you have a good patent position.'

Even when the bioprinting company is not an academic spin-off, they seek to build up collaborations not only with academics but also with companies of close economic sectors. For EnvisionTEC, a German bioprinting company, this list comprises two foreign universities, two foreign biomedical companies, one foreign pharma company, three foreign electronic companies, three foreign medical device companies, one hospital, among others[7]. For the South Korean bioprinting company Rokit, this list includes, in addition to the impressive number of forty universities, three national research agencies, seven local electronic companies, two medical device companies, among others[8].

Two consequences of the emergence of this set of specialized bioprinting companies will be highlighted here. First, on the empirical side, bioprinting companies are capable of speeding up the translational movement of the field. Let us consider the following table.

[7] https://envisiontec.com/
[8] http://rokithealthcare.com/

Table 4. Bioprinting companies with bioprinting patents (as either applicants or holders): 2001-2019

Company	Foundation	Headquarters	Country	Products	Patents
Organovo	2007	Solana Beach	United States	Bioprinted tissues	84
Revotek	2014	Chengdu	China	Bioinks, bioprinters, and software	36
Modern Meadow	2011	Nutley	United States	Bioprinted tissues	28
Cellink	2016	Gothenburg	Sweden	Bioinks, bioprinters, and software	20
Aspect Biosystems	2013	Vancouver	Canada	Bioprinted tissues and bioprinters	18
Allevi (former Biobots)	2014	Philadelphia	United States	Bioinks, bioprinters, and software	13
Advanced Solutions	2013	Louisville	United States	Bioinks, bioprinters, and software	12
Poietis	2014	Pessac	France	Bioprinted tissues and bioprinters	11
T&R Biofab	2013	Siheung	South Korea	Bioinks, bioprinters, and medical devices	11

The first company in Table 4(Organovo) has been described as "a recognized leader and pioneer in 3D bioprinting" (Hornick and Rajan, 2016)[9]. It explores the domain of bioprinted tissues, an area in which other companies in the table operate. Those bioprinted tissues, which are developed for academic researchers, could potentially be used, for example, to repair damaged skin or treat a liver condition. Even though no clinical application has derived from bioprinting yet, companies such as Organovo and Modern Meadow constitute a spur to such clinical achievements

[9] Organovo, Revotek, and Modern Meadow continue to occupy the first three positions when all the patents found in our analysis are considered.

(or, at least, they foster expectations in this regard). In the medium term, their commercial success depends on the successful passage from basic research to concrete applications of bioprinting, which they stimulate.

Second, on the interpretive side, the formation of a specialized bioprinting market changes the social configuration of the experimental space. We are no longer dealing with actors for whom bioprinting is an enabling or ancillary technology. For these new specialized actors, bioprinting is the main focus of attention and operation. They are potential collaborators of cognate fields such as pharmaceuticals and medical devices. However, depending on the upcoming advancement of both bioprinting and its close domains, some conflicts and disagreements might also occur. If the technology comes to gain large recognition and attract widespread interest, a player like Organovo, with its vast range of patents, is likely to shape the field and even impose some types of restrictions and exclusions that will hinder access. For example, the company could strategically select players to whom its patents would be licensed in the future. In this sense, the experimental space is also constituted by a set of institutional relations whose scope is an object of experimentation.

6. Patent jurisdictions: the geography of the experimental space

One of the bioprinting companies interviewed in our fieldwork decided to open up a unit in Mexico from where it will control its operations in Latin America. The decision was made because some Latin American countries have regulated the implantation of human cells. According to the interviewee: 'In Europe, there is nothing written about this application of bioprinting but in Mexico or Colombia and in general in Latin America, they are more open.' In Mexico, for example, the Federal Commission for Protection against Sanitary Risks (Cofepris) has been open to some clinical approaches using implanted cells. This has enabled, for example, the Tijuana Regenerative Medicine Institute to get approval for two therapies based on the implantation of stem cells, one of which, according to the Institute, has achieved growing recognition. '[…] our congestive heart failure protocol, has already won two national awards for research in cardiology, due in large part to the extent of repair that was achieved, surpassing all expectations.'[10] Even though the Mexican

