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Article

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Abstract: In this paper we explore patenting activity in two peripheral economies (Portugal and Greece), to analyze the dispersion of inventor networks. Inventor networks are key conduits through which knowledge flows. Therefore, they can be critical in the catch-up process of peripheral economies – economies that belong to the group of rich countries but have weaker innovation systems. As global value chains fragment into geographically dispersed activities, opportunities arise for peripheral economies to participate in global innovation processes. However, different types of innovation activities have distinct network properties. More codifiable innovative activities can be carried out through collaboration by internationally dispersed teams. On the other hand, activities that are more dependent on tacit knowledge are likely to require the co-location of knowledge workers. This implies that innovation that relies mostly on tacit knowledge will provide limited connectivity benefits for peripheral economies' innovation systems. We hypothesize that, while this is generally true, "leading" innovative multinational enterprises may possess more sophisticated capabilities for transnational collaboration than less innovative firms. Therefore, innovation in activities involving tacit knowledge may show different network characteristics depending on who performs them: leading firms or "laggards". Our results, based on data from Portugal and Greece are consistent with our hypotheses.

Keywords: Peripheral economies, Innovation, connectivity, patents

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Introduction

What determines the level of connectivity of a peripheral economy to global networks of inventors? Global innovation systems are becoming increasingly complex, involving a wider range of locations[1]. As value chains are disaggregated across borders, countries are increasingly interconnected in global innovation networks, part of which is reflected by the growing dispersion of patenting activities (Balconi et al., 2004; Breschi and Lissoni, 2009). Locations outside core OECD countries, attempting to catch up technologically with core developed economies, try to attract multinational enterprises to perform innovative activities in their territories and create linkages to these global innovation networks. Connectivity provides an economy with access to a wider variety of world-class pools of knowledge (Medina et al., 2020; Qiu et al., 2017).

The factors affecting the connectivity of core and peripheral regions have attracted some attention in the last few years (Cano-Kollmann et al., 2016; 2018; Glückler, 2014). However, there is still ample room to explore how peripheral economies create or source different types of knowledge, and what role organization-based linkages (i. e., "pipelines") play in this process (Lorenzen and Mudambi, 2013). This is the main motivation for our paper.

We make two related arguments. First, it has been noted that value chain activities involving a high level of tacit knowledge "tend to remain more agglomerated in the parent company" (Cantwell and Santangelo, 1999: 101). These activities will be performed mostly by collocated teams or teams with members in global centers of excellence (Gittelman, 2007). Therefore, we argue that the local economy obtains limited connectivity to global innovation networks. Second, we argue that some leading innovative firms may possess complex organizational capabil-

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1 The term "location" is used here in the international business tradition, referring to a country context, and not as in economic geography, where it is always connected to a subnational locality.

ities that give them the ability to orchestrate these such activities when they are dispersed over geographic space (Cantwell, 1995; Cantwell and Mudambi, 2011; Tallman and Chacar, 2011).

The connectivity of a location is defined as the particular configuration of its global linkages combined with the specific network structure of these linkages (Lorenzen and Mudambi, 2013). In general, linkages between locations can arise either from organizations or from individuals. Since we use patent data, we will mostly refer to organizations as "assignees" (the owners of the patent) and to individuals as "inventors" (the individuals listed as inventors in the patent). In the literature, organization-based linkages have been referred to as "pipelines" (Bathelt et al., 2004), while those arising from individuals have been referred to as "personal relationships" (Lorenzen and Mudambi, 2013). Further, locations differ in terms of the extent to which their linkages are concentrated in a few central actors. In this paper, we do not analyze personal relationships (i. e., networks between individual inventors working together without being affiliated to an assignee). We focus on organization-based networks, i. e., networks coordinated by assignees for which inventors work. We examine empirically one aspect of connectivity in detail: the geographical dispersion of organization-based pipelines across national borders, as reflected by the patenting activity.

Non-core locations have the most to gain from connectivity to global innovation systems (Abramovitz, 1986). In particular, these gains can be best leveraged by economies that have achieved some degree of maturity in terms of local innovative capabilities. "Peripheral economies" form a particularly important class of non-core economies. In the international business literature, the concept of a "peripheral" economy fills an intermediate category (Molero, 1995) in the rigid "developed vs. developing/emerging" economies dichotomy. Benito and Narula (2008) provide a definition that characterizes peripheral economies according to detailed criteria like levels of foreign direct investment (FDI), trade in intermediate and manufactured goods, and levels of innovation, in order to distinguish them from core OECD economies. Some southern and eastern European countries are good examples (Benito and Narula, 2008; Liagouras, 2010; Narula and Guimón, 2010). As value chains are disaggregated across multiple countries, this provides opportunities for non-core locations to participate in the high knowledge components of those global value chains (McWilliam et al., 2020). Further, since peripheral economies are likely to lag the core in terms of innovation capabilities in almost all sectors, connectivity is likely to have particularly strong effects for them.

We study one particular aspect of the global connectivity of peripheral economies, namely the international dispersion of inventor networks. These inventors are typically employed by organizations so that we capture organizational networks that are defined by relationships between these individuals that are part of inventor networks. We use Portugal and Greece as examples of peripheral economies (Benito and Narula, 2008; Narula and Guimón, 2010). Both countries can be considered peripheral to the core region of Europe and are comparable in size, income and the level of development of their innovation systems. Furthermore, their location in the perimeter of the European continent (Portugal in the southwest and Greece in the southeast), and the fact that they do not share borders with the core European economies, create similar challenges in terms of integration with the rest of the continent. We analyze patent data for both countries, encompassing all the patenting activity linked to Portugal and Greece. We include patents from local firms with local inventors, patents from foreign-based assignees with local Portuguese or Greek inventors, and patents from local Portuguese or Greek firms with foreign-based inventors. Therefore, our sample includes the patenting networks of firms and inventors located in 44 countries. By understanding how these networks (organization-based pipelines) work in these peripheral economies, we highlight characteristics that may be typical of peripheral economies in general.

