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Asymmetric Power of the Core: Technological Cooperation and Technological Competition in the Transnational Innovation Networks of Big Pharma

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ABSTRACT

This article theoretically and empirically analyzes leader corporations' innovation processes in contemporary capitalism. We highlight three characteristics: their transnational scope, the primacy of power or asymmetric relations exercised by leaders over the participants of their innovation circuits or networks, and the relevance of what we called technological competition and technological cooperation between leaders. Focusing on the latter, our theoretical contribution integrates the concepts of innovation circuit, global innovation network and modularity of knowledge production in order to elaborate a preliminary model for synthesizing leader's technological competition and collaboration behaviors. This model is the general framework used for studying three big pharma's innovation networks (Roche, Novartis and Pfizer). In particular, we study those networks by considering two outputs: scientific publications and patents. Network maps are constructed based on institutions' co-occurrences, thus looking at who is co-authoring their publications and co-owning these corporations' patents. We find that big pharmaceuticals co-produce together mainly generic knowledge modules, thus develop a strong technological cooperation. Simultaneously, to succeed in their technological competition they outsource stages of their innovation networks to subordinate institutions that, even if they contribute to achieve the innovation, will not be co-owners of the resulting patents, while big pharmaceuticals enjoy associated innovation rents.

KEYWORDS

Intellectual monopoly; technological competition; technological cooperation; innovation networks; innovation rents; pharmaceutical industry

1. Introduction

This article theoretically and empirically analyzes leader corporations' innovation processes in contemporary capitalism. We highlight three characteristics: their transnational scope, the primacy of power or asymmetric relations exercised by leaders over the rest their innovation circuits or networks' participants, and the relevance of what we called technological competition and technological cooperation between leaders. These features are a blind spot of the literature on innovation.

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Among the latter, the national innovation system (NIS) framework (Freeman, 1987; Lundvall, 1985, 1992; Nelson, 1993) is widely disseminated in the scientific literature and within international organizations and States' reports. It focuses on the interrelations between firms, the State and research institutions (in particular universities) that contribute to the production of innovations. Nevertheless, in accordance with Lane (2007), we argue that approaches circumscribed to a national sphere need to be reviewed in the light of globalization. In the case of the NIS, the three poles are now articulated on a transnational scale and through multiple power or asymmetric relations. Therefore, concentrating solely on a national scale and neglecting those power relations appears as a limitation of this framework.[1] On the contrary, concepts designed to explain the transnational dynamics of capitalism, such as global value chains (GVC), seem relevant to take up the analysis of leaders' innovation processes, including their national effects.

In this article, we will contribute to the GVC framework, pioneered by Gereffi et al. (1994) and Gereffi (1996) who originally called them Global Commodity Chains, by theoretically and empirically reconceiving leaders as innovation or intellectual monopolies that organize innovations as transnational and modular processes. A contribution of this article is to show how the modules or stages of a leader's innovation networks are alternatively in technological cooperation or technological competition with other leaders.

In order to develop our theoretical contribution, we will integrate two approaches on innovation with a more general framework focused on the modularization of knowledge production. We consider global innovation networks (Ernst, 2008, 2009, 2016) and innovation circuits (Rikap, 2018; Levín, 1977; Piqué, 2016) as structures conceived to explain the transnational scope of innovation production processes where power is exercised by leaders on the rest of the involved actors. Furthermore, both concepts stress on the division of innovative labor which can also be traced in the studies on how (scientific and technological) knowledge production became an increasingly modular process (Arora & Gambardella, 1994; Arora, Gambardella, & Rullani, 1997).

For each innovation, we will state that a circuit is organized involving more or less connected actors. The circuit consists of a series of stakeholders (leaders, start-ups, private and public laboratories for research and development, universities, etc.) whose participation in the innovation process is planned by the leader. The leader is at the center of each circuit and reaps out its main returns (Rikap, 2018). Planning is understood here as a relationship of both technological and economic domination. In addition, global innovation networks focus on the division of the innovation process into specialized tasks in order to enable its realization by distinct and geographically dispersed actors that have institutionalized an innovation production partnership (Ernst, 2009). Thus, we may say that if a leader systematically outsources to the same actors steps or modules of different innovation circuits, it will develop an institutionalized relationship with them, conforming altogether an innovation network led by that leader.

As we previously stated, we aim to show how knowledge modularity opens the gate for technological cooperation between leaders. Generic modules may be co-produced by multiple leaders and then integrated and combined with other equally generic or more specific modules belonging to these leaders' different innovation circuits. Furthermore, we will explain that leaders not only cooperate for the

production of certain knowledge modules but also compete for technology. Public research organizations, in particular universities and their hospitals, together with smaller Research & Development (R&D) laboratories participate in this process and we will argue that they do so in a subordinated way. Hence, leaders cooperate and compete for technology alternatively in different stages of their innovation circuits.

The pharmaceutical industry is paradigmatic for studying the aforementioned traits of innovation in contemporary capitalism. In fact, leaders' innovation processes in this industry have been reorganized and made more complex in this century in line with the exhaustion of the blockbuster model (Angell, 2004; Khanna, 2012; Orsi, Moatti, Eisinger, & Chabannon, 2000; Rai, 2007; Tralau-Stewart, Wyatt, Kleyn, & Ayad, 2009). As a result, following the literature on this industry, big pharmaceuticals that are focused on patented prescription drugs can be considered as leaders planning innovation circuits that are sometimes institutionalized in global (or at least transnational) innovation networks (Baranes, 2017; Khanna, 2012; Lane, 2007).

To conduct our study we selected three big pharmaceuticals with the highest cumulative R&D expenditure throughout our analyzed period defined as 2008–2017 included: Roche, Novartis and Pfizer. We built network maps for studying the dynamics and participating actors of their innovation networks. We used Web of Science and Derwent Innovation databases which provide detailed information on two innovation network outcomes: scientific publications and patents. Certainly, not every scientific publication is a preliminary result of an innovation circuit and probably most of them are not. Nevertheless, it seems reasonable to conceive big corporations' scientific publications as outcomes of their innovation circuits since leaders get involved in scientific research as long as it contributes to achieve innovations. Thus, if we strictly look at a leader's publications, they will be a partial depiction of the actors and subjects involved in its innovation circuits. In particular, looking at most frequent co-authors provides information about leaders' institutionalized innovation networks.

Our co-publication results point to the richness of our general framework since, as shown later, each map depicts a technological cooperation cluster between big pharmaceuticals, and multiple clusters where the selected leader works with subordinated organizations in what could be described as technological competition clusters. Furthermore, the comparison between co-publications and co-patenting networks will also shed light on who contributes to innovation circuits and who profits from them showing how universities (and public research organizations in general) occupy an almost neglected position in co-patenting maps (thus do not enjoy innovation rents), while they are indispensable in the research process that leads to those patents. This result contributes to explain power relations within innovation circuits and networks.

The rest of this article is organized as follows. Section 2 elaborates on our theoretical framework for understanding innovation dynamics in contemporary capitalism. Section 3 briefly overviews the transformations of the pharmaceutical industry since the 2000s, and Section 4 presents our methodology and empirical results. Final remarks and our future research agenda conclude this article in Section 5.

2. The transnational and modular traits of innovation conceived as an asymmetric production relation

In this section, we argue that understanding innovation's transnational dynamics requires to go beyond frameworks that focus on national states and requires a deep study of power relations within the innovation process. This is particularly relevant since the emergence of GVCs (Gereffi et al., 1994, Gereffi 2014; Gereffi, Humphrey, & Sturgeon, 2005; Ponte & Sturgeon, 2014; Sturgeon, 2009) or Global Production Networks (Mahutga, 2014; Neilson, Pritchard, & Yeung, 2014; Parrilli, Nadvi, & Yeung, 2013; Rainnie, Herod, & McGrath-Champ, 2013; Smith, Pickles, Buček, Pástor, & Begg, 2014) because, as noted by Baldwin (2014, p. 41), transnational supply chains do not only concern trading intermediate goods, but also deploying intangible assets, particularly innovation and know-how, all along the chain. In this sense, they developed what the author has called a 'trade-investment-services-intellectual-property (IP) nexus'. Indeed, Durand and Milberg's (2018) findings support the hypothesis that increasing GVC trade and the expansion of stricter Intellectual Property Rights (IPR) are reinforcing each other, even if it should be noted that innovation cannot be reduced to IPR.

We conceive innovations as the creation of a new production technique, whether it is a more efficient way of producing the same product or a technique for producing previously inexistent products, including the creation of a new market (see also Fagerberg, Fosaas, & Sapprasert, 2012; Mazzucato, 2015). Furthermore, according to Lazonick (2005), the innovative firm transforms productive resources under its control into higher quality and/or lower cost products that were unavailable before. Hence, innovations are not only the result of engineering transformations but also new designs.[2]

Drawing on Ernst (2009), we may distinguish between science based and non-science based innovations. While the former points to major innovations, the latter refers to new techniques that are produced inside the production unit by using existing capacities in a novel way. Science based innovations are frequent in industries with a prevalent analytical knowledge base as is the case of the pharmaceutical industry, while non-science based innovations can be considered as the prevalent innovation type in industries with a predominant synthetic knowledge or engineering base (Asheim, Coenen, & Vang, 2007; Liu, Chaminade, & Asheim, 2013).

Innovations provide monopoly power evidenced by the generation of a particular form of rent (Kaplinsky, 1998). Hence, innovations engender an asymmetric relation between the innovator and those still producing with an old technique. If we initially assume, like Kurz (2017), that innovations' monopoly power is temporary because it will eventually be eroded by competing ideas, thus associated rents will eventually vanish. However, as it was explained more in-depth in Rikap (2018), it is possible to conceive that some haphazardly successful individual capitals, before exhausting (most probably science based) innovation rents, may decide to reinvest at least part of those profits in R&D. A second consecutive success, achieved before the rest of the industry has completed the adoption of the first technical change, will lead to a renewal of that process and so on. In other words, after innovating, instead of using all its associated rent to further extend capital accumulation (or alternatively pay more to shareholders), this firm will privilege the development of new potential innovations. If successful, they will expand

innovation rents in time, leading to the formation of intellectual or innovation monopolies.[3]

As shown by Dosi (1988), since innovation is a cumulative process with economies of scale, copies demand minimum knowledge thresholds. This leaves big corporations in a better position to appropriate their own and others' innovation rents. Indeed, as explained by Pagano (2014, p. 1423), firms that have more 'intellectual endowments will continue to do (possibly increasingly) better than those lacking this monopoly power'. Furthermore, Noel and Schankerman (2013, p. 514) found that 'patenting by technology rivals reduces the firm's Research and Development (R&D) investment, patenting and market value'.

We believe these conditions contribute to explain how, once a firm started to systematically win the innovation race, the resulting gap with its industry widens. It is the capacity to monopolize innovation in a branch and not the limited impact of innovations as particular hits, what we conceive as a source of a lasting power that engenders leaders, while reducing the innovative capacity of the rest of the industry (Rikap, 2018).[4] The resulting concentration of higher profits due to a systematic renewal of innovation rents facilitates intellectual monopolies' perpetuation, while lower profits for the rest of the industry diminish these firms' capacity to catch up. Empirical evidence based on the distribution of cash holdings by US corporations suggests that profit differentials are indeed explained by an uneven distribution of intellectual property rights. Firms owning more IPR enjoy greater cash holdings which accounts for greater profits. Concerning our chosen industry, by 2014, four of the top ten US corporations by cash holding were big pharmaceuticals (Schwartz, 2016).