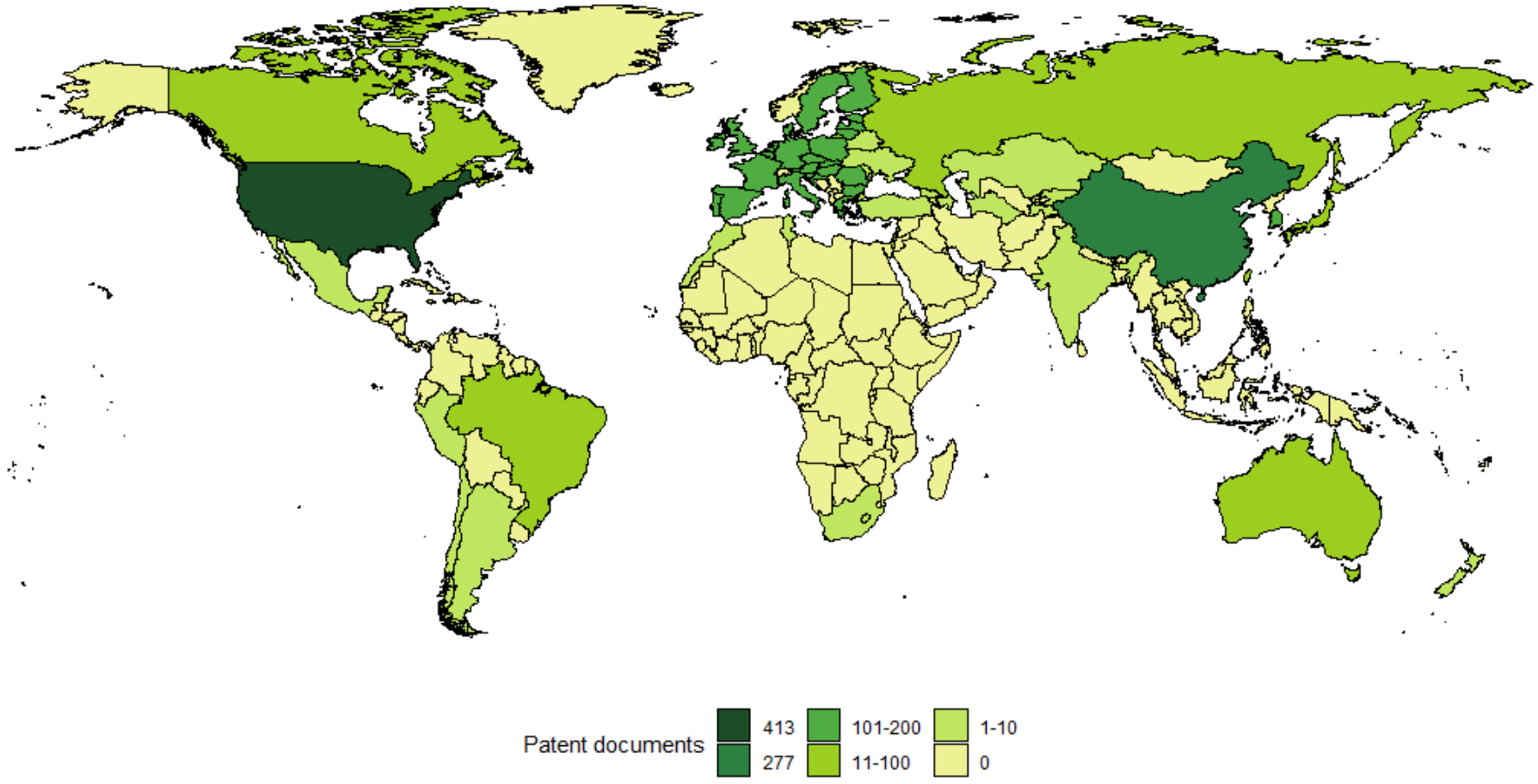
[10] https://www.regenerativemedicine.mx/index.php/portal/steam_cells_seccion

framework cannot be described as permissive, the example of the bioprinting company interviewed in our study, as well as that of the Tijuana Institute, show why regulations 'as handled in the United States and Europe' are sometimes described, by 'many researchers and bioethicists,' as relatively 'strict regulations' (Rosemann and Chaisinthop, 2016, p. 129).