We find that peripheral economy inventors who collaborate with inventors in core economies tend to have more internationally dispersed networks. In addition, we provide some of the first empirical evidence on the Cantwell and Santangelo (1999; 2000) research on the dispersion of innovation activities involving tacit knowledge, in this case extending it to the context of peripheral economies.

The rest of the paper is structured as follows. Next, we review relevant literature. Then, we develop the theoretical bases of our analysis and derive our research hypotheses. Subsequently, data and empirical methods are described. Finally, we discuss our results and the associated implications.

Literature review

Peripheral economies

Periphery is not a new concept in the economics and international business literatures. Its roots can be traced to early works on the foundations of capitalism (Wallerstein,

1974) and dependency theory (Prebisch, 1962), which addressed the challenges of economic and technological catch-up for peripheral countries. Much of this early work involved a rather simple definition of the periphery, basing it on the realities of nineteenth century imperialism. By the last decades of the twentieth century, this research had become less useful in understanding the nature of global interactions (Cantwell, 1995). It is important to clarify that our understanding of "periphery" is aligned with the use of the term in international business and economics; the term, however, has a different meaning in the geography literature.

More recently, Molero (1998) defines peripheral economies as an intermediate group that displays less developed productive structures than the core, less internationalization via outward FDI, and with innovation systems marked by medium-low research and development (R&D) effort and modest levels of patenting. For Benito and Narula (2008), peripheral economies are "not significant destinations for or home to many multinational enterprises (MNEs); they engage in relatively little trade in intermediate and manufactured goods; they contribute relatively little to innovation and scientific progress; they are weakly linked or accessible physically to the core; they do not play significant decision-making roles within supranational organizations; and they do not share a significant number of formal institutions with core countries". While displaying these weaknesses, these are relatively affluent economies, with per capita incomes significantly higher than emerging countries, but below the more affluent core economies.

Benito and Narula (2008) specifically emphasize the role of interdependence. For them, the critical difference between core and periphery is the degree of social, political and economic international integration in the world economy. Cross-border activity (like international trade) or vertical cross-border linkages do not necessarily qualify as interdependence; they are merely internationalization. The key to interdependence is reciprocity, which involves ongoing, mutual relationships between economic actors. More unequal relationships weaken integration, leading to peripheral status.

Peripheral regions and knowledge networks

According to Saxenian (2006, p. 3), innovation is the key factor driving the evolution of formerly peripheral economies. One of the ways to foster innovation is to attract and embed MNE R&D activity. Since MNEs form internationally integrated intra-firm networks (Cantwell and Piscitello, 2000; McCann and Mudambi, 2005), *ceteris paribus*, more MNE activity is likely to increase the integration of the economy into global networks. However, technologically advanced MNEs are likely to seek locations with significant levels of academic activity (Alcácer and Chung, 2007), with high R&D intensity and a significant magnitude of technical activity (Chung and Alcácer, 2002), all of which is not typical of peripheral economies. In general, these economies are not very attractive locations for MNE R&D activities, because of weak location advantages, relatively under-developed scientific and educational infrastructure, low potential for knowledge spillovers, small market size (Cantwell and Piscitello, 2002, 2005), and low absorptive capacity (Cohen and Levinthal, 1990).

The activity of MNEs in these peripheral economies brings the greatest local benefits when it is associated with "capability/knowledge-augmenting" R&D activities – which seek to tap into local sources of knowledge and resources (Cantwell and Mudambi, 2005). Though "competence-creating" MNE subsidiaries are the most attractive, they usually require locations with a rich resource base (Cantwell and Mudambi, 2000). Further, they take time to develop, a process called subsidiary evolution (Cantwell and Mudambi, 2005). Over time simple headquarters to subsidiary knowledge transfer processes gradually give way to higher value-added processes (Monteiro and Birkinshaw, 2017).

Peripheral economies tend to attract "competence-exploiting", demand-driven R&D activities due to their disadvantage in technological capabilities *vis-à-vis* the core (Cantwell and Mudambi, 2000; Narula and Guimón, 2010). In line with this, Ambos and Ambos (2009) explored the location of R&D laboratories and found that out of 25 labs in non-core locations, only 5 had a capability-creating mandate. Competence-exploiting subsidiaries focus on routine replication and local adaptation and are the dominant type in Greece and in Portugal, according to Manolopoulos (2010) and Tavares-Lehmann (2008). In some cases, especially in oligopolistic industries, the main reason to enter the economy is to preempt a competitor or limit its growth prospects (Alcácer et al., 2013). Such subsidiaries are unlikely to spark innovation applicable beyond the local milieu (Cantwell and Mudambi, 2005). Hence, attracting MNEs to peripheral economies may have a limited impact on sparking high-quality innovative activity in those economies.