It must be noted that intellectual monopolies do not arise from isolated innovations which are porous entry barriers, as explained by Moudud (2013). In our explanation, entry barriers are constantly reinforced after each innovation. Therefore, the constant flow of innovations for some enterprises overcomes entry barriers' porosity. As a result, polarization arises from the differences in firms' innovativeness engendering leaders that are intellectual or innovation monopolies (Levín, 1997; Pagano, 2014). As synthesized by Durand and Milberg (2018, p. 9), 'the market power of lead firms is enhanced by intellectual monopoly, which is fueled by a combination of dynamic advantages arising from GVCs network externalities and increasing returns on intangibles and legally-enforced proprietary control over standards, technologies and brands'.

In this context, serendipity or haphazard innovations are still feasible, but the maximum aspiration of whoever produces them (if it is not a leader) will be to sell them to an intellectual monopoly. Otherwise, it will have slimmer chances to profit from that success.

Leaders must have had a systemic internal capacity to innovate for initially differentiating from other enterprises in their branch. Nevertheless, once they become intellectual monopolies, innovations are not compelled to be produced (at least not entirely) inside their R&D laboratories. Along the different stages of an innovation process, they can outsource capital (Ernst, 2008, 2009; Parrilli et al., 2013). This process has been the object of both innovation circuits (Levín, 1977) and global innovation networks (Ernst, 2009; Liu et al., 2013). Moreover, both approaches are completely in line with the idea of a new division of innovative labour that is

feasible due to the larger use of general or abstract knowledge for innovating (Arora & Gambardella, 1994; Arora et al., 1997).

Innovation circuits were initially defined by Levín (1977) as the interlocking of all the actors and institutions that produce an innovation (ranging from marginal or non-science based to science based projects) through integrated and planned steps. All the institutions involved in the innovation process, from the basic research discovery to the required industrial adaptations to adopt the innovation, participate in innovation circuits (Cazenave & Gonilski, 2016; Levín, 1977). In accordance, global innovation networks focus on how 'innovation is being sliced and diced into modular building blocks of specialized tasks for geographically dispersed R&D teams' (Ernst, 2009, p. 3).

The growing modularity of innovation processes (in particular in the case of science based innovations) is a trait that has also been observed by Arora and Gambardella (1994) and by Arora et al (1997). According to these authors, innovations can be conceived as a twofold process integrating the production of modules and their combination. The former 'is the production of basic knowledge components, of "general-purpose" technologies or of basic product designs' which are then combined to achieve tailored applications (Arora et al., 1997, p. 125). The high investment needed to produce generic modules leads to think that they will be produced by fewer big corporations while their combination can be more decentralized. This modularity of knowledge was triggered by advancements in scientific disciplines together with specific innovations in computational capabilities and the instruments used to perform experiments, analyze and record results (Arora & Gambardella, 1994). Once knowledge is modularized, it can be produced anywhere. In fact, innovation circuits can have a global, transnational, regional, national or local scale.

Even if multiple actors from different parts of the world participate in the innovation process, these approaches agree on giving a central role to the leader or multinational corporation who, as stated by Levín (1997), plans and dominates innovation circuits. In accordance, Ernst (2009) observes that global innovation networks are created by global corporations to increase their return on investment, among others by penetrating high-growth emerging markets. Contrary to intellectual monopolies, companies that produce at least one stage of an innovation circuit but lose its associated rent – which is collected by intellectual monopolies – were initially called by Levín (1997) technological capital enterprises. Start-ups are an archetypical example of these enterprises.

The concepts of innovation circuit and global innovation network complement each other. While the former is conceived to describe the uniqueness of each innovation as a creative process organized by leaders through uneven or power relations, the latter highlights the institutionalization of those relationships showing how certain actors have become systematic participants of a leader's innovation circuits, thus conforming an innovation network.

By organizing multiple innovation circuits, intellectual monopolies simultaneously control and orient R&D in order to preserve their position of power. They provide the general orientations and desired results to the rest of the circuit, of course without being able to anticipate every step that needs to be followed in order to achieve those results and leaving degrees of autonomy to subordinated actors. The results remain uncertain, but the associated economic risk is diverted by leaders to other participants, eliminating a source of exit barriers (Rikap, 2018).

Not only private firms participate in innovation circuits as technological capital enterprises. In fact, Rikap (2017) has explained that universities and public research organizations can also occupy this subordinated position. Furthermore, national states have been among the risk-takers. They have been major R&D investors especially of the most radical and path-breaking innovations without enjoying their associated profits (Barringer & Slaughter, 2016; Mazzucato, 2015, Chapter 3). We may say that when the state organizes the innovation process and enjoys the associated profits it will be acting as a value chain leader. When it does not, it will end up producing key modules for big multinational corporations, as shown by Mazzucato (2015).

In this article we contribute to this literature by arguing that leaders share the production and planning of certain stages or modules. We conceive technological cooperation as the intersection of multiple innovation circuits conducted and planned by different intellectual monopolies, thus interconnecting phases of their innovation circuits. For instance, anticipating our empirical results, we state that big pharmaceuticals cooperate in the production of the most generic knowledge modules of their innovation circuits. It may be said, thus, that we add another dimension to Munkirs and Sturgeon (1985) oligopolistic cooperation model. These authors defined oligopolistic cooperation as a market structure with structural intra-dependence based on shared administrative control, stock control and ownership of the means of production. Here we add that cooperation can also be based on the joint production of, mainly generic, knowledge modules or general-purpose technology modules (Arora & Gambardella, 1994). Nevertheless, technological cooperation may include more specific steps or modules too, and lead to jointly owned patents. Still, we may consider the latter as a less frequent strategy as we will show later in this article for the case of technological cooperation between big pharmaceuticals. While leaders cooperate in certain steps of their innovation processes, they also undertake a fierce technological competition. The latter refers to the multiple innovation circuits and modules or stages of innovation circuits planned by each leader independently, with the aim of achieving innovations to remain ahead of the rest and profit from intellectual monopolies.

Summing up, different approaches explain innovation's vertical specialization or modularity, assigning a central role to the leader who tends to be the main beneficiary of the triggered rents. Thus, we focus on GVC leaders as innovation or intellectual monopolies that have the capacity to plan innovations. The latter is in line with Munkirs's (1983) private sector planning theory where a small number of corporations, the core, plans the whole industry. Therefore, we conceive innovation as a transnational and modular process organized as an asymmetrical or power relation. From this starting point, we contribute to the literature on leader's innovation dynamics by focusing on what we have called technological cooperation and technological competition. In order to further develop this contribution, next we offer a simple model aimed at synthesizing leader's behavior towards innovation focusing on the relations within leaders, or what Munkirs's (1983) called the core.

2.1. Technological cooperation and competition between leaders: a preliminary model

We may summarize our previously explained framework as a two-period model whose main characteristics are briefly introduced in Table 1.

Table 1. A preliminary two-period model for understanding the innovative behaviors of an intellectual or innovation monopoly.

	$t=1$ (Wannabe Leader A)	$t=2$ (Leader A)
Innovation strategy	Systematic investment for in-house R&D	In house R&D is complemented by outsourcing innovation modules
Associated risk	Mainly taken by the Wannabe Leader A	Mainly taken by other participants of Leader A innovation circuits
Relation with Leaders	Technological competition	Technological competition and Technological cooperation
Innovation rents	Profits from its own/internally triggered rents	Appropriates the majority of the innovation rent of the circuits it controls.

In $t=1$, we find the inception of an intellectual monopoly, let's call it Wannabe Leader A. This period is characterized by high technological competition and in-house innovation. In order to become an intellectual monopoly, a once successful innovator needs to, at least, keep that pace. While it reinvests innovation rents in more R&D, cooperating with other leaders or with other wannabe leaders may not be its best strategy. Companies that are already enjoying intellectual monopolies will not cooperate with Wannabe Leader A but actually use their monopoly power to subordinate it. Moreover, it is complicated to see whether other companies in the same wannabe path could be more advanced in terms of their intellectual or innovation monopoly and, thus, end up subordinating Wannabe Leader A. At the other end, if these other wannabes are still far from reaching a leading position, they may not be as useful as Wannabe Leader A needs. All in all, we state that the smartest strategy is to try to achieve systematic innovations by itself, thus continuously wining the innovation race in certain industry/ies.

In $t=2$, we assume Wannabe Leader A became Leader A. Leader A is an intellectual or innovation monopoly. As a leader, outsourcing stages of the innovation process is a feasible and, actually, a convenient strategy due to its planning capacity together with knowledge modularity. Outsourcing will diminish risks, which are even higher for innovation than for reproducing already existent commodities (also outsourced forming GVC). Furthermore, its planning capacity will entitle Leader A to reap the majority of the innovation rents.

In $t=2$, Leader A competes with other leaders but not mainly in terms of price. Price is not the main variable determining its revenues. Prices are secondary because what looms large is the technological competition. The most innovative product will assure greater sales and, most important, greater profits and profit rates due to a higher innovation rent. Hence, to remain as a leader, Leader A needs to constantly and systematically plan innovation circuits. Analogously cooperation or collusion between innovation monopolies such as Leader A is not just based, as it was for instance argued by Baran and Sweezy (1966), on agreeing on the terms of sales, the dates of payments, etc. Their focus is not how to divide the market among themselves fixing prices and quantities (even if they may also agree on these), but on how to produce in a collaborative way generic modules that can be integrated to their innovation circuits (when these modules are not produced or at least funded by national states or international organizations).

Moreover, in $t=2$ both technological competition and technological cooperation are viable strategies among leaders. For more generic knowledge modules, cooperation between leaders will reduce associated risks and increase chances of success.

The intensity of this partnership will depend on the specificities of each industry worldwide. Furthermore, Leader A may have more than one technological cooperation cluster or module depending on how diversified its innovation circuits are and on the level of interconnection between the other leaders of its network.

States may also participate in these modules, generally in a subordinated position in terms of the profits they can reap out, as explained by Mazzucato (2015) for the United States. In schematic terms, once or while Leader A participates in generic knowledge modules with other leaders, Leader A (as any other intellectual monopoly) will organize other stages or modules (generic and also specific) of its innovation circuits. In these cases, results are achieved by dominating others, such as universities, public research institutions and start-ups, that are subordinated participants of Leader A's innovation circuits. These specific modules are in technological competition with the corresponding modules of other leaders in the same industry (or in a close industry, since innovation reconfigures industry's frontiers). Furthermore, Leader A can foster competition between modules that belong to its innovation circuit as a means to accelerate achievements.

In time, different stages or modules will be combined by Leader A finishing the innovation circuit. When successful, specific clusters lead to innovations that may or may not be patented, depending on the characteristics of the innovation and of the industry. In the pharma case, patenting is almost always the end of the circuit since otherwise it would be easy to copy achieved results. At the same time, Leader A may have already started other innovation circuits with the same or a different mix of participants. When it persistently chooses the same partners, it builds innovation networks where this technological cooperation and competition logics prevail.