This global regulatory variation are surely manifested in the field of stem cells research and therapy (Rosemann and Chaisinthop, 2016, Rosemann et al., 2019) but are present in other fields as well. Companies, especially when they explore emerging niche markets like bioprinting, have to consider these regulatory aspects, which mingle with geographic ones. A British patent attorney interviewed in this project explained that, for companies exploring the life sciences, a default strategy has emerged. "[…] if people haven't got a lot of money, at the end of the day the essential thing is, we will say 'Keep the U.S., let everything else go' […] What we would normally recommend is Europe, U.S., and China."

Patents surely help refine the geographical awareness of companies and institutions. Depending on actors' interests and strategies, patents will be preferably submitted in certain jurisdictions, not others. As a result of such decisions, a particular global geography of bioprinting patents is designed, as depicted in the following map.

Map 1. Bioprinting patents by jurisdiction: 2001-2019



Map 1 reveals at least three interesting phenomena. First, bioprinting has been the object of patents in a small number of world jurisdictions, with some areas (namely Africa and the Middle-East) being almost completely excluded from this patent scenario. Second, the dominance of the United States and China is evidenced. Third, Europe really functions as a block, as the vast majority of patents submitted in this region are filed at the European Patent Office, instead of individual countries.

In order to further refine this analysis, let us derive, from the observation of Map 1, the existence of three areas. The *core* would be formed by the United States, China, South Korea, and the countries covered by the European Patent Office. These areas are mandatory for different companies, because of the sheer weight of their economies or because of their investments in science and technology. The *sub-core* (formed by Australia, Brazil, Canada, Israel, Japan, Russia, Singapore, and Taiwan) is an area which, from the viewpoint of intellectual property, is also important albeit less strategic. Finally, there is a *periphery* formed by twenty countries where the filing of patents is still residual (1 to 10 documents).

In the previous section, it was seen that bioprinting companies brought about a new dynamic and rationale to the investigation and commercial exploration of bioprinting. So it is interesting to ask how these players have operated in the three world areas just described. The following table provides us with a revealing picture.

Table 5. Number and percentage of bioprinting patents filed in the different world areas: 2001-2019

Nature	Core	Sub-core	Periphery
Bioprinting companies	163 **(68.0%)**	77 **(32.0%)**	0 **(0)**
Non-bioprinting companies	472 **(73.3%)**	161 **(25.0%)**	11 **(1.7%)**
Universities	217 **(83.9%)**	40 **(15.4%)**	2 **(0.7%)**

In the core, universities are the main patent holders (with 83.9% of their patents filed there), followed by non-bioprinting companies (73.3%), and bioprinting

companies (68%). In the sub-core, the order is reversed, with bioprinting companies leading the percentual filing of patents; almost one-third (32%) of their patents have been filed in this area. In relative terms, then, the sub-core has received special attention from the bioprinting sector. To be sure, this geographical pattern has to do with the relatively modest force of bioprinting companies, which, in the most competitive areas, are not yet capable of keeping pace with the research dynamic of universities, as well as with the innovative power of companies such as GE Healthcare or Genzyme. However, such pattern has also to do with strategic decisions. The eight countries of the sub-core have characteristics turning them into promising bioprinting hubs: the presence of high-skilled researchers; the existence of robust research institutions; and the presence of national university systems (which are interesting for bioprinting companies for which academic researchers are still the main clients).

For example, one Brazilian company visited in our fieldwork has already benefited from the expansion of bioprinting in the country, having established collaborations with universities and research institutions. The company managers are considering filing a bioprinting-related patent. One of our interviewees spoke of the field's growth. '[…] it's promising, because there are many people working on it, many researchers beginning to want to work on bioprinting, and so on.'