There are, *a priori*, clear differences in knowledge-sourcing patterns between MNEs and local firms. MNEs are characterized by "multiple embeddedness" (Andersson and Forsgren, 1996; Meyer et al., 2011) in their home country context and in that of their subsidiaries. Simultaneously, MNE subsidiaries are externally embed-

ded in their host milieu and internally embedded within their parent organization network (Andersson and Forsgren, 1996). This multiple embeddedness allows MNEs to integrate diverse knowledge sources and create value through "knowledge arbitrage". Henderson (2003) found that single-plant firms benefit more than multi-unit firms from local information spillovers derived from the local concentration of other plants in the same industry. Li and Bathelt (2020) emphasize that the nature of knowledge transfer depends on the local milieu of sending and receiving units wherein replicating strategies occur in cluster-to-non-cluster contexts or in fields with a knowledge gap between the two countries, whereas scouting strategies are typical in non-cluster-to-cluster investments.

This implies that, while location is also important for MNEs, they can source knowledge from units within the organization that is situated in other geographies. However, for domestic firms, the local environment is critical because it is their main source of resources. Bathelt, Malmberg and Maskell (2004) launched the argument of "local buzz, global pipelines" to discuss the complementarity of knowledge flows confined to the local milieu (the "buzz") and the extra-local exchange of knowledge (the "pipelines"). They challenge the idea that tacit knowledge can only be transmitted locally and that codified knowledge can be exchanged remotely without major obstacles. They argue that both types of knowledge can be either local or global under certain conditions, and assert that the availability of both high levels of buzz as well as many pipelines in a certain location provides firms with significant advantages.

In peripheral economies, pipelines are basically orchestrated by MNEs. Some factors may drive the creation of thicker pipelines; Alcácer and Zhao (2012) found that the presence of direct competitors in the same location tends to favor the creation of more internal linkages across different subsidiaries and more use of cross-cluster teams. However, pipelines are expensive to build and maintain since the establishment of subsidiaries requires relatively large investments. Furthermore, pipelines to other subsidiaries provide access to networks of inventors that are relatively constrained. A subsidiary 'A' collaborating with another subsidiary 'B' may only have access to its local network of inventors and to the local network of subsidiary 'B'. This is especially true as MNEs are concerned about the protection of their intellectual property, and are likely to refrain from open collaboration with external parties whose loyalty may be unknown (Mariotti et al., 2010; McCann and Mudambi, 2005).

Organization-based linkages or "pipelines" are not the only conduits through which specialized knowledge circulates. Personal networks also play an important role in the generation and exchange of knowledge and information, both in peripheral and core economies. Lorenzen and Mudambi (2013) refer to these networks as "person-based linkages", which tend to be serendipitous in origin, to distinguish them from "organization-based linkages" (i. e. "pipelines"), which are usually strategic in origin. Incorporating a social network view, they argue that the impact of global linkages on the catch-up ability of clusters in emerging regions depends on the network structure of those linkages. Other authors talk about "epistemic communities", or networks of specialized individuals spanning different organizations. Firms that don't belong to these knowledge networks are excluded from important knowledge-sharing (Lissoni, 2001). These person-based networks sometimes originate from connection-creating events have been described as "temporary clusters" (Maskell et al., 2006). Trade fairs, conferences and conventions are good examples (Cano-Kollmann et al. 2017); In those cases, the short-term co-location creates conditions for knowledge sharing, and is the basis for long-term personal networks.

Patenting networks across regions or countries allow firms to search non-locally for knowledge that is not available in their home territory. These patenting networks can be either organization-based or person-based. Organization-based patenting networks occur when multiple assignees join forces to patent together or when inventors working for different subsidiaries of the same assignee are listed in the same patent. Person-based patenting networks occur when individual inventors not affiliated with a corporation collaborate to patent an innovation (this is typical of independent inventors or entrepreneurs).

Knowledge sourcing and patenting collaboration patterns vary depending on regional characteristics. Munificent (i. e., "core") regions, with high levels of innovation, favor local collaboration, given the availability of local knowledge (Doh et al., 2005). Conversely, firms in peripheral economies, given their less favorable location, may be compelled to source knowledge from more remote sources by establishing more geographically dispersed networks based on personal relationships. Belussi et al. (2010) explored research networks in one of the most innovative regions of Italy and found a high propensity to establish local or national ties rather than transnational linkages to source knowledge. In turn, Boschma and Ter Wal (2007) explored the knowledge network of firms from a cluster located in a peripheral region (southern Italy) and found that firms having knowledge linkages with non-local firms had better innovation performance than those relying only on local relationships. This implies that firms in peripheral regions benefit from searching knowledge beyond the local milieu, even if they are located in a specialized

cluster. Asheim and Isaksen (2002) found that external contacts, outside the local milieu, are crucial for the innovation process of SMEs; too much reliance on local knowledge seems harmful for innovative capacity and can lead to a "technology trap" (Gewin, 2005). Consistent with this local-global dichotomy, Gittelman (2007) found that the spatial distribution of these collaborations tends to be strongly bimodal. Most knowledge networks show large numbers of local collaborations and large numbers of long distance collaborations, but few at intermediate distances. The rationale behind this distribution is that, when knowledge is not available locally, there is little to gain from tapping regions at intermediate distances if those regions do not possess that knowledge either. Once organizations need to establish collaborations outside the local milieu, they tend to do it with centers of excellence elsewhere, driven more by the availability of the knowledge than by distance considerations.

Finally, a key determinant of the dispersion of patenting activities is the tacitness of knowledge. Cantwell and Santangelo (1999; 2000) argue that co-location of inventors tends to be more prevalent in innovation activities that depend upon tacit knowledge. R&D related to the firm's core technologies and in science-based fields also seem to require more face-to-face interaction. These authors argue that activities involving tacit knowledge are geographically dispersed only in certain cases: (1) when the knowledge is locally embedded, unique and specialized or (2) when there are complex organizational networks in place. Point (2) implies that the "international dispersion of activity is led by technology leaders" (Cantwell, 1995: 155), i. e., that only leading firms possess the capabilities to effectively conduct this type of R&D through geographically dispersed teams. We test the findings of Cantwell and Santangelo (1999; 2000) in the context of peripheral economies.