Since all the modules that are combined to arrive to an innovation can be produced in different or the same moments in time (thus we are not following a linear model of innovation), Leader A's strategic behavior could be better illustrated without a chronology. Figure 1 depicts a simple sketch of Leader A's innovation strategies in $t = 2$. We see a cluster relating Leader A with other leaders. This cluster mainly concentrates generic modules that are produced through technological cooperation between leaders. They may include the creation of new regulations affecting the whole industry, as we will see for the pharma industry next. These generic modules that are produced as a technological cooperation open multiple innovation paths pursued by different leaders. In the case of Leader A, together with this cluster, we observe different specific clusters where it relates with other organizations that are not leaders but subordinated institutions. These multiple clusters may include both more fundamental and more applied knowledge. Clusters depict integrated institutions that work together in a systematic or persistent way at least for a certain period of time, thus conforming Leader A innovation network.

All in all, we consider that this framework is richer than the NIS for understanding transnational innovation dynamics. It overcomes the contradiction between conceptualizing innovation as nationally bounded and its actual transnational scope, which has been recognized as a limitation even by authors within the NIS approach (Soete, 2009). Moreover, we also address another aspect of innovation processes neglected when thinking in terms of NIS, which focuses on

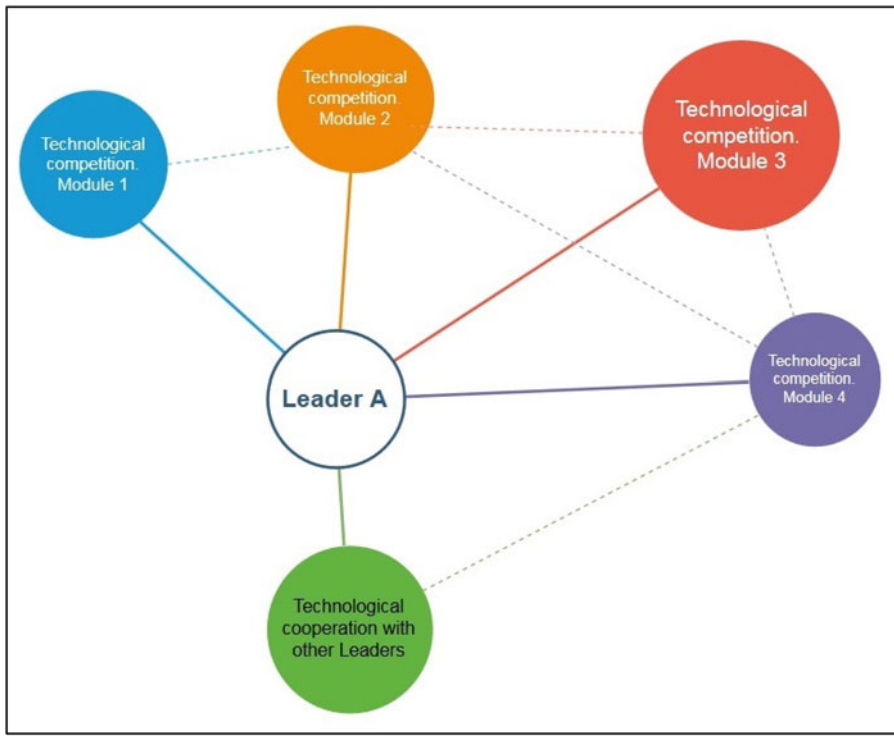

Figure 1. Innovation or intellectual monopoly strategic behavior: a simple sketch.

the links and not on the actors: the power relations that take place within innovation processes (Versino and Guido y Di Bello, 2012; Rikap, 2018).

One last point should be raised. Even if innovation is produced in multiple geographies, the relevance of national regulations as well as science, technology and innovation policies should not be neglected. More in general, national regulatory structures have international implications.

Concerning national regulations, our results support the idea that in a transnational innovation context dominant countries' regulations have transnational implications (Farrell & Newman, 2010) and could become the global benchmark. Indeed, as pointed out by Lane (2007), this is the case of the United States in the pharmaceutical industry; the country with the most important research collaborations. In line with Farrell and Newman's (2010) analysis, we may add that the United States managed to use a domestic institution, the United States Food and Drug Administration (USFDA), to externalize its national rules at a global scale. In our empirical analysis, we will emphasize on the role of the USFDA as a member of big pharma's technological cooperation cluster.

3. Big pharma innovation dynamics

In the rest of this article we will illustrate the richness of our framework by analyzing innovation processes in the prescription drug pharmaceutical industry. This

can be considered as an illustrative case of an industry organized by multiple GVCs, each led by a different company that has monopolized innovation over certain drugs. Indeed, this industry has been conceptualized as led by a powerful core with 'a supporting nexus that carries out commands' (Baranes, 2016, p. 82). Baranes (2016) observes that since the 1990s, even if the pharmaceutical industry was growing in number of firms due to the biotechnology revolution, this industry's core concentration ratio was increasing. The pharmaceutical core is characterized, according to the author, by their autonomous capacity to steer the industry, organizing all the processes that go from discovery to the distribution of new drugs.

This industry is among the most innovative, both in terms of number of patents and worldwide investment in R&D. Therefore, it is an illuminating case for studying innovation as transnational, modular (distinguishing between technological cooperation and competition between leaders) and developed through power or asymmetric relations. We will focus on three big pharmaceuticals. Roche (7th global in 2017), Novartis (10th global in 2017) and Pfizer (14th global in 2017) had the highest R&D expense of the industry between 2008 and 2017.[5] They are among the largest pharmaceutical companies in the world in terms of revenues and profits, and belong to this industry's core (Baranes, 2016) (Table 2).

We conceive these big pharmaceuticals as intellectual or innovation monopolies, thus innovation should be performed party by outsourcing stages to less powerful stakeholders around the world. In particular, public research organizations, universities and start-ups. From a historical perspective, even if collaborations between pharmaceuticals and public researchers date from the beginning of last century, according to the pharmaceutical industry expert Khanna (2012), the nature of this relationship has recently changed. Until the 2000s, academy and industry in this sector worked independently. The former was in charge of basic research and, when results were promising enough, they licensed them to the latter who tried to turn them into marketable drugs. The author explains that in this century these actors became intertwined. Therefore, intertwining should be observed in significant co-publication relations between big pharmaceuticals and universities (as well as public research organizations), as we depict next.

As universities were seeking to increase their collaborations with pharmaceuticals in part due to tightened research budgets, pharmaceutical leaders also reconfigured their innovation strategies in a context of blockbuster patents' expiration and consequent growth of generics' market (Abecassis & Coutinet, 2008). Big pharmaceuticals deconcentrated or outsourced research functions, as well as other activities or parts of their production process (Abecassis & Coutinet, 2006; Baranes, 2016; Danzon, Nicholson, & Pereira, 2005; Lane, 2007).

Table 2. Basic figures chosen big Pharma (in USD).

	Country of origin	Cumulative sales revenues (2008–2017)	Cumulative R&D investment (2008–2017)	Scientific publications (2008–2017)	Corporate Tree Granted Patents (2008–2017)
Roche	Switzerland	505,412 b$	98,305 b$	17 717	8 518
Novartis AG	Switzerland	509,056 b$	87,406 b$	10 895	5 948
Pfizer	United States	547,887 b$	81,774 b$	20 170	3 332

Source: Compustat, Web of Science and Derwent Innovation.

By conforming innovation circuits, big pharmaceuticals gather the major part of their innovation rents when hits are accomplished, while the risk of drug failure is significantly reduced by outsourcing research (Lane, 2007). Furthermore, pharmaceutical leaders can control, or at least influence, the research done by scholars and start-ups (such as biotechnology firms). Their structural power in innovation circuits was shown by Lane (2007) in his study of the licensing deals between those smaller actors and big pharmaceuticals from the United Kingdom (UK) and Germany who maximize value extraction from those deals.

Research outsourcing takes place across national borders. Still, UK and German big pharmaceuticals mainly outsource in the triad region (US, Europe and Japan) with a higher focus on the US (Lane, 2007). As Angell (2004) had pointed out, our results will reinforce the explanation that big pharmaceuticals are based in the US because there they can profit from successful public research, both from universities and the National Institute of Health. Anyway, European efforts are also seen in these fields. In fact, Europe holds the largest public-private partnership in life sciences, the Innovative Medicines Initiative (IMI).[6]

While vertically deconcentrating capital, big pharmaceuticals kept horizontally centralizing by mergers and acquisitions (M&A). In the last two decades, major deals included Pfizer acquisition of Warner-Lambert (USD 122.8 bn, in 1999), Pharmacia (USD 64.3 bn, in 2002) and Wyeth (USD 64.2 bn, in 2009). Moreover, Roche acquired Genetech in 2008 in a USD 44 bn deal. M&A are a structural feature of this industry. Recent purchases also included Sanofi merger with Aventis in 2004 (USD 51.5 bn), Merck acquisition of Schering-Plough in 2009, Actavis acquisition of Allergan in 2014, Bayer acquisition of Monsanto in 2016, and CVS acquisition of Aetna in 2017.[7]

Furthermore, this tendency will continue in the near future and in spite of the greater centralization that resulted from those and other M&A and a slowdown in total acquisitions due to geopolitical uncertainties, such as concerns on global economic growth, Brexit and US-China trade war.[8] Two major deals were announced by the end of 2018 and beginning of 2019: Bristol-Myers Squibb acquisition of Celgene, a bio-technology company, and Takeda's takeover of Shire. While the former responds to a paramount race among big pharma for new blockbuster cancer drugs, the latter was focused on ultra-rare diseases.[9]

In this industry, M&A are based on the analysis of the patent portfolio of the to-be-acquired corporation, but they are also used as a means to increase stock value in the short-term (Baranes, 2016). Horizontal M&A -particularly of biotechnology companies- are combined with vertical R&D outsourcing to leading academic institutions and start-ups. Seeing together, both tactics highlight big pharmaceuticals' innovation strategy: profit from others' earlier research before engaging. In this respect, big pharmaceuticals fit Baranes's (2017) characterization of rent-collecting corporations.

To sum up, we are looking at an industry that could accurately be described by our proposed framework with leaders already settled in $t = 2$ in terms of our model. To do so, in the next section we study two main outputs of innovation circuits, which are globally measured: scientific publications and patents. Hence, we will not capture all the stages or modules of chosen big pharmaceuticals' innovation circuits, but only those that have a publication and/or patent as a result. For instance, we are not considering where the clinical trials take place. Simplifying our

analysis, we may say that we are looking at intermediate results of innovation circuits, which are typically published in scientific articles, and to the final step of the circuit which, in this particular industry, requires patenting.

4. Empirical analysis

Our empirical analysis will be organized as follows: we will focus on chosen pharmaceuticals' published articles and patents between 2008 and 2017. We will use Web of Science and Derwent Innovation[10] databases, both provided by Clarivate Analytics. In the case of scientific publications, we study the co-occurrences of authors' affiliations (research institutions), and we look at the co-occurrences of assignees, for the case of granted patents.

Considering M&A as well as how big pharmaceuticals sometimes operate under different company names, we used the corporate tree tool provided by Clarivate Analytics. For each company we retrieved all the patents and publications that corresponded to each chosen big pharmaceutical's tree. For instance, as we previously mentioned Genentech was acquired by Roche in 2009, while Alcon, Sandoz and Ciba-Geigy are examples of enterprises that were acquired by Novartis. Moreover, Medivation Prostate Therapeutics and Wyeth are some of the companies that were acquired by Pfizer.

