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and legitimacy ties**

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Innovation from science: the role of network content and legitimacy ties

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Abstract: This study contributes to advance understanding on the micro-level foundations of the relationship between scientific research and innovation. We adopt a relational approach to scientific research networks through the analysis of the content of network ties, in contrast to more standard network approaches which are grounded on structural features of networks. We argue that the perceived legitimacy afforded through ties within research networks play a critical role in reconciling the conflicting logics of science and innovation. The proposed hypotheses are empirically tested in the context of the Spanish biomedical research system, drawing on a large scale survey of biomedical scientists. Our results indicate that the scientists' acquisition of legitimacy through their research network play a critical role in the context of the translation from scientific research to technological achievements and innovations. Our findings also show that past scientific impact has a reinforcing effect on the relationship between legitimacy acquisition and technological achievements. On the contrary, we find that direct interaction with beneficiaries provides an alternative path to reconcile the conflicting logics of science and market, by compensating for the lack of acquired legitimacy from research network.

1 Introduction

Although the analysis of the socio-economic benefits from publicly funded research has been a topic of extensive research in the last decades (Cohen et al., 2002; Salter and Martin, 2001), the factors that underlie innovation and technological performance from scientific activities remain a subject of open debate. This is becoming a particularly pressing topic in both science policy and innovation management literatures. On the one hand, publicly funded research is becoming increasingly accountable to demonstrate its capacity to contribute both to scientific discoveries and useful applications (EC 2016; Von Schomberg, 2013). More recently, science policies also advocate for the active involvement of stakeholders in the setting of scientific research goals and the assessment of translational achievements and societal impacts, particularly so in the case of biomedical research (Morgan et al., 2011). On the other hand, the management literature has highlighted the inherent difficulty of reconciling innovation achievements and scientific goals since they often respond to conflicting logics (Gittelman and Kogut, 2003; Dasgupta and David, 1994) - i.e. market versus science logics - and rely upon different cognitive bases (Nightingale, 1998).

Drawing on the preceding debates, this study aims to improve our understanding of the micro-level foundations of the relationship between scientific research and development of new applications. We do so by considering a relational approach to scientific research networks through the analysis of the content of network ties (Levin et al., 2015; Walter et al., 2015). This perspective is in contrast to more standard network approaches, which are grounded on structural features of networks and have received much more theoretical and empirical attention in the literature (e.g.: Balkundi et al., 2007; Burt, 2004; Tan et al., 2015). Given the crucial role that scientific collaboration networks play in knowledge creation processes (Adams, 2012; Miguélez and Moreno, 2013), we investigate the extent to which the types of social exchanges in research networks are conducive to the generation of valuable applications from scientific endeavours. More specifically, we examine a particular type of social

exchange from network contacts: the specialised advice and guidance that contribute to gain credibility on research-related activities obtained through ties to network partners (Levin and Cross, 2004). Our results thus suggest that the perceived legitimacy afforded through ties within research networks play a critical role in reconciling the conflicting logics of science and innovation. Moreover, we examine two additional factors that may contribute to enhance the capacity of scientific research activities to generate valuable applications and innovations: the past scientific performance of scientists and the direct interactions of scientists with the potential beneficiaries of their research.

We develop a set of hypotheses which are empirically tested in the context of the Spanish biomedical research system. While the social and economic benefits associated with public spending on biomedical research may seem obvious, they are by no means easy to realise. Indeed, the surge of policy initiatives in most countries, oriented to encourage translational research in biomedicine, reflects that the “substantial investment in laboratory based biomedical research has led to considerable success in terms of scientific discoveries, but is regarded as failing to achieve comparable advances in diagnosis and treatments” (Morgan et al., 2011, p. 946). We focus on the total population of biomedical scientists who are part of one the most important policy initiatives to support translational research in Spain: the CIBER programme (Spanish Biomedical Research Networking Centers). Our empirical results derive from an analysis of a survey of all the biomedical scientists participating in the CIBER programme.

Our interpretation of these results is that the scientists’ acquisition of legitimacy through their research network plays a critical role in the context of the translation from scientific research to technological achievements and innovations. Our findings also show that past scientific impact strengthens the positive effect between legitimacy acquisition and technological achievements. These findings support our claim that past scientific performance contribute to endorse greater credibility to the science on which research projects draw upon. Finally, our results indicate that direct interaction with beneficiaries provides an alternative path to reconcile the conflicting logics of science and market,

by contributing to a greater understanding of the context of application and to an enhanced motivation of scientists to make a positive impact on beneficiaries. Thus, we infer that interaction with beneficiaries compensates for the lack of acquired legitimacy from the research network, exerting a weakening effect on the relationship between the latter and innovation performance.

The remaining of the document is organised as follows. We begin by discussing the problematic balance that scientists face when aiming to reach scientific contributions and useful technological applications. We then examine the importance of social exchanges as a mean to achieve legitimacy to reach this balance. We then explore the contingent role of past scientific performance and contact with beneficiaries in shaping the relationship between legitimacy acquisition and technological achievements. Finally, we discuss results and develop the implications of our findings.