Hypotheses

Our first hypothesis focuses on the relationship between the location of inventors and the level of disaggregation of patenting activity across national borders, specifically the dispersion of inventor networks. Inventors related to any country (e. g., Portugal) can be based locally (in this case, in Portugal) or based in foreign locations. In the second case, the relationship to Portugal arises from the fact that they work for an organization located in Portugal, i. e., an inventor working for a firm located in Portugal, but based in a foreign country. This foreign country can be a core economy or a peripheral economy.

In this paper, we focus on the case of inventors working for a firm in Portugal or Greece but located abroad. Organizations in peripheral economies (firms, research institutions, universities, etc.) seek knowledge from both local and non-local inventors, but they are likely to source the most complex, capability-driven, explorative knowledge (requiring the highest degree of collaboration) from core regions, since, on average, those locations have deeper pools of knowledge. Hence, the foreign-based inventors of peripheral-economy organizations who are located in core economies have access to wider innovation networks than those located in other peripheral economies. On the other hand, firms usually go to peripheral regions in search of exploitative, cost-driven knowledge. As the inventors they hire in peripheral economies undertake mainly exploitative work, they are only locally connected or at most, connected to a home economy subsidiary or to headquarters. Therefore, their networks will be more limited than those of inventors residing in core economies.

Drawing on the literature and the arguments discussed above, we state the following hypothesis:

> **Hypothesis 1:** When foreign-based inventors of organizations based in a peripheral economy are located in core innovative economies, they will be connected to more internationally dispersed inventor networks than when they are located in other peripheral economies.

We analyze two aspects of the phenomenon of patenting activities in peripheral economies. H1 focuses on the dispersion of inventor networks of organizations based in peripheral economies. It examines the foreign-based inventors of these organizations, comparing those based in core innovative economies with those based in peripheral economies. On the other hand, the next hypothesis focuses on the type of knowledge. As discussed in the literature section, it is widely accepted that different activities within the value chain have different degrees of transferability, depending fundamentally on the extent of codifiability. More codifiable patenting activities can be either outsourced or disaggregated (even across national borders), through geographically dispersed innovation networks. In contrast, more tacit innovative activities, as a general rule, are more likely to be internalized and conducted by collocated teams. This is true in peripheral economies as much as in other contexts. Therefore, our second hypothesis is the following:

> **Hypothesis 2:** When patenting in peripheral economies involves tacit knowledge activities, the inventor networks will be less internationally dispersed than when knowledge is more codifiable.

As Cantwell and Santangelo (1999) argue, there are two factors that facilitate the orchestration of tacit-knowledge patenting across dispersed networks. The first is organization-specific capability, typically associated with leading firms in the relevant knowledge space. The second is that the patenting is focused on competencies that are "non-core" for the company (Cantwell and Santangelo, 2000). Calantone and Stanko (2007) found that firms that are experienced in conducting exploratory research tend to outsource innovation activities (of any kind) to a higher degree. We argue that being an experienced innovator and having the capabilities associated with it will be most critical when the innovation is focused on tacit components. In addition, as argued by Cantwell and Santangelo (2000), for the largest and most experienced MNEs, most patenting with tacit components (such as design innovation) that is dispersed is typically not a core activity. Based on these arguments, we arrive at the following hypothesis.

> **Hypothesis 3:** The relationship between tacit knowledge and the international dispersion of inventor networks will be moderated by the innovation capabilities of the firms. Leading innovative firms will be able to disperse their tacit knowledge patenting across borders to a higher degree than innovation laggards.

In summary, we hypothesize that in the context of peripheral economies, the dispersion of patenting inventor networks across national borders will depend on the combination of the location of inventors, knowledge tacitness, and organizational capabilities of the innovating organization. Our hypotheses only predict the spatial form of the co-patenting networks, based on the three factors listed above. We do not make predictions about the overall success of those networks, in terms of total output or in terms of the impact of the patents they generate.

The empirical context: Portugal and Greece

We chose two typical European peripheral countries as the empirical settings to illustrate the processes underlying patenting networks in peripheral economies: Portugal and Greece. Both countries can be considered textbook cases of European peripheral economies, as they display all characteristics usually attributed to such economies. These include the structure of production, the degree of internationalization and international openness, foreign subsidiary roles, linkages among actors, innovation-related indicators, connectivity with the core, and organizational/institutional characteristics (Benito and Narula, 2008; Molero, 1995; Molero, 1998).

Compared to core European Union (EU) economies, their economies are marked by a low degree of internationalization, low relevance of high-tech sectors and a low weight of high-tech exports. Their patent production represents only a minimal fraction of the European patenting activity (Paci and Usai, 2000). They also show a predominance of SMEs and micro-enterprises with low productivity and often offering non-tradable services (Simões and Godinho, 2011), and a paucity of indigenous MNEs, a relatively low supply of technology, and (in the case of Greece) a risk-averse national culture (Souitaris, 2001). Particularly in Greece, there is also a significant number of under-educated or under-qualified people in senior positions in numerous companies, which poses additional challenges to fostering an innovative culture (Souitaris, 2002).

At a more general level, both countries have a similar population size: 10.3 million for Portugal and 10.6 million for Greece (CIA, 2013b) and similar income levels: the GDP per capita (PPP) of Greece is US$27,300 and that of Portugal is US$32,200 (CIA, 2013a). They also have a comparable area and have the disadvantage of being located at the extremes of Europe, relatively far from the core economic and innovative regions in the continent.