The importance of the sub-core helps explain, for example, the strategy of a thriving bioprinting company like Allevi, which has established collaborations with players of different countries, including institutions in Brazil (the University of the State of Sao Paulo), Australia (the University of Wollongong), and Canada (the University of Toronto)[11]. In this way, the outstanding presence of bioprinting companies in the eight countries of the sub-core reveals a geographical awareness whereby companies try to become commercial and patent pioneers in areas that can display an important expansion in the years to come. At the same time, they do not eschew more central areas where their presence is needed if they want their global activities to be any viable. Therefore, the legal, technological, and scientific strategies of different actors require an important attention to geographical issues.

The modelling of the experimental space is therefore determined, to an important degree, by the configuration of the global geography of bioprinting. In this configuration, various situations can be identified, from the dominance of countries

[11] https://allevi3d.com/

hosting the most dynamic R&D activities and the largest numbers of patents, through countries which are awaiting substantial waves of investments and patent applications, to countries which are marginal or even excluded. Aware of such differentiation, companies try to strategically position their actions into the experimental space, so as to survive and prosper in a techno-scientific environment whose development is still considerably uncertain.

7. Experimenting with legal tools, social relations, and geographical contexts

Some analysts focusing on patents, and particularly those who adopt purely quantitative approaches, may disregard the point made by Qian (2007): for stimulating innovations, the presence of patent schemes are less important than economic development, educational improvements, and economic creativity. In this paper, this point has been taken into consideration, as patents are not considered, here, as technical goals but as instruments used by various actors holding different rationales and formulating different geographical strategies. In this sense, the concept of experimental space has been central because it enables us to foreground three pivotal phenomena.

First, the experimental space needs to be legally constituted and modelled. The steady proliferation of bioprinting patents, filed in various countries, constitute a sort of innovative language on which different actors can rely whenever they wish to make a new patent application. In this sense, it can be argued '[…] that documents are ordinarily positioned to fulfil a dual role; for they appear as both receptacles of content, and as active agents in networks of action' (Prior, 2008, p. 822). Patent documents refer to one another, forming a discursive network that help prospective innovators to make a case for the intellectual protection of their inventions.

Second, the experimental space needs to be populated. Over the last two decades, a variety of actors have been responsible for developing the bioprinting field and generating innovations. Of these actors, three groups have emerged as the main patent applicants/owners: universities, companies, and specialized bioprinting companies. The latter have been particularly decisive, being responsible for a quickly growing number of bioprinting patents. Even though the collaboration between different bioprinting companies has been scant, they have established partnerships with other kinds of players (especially universities), thus providing the experimental

space with a series of decisive social relations. Because the nature of such rationales and relations is still the object of experimentation, the regulatory control of this field becomes quite complex. In other words: 'The legal uncertainties of bioprinting are further compounded by the multiple actors involved in the supply and production chain' (Li and Faulkner, 2017, p. 443). In addition, one must be aware of the ways in which the field will evolve, with much potential for a commercial dominance. In a not so distant future, the prediction made by Hornick and Rajan (2016) may come true: "Companies with deeper pockets will purchase patents and acquire companies, thereby consolidating or shifting the bioprinting IP power structure."

Finally, this paper has emphasized the importance of geographical processes and relations. Bioprinting companies have at their disposal a relatively modest market, formed by researchers based in either universities or research institutions. In order to enlarge their range of potential clients, they have globalized their actions, which includes the filing of patents in different countries. A certain geography of bioprinting innovations is then defined. As a result, the geographical side of the experimental space gains subdivisions, with certain countries receiving the largest numbers of patents applications whereas other countries seem to wait for an impending moment when patents will mushroom in their territories.

These three dimensions of the experimental space have each their own dynamics but are also related, as summarized in the following scheme.