2 Conceptual background and hypotheses

Reaching scientific contributions and useful applications: a problematic balance

Academic researchers may contribute to both scientific discoveries and technological advances and inventions with market potential. Prior research has provided evidence that publicly funded research may result in both fundamental insights and useful applications (Sauermann and Stephan, 2012). Moreover, research on university – industry relationships has shed light on the impact that the multiple interplays between scientific discoveries and technological advances have played in the shaping of technological trajectories and the emergence of new industries (Rosenberg and Nelson, 1994).

However, scientists who contribute to both scientific discoveries and useful applications, and who are capable to transform new scientific ideas into innovations, are in short supply. A fundamental reason for this assertion is that the norms and incentive structures governing the reward system in science often militate against the joint achievement of these two outcomes. The science reward system

has systematically led to prioritizing peer recognition and academic reputation within the scientific community, while placing the societal impact of the research in a secondary consideration regarding career progress in academia (Stephan, 2010). As pointed out by Subramanian et al. (2013), when addressing the challenges of academic scientists in achieving above-average publication and patenting performance: “the goal of publishing is largely for the establishment of academic reputation. Journal editors and the peer review process seldom require the degree of practicality expected of a patent application” (p. 597). In such an institutional setting, the decision of scientists to actively embrace the challenge of contributing to useful applications may be viewed as a signal of deviance from the dominant reward system in science, switching from a system governed by the traditional norms to one where researchers are more strongly focused to, and aware of, the societal impact of their research findings (Hessels and Van Lente, 2008).

Another reason to support the claim that this type of scientists are a rare species refers to the inherent challenges involved in the processes associated with the transformation of scientific discoveries into useful applications and innovations. The joint achievement of these two research outcomes is likely to involve higher rates of failure, demand longer time-spans for the realisation of outputs and require a greater diversity of skills, which may range well-beyond the competence of ordinary researchers or research teams (Fini et al., 2010). Relatedly, it has been suggested that scientists involved in technology transfer endeavours should undertake a costly sense-making process to successfully reconcile their “academic role” with their “entrepreneurial role” towards a “hybrid role” identity (Jain et al., 2009).

In short, there is something special about those scientists who manage to bridge the scientific and technological domains, and who have often been referred in the literature as “bridging” scientists (Gittelman and Kogut, 2003; Bourellos et al., 2012; Subramanian et al., 2013) The following subsections discuss which factors are expected to contribute to balance the conflicting goals associated with the joint achievement of scientific and technological outcomes.

A relational network approach: legitimacy acquisition through network ties

In this study we adopt a relational approach to social capital. Network relational approaches focus on the relational properties of the dyadic linkages between network partners (Levin et al., 2006; Levin and Cross 2004). The relational view of social capital has received much less attention than aspects related to network structure, such as network closure (Gargiulo et al., 2009; Tan et al., 2015), brokerage (e.g. Burt, 2004; Collet et al., 2014; Fleming et al., 2007) or structural embeddedness (Hernandez et al., 2015; Uzzi, 1997). The relational approach is rooted in an essential distinction between the configurations of networks and the quality of the relationships established among network partners. Rather than inferring network effects from structural features of the network, relational approaches have focused on the content of network ties, such as the specific type of support that each network contact provides (Chua et al., 2008). Tie content can enlarge the potential benefits derived from sparse networks, providing a fine-grained understanding on how valuable knowledge (e.g. innovations) from heterogeneous networks is actually realised (Moran, 2005). Thus, the relational approach allows to directly capturing certain features of social connections which remain obscured when adopting structural approaches.

A particularly interesting category of network connection refers to those ties that are associated with the enhancement of legitimacy. Legitimacy has been defined as “a generalized perception or assumption that the actions of an entity are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs, and definitions” (Suchman, 1995: 574). Research in the fields of sociology and science policy illustrate that the perceived legitimacy of actors is an intangible asset acquired as a result of social evaluation processes coming from third parties (Bitektine and Haack, 2015). Thus, legitimacy can be regarded as a fundamentally social constructed perception rooted in the set of social relationships where individuals are embedded. For instance, establishing trust-based collaborative relationships with stakeholders help actors build legitimacy (Castelló et al., 2016).

Actors involved in actions that deviate from the set of norms and values of their professional communities are particularly compelled to build legitimacy to support their actions. In their research-related activities, scientists form and maintain different types of network ties. While some of them can be instrumental (e.g.: network contacts providing financial resources or access to relevant information sources), others can be more credibility-seeking in nature (e.g.: network contacts providing social support to convince others). The acquisition of such resources is achieved through the formation of networks with a heterogeneous range of actors who contribute to endorse deviant or atypical behaviour, providing legitimacy to these actions. As previously discussed, in the scientific research context, being involved in innovation-related activities is more the exception than the norm. Even more exceptional is to succeed in the generation of valuable applications, since there is a large path from the conception of a novel idea to its implementation. Gaining legitimacy through the scientists' range of network contacts may be a central piece to successfully navigate throughout the stages of this process (Baer, 2012; Perry-Smith and Mannucci, 2017).