As expected in peripheral economies, linkages among actors in these countries are modest. In Portugal, the low degree of autonomy of foreign subsidiaries limits linkages with the Portuguese science, technology, and innovation (STI) system (Tavares-Lehmann, 2008). Foreign-owned subsidiaries in Portugal also tend to source less locally than their domestic counterparts, since few local suppliers can fulfill the standards they require, in quantity and quality, though this is changing (Tavares-Lehmann, 2008). In Greece, there is also little engagement and interaction between the STI programs designed by the government and the innovative firms in the private sector, particularly MNEs (Collins and Pontikakis, 2006). Another problem in Greece is the uneven regional distribution of both big companies and R&D, with the bulk of activity concentrated in Southern Greece relatively little activity in other regions such as Thessaloniki (Huggins and Strakova, 2012).

Literature on patenting activities is more abundant for Portugal than for Greece. Most studies about Portugal (Godinho, 2009; Godinho et al., 2004; Godinho et al., 2008) show that the country is well below the OECD average in terms of patent indicators. Yet, there has been an acceleration in patent applications since 2000 (Godinho, 2009). The recent increase in international patenting is mainly driven by the business sector. Subsidiaries of foreign MNEs and born-globals have been particularly active in

filing patents internationally, notably in the United States Patents and Trademark Office (USPTO) (Godinho et al., 2008). For high-tech firms, most of which are SME start-ups, patenting in the USPTO is a matter of reputation and "signaling" to potential partners and clients. MNE subsidiaries tend to centralize patenting processes, including patent applications, at headquarters or at a central R&D base. In Greece, there have been a number of programs (EPET I and II, STRIDE Hellas) aimed at increasing the scientific and innovative production of the country. In spite of steady increases in overall production of patents and publications since the 1980s, the country is still a clear innovation laggard in the context of the European Union (Collins and Pontikakis, 2006).

Data and methodology

Data

Patent co-inventorship has been used to explore collaboration patterns of inventors (Ejermo and Karlsson, 2006). However, patent data have certain limitations (Archibugi, 1992; Pavitt, 1988), such as lack of consistent quality across national patent systems and uneven approval rates in different countries; for that reason it is recommended that datasets contain patents registered in one single patent institution (Archibugi and Coco, 2005). Another limitation is that patents are poor indicators of innovation output for sectors where most innovations go unpatented (Hu, 2012). The propensity to patent in a foreign system depends on many factors, but the most valuable inventions tend to be patented in the most important patent systems, particularly in the USPTO (Archibugi and Coco, 2005).

Finally, we use design patents as a proxy for innovation that involves tacit knowledge. A potential issue with this is that design patents may be, on average, easier to obtain than utility patents, and therefore may require less collaboration. This is a broad generalization since some design patents are for relatively sophisticated items such as surgical implants or vending machines. However, there is no systematic way to assess whether design patents are "easier" than utility patents and therefore may potentially require less collaboration. This is a limitation of our data.

Our empirical analysis is based on patenting activity involving Portuguese and Greek assignees and inventors. We constructed a population dataset of patents obtained from the USPTO, granted between 1976 and 2013, to assignees or inventors located in Portugal and Greece. While the USPTO does not represent the entire innovation output of foreign countries, it tends to contain a valuable portion of the knowledge generated in a country. Another advantage of USPTO is the predominance of patents granted to firms (the focus of this study), whereas national patent systems, particularly in developing countries, show a high incidence of patents granted to individuals (Da Motta e Albuquerque, 2000; Penrose, 1973). In our study, the use of USPTO data (rather than European patents) is justified for several reasons.

First, we want to include the interactions of foreign-based firms with local inventors based in the focal peripheral economy. This particular case (for instance, a firm that conducts innovation in the U.S. but uses a Portuguese inventor) is not likely to be captured in the Portuguese patent system, since the firm is more likely to patent in its home country and in USPTO rather than in Portugal.

Second, the European Patent Office (EPO) treats design innovation separately (i. e., there are no design patents), which makes it impossible to use our proxy for tacit knowledge innovation. Third, EPO provides information not only on patents granted but also includes on the listings applications not yet granted, applications withdrawn, applications deemed to be rejected or withdrawn, among others, for a total of 12 different statuses. This creates a number of problems. For instance it doesn't allow us to estimate the number of patents a firm possesses since a search by assignee yields a number of references that are not actual patents (they are applications, patents rejected, etc.).

Fourth, the EPO search engine mixes search fields (for instance, company name and street name), which results in unreliable results. And fifth, in Europe it is possible to apply for a patent in the local office of the country (instead of EPO), so many applications are done only in two or three countries and not in EPO; but if these patents are valuable enough, are also likely to be submitted to USPTO.

We did, however, conduct an empirical analysis with EPO data. The results are incomplete since we are missing several variables (Design, MNE, Leader), but the coefficients are consistent with our conceptualization. Based on our partial results, we believe that EPO data would be consistent with the results obtained using USPTO patents. As such, the USPTO displays a realistic picture of the invention activity in these peripheral economies.

It is important to emphasize that, while the setting of our study is Portugal and Greece, our sample captures the entirety of these countries' innovation systems, which comprises a set of assignees and inventors located in 44 countries. It includes every firm in the world that patents using a Portuguese or Greek inventor and every inventor in the world that works for a Portugal or Greece-based firm.

Obviously, such interactions are better captured by USPTO rather than by local patent data.