Data was processed using CorText platform.[11] We built co-occurrence maps. As explained by Barbier et al (2012) these maps are built by using specific algorithms

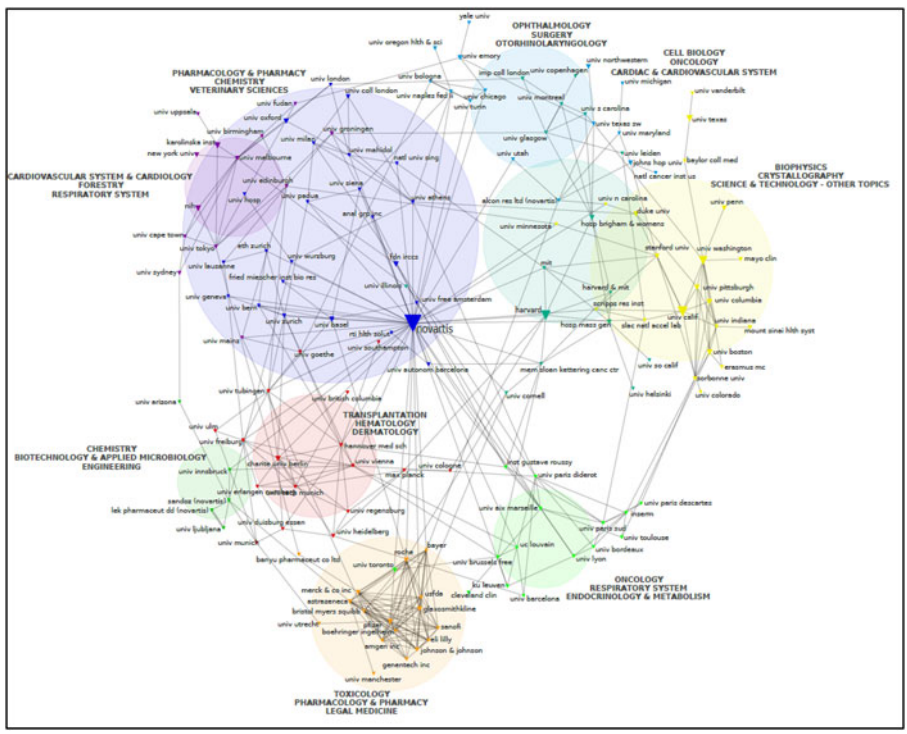

Figure 2. Top 150 research institutions. Novartis's Publications (2008–2017). Source: Author's analysis based on Web of Science data extraction.

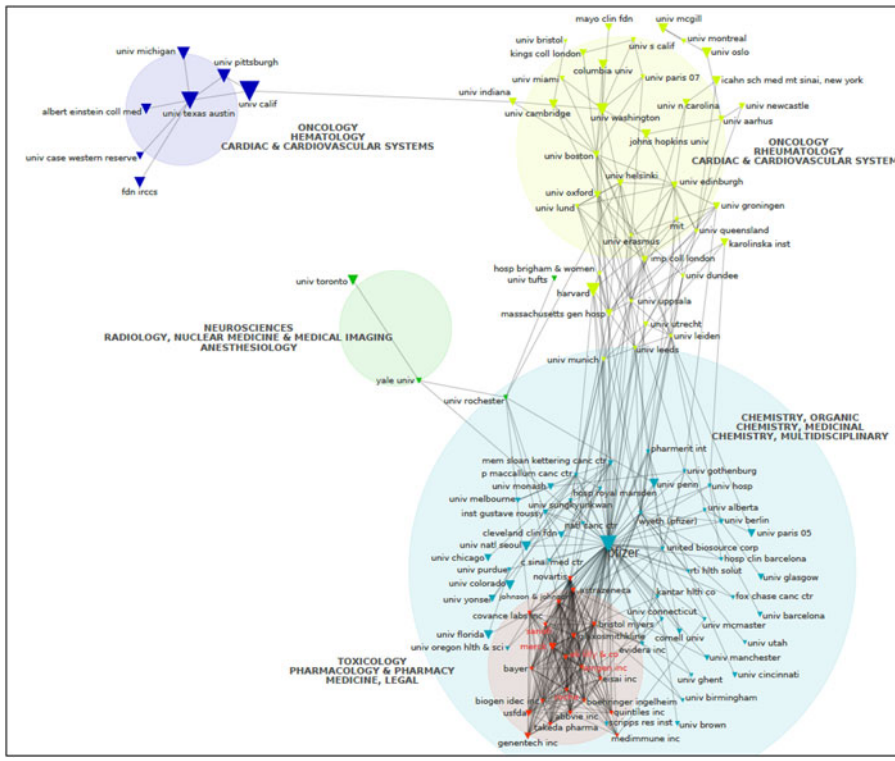

Figure 3. Top 150 research institutions. Pfizer's Publications Chi2 (2008–2017). Source: Author's analysis based on Web of Science data extraction. Some names were colored only to make reading easier.

that associate terms (in our case the names of research institutions and patent assignees, respectively) according to the frequency of their co-occurrence within a corpus of texts. The procedure used to draw these maps, including our corpuses cleaning, follows Tancoigne et al (2014). Due to the high density of the links and in order to concentrate on most important ones, we used a chi2 metric for determining nodes proximity (Figures 2–4). We also used a raw metric to build these network maps, which means that we considered the raw number of co-occurrences between every possible pair of nodes (Wu & Leahy, 1993) (Figures A2–A4). Considering our proposed model (Section 2.1), results do not vary according to the used metric.[12]

Nodes are defined as different assignees, in the case of patents, and research institutions or organizations (universities, enterprises, etc.) in the case of publications. The frequency of co-authorship or co-ownership with the corresponding big pharmaceutical is represented by the nodes' size. We always prioritize the top 150 nodes, meaning that we consider for each chosen pharmaceutical its top 149 partners (or less in case there are not at least 149 partners with a minimum proximity threshold of 0.1).

One specificity of the pharma industry is that the patent holder can easily produce the resulting drug. Furthermore, as innovation monopolies, big pharmaceuticals should have the power to be the only owner that manufactures patents' associated drugs. Thus, it is less expected that the big pharmaceuticals will share

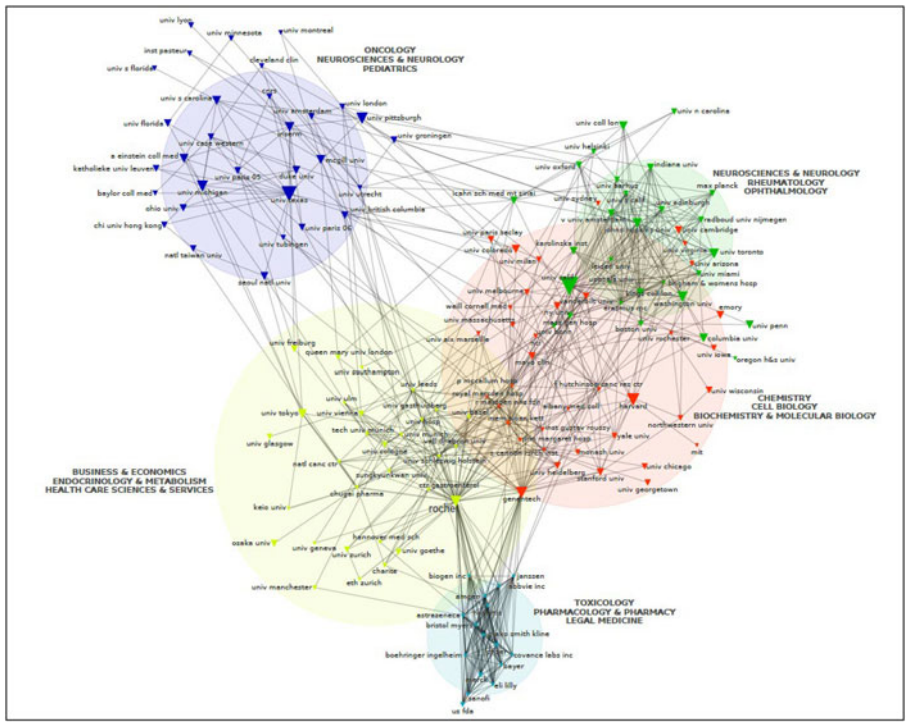

Figure 4. Top 150 research institutions. Roche's Publications (2008–2017). Source: Author's analysis based on Web of Science data extraction.

patent ownership with other enterprises or even universities. On the contrary, it makes sense to expect that patents will mostly be co-owned solely with the individuals (in general working inside the big pharmaceutical) that performed the ultimate steps of the innovation circuit, and only seldom with other enterprises and universities. The latter even if those institutions participated in the innovation circuit. Therefore, scientific publications could provide a more accurate depiction of the variety of stakeholders and of the geographic scope of these companies' innovation networks. In addition, scientific publications will mainly be used to show generic modules' results, but these modules will not usually lead to patents. Furthermore, not sharing property of the patent provides convincing evidence showing how big pharmaceuticals appropriate innovation rents.[13] With this in mind, we start our analysis by studying scientific publication maps which were also complemented with a semantic analysis of each cluster's main topics.[14]

4.1. Scientific publications' co-authorship

Our results illustrate the greater fertility of the developed framework. To begin with, all the maps confirm that big pharmaceuticals' innovation circuits connect organizations from multiple countries at the same time. Also as expected, there is a majority of American institutions followed by other countries from the triad region. The latter also holds for the case of Pfizer even if its origin is the core country of this industry. Concerning Pfizer, half of its top partners are not based

in the United States, and among its most frequent partners within that group we found, for instance, the Karolinska Institute and Seoul National University as well as different big pharmaceuticals originally from the United Kingdom and Germany (see Table A1).

The supremacy of United States co-authors is reinforced by looking at the countries of origin of the institutions publishing with Roche (43.2% of total institutions in its network map come from the US) and Novartis (39% of total institutions in its network map are US based). In fact, regardless of their country of origin, Switzerland occupies the fifth position both among Novartis and Roche most frequent co-authors' countries of origin with less than 5%, preceded by the United States, the United Kingdom, Germany and France (see Tables A2 and A3).

Beyond the primacy of the triad region, institutions from other core countries participate in these maps, such as Fudan University, the National University of Singapore and Melbourne and Sidney Universities in Novartis's map. The latter is also in Roche's map, and three universities from Korea (the National University of Seoul, Sungkyunkwan University and Yonsei University) participate in Pfizer's main cluster.

Furthermore, in the three cases we find a cluster integrated by big pharmaceutical companies which can be interpreted as a technological cooperation cluster producing generic knowledge modules. This could have been a surprising result if we had only thought of big pharmaceuticals in technological competition, but is actually an expected one given our framework. In fact, among Pfizer's top 50 partners there are 11 big pharma co-authoring 9.9% of its total publications. In the case of Novartis, 11 big pharma are within its top 50 co-author institutions (with Roche and Pfizer as its preferred big pharma with a 2.9% and 2.5% frequency, respectively). This figure is 8 for Roche (with Novartis at the top with a 2.1% frequency).[15]

The eventually successful results of technological cooperation between leaders are potentially but not directly useful for all the specific innovation circuits each of the big pharma plans and leads. The results of these research partnerships are not directly useful in the sense that more R&D is needed to complete the innovation process and, thus, profit from it. The high degree of connectivity in terms of article publishing together with the fact that big pharmaceuticals do not tend to share property of their patents with other big pharma, as shown later in this article, supports the latter. In this industry it is pretty clear that the generic stages demand such a high R&D investment that it makes more sense to work together, colluding technologically, than attempting to achieve those results separately.