	Legal dimension	**Social dimension**	**Geographical dimension**
Patents	Patents forming a discursive legal network	Patents shaping expectations	Patents being enforceable in particular jurisdictions
Actors	Actors as holders of patents (innovator legitimacy)	Actors in social relations enabling innovations	Actors with a particular geographical reach
Places	Places with particular regulatory frameworks	Places hosting particular actors and relations	Places in mutual relations (globalization of bioprinting)

In addition to the differentiations and relations displayed in this scheme and explored throughout this paper, it is important to remember that the experimental space has other dimensions, which have not been analysed here. For example, there is a governance dimension where the state appears as a key actor. The state can change the conditions in which patents are filed by giving institutional or financial support to some players (such as companies or universities); by launching initiatives encouraging relations with countries where bioprinting is at relatively advanced stages; by changing the conditions in which bioprinting technologies (such as bioprinters, bioinks, bioreactors, specialized software, and so on) are funded, produced, commercialized, and traded in the international market; by changing the patentability of some types of technologies or products, and so on.

The success of governance decisions taken by the state will depend on the proper comprehension of the dimensions taken into account in this paper. '[…] regulatory preferences that do not respect the complex nature of the system they seek to regulate […] have the potential to harm the innovative outputs of the system' (Bouchard, 2012, p. 134). By the same token, every player operating within the bioprinting experimental space (whether a research team, a university or a company) has to take into account the regulatory, social, and geographical conditions in which the field has been unfolding.

As argued here, specialized bioprinting companies, whose appearance in the experimental space is relatively more recent, can be said to have paid attention to the rules of this complex game. In this regard, they are not different from companies operating in other fields such as international clinical trials (Bicudo, 2011, Bicudo, 2014, Lakoff, 2005, Petryna, 2009, Shah, 2006), medical devices (Faulkner, 2009) or genomics/bioinformatics (Harvey and McMeekin, 2005, Rajan, 2003, Salter et al., 2016, Bicudo, 2018).

However, the bioprinting field has three characteristics that makes it different from the pharmaceutical field and other fields. First, in terms of legislation, most countries are still lacking precise risk, safety, and liability regulations for bioprinting (Li and Faulkner, 2017, Li et al., 2020). If, on the one hand, this situation provokes regulatory uncertainties, on the other hand it creates regulatory voids in which different players can operate freely. For example, the fact that, in most countries, current bioprinters are not legally classified as medical devices makes it easy, from a regulatory point of view, for companies to produce such devices and for academic

researchers to acquire them. Because bioprinters have not been used in clinical contexts, they can be produced and sold as if they were laboratory instruments whose certification and commercialization becomes then relatively simple.

Second, in terms of social relations, the actors that can be considered as leaders of the bioprinting domain (in terms of the number of patents held) are far from having the economic and political power held by actors of the pharmaceutical sector, for example. Furthermore, it is still unclear whether, at some point, promising bioprinting companies will be acquired by larger corporations and be made part of more traditional corporate schemes.

Finally, the global geography of bioprinting is still fraught with underexplored or completely non-explored territories. The current economic expansion of China might turn it into a global bioprinting leader, surpassing even the United States. At the same time, countries occupying the position of what we named 'periphery' might join the group that we named 'sub-core.' In this way, as different players continue to tinker with locations and jurisdictions, a new geography can emerge, changing the geographical face of the experimental space.

In conclusion, we have sought here to contribute novel data and theorisation about a regenerative medicine technology and its multidimensional, global context at an early point of development. We have claimed that experimentation has to do not only with the evolution of technologies (bioprinters, software packages, bioinks, and so on) but also with larger processes. In parallel with the technical experiments carried out by companies and universities, it is possible to witness the outcomes of experimental developments whose target is the patent discourse itself, social relations themselves, and the geographical space itself. In the course of such experiments, the experimental space is open-ended and never ceases to gain new forms, changing the global and local dynamics of bioprinting.

8. References

ABRAHAM, J. 2009. Sociology of pharmaceuticals development and regulation: a realistic empirical research programme. In: WILLIAMS, S. J., GABE, J. & DAVIS, P. (eds.) Pharmaceuticals and society : critical discourses and debates. Oxford ; Malden, MA: Wiley-Blackwell.