We collected all USPTO patents associated with the Portuguese and Greek innovation systems in batches. First, we collected all the patents that listed at least one assignee based in Portugal. The second batch contained all patents granted where at least one of the inventors was based in Portugal, regardless of the location of the assignee (Portugal- or foreign-based). Then we eliminated duplicate observations (patents included in both batches because they had both assignee and inventors based in Portugal) and dropped patents assigned to individuals, to focus on the patenting activity of companies. We arrived at the first subset of 503 unique patents corresponding to the Portuguese national system of innovation. We repeated the same steps for Greece, constructing a second subset with 864 unique patents corresponding to the Greek national system of innovation. We "pooled" both subsets into one dataset, which we used for our main empirical models. We distinguished the country-subsets by using a dummy variable (*GREE_NSI*) for the patents that are linked to Greece. The final dataset (after dropping duplicate patents) contains 1,355 unique patents.

Variable definitions

Dependent variable

- *International dispersion of the network of inventors* (*INV_DISP*): we constructed our dependent variable in two steps, following Hannigan, Cano-Kollmann and Mudambi (2015) and Lee, Mudambi and Cano-Kollmann (2016). First, we computed the Herfindahl index of inventor concentration at the country level. For instance, if a patent was authored by four inventors, of which three are located in country A and one is located in country B, the associated Herfindahl index *'H'* is equal to: $0.75^2 + 0.25^2 = 0.625$. If all inventors are in one country, the Herfindahl index is equal to 1. Since we are interested in the dispersion rather than the concentration of inventor networks, the second step was to construct our dependent variable *'Y'* by transforming Herfindahl index '*H*', such that:
  $Y = 1 - H$
  As a result, our dependent variable is censored, with a minimum value of 0 (when all inventors are concentrated in one country), and an upper limit asymptotically approaching 1 as the inventors are more dispersed across countries.

Independent variables

- *Inventor-country GDP per capita (IC_GDP*): we use GDP as a proxy for the type of country where inventors are located (i. e., core, peripheral, emerging). This indicator is longitudinal and corresponds to the year each patent was filed. In patents with inventors in more than one country, the weighted average is used (weighing each country score based on the share of inventors from each country in the inventor group).
- *Firm innovative leadership (LEADER*): *LEADER* is a dummy variable for firms in the upper quartile of the sample in terms of their patent pool. We operationalized 'patent pool' as the natural logarithm of the number of USPTO patents issued to each company.
- *Tacit Knowledge activity (DESIGN)*: is operationalized by a dummy variable for any "design patent" in our dataset. According to the USPTO description, a "design patent" protects "the way an article looks", in contrast to a "utility patent", which protects "the way an article is used and works". In practical terms, a design patent has a "D" before the number. In the literature, design knowledge has been described as the combination of both explicit components and tacit ones, also dubbed "know-x" (Wong and Radcliffe, 2000). The "know-x" component is the ability to select the right piece of information and to use it in the right way, at a right time and place, to carry out a design. In the same vein, other authors (Arora et al., 2001; Leonardi and Bailey, 2008; Yoo et al., 2006) have described different aspects of design as having a significant tacit component. All of this is consistent with our arguments that (1) design contains tacit elements and (2) design usually requires co-location or proximity of inventors.

Interactions terms and control variables

- *Tacit knowledge activities by innovation leaders (LEAD_X_DES)*: this interaction term is the multiplication of *LEADER* and *DESIGN* and reflects the effect of doing innovation in design if the assignee is an innovation "leader", compared to the effect of doing design by any other assignee who is a "laggard".
- *Multinational enterprise (MNE)*: we searched for information on every patent assignee; we considered MNE any firm which had operations in more than one country (not counting sales exports). Universities or research organization with only local operations were not considered MNEs. As our data goes back to 1976, it

contains a number of defunct firms or assignees that left no trace on the internet. In these cases, we adopted an inclusive criterion, considering the assignee as 'MNE' if at least one inventor in the patent was located in a country different than that of the assignee.
- *Geographical dispersion of assignees (ASSI_DISP)*: the international dispersion of assignees calculated in the same way we calculated the dispersion of inventors.
- *Number of inventors (NUM_INV)*: number of inventors participating in the patent.
- *Other organizations (OTHER_ORG): dummy variable for organizations that are not business firms (for example universities, research institutions, etc.)*

We also incorporated technology controls. We used each patent class and classified it into a taxonomy based on HALL et al. (2001), which organizes utility patent classes into six major categories. Those six categories are 1) Chemical, 2) Computers and Communications, 3) Drugs & Medical, 4) Electrical & Electronic, 5) Mechanical and 6) Others. Design constitutes a seventh category of patents. In addition, we also controlled for whether the patent is part of the Portugal or Greece subsets and used year fixed effects.

Estimation

Table 1 presents the summary statistics for our sample. The dependent variable is bounded, with a minimum value of 0 when all the inventors are in the same country, and a maximum observed value of 0.800. Of the patents in the data set, 50.8 % only have one inventor-country, which means there was no international collaboration involved. The other 49.2 % of the patents involved networks of collaboration between inventors in different countries. There is a large dispersion of innovative capabilities among the sample firms, as measured by their patent pool. The median firm in our sample holds approximately 40 patents.

We employ a multiple regression approach to test our hypotheses. As described previously, our dependent variable is double censored; the most appropriate technique for this type of dependent variable is a Tobit regression (GREENE, 2000: 905–926). Tobit models have been used in many studies with similarly censored dependent variables (Jeong and Weiner, 2012; Laursen and Salter, 2006; Mudambi and Helper, 1998; Ragozzino and Reuer, 2011).