At the same time, the technological competition between leaders of the pharmaceutical industry is depicted in the network maps as all the clusters that do not include other big pharmaceuticals but mainly academic research institutions, in particular universities and their research hospitals with the University of California and Harvard as the most frequent partners of the three chosen pharmaceuticals. In addition, some clusters also include foundations and start-ups. Among Pfizer's 50 most frequent co-authors there are 32 universities participating in 25.5% of Pfizer's publications. Within them, as we said, the University of California (4.89%) and Harvard (3%) stand out. In the case of Roche, 36 universities are among its 50 most frequent co-authors (co-authoring 31.6% of Roche's total publications within the analyzed period). Novartis, for its part, has 31 universities among its 50 most

frequent co-authors, co-authoring 31.8% of its total publications between 2008 and 2017. The frequency of the University of California is 5.9% for Novartis and 8.3% for Roche, while for Harvard it is 5.2% for Novartis and 3.9% for Roche.

This outcome is in line with our framework (see Figure 1) in the sense that it is coherent to think that each big pharma plans and organizes its own innovation circuits privileging some institutions with whom it works together to produce certain stages of the innovation process trying to win the innovation race of its industry (technological competition) and thus creating more price/provision monopolies (once it has the patent of the new drug, it will be the only one producing it and will have a price and provision monopoly). Meanwhile, in the same or in different innovation circuits, each intellectual monopoly produces other stages of the innovation process in collaboration with other big pharma.

The term 'other stages' must be highlighted because it is the existence of different clusters in the network map what depicts that actually big pharma develop links among them that remain to some extent isolated from the other networks that each of those big pharma build with other institutions and organizations, particularly universities and other research institutions in the case of the phases of the innovation circuit that require scientific research or academic expertise. Moreover, even if the most relevant universities within each of the big pharma networks coincide (such as Harvard, University of California, University of Pennsylvania, University of Pittsburgh and University of Texas Austin, and even Basel University for Roche and Novartis), these universities do not belong to the big pharma cluster in either of the maps, but relate separately with each of the analyzed big pharma. In other words, there is a high reliance on the same institutions for key stages or modules of their innovation circuits, reasonably explained by the expertise of the scholars working in those institutions, but those collaborations are not generally established jointly. On the contrary, each big pharmaceutical works with the same institutional partners separately.[16] Hence, we can think that this type of clusters from the three different maps are, most likely, in technological competition with each other. As we anticipated in our preliminary model, clusters from the same big pharmaceutical network map can also be in technological competition with each other. Intellectual monopolies sometimes sponsor and work with different research institutions for the same steps of an innovation circuit. Competition in this case will be used as an engine to accelerate the investigations in each cluster.

A possible way to analyze the latter is to look at the most frequent research subjects of each cluster which we depicted as a third variable in the network maps (Figures 2–4). For instance, 'oncology' and 'cardiac and cardiovascular systems' are two of the three most frequent topics of the light green cluster led by Harvard in Novartis's map and of the blue cluster with the University of Texas Austin at the center in Pfizer's map. Certainly, this observation is still too wide and must be complemented with a more detailed semantic analysis of the abstracts and keywords of each map's publications, which is out of the scope of this article but integrates our future research agenda. Our semantic analysis only provides a clue in terms of where to look for technological competition.

Finally, co-publication maps show an interesting result that also needs to be further studied. The United States Food and Drug Administration (USFDA) participates in the big pharma cluster in the three maps, and actually presents a significant level of co-occurrences given the size of its node in Figures 2–4, and

also considering its frequencies. The USFDA published 0.82% of Roche's articles in the analyzed period, 0.92% in the case of Novartis and 1.25% of Pfizer's publications. It must be outlined that the USFDA is in charge of approving every drug (thus every innovation) for its legal provision in the United States.

Hence, we are observing here a blurred frontier between public and private domains. There is a diluted border between big pharma and the USFDA because they do research together, whose final results will need to be approved by the USFDA in order to become a provision drug. Concerning the topics of this cluster in the different figures, we observe both articles dealing with legal issues, which may imply that big pharma work together with the USFDA to define the legal conditions under which their future drugs will be approved. They also work together on articles that deal with actual research in a wide variety of topics ranging from veterinary science to pharmacology and pharmacy.

Therefore, big pharmaceuticals, as the relevant interest group, have 'embed themselves deeply in the relevant domestic regulatory structures' of the USFDA which in time influences the pharmaceutical international market (Farrell & Newman, 2010, p. 620). Co-publications and lobbying with the latter could be considered as mechanisms by which that embeddedness took place. These results point out a potential conflict of interests that should be further conceptualized.

4.2. Patents' co-ownership analysis

The analysis performed so far is complemented here by elaborating on patent assignees' network maps. Since these maps reconfirm our hypothesis of significantly fewer institutional partnerships for this outcome, maps are presented in Appendix (Figures A5–A7), while we focus here on their shared traits.

It is worth noting that, in general, when publications or patents are extracted for a particular actor, it is expected to have as results network maps showing a star form with the corresponding actor at the center. However, since for each extraction we considered the corresponding big pharma's corporate tree, results do not depict that shape (neither they did so, although the shape was closer to a star, in the case of co-publishing maps). In fact, there are certain clusters completely detached from the analyzed big pharma showing that some patents were achieved by corporations that were afterwards acquired by the former, but that did not have a significant innovation link with it before the acquisition. More precisely, this tells us that at least the final steps of those innovation circuits were accomplished in total independence from the big pharma that later acquired the smaller company, enlarging its own patent portfolio, thus its intellectual monopoly.

Another paramount result is that big pharmaceuticals rarely share the ownership of their patents with other stakeholders like universities, public research institutions or other corporations. In fact, companies that are not in big pharma's corporate trees are rare partners. For instance, the external company with more shared patents with Roche is Array Biopharma Inc. (a mainly clinical trial company) that shares 0.57% of Roche's total owned patents during the analyzed period, followed by Curis inc., a biotechnology company, with a 0.3% share. Moreover, Novartis is the big pharma with the greatest number (9) of co-owned patents representing a 0.1% of Roche's granted patents in the analyzed period (Table A4). Similar results are observed for Pfizer where the first outside partner is Amgen Fremont inc., a

company acquired by Boehringer Ingelheim in 2011, which shares 1.3% of Pfizer's granted patents in our chosen period. This company is followed by the University of Iowa, who co-owns 0.7% of Pfizer's granted patents between 2008 and 2017. Furthermore, Bristol-Myers Squibb is the most frequent big pharmaceutical co-owning granted patents during the studied period with a 0.54% share (18 patents) (Table A5). Finally, in the case of Novartis, the most frequent corporate partner is the big pharma GlaxoSmithKline with 57 co-owned patents between 2008 and 2017 (0.94% of Novartis' patents in that period) (Table A6). Scripps Research Institute is the academic institution with the highest co-ownership frequency (15 patents, 0.25% share), ranking 42 among Novartis patent co-owners. Among Novartis's (including its acquired companies) top 50 co-owners there are only 4 corporations and 2 academic institutions, all the rest are individuals.

Among partners there is a vast majority of individuals co-owning big pharmaceutical patents, while in the maps we only find the University of Iowa in Pfizer's map and two academic institutions in Novartis's map (the aforementioned Scripps Research Institute and Harvard). After looking at Researchgate and LinkedIn we confirmed that almost in every case individuals co-owning more than 20 patents with a big pharmaceutical are (or were) researchers working for the corresponding big pharmaceutical.[17] We may think of them as the individuals working in big pharma's laboratories that actually conducted the final, thus decisive, steps of the innovation circuit. Therefore, just looking at co-patenting maps could have led us to a misleading conclusion: to assume that innovations are still mainly in-house produced by big pharmaceuticals, neglecting the contribution of universities, public research institutions, and start-ups, and ignoring the strong technological cooperation between big pharmaceuticals. On the contrary, analyzing together co-publication and co-patenting provides more information about the complexity and scope of their innovation networks.

To conclude, the comparison between the networks of co-publications and co-patenting also sheds light on who contributes to innovation circuits and who profits from them. Universities occupy an almost neglected position as patent owners, entitled to collect innovation rents, while they are indispensable in the research process that leads to those patents. The same holds for smaller companies in the industry. From our perspective, leaders have the power to secure and appropriate innovation rents. Hence, considering that the pharmaceutical industry is highly dependent on patents in order to assure those rents, having fewer connections in the final steps of an innovation process is a reasonable strategy for leaders in order to assure those rents. Even more, if we take into account that the confidentiality of the final steps of pharmaceutical innovation circuits is of utmost importance, conceiving big pharmaceuticals as intellectual monopolies that plan and organize those circuits, means that they should have the capacity to effectively profit from them by limiting the actors that participate in those final steps, thus limiting co-ownership of the resulting patents. This seems to be the strategy followed by the three analyzed big pharmaceuticals.

5. Final remarks

This article has contributed to enlarge our understanding of innovation as a power relation that explains the emergence and maintenance of leaders –recalled

intellectual monopolies- that organize and plan GVCs in contemporary capitalism. Indeed, we have contributed to GVC analysis by placing innovation, and more in general knowledge production, at its core. We have done so by elaborating on: (1) the transnational condition of innovation circuits and of institutionalized innovation networks which was enabled by knowledge modularity, (2) the primacy of power or asymmetric relations exercised by leaders over the rest of the stakeholders (that are not leaders) participating in their innovation circuits and networks and (3) the capacity of intellectual or innovation monopolies (such as Leader A in $t=2$ in our model) to decide in which modules or stages it should compete or collaborate for technology with other leaders. This emergence of intellectual monopolies that technologically compete and cooperate according to their convenience shapes capital accumulation, industrial organization and knowledge production and circulation at a transnational scale.

These conceptual elaborations were illustrated by our analysis of the innovation networks of three core or big pharmaceutical corporations. First, co-publication maps showed the diversity in terms of research institutions and, more in general, in terms of countries participating in big pharma innovation networks. Concerning the scope of these networks, this article also contributes to explain the endurance of a historical trend: the existence of a wide technological gap between the core and the peripheries, in line with Niosi and Bellon's (1996 in Arocena & Sutz, 2000) conclusion. In our article this was observed for the case of the pharmaceutical industry. The core may have widened since their article but, at least in this industry, it is still highly concentrated. Innovation flows are not limited by national boundaries since they involve actors from multiple countries working together, but are still subjected to a geographical distribution of actors with uneven technological capacities worldwide. The absence of the peripheries in our maps may be explained by the fact that they are, in innovation terms, still significantly lagging behind. Furthermore, the reappearance of the same institutions in the three maps points to the higher capacities of certain but definitely not all (nor most) of the research institutions from core countries, evidencing these countries' internal heterogeneities.

Second, co-publication network maps also depicted a neat technological collaboration cluster and multiple specific modules for each leader where other big pharmaceuticals do not participate, and that can be conceived as in technological competition with each other. In other words, we conceived the specific clusters of a big pharma where only non-leaders participate (universities, start-ups, etc.) as in technological competition with those of the other big pharmaceuticals. It must be said that the neat clusters that were found in our empirical study may not be as neat for other industries and, as we pointed out when presenting our model, leaders may have more than one technological cooperation cluster, especially if they have diversified innovation circuits or there is a lower level of interconnection between all the leaders together. We could have found, for instance, two distinct groups within the core of the pharmaceutical industry, depicted as two distinct clusters of the same map if the analyzed leader participates in both of them or in two different maps if the studied leaders do not participate in both of them but only in one.