ABUDAYYEH, I., GORDON, B., ANSARI, M. M., JUTZY, K., STOLETNIY, L. & HILLIARD, A. 2018. A practical guide to cardiovascular 3D printing in clinical practice: overview and examples. Journal of Interventional Cardiology, 31, 375-383.

ADELMAN, D. E. & DEANGELIS, K. L. 2007. Patent metrics: the mismeasure of innovation in the biotech patent debate. Texas Law Review, 85, 1677-1744.

AHADIAN, S. & KHADEMHOSSEINI, A. 2018. A perspective on 3D bioprinting in tissue regeneration. Bio-Design and Manufacturing, 1, 157-160.

ARROW, K. J. 1962. Economic welfare and the allocation of resources for invention. In: NELSON, R. R. (ed.) The rate and direction of inventive activity. New York: Princeton University Press.

BAUER, H.-K., HELLER, M., FINK, M., MARESCH, D., GARTNER, J., GASSNER, U. M. & AL-NAWAS, B. 2016. Social and legal frame conditions for 3D (and) bioprinting in medicine. International Journal of Computerized Dentistry, 19, 293-299.

BICUDO, E. 2011. "Geographical randomization" and "Social exploitation" in clinical research: world trials in Santiago, Chile. Health and Place, 17, 807-813.

BICUDO, E. 2014. Pharmaceutical research, democracy and conspiracy: international clinical trials in local medical institutions, London, Gower/Ashgate.

BICUDO, E. 2018. 'Big data' or 'big knowledge'? Brazilian genomics and the process of academic marketization. BioSocieties, 13, 1-20.

BOUCHARD, R. 2012. Patently innovative: how pharmaceutical firms use emerging patent law to extend monopolies on blockbuster drugs, Amsterdam, Elsevier Science.

BROWN, N. & MICHAEL, M. 2003. A sociology of expectations: retrospecting prospects and prospecting retrospects. Technology Analysis & Strategic Management, 15, 3-18.

BUSFIELD, J. 2006. Pills, power, people: sociological understandings of the pharmaceutical industry. Sociology - the Journal of the British Sociological Association, 40, 297-314.

CASTRO, J. O., RAMESAN, S., REZK, A. R. & YEO, L. Y. 2018. Continuous tuneable droplet ejection via pulsed surface acoustic wave jetting. Soft Matter, 14, 5271-5277.

DAVIS, C. & ABRAHAM, J. 2013. Is there a cure for corporate crime in the drug industry? BMJ, 346, 1-2.

DIXON-WOODS, M., ANGELL, E., ASHCROFT, R. E. & BRYMAN, A. 2007. Written work: The social functions of Research Ethics Committee letters. Social Science & Medicine, 65, 792-802.

FAULKNER, A. 2009. Medical technology into healthcare and society: a sociology of devices, innovation and governance, London, Palgrave.

FAULKNER, A. 2012. Law's performativities: shaping the emergence of regenerative medicine through European Union legislation. Social Studies of Science, 42, 753-774.

FREEMAN, C. 1987. Technology and economic performance: lessons from Japan, London, Pinter.

FROMHOLD-EISEBITH, M. 2007. Bridging scales in innovation policies: how to link regional, national and international innovation systems. European Planning Studies, 15, 217-233.

GARCIA-GARCIA, L. A. & RODRIGUEZ-SALVADOR, M. 2018. Uncovering 3D bioprinting research trends: a keyword network mapping analysis. International Journal of Bioprinting, 4, 1-8.

GARDNER, J., SAMUEL, G. & WILLIAMS, C. 2015. Sociology of low expectations: recalibration as innovation work in biomedicine. Science, Technology and Human Values, 40, 998-1021.

GRABOSWKI, H. 2002. Patents, innovation and access to new pharmaceuticals. Journal of International Economic Law, 5, 849-860.