Multicollinearity diagnostic checks were performed by running each model with an OLS regression and calcu-

Table 1: Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
International dispersion of inventor networks (INV_DISP)	1366	0.225	0.240	0	0.800
Inventor-country GDP per capita (IC_GDP)	1366	22,211	10,264	2,028	50,371
Firm innovative leadership (LEADER)	1366	0.250	0.433	0	1
Multinational enterprise (MNE)	1366	0.684	0.465	0	1
Design patent (DESIGN)	1366	0.138	0.345	0	1
Geographical dispersion of assignees (ASSI_DISP)	1366	0.011	0.074	0	1
Number of inventors (NUM_INV)	1366	2.856	1.882	1	13
Non-business organization (OTHER_ORG)	1366	0.147	0.354	0	1
Design by innovation leaders (LEAD_X_DES)	1366	0.008	0.089	0	1
Greek national system of innovation (GREE_NSI)	1366	0.633	0.482	0	1

Table 2: Pearson correlation coefficients

	1	2	3	4	5	6	7	8
1 International dispersion of inventor networks (INV_DISP)	1.000							
2 Inventor-country GDP per capita (IC_GDP)	0.378	1.000						
3 Firm innovative leadership (LEADER)	0.283	0.188	1.000					
4 Multinational enterprise (MNE)	0.087	0.087	0.155	1.000				
5 Design patent (DESIGN)	-0.260	-0.154	-0.180	0.066	1.000			
6 Geographical dispersion of assignees (ASSI_DISP)	0.103	0.073	0.111	-0.041	-0.061	1.000		
7 Number of inventors (NUM_INV)	0.418	0.378	0.241	0.045	0.242	0.143	1.000	
8 Non-business organization (OTHER_ORG)	0.204	0.017	0.027	-0.565	0.168	0.110	0.151	1.000

lating variance inflation factors (VIFs). All the estimates showed values of less than 3, well below the commonly accepted threshold of 10 for VIF values (Chatterjee and Price, 1991). Finally, we acknowledge that there may be other factors not included in our model that affect both location and inventor dispersion. For this reason, we do not take our coefficients as indicators of causality but rather as indicators of associations between constructs.

Results

We ran three regression models to test our hypotheses (see Table 3). All models use censored Tobit analysis and the dependent variable is the dispersion of inventors across countries (measured for each focal patent).

Model 1 is the base model and Model 2 is our full model containing the interaction term *Tacit knowledge activities by innovation leaders (LEAD_X_DES)*. Model 3 is similar to Model 2 but only includes patents linked to Greece. As predicted by our Hypotheses 1, higher GDP per capita is associated with more international dispersion of inventors. This implies that inventors located in core economies have access to richer networks of innovation. This finding is consistent with our conception. As we hypothesize, inventors of in richer economies usually can tap into deeper pools of knowledge, which usually means more geographically dispersed inventor pools collaborating in the patents. On the other hand, since firms in peripheral regions usually undertake exploitative, cost-driven knowledge creation, their connections tend to be more geographically restricted. The coefficients for Inventor-Country GDP per capita are significant but very small. Since our DV is an index, it is not possible to interpret the magnitude of the effect, and we acknowledge this is a limitation.

Hypothesis 2 focuses on tacit knowledge activities operationalized by design patents. We predict that design patents will be usually authored by co-located teams, due to the high component of tacit knowledge they contain. The degree of codifiability is one of the main determinants of the ability to transfer knowledge across distances. Codifiable knowledge can be exchanged across long distances, facilitating the dispersion of patenting teams. More tacit innovative activities, on the other hand, require co-location, observation, and learning-by-doing for their transmission, therefore setting a constraint for the dispersion of inventors. Therefore, when the knowledge is highly tacit, teams are more likely to be collocated than dispersed. This is true in peripheral economies as much as in other contexts. In other words, the geographical dispersion of teams involved in design patents will be less than for utility patents. The coefficients for DESIGN are negative in all models and significant in our full models 2. This is consistent with H2.

Finally, Hypothesis 3 predicts that innovation leaders are more capable to integrate tacit knowledge innovation across geographic space. This is based on Cantwell and Santangelo (1999, 2000) and Calantone and Stanko (2007), who predict that experienced innovators develop both the absorptive capacity, and the recombination and knowledge management capabilities to disperse even those knowledge creation activities that involve tacit knowledge. Less capable or experienced firms are unlikely to possess these competencies. In other words, innovation in design can only be geographically dispersed when it is carried out by leading firms. Our interaction coefficient LEAD_X_DES is positive and significant in both model 2 and 3, consistent with H3.

In terms of controls, MNE shows positive and significant coefficients. This is consistent with the notion that MNEs will have access to networks in multiple countries, which local firms will not be able to match. The *geographical dispersion of assignees (ASSI_DISP)* is positive and significant. This is intuitive; if a patent is coauthored by assignees dispersed in different countries, the inventors are also likely to be geographically dispersed. The coefficient for *number of inventors (NUM_INV)* is also positive and significant. This is not surprising either; the larger the group of inventors participating in the patent, the larger the chance that one or more of them are located in a different country. The coefficient for *other organizations (OTHER_ORG)* is also positive and significant. This is consistent with the notion that person-based linkages (the type favored by research institutions or universities) are easier to establish than organization-based linkages (the type favored by business firms). Research institutions or universities also facilitate the temporary co-location mechanisms (in the form of conferences, seminars, etc.) that are the basis for the creation of long-term person-based linkages. Finally, the coefficient for the *Greek national system of innovation (GREE_NSI)* is not significant, meaning that Greek innovators and their Portuguese counterparts do not show significantly different levels of dispersion.