Third, the comparison between scientific co-publication and patent co-ownership maps points to a subordination of the universities, public research organizations and start-ups that have a fundamental role in the former, but an almost

negligible participation in the latter. Anyway, these results could benefit from more in-depth research, for instance by performing interviews on both leaders and subordinated actors or by analyzing the profit rates of the different types of corporations involved in big pharmaceuticals' innovation networks. These are just some of the future research lines that this article opens.

Looking at both types of network maps, United States looms large in terms of countries' representation for the three analyzed big pharma (and not only for Pfizer). Therefore, our results are in accordance with the fact that the expertise and wide variety of the R&D performed by institutions and organizations in that country outlines globally. Together with the fact that the United States remains to be the most powerful country in the world, our results may contribute to explain why big pharma that are not originally from this country also open R&D departments there, together with the central role of the USFDA as the institution that sets standards not only within the United States but globally. As we have already mentioned, this institution belongs to the technological cooperation cluster and further studying its links with the big pharma will involve a discussion on the blurred frontiers between public and private in this industry.

All in all, we have seen that big pharmaceuticals plan and organize innovation circuits throughout the core or developed world, regardless of their country of origin. Furthermore, the centrality of the United States for the three companies shows its historically thriving community of researchers in the pharmaceutical domain. We have also provided proof of the power exercised by leaders on the rest of the participants of their innovation networks and changed the way competition and cooperation between leaders is typically analyzed: from focusing on price determination and the market structure, to looking at technological cooperation and competition.

Besides the already mentioned future research lines, our agenda will also focus on publications' funding institutions in the pharmaceutical industry -where we expect to find the United States National Institute of Health as a key provider-, as well as on other industries. Our results also call for rethinking policy advices which should be derived from a general analysis of the dynamics of capitalism, acknowledging at the same time the different hierarchies between national states and thus their different enforcement capacities. Finally, our results call for a discussion concerning the aims and priorities of academic knowledge production, and more generally on the place of research universities in contemporary capitalism, taking into account the premise of knowledge as a public good.

Notes

1. Another shortfall is that it starts from the basic assumption of a generic country, leaving aside economic and political hierarchies between countries. In fact, concerning innovation matters, by the end of the last century Niosi and Bellon (1996 in Arocena & Sutz, 2000) pointed out that international flows of technology were concentrated in already developed countries. According to these authors, this was a sign of the slim technical gap between those countries, while at the same time it highlighted the prevailing wide gap with underdeveloped nations. This context needs to be considered when directly applying an approach developed for explaining core countries' innovation patterns. Indeed, Arocena and Sutz (2000) explained that there was not a NIS in Latin American countries by the time when policy advisors started

referring to it in policy recommendations, thus using the concept regardless of its accuracy.

2. In fact, the United States Patent and Trademark Office has a single database that includes designs.
3. The first-mover advantage, as any isolated innovation, is a porous entry barrier. For instance, Facebook was not the first social network, others like MySpace or the German StudiVZ came first, and Google was not the first search engine either (take for instance Yahoo or Altavista). Being the first confers an innovation rent but, if that innovation is not fed with permanent new breakthroughs it risks to be surpassed by others. This porosity is overcome in our theory by explaining that intellectual monopolies lie not on a first-mover advantage but on continuous and systematic innovations that allow them to stay always ahead (Rikap, 2018).
4. Monopolizing innovation in a branch is not the only source of a lasting power relation between individual capitals. For a discussion on these alternative sources see Rikap (2018). Yet, different authors agree that more tangible entry barriers have tended to fall, while current GVC's dynamics are increasingly relying on intangible assets (Durand & Milberg, 2018; Gereffi, 2014), which includes patents, copyright and goodwill, among other assets ('IFRS 3 — Business Combinations', n.d.). Therefore, without ignoring the existence of tangible barriers as well as other factors that enlarge leaders' power once they are already settled (such as lobby or using patents to encapsulate knowledge and thus limit potential competition), we consider that monopolizing innovation is at the core of contemporary capitalism.
5. In fact, considering cumulative R&D expenses for our chosen period (2008-2017), Roche, Novartis and Johnson and Johnson are the top 3 companies. However, the latter is not strictly a pharmaceutical company (it produces also medical devices and consumer packed goods) thus choosing it could lead to misleading results. Therefore, we will consider Pfizer which is the fourth pharmaceutical company in terms of cumulative R&D expenditure. We verified the relevancy of chosen corporations by looking at their rank in terms of sales revenues for the same period and we verified that they are among the top 5 big pharmaceuticals.
6. Representatives of the European Commission and the European Federation of Pharmaceutical Industries and Associations equally compose its governing board. The IMI finances exclusively public partners. 845 academic and research teams from universities and other public organisms had participated in the IMI projects until December 2014. Among the private funds that it comprises, Janssen, Sanofi and AstraZeneca are the major contributors (11% of total private funds until the end of 2014, each). The IMI was created with the aim of improving 'the efficiency and effectiveness of the drug development process with the long-term aim that the pharmaceutical sector produces more effective and safer innovative medicines' (Article 2, legislation creating IMI). Thus, its aim is to benefit pharmaceutical companies.
7. Retrieved from: https://www.ft.com/content/d78fe796-0f70-11e9-a3aa-118c761d2745 last access February 23, 2019.
8. Retrieved from: https://www.ft.com/content/7dc80cda-27d9-11e9-88a4-c32129756dd8 last access February 27, 2019.
9. Retrieved from: https://www.ft.com/content/d78fe796-0f70-11e9-a3aa-118c761d2745 last access March 1, 2019.
10. This database includes all the information from the following patent offices: USPTO, WIPO, European, Japan, Australian, British, Canadian, French, German, Russian and Korean patent offices.
11. Cortext is an open platform for performing bibliometric and semantic analysis that uses the spatial algorithms that draw on classic graph visualisation methods for depicting the network maps (Fruchterman–Reingold). It can be accessed online at: https://www.cortext.net/
12. Both metrics are direct local measures, meaning that they consider the actual co-occurrences of the considered terms. Indirect measures like the distributional one are

not useful in our examination because we are looking at actual links and not at the similarity of two nodes based on their entire c-occurrence profile with the other terms identified (Tancoigne, Barbier, Cointet, & Richard, 2014, p. 40).

13. Still, sharing the property of a patent is not enough to assure that all the owners enjoy innovation rents. In fact, the case of the National University of Singapore shows how universities co-owning patents with corporations do not profit from them. Since the corporation produces the resulting good, it leaves the university in a weaker bargaining position to license the patent to a third corporation that will have to produce with an extra cost that the corporation that co-owns that patent is free of (Rikap, 2017).
14. This was achieved by introducing another variable to our maps on the main topics or subjects characterizing each paper. This information is provided by Web of Science and we used Cortext to include it in each network map by producing tags that are associated to each cluster. For this new dimension taken from our dataset, we also used a chi2 metric. Only top 3 most frequent tags are associated to each cluster on the maps.
15. The existence of a technological cooperation cluster between intellectual monopolies is further verified with a robustness test (Figure A1 in the Appendix).
16. Strict confidentiality agreements enable big pharmaceuticals to work with the same research institutions separately. Furthermore, subordinate research institutions may not know all the modules or stages of the innovation circuits where they participate.
17. We presume the same holds for the rest of the individuals but we only checked their affiliations/working place if they had more than 20 patents co-owned with a big pharmaceutical.

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Appendix A

Robustness test

A robustness test was performed by choosing the top 4 journals within the medical and pharmaceutical domains according to Web of Science's Journal Impact Factor. These journals and their impact factors are: CA-A CANCER JOURNAL FOR CLINICIANS (187.040), NATURE REVIEWS DRUG DISCOVERY (57.000), NATURE REVIEWS MOLECULAR CELL BIOLOGY (46.602), and NATURE BIOTECHNOLOGY (41.667). We analyzed the map of co-authors of all their papers between 2003 and 2017 and found that the big pharma cluster reappears in this depiction and that the USFDA also belongs to this group (Figure A1), in line with our aforementioned results.

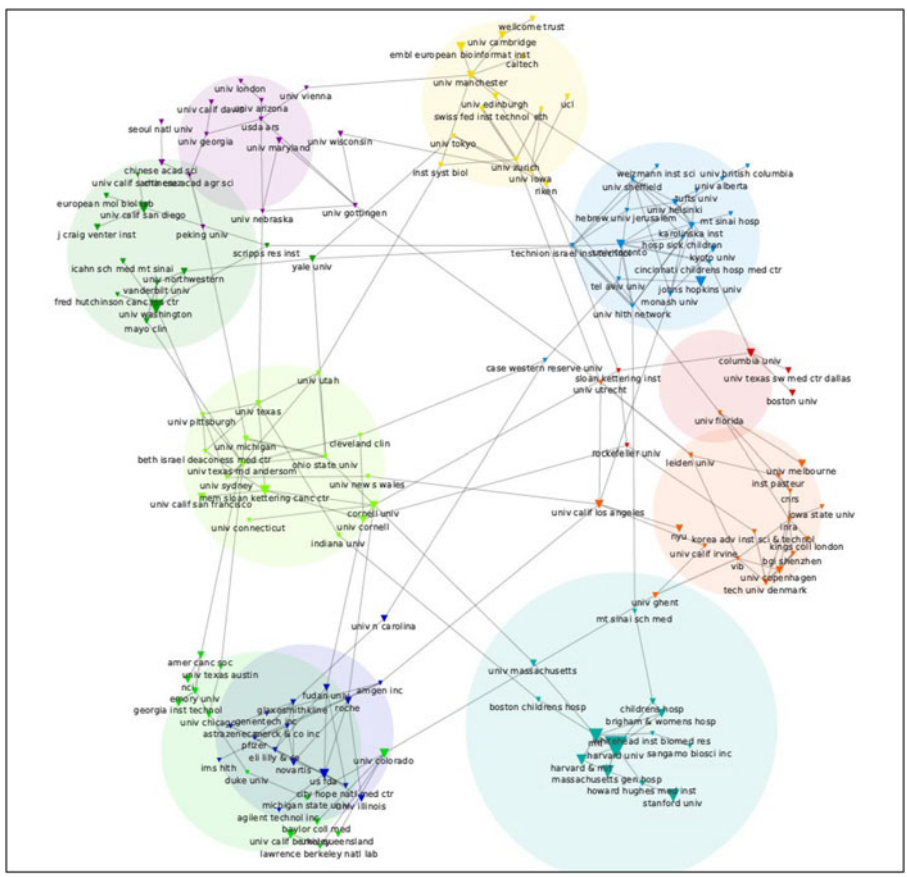

Figure A1. Top Pharmaceutical Journals co-authorship network map. Source: Author's analysis based on Web of Science data extraction.

Co-publication network maps. Raw metrics

As a whole, network maps using raw metrics provide the same results as the chi2 ones: a higher concentration of links or co-occurrences between big pharmaceuticals on the one hand, and a cumulus of diverse institutions that work together with each big pharma conforming their technology competition clusters. Since chi2 metric constructs clusters by focusing on the most frequent partners, it depicts a clearer illustration of the different modules or clusters, visibly distinguishing between those conceived as technological cooperation and the technological competition one. Yet, the raw metrics is closer to reality in the sense that, as we argued in the presentation of our model, in reality these modules can be more intertwined showing innovation circuits that are in constant relation to each other, in particular between the technological competition clusters. Still, the chi2 metric is a better one because by highlighting the most frequent links it helps us to illustrate which innovation circuits led to institutionalized innovation networks and which are less frequent interlocks.