HABERMAS, J. 1996. Between facts and norms: contributions to a discourse theory of law and democracy, Cambridge, Mass., MIT Press.

HARRISON, C. 2019. Berkeley strikes back in CRISPR patent tussle. Nature Biotechnology, 37, 338-339.

HARVEY, M. & MCMEEKIN, A. 2005. Brazilian genomics and bioinformatics: instituting new innovation pathways in a global context. Economy & Society, 34, 634-658.

HELLER, M. A. & EISENBERG, R. S. 1998. Can patents deter innovation? The anticommons in biomedical research. Science, 280, 698-701.

HIRST, P. 1977. On law and ideology, London, Palgrave Macmillan.

HORNICK, J. F. & RAJAN, K. 2016. The 3D bioprinting patent landscape takes shape as IP leaders emerge. 3D Printing Industry. Available at: http://3dprintingindustry.com/news/3d-bioprinting-patent-landscape-takes-shape-ip-leaders-emerge-84541/ [Online].

HUMPHREYS, S. 1985. Law as discourse. History and Anthropology, 1, 241-264.

KELLY, E. 2018. FDA Regulation of 3D-printed organs and associated ethical challenges. University of Pennsylvania Law Review, 166, 515-545.

KESSELHEIM, A. & AVORN, J. 2009. Using patent data to assess the value of pharmaceutical innovation. Journal of Law Medicine & Ethics, 37, 176-183.

KUMAZAWA, R. 2017. Patenting in the pharmaceutical industry. In: PRABU, S. L. & SURIYAPRAKASHA, T. N. K. (eds.) Intellectual Property Rights. London: IntechOpen.

LAFFONT, J.-J. & TIROLE, J. 1991. The politics of government decision-making: a theory of regulatory capture. The Quarterly Journal of Economics, 106, 1089-1127.

LAKOFF, A. 2005. Pharmaceutical reason: knowledge and value in global psychiatry, Cambridge/New York, Cambridge University Press.

LATOUR, B. 1987. Science in action: how to follow scientists and engineers through society, Cambridge, Harvard University Press.

LEVIN, R. C., KLEVORICK, A. K., NELSON, R. R. & WINTER, S. G. 1987. Appropriating the returns from industrial research and development Brookings Paper on Economic Activity, 3, 783-820.

LEVINE, M. E. & FORRENCE, J. L. 1990. Regulatory capture, public interest, and the public agenda: toward a synthesis. Journal of Law, Economics & Organization, 6, 167-198.

LI, P. & FAULKNER, A. 2017. 3D bioprinting regulations: a UK/EU perspective. European Journal of Risk Regulation, 8, 441-447.

LI, P., FAULKNER, A. & MEDCALF, N. 2020. 3D bioprinting in a 2D regulatory landscape: gaps, uncertainties, and problems. Law, Innovation and Technology, 12.

LIM, D. 2018. Disruption and development: the evolving CRISPR patent and technology landscape. Pharmaceutical Patent Analyst, 7, 141-145.

LUHMANN, N. 1972. A sociological theory of law, London/Boston, Routledge & Kegal Paul.

MA, X., LIU, J., ZHU, W., TANG, M., LAWRENCE, N., YU, C., GOU, M. & CHEN, S. 2018. 3D bioprinting of functional tissue models for personalized drug screening and in vitro disease modeling. Advanced Drug Delivery Reviews, 132, 235-251.

MALERBA, F. 2002. Sectoral systems of innovation and production. Research Policy, 31, 247-264.

MANSFIELD, E. 1986. Patents and innovation: an empirical study. Management Science, 32, 173-181.

MIRONOV, V., KASYANOV, V., DRAKE, C. & MARKWALD, R. R. 2008. Organ printing: promises and challenges. Regenerative Medicine, 3, 93-103.

NELSON, R. R. 1993. National innovation systems. a comparative analysis, New York/Oxford, Oxford University Press.