To test the robustness of our data, we analyze data from other patent sources (EPO) and from other peripheral economies (Czech Republic, Slovakia and Slovenia). The data is not fully comparable, since some variables were missing. However, results (not reported here) seem consistent with our first hypothesis, that inventors in core economies are connected to more internationally dispersed inventor networks.

Concluding remarks and implications

The traditional development economics literature distinguishes between developed and developing countries (Meier and Rauch, 2005). Later literature identifies some members of the old developing country group that experienced rapid catch up along a number of dimensions as 'emerging economies' (Awate et al., 2012). But, with few exceptions, the growing diversity within the developed country group has not received much attention (Benito and Narula, 2008; Narula and Guimón, 2010). This paper focuses on the sub-group of developed countries that have been labeled 'peripheral' due to their relatively lower con-

Table 3: Tobit regression results for international dispersion of inventor networks

DV: International dispersion of inventor networks (INV_DISP)	Model 1	Model 2	Model 3
Inventor-country GDP per capita (IC_GDP)	0.0004 **	0.0000 **	0.0000 **
	(0.000)	(0.000)	(0.000)
Firm innovative leadership (LEADER)	0.0890 **	0.0685 **	0.0439 †
	(0.021)	(0.021)	(0.023)
Multinational company (MNE)	0.2317 **	0.2258 **	0.1070 **
	(0.029)	(0.029)	(0.033)
Design (DESIGN)	-0.0387	-0.1090 *	-0.0667
	(0.046)	(0.049)	(0.063)
Geographical dispersion of assignees (ASSI_DISP)	-0.1287	-0.1124	-0.1609
	(0.106)	(0.105)	(0.129)
Number of inventors (NUM_INV)	0.0353 **	0.0341 **	0.0123 *
	(0.005)	(0.005)	(0.006)
Non-business organization (OTHER_ORG)	0.3168 **	0.3109 **	0.2003 **
	(0.034)	(0.033)	(0.037)
Design by innovation leaders (LEAD_X_DES)		0.4160 **	0.4424 **
		(0.092)	(0.114)
Greek national system of innovation (GREE_NSI)	-0.0229	-0.0243	
	(0.020)	0.020	
Technology controls	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Constant	-0.4798 **	-0.4723	-0.3633 **
	(0.116)	(0.115)	(0.110)
Observations	1,355	1,355	854
Prob>chi2	0.000	0.000	0.000
Pseudo R2	0.620	0.631	0.742

† p <0.10; * p < 0.05; ** p < 0.01

nectivity with the global economic system, as compared to the 'core' developed countries.

We use the comprehensive population data set of U.S. patents issued between 1976 and 2013 to Portuguese and Greek assignees (organizations) and inventors (individuals) to analyze the dispersion of inventor networks across national borders in these peripheral economies. Most studies of innovation systems are either couched at the level of organizations or at the level of individual inventors. We build on prior work on inventor networks (Balconi et al., 2004; Fleming and Marx, 2006; Zucker and Darby, 1996) and disentangle three factors that are associated with the dispersion of those networks: the location of the inventors, the type of knowledge, and the capabilities of the firm.

The first part analyzes the association between location of inventors and the international dispersion of inventor networks. Our findings are consistent with our conception that inventors located in core innovative countries have access to more internationally dispersed inventor networks. Thus, interaction with them will provide organizations based in peripheral economies with the potential benefits derived from this dispersion. In contrast, too much reliance on local knowledge sources may be harmful for innovative capacity and can lead to a "technology trap" (Gewin, 2005).

The second part explores how the tacitness of the knowledge involved in the innovation process hinders dispersion. Consistent with our conception, we find that design patents are associated with less dispersed inventor networks. This relationship, however, is moderated by the capabilities of the firms conducting the innovation. Highly innovative firms develop capabilities that allow them to conduct this type of innovation in a more dispersed manner. These findings are consistent with our second and third hypotheses. To the best of our knowledge, this is the first empirical testing of the theoretical work of Cantwell and Santangelo (1999; 2000) about the factors affecting the dispersion of tacit knowledge creation.

We believe our work has two types of implications. For academics, it opens the way to the exploration of a potentially very interesting area of inquiry: the characteristics of innovation in peripheral economies and the differences between the creation of tacit and codified knowledge in those contexts. Further work will be needed to disentangle the complex realities of these economies, but we think this a first step in that direction.

For policymakers, we provide some important distinctions about the factor that may affect connectivity in peripheral economies. For economies that are striving to catch up with the core, understanding these drivers may prove to be a very valuable tool. Concerning policy, the way to diminish the disadvantages of peripherality is to increase connectivity – by promoting the presence of locally based (domestic and foreign-owned) actors in international innovation and supply networks. Such connectivity to global value chains is a key aspect of high levels of local value creation (Humphrey and Schmitz, 2002; Mudambi, 2008; McWilliam et al., 2020).

In this context, our findings highlight the crucial role of the individual level of analysis (networks of inventors). Such connectivity requires a strengthening of system linkages (Mudambi, 2008) and "systemic density" (Godinho and Simões, 2013). Our results suggest that connectivity to core economies would potentially yield the highest benefits for peripheral economies, and this is where policymakers should focus their efforts. A context where technologies reduce spatial transaction costs, but policies may increase them, tends to favor large MNEs, because they have the resources to afford these transaction costs. It is therefore important that policies interfere in connectivity as little as possible, to create a level playing field for all companies, large and small. Given that linkages and networks need time to develop, consistency and predictability of policies are key factors.

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