Finally, the raw metrics for Pfizer shows how Merck is an almost obligatory passage for the former to link with the other big pharma. The closer link between these two big pharma should be further studied in future investigations.

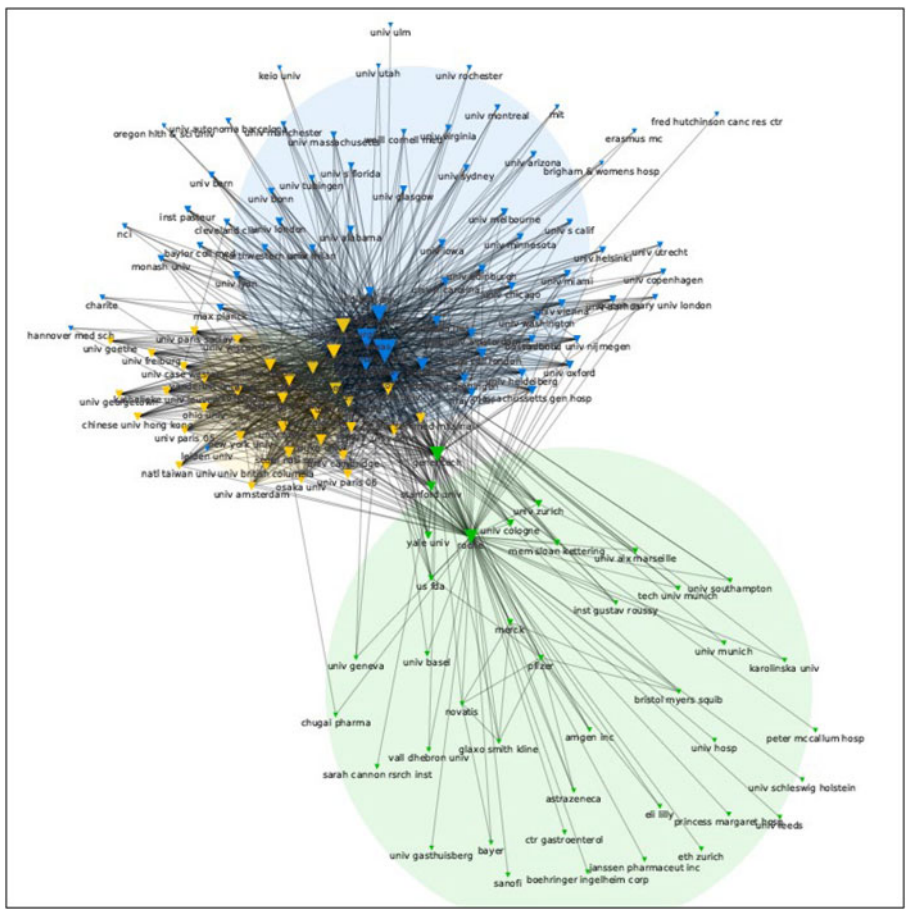

Figure A2. Research institutions. Roche's Publications Raw (2008–2017). Source: Author's analysis based on Web of Science data extraction.

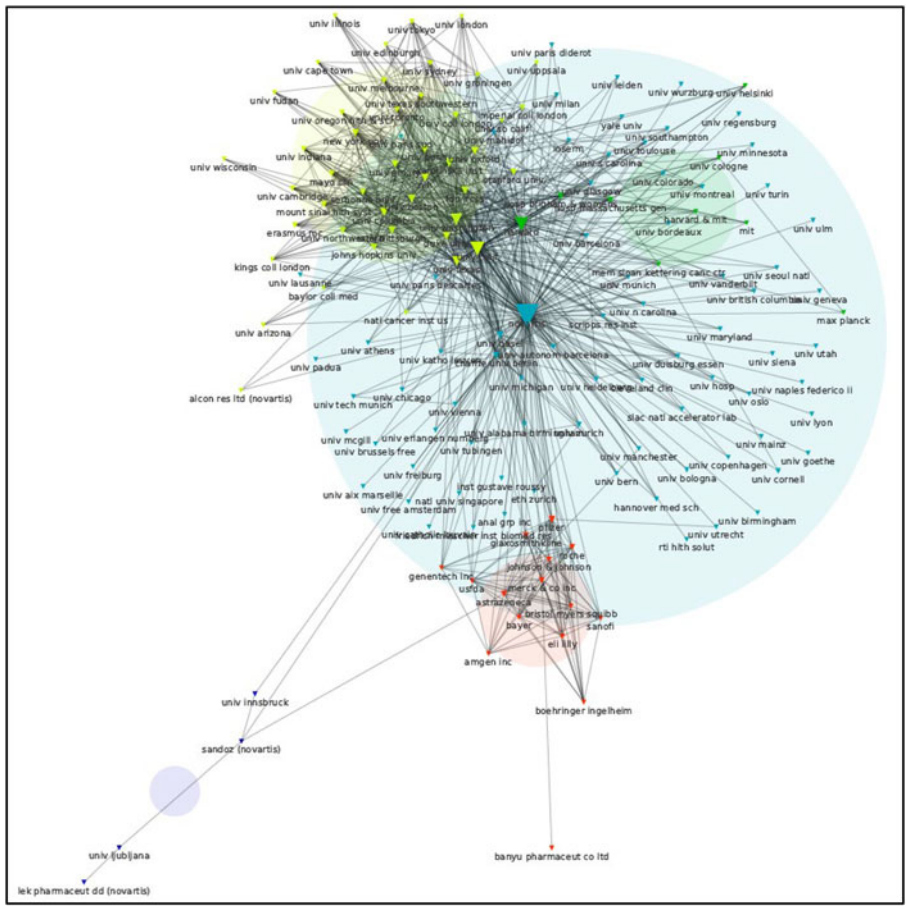

Figure A3. Research institutions. Novartis's Publications Raw (2008–2017). Source: Author's analysis based on Web of Science data extraction.

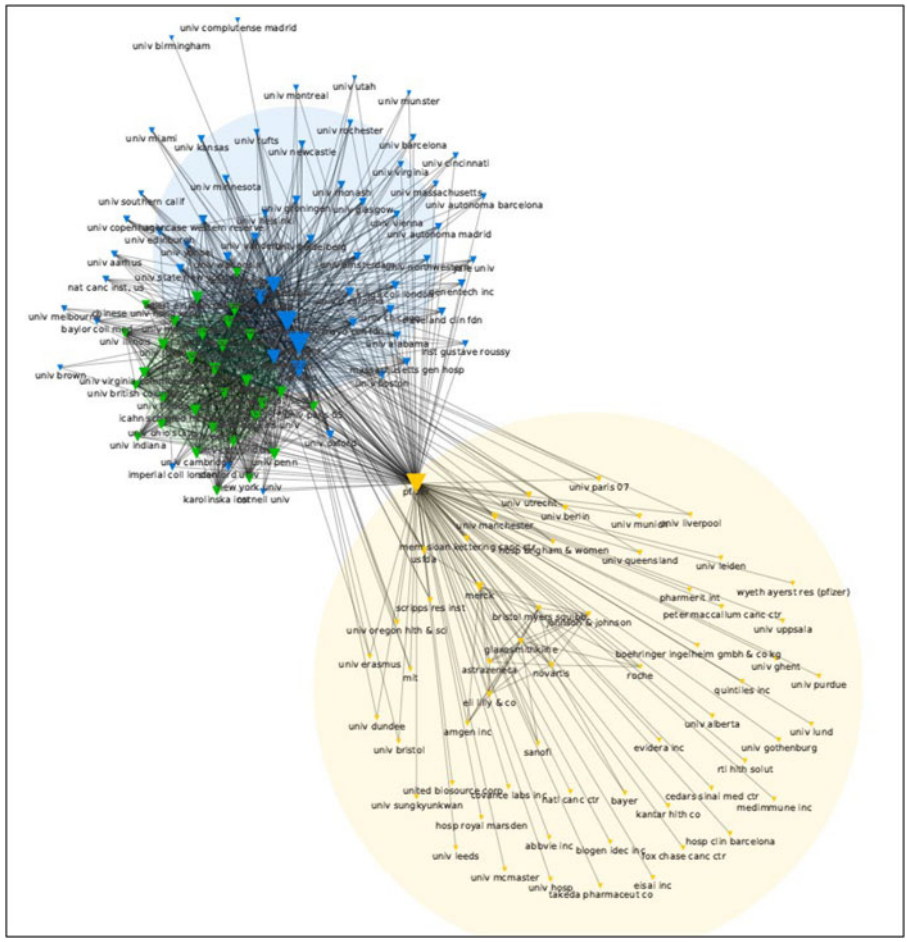

Figure A4. Research institutions. Pfizer's Publications Raw (2008–2017). Source: Author's analysis based on Web of Science data extraction.

Country of Origin. Chosen big pharmaceuticals' co-publication partners

Table A1. Country of origin – Pfizer's top co-publication partners.

Country	Number of partners	Proportion
Australia	4	3.5%
Belgium	1	0.9%
Canada	5	4.4%
Denmark	1	0.9%
United States	56	49.6%
Finland	1	0.9%
France	4	3.5%
Germany	5	4.4%
Italy	1	0.9%
Japan	2	1.8%
Korea	4	3.5%
Netherlands	4	3.5%
Norway	1	0.9%
Spain	2	1.8%
Sweden	4	3.5%
Switzerland	2	1.8%
United Kingdom	15	13.3%
Undefined	1	0.9%

Source: Author's analysis based on Web of Science data extraction.

Table A2. **Country of origin – Novartis's top co-publication partners.**

Country	Number of partners	Proportion
Australia	2	1.4%
Austria	2	1.4%
Belgum	2	1.4%
Canada	4	2.7%
China	1	0.7%
Finland	1	0.7%
France	11	7.5%
Germany	20	13.7%
Greece	1	0.7%
Italy	7	4.8%
Japan	1	0.7%
Korea	1	0.7%
Netherlands	5	3.4%
Norway	1	0.7%
Singapore	1	0.7%
Slovenia	1	0.7%
South Africa	1	0.7%
Spain	2	1.4%
Sweden	3	2.1%
Swiss	7	4.8%
Tailand	1	0.7%
United Kingdom	13	8.9%
United States	57	39.0%
unspecified	1	0.7%

Source: Author's analysis based on Web of Science data extraction.

Table A3. Country of origin – Roche's top co-publication partners.

Country	Number of partners	Proportion
Australia	4	2.7%
Austria	1	0.7%
Belgum	3	2.1%
Canada	5	3.4%
Denmark	1	0.7%
Finland	1	0.7%
France	10	6.8%
Germany	16	11.0%
Hong Kong	1	0.7%
Italy	1	0.7%
Japan	2	1.4%
Korea	2	1.4%
Netherlands	7	4.8%
Spain	2	1.4%
Sweden	4	2.7%
Switzerland	6	4.1%
Taiwan	1	0.7%
United Kingdo	13	8.9%
United States	63	43.2%
unspecified	3	2.1%

Source: Author's analysis based on Web of Science data extraction.