NICOL, D. 2009. Strong patent rights, weak patent standards and innovation in biomedicine. In: ARUP, C. & VAN CAENEGEM, W. (eds.) Intellectual property policy reform: fostering innovation and development. Cheltenham: Edward Elgar.

NORDHAUS, W. D. 1969. Invention, growth, and welfare: a theoretical treatment of technological change, Cambridge, MIT Press.

ORGANISATION FOR ECONOMIC COOPERATION AND DEVELOPMENT (OECD) 1997. National innovation systems. Paris: Organisation for Economic Cooperation and Development (OECD). Available at: http://www.oecd.org/science/inno/2101733.pdf.

PATEL, P. & PAVITT, K. 1994. The nature and economic importance of national innovation systems. STI Review, 14, 9-32.

PELTZMAN, S. 1976. Toward a more general theory of regulation. Journal of Law and Economics, 19, 211-240.

PETRYNA, A. 2009. When experiments travel: clinical trials and the global search for human subjects, Princeton/Oxford, Princeton University Press.

PRIOR, L. 2008. Repositioning documents in social research. Sociology, 42, 821-836.

QIAN, Y. 2007. National patent laws stimulate domestic innovation in a global patenting environment? A cross-country analysis of pharmaceutical patent protection, 1978-2002. Review of Economcis and Statistics, 89, 436-453.

RAJAN, K. S. 2003. Genomics capital: public cultures and market logics of corporate biotechnology. Science as Culture, 12, 87-121.

ROBERTS, M., WALL, I. B., BINGHAM, I., ICELY, D., REEVE, B., BURE, K., FRENCH, A. & BRINDLEY, D. A. 2014. The global intellectual property landscape of induced pluripotent stem cell technologies. Nature Biotechnology, 32, 742-748.

RODRÍGUEZ-SALVADOR, M., RIO-BELVER, R. M. & GARECHANA-ANACABE, G. 2017. Scientometric and patentometric analyses to determine the knowledge landscape in innovative technologies: the case of 3D bioprinting. Plos One, 12, 1-22.

ROSEMANN, A. & CHAISINTHOP, N. 2016. The pluralization of the international: resistance and alter-standardization in regenerative stem cell medicine. Social Studies of Science, 46, 112-139.

ROSEMANN, A., VASEN, F. & BORTZ, G. 2019. Global diversification in medicine regulation: insights from regenerative stem cell medicine. Science as Culture, 28, 223-249.

SALTER, B., ZHOU, Y., DATTA, S. & SALTER, C. 2016. Bioinformatics and the politics of innovation in the life sciences: science and the state in the United Kingdom, China, and India. Science, Technology & Human Values, Online first, 1-34.

SCHERER, F. M. 1972. Nordhaus's theory of optimal patent life: a geometric reinterpretation. The American Economic Review, 62, 422-427.

SCHWARTE, L. 2005. Anatomical theatre as experimental space. In: SCHRAMM, H., SCWARTE, L. & LAZARDZIG, J. (eds.) Collection - Laboratory - Theatre: scenes of knowledge in the 17th century. Berlin: Walter de Gruyter.

SHAH, S. 2006. The body hunters: testing new drugs on the world's poorest patients, New York/London, New Press.

STIGLER, G. J. 1971. The theory of economic regulation. The Bell Journal of Economics and Management Science, 2, 3-21.

TANG, W. 2013. Revitalizing the patent system to incentivize pharmaceutical innovation: the potential of claims with means-plus-functions clauses. Duke Law Journal, 62, 1069-1108.

TAYLOR, C. T. & SILBERSTON, Z. A. 1973. The economic impact of the patent system, Cambridge, Cambridge University Press.

VAN LENTE, H. 2012. Navigating foresight in a sea of expectations: lessons from the sociology of expectations. Technology Analysis & Strategic Management, 24, 769-782.

WITTGENSTEIN, L. 1922. Tractatus logico-philosophicus, London, Kegan Paul.

YOO, S.-S. 2015. 3D-printed biological organs: medical potential and patenting opportunity. Expert Opinion on Therapeutic Patents, 25, 507-511.