Co-patenting network maps. Chi2 metrics

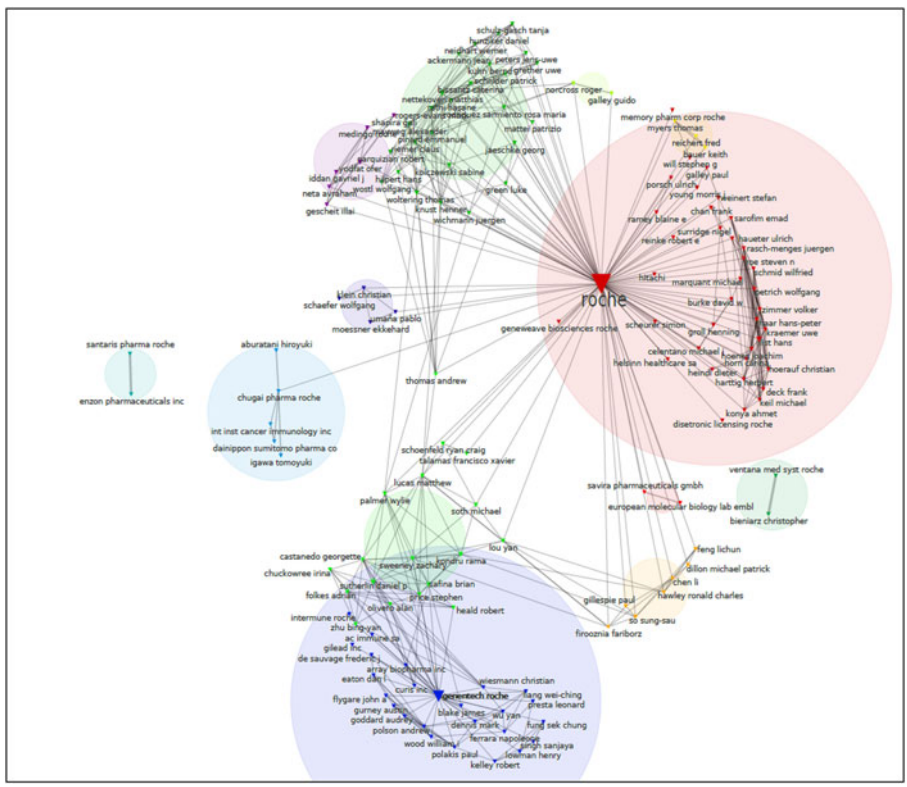

Figure A5. Roche Corporate Tree Granted Patents Assignees (2008–2017). Source: Author's analysis based on Derwent Innovation data extraction.

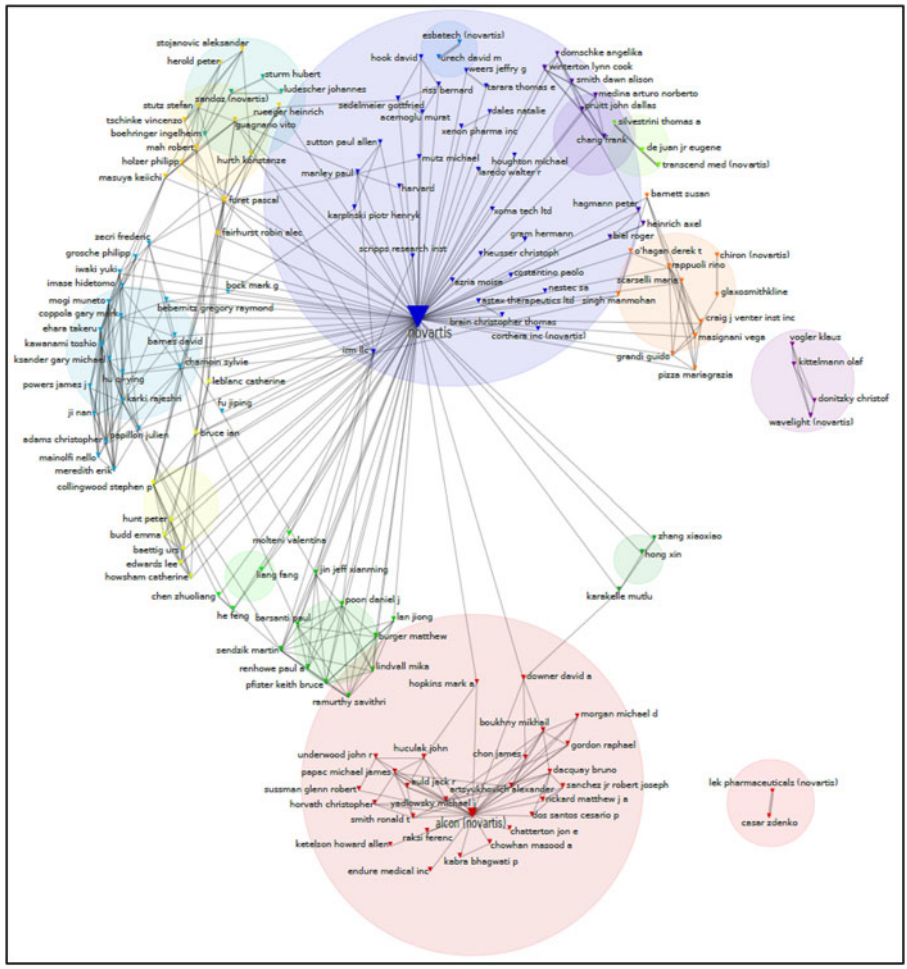

Figure A6. Novartis Corporate Tree Granted Patents Assignees (2008–2017). Source: Author's analysis based on Derwent Innovation data extraction.

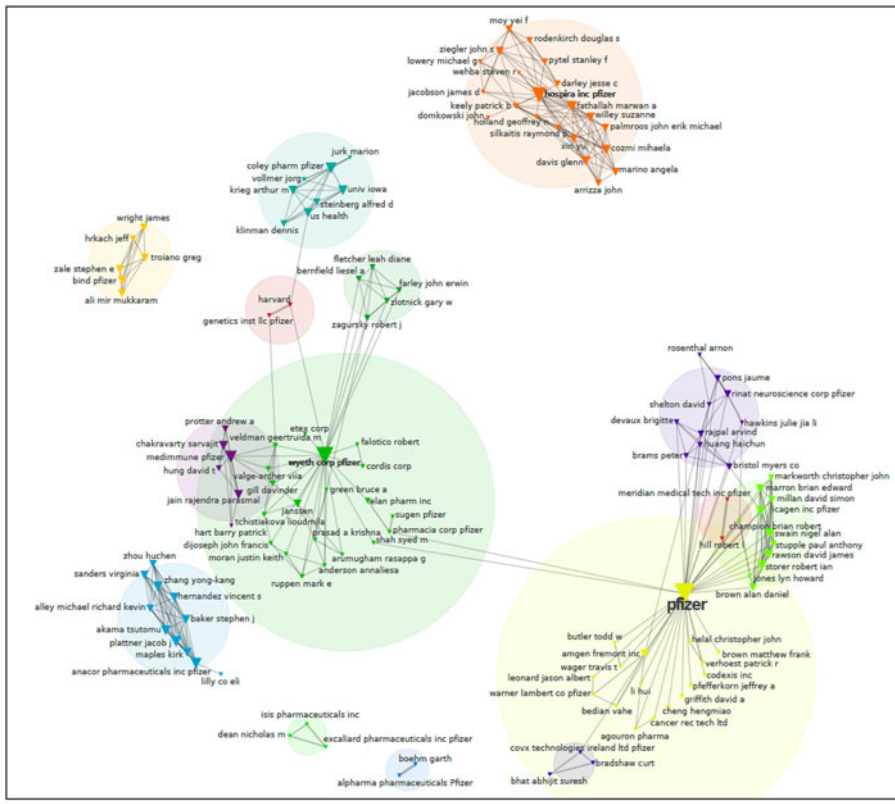

Figure A7. Pfizer Corporate Tree Granted Patents Assignees (2008–2017). Source: Author's analysis based on Derwent Innovation data extraction.

Table A4. Roche Corporate Tree Granted Patents 2008–2017: top 20 Assignees' frequencies.

Entity	Frequency	Number of distinct documents	Type of stakeholder
Roche	6946	5610	Roche
Genentech Roche	1655	1636	Roche
Chugai Pharma Roche	524	521	Roche
Ventana Med Syst Roche	183	183	Roche
Santaris Pharma Roche	66	66	Roche
Intermune Roche	59	59	Roche
Yodfat Ofer	54	54	Individual
Array Biopharma Inc.	51	49	Another corporation
List Hans	49	49	Individual
Anadys Pharma Roche	48	48	Roche
Memory Pharm Corp Roche	44	44	Roche
Medingo Roche	39	39	Roche
Wu Yan	33	33	Individual
454 Life Sciences Roche	31	31	Roche
Disetronic Licensing Roche	30	30	Roche
Nettekoven Matthias	30	30	Individual
Genia Tech Inc. Roche	30	30	Roche
Harttig Herbert	28	28	Individual
Roe Steven N	28	28	Individual
Hoenes Joachim	27	27	Individual

Source: Author's analysis based on Derwent Innovation data extraction.

Table A5. Pfizer Corporate Tree Granted Patents 2008–2017: top 20 Assignees' frequencies.

Entity	Frequency	Number of distinct documents	Type of Stakeholder
Pfizer	1200	1137	Pfizer
Wyeth Corp Pfizer	1075	1071	Pfizer
Hospira Inc Pfizer	129	129	Pfizer
Warner Lambert Co. Pfizer	99	99	Pfizer
Pharmacia Corp. Pfizer	88	88	Pfizer
Coley Pharm Pfizer	82	64	Pfizer
Medimmune Pfizer	78	76	Pfizer
Genetics Inst LLC Pfizer	66	66	Pfizer
Anacor Pharmaceuticals Inc. Pfizer	62	62	Pfizer
Icagen Inc. Pfizer	60	60	Pfizer
Bind Pfizer	47	44	Pfizer
Rinat Neuroscience Corp. Pfizer	46	45	Pfizer
Zoetis LLC (ex Pfizer)	44	43	Pfizer
Amgen Fremont Inc.	43	43	Another Corporation
Meridian Medical Tech Inc. Pfizer	38	38	Pfizer
Janssen	34	34	Another Corporation
Univ Iowa	24	24	University
Elan Pharm Inc.	24	24	Another Corporation
Chakravarty Sarvajit	22	22	Individual
Jain Rajendra Parasmal	22	22	Individual

Source: Author's analysis based on Derwent Innovation data extraction.

Table A6. Novartis Corporate Tree Granted Patents 2008–2017: top 20 Assignees' frequencies.

Entity	Frequency	Number of distinct documents	Type of stakeholder
Novartis	4487	4125	Novartis
Alcon (Novartis)	950	942	Novartis
Sandoz (Novartis)	218	217	Novartis
Lek Pharmaceuticals (Novartis)	188	188	Novartis
Wavelight (Novartis)	144	142	Novartis
GlaxoSmithKline	56	56	Another Corporation
Esbatech (Novartis)	47	44	Novartis
Hexal (Novartis)	44	44	Novartis
Transcend Med (Novartis)	43	43	Novartis
Furet Pascal	36	36	Individual
IRM LLC	32	32	Another Corporation
Wavetec Vision Systems Inc. (Novartis)	31	31	Novartis
Xoma Tech Ltd.	30	30	Another Corporation
Smith Ronald T	28	28	Individual
Boukhny Mikhail	28	28	Individual
Huculak John Christopher	27	27	Individual
Fairhurst Robin Alec	26	26	Individual
Donitzky Christof	25	25	Individual
Grandi Guido	24	24	Individual
Masignani Vega	22	22	Individual

Source: Author's analysis based on Derwent Innovation data extraction.