Indeed, legitimacy is fundamental to overcome resistance to change in innovation-related processes (Hekkert et al., 2007), and it has been demonstrated to constitute a critical driver of institutional and organizational change (Greenwood et al., 2002, 2011). The relevance of a networked legitimacy strategy seems particularly salient in innovation-related activities within the biomedical context, where the perceived lack of legitimacy of research goals between basic and clinical scientists has been recognised as a critical barrier to innovation diffusion (Adler and Kwon, 2013). Thus, in the context of biomedical scientific research, gaining legitimacy through social exchange processes should be expected to play a critical role to achieve success in the capacity to translate research findings into useful applications. Therefore, we propose the following hypothesis:

***Hypothesis 1:** The more legitimacy that scientists acquire (gain) from their research network ties, the higher the likelihood that scientists will achieve technological advances from scientific research.*

The moderating role of past scientific performance and contact with beneficiaries

The literatures of academic entrepreneurship and university-industry collaborations have provided strong support about the role of star scientists and interaction with stakeholders as factors that influence the capacity of scientists to be involved in commercialisation and technology transfer activities (Landry et al., 2007; Zucker et al., 1998). We draw upon these streams of research to suggest a moderation role of these factors on the relationship between network legitimacy ties and innovation performance in scientific research activities.

Past scientific performance

The academic entrepreneurship literature has shown that scientists who have significantly contributed to breakthrough scientific discoveries and have achieved a prominent position within the academic community in terms of reputation and recognition (i.e. star scientists), have played a distinct role in terms of expanding the pool of inventions with potentially high commercial value (Lowe and Gonzalez-Brambila, 2007; Zucker et al., 1998). According to this stream of research, past breakthrough scientific discoveries would exert a signalling effect on the scientific and non-scientific communities. Regarding the former, past scientific impact would contribute to increase a symbolic dimension of social capital: i.e. reputation and credibility. We argue that a past record of breakthrough discoveries is likely to reinforce the centrality of scientists in the scientific community, increasing their reputation and authority to undertake research avenues that might be seen as departing from the dominant norms in science. Thus, the enhancement of the scientists' reputation and authority within the scientific community should increase their autonomy to undertake activities associated, for instance, with the commercialisation of research results.

Regarding the signalling effect on non-academic communities, we claim that scientists who have a track record of high scientific impact are likely to attract the attention of non-academic audiences, enhancing the probability to translate research ideas and embryonic inventions into useful applications (Bourellos et al., 2012). A case in point is represented by scientists who, by virtue of

reputation and credibility achieved within the scientific community, have managed to attract funding from industrial companies and venture capital firms to enhance the commercial feasibility of inventions and working-prototypes (Zhang, 2009). Therefore, we propose that:

***Hypothesis 2a:** The greater the scientists' past scientific performance, the higher the likelihood that scientists will achieve technological advances from scientific research.*

Moreover, scientists with a track record of high scientific impact provide a form of research legitimacy that complements the one afforded through social exchange processes. Scientists' past scientific performance contributes to sanction rigour and credibility to the science underlying research projects. This complements the legitimacy gained through the endorsement from different actors within the research network in order to enhance the capacity to translate upstream knowledge into new technological outputs and useful applications. Therefore, we claim that past scientific impact has a reinforcing effect on the relationship between acquisition of legitimacy through social exchange processes and innovation performance, by virtue of endorsing greater scientific credibility. Following this argument, we propose that:

***Hypothesis 2b:** Scientists' past scientific performance enhances the positive relationship between acquisition of legitimacy from their research network ties and achievement of technological advances from scientific research.*

Contact with beneficiaries

Beneficiary contact refers to the direct connection between employees and the beneficiaries of their work, and has been identified as an important relational aspect of jobs (Grant, 2012, 2008). In the context of this study, we define beneficiary contact as scientists having social exchanges with patients and clinical practitioners and argue that scientist' ties with beneficiaries will be a critical factor to facilitate scientists' shift from scientific discoveries to technological advances.

On the one hand, direct interactions with beneficiaries provides a better understanding of the context of application and a greater awareness of the potential market value from fundamental and applied research. Indeed, direct contact with research beneficiaries has traditionally represented a critical source of knowledge to identify potential pathways for the commercial exploitation of findings from scientific research. For instance, interaction with industrial practitioners in the context of scientific research activities has been identified as a strong predictor of effective technology transfer (D’Este et al., 2012; Grandi and Grimaldi, 2005; Landry et al., 2007).

On the other hand, interaction with beneficiaries of research is likely to influence scientists’ pro-social motivations and to shape attitudes and awareness about what constitutes valuable research. Increasing awareness about the needs of research beneficiaries is likely to shift the balance of research motivations from gaining reputation and curiosity-driven modes, towards a pro-social motivation oriented to making a difference in the wellbeing of end-beneficiaries (Lam, 2011; Llopis and D’Este, 2016). This pro-social motivation should help scientists to navigate the conflicting set of incentives from the prevailing dominant research system which prioritises scientific goals and reputation, often at the expense of the attainment of useful applications. In other words, achieving a “hybrid role” identity (Jain et al., 2009) will be easier when scientists have direct access to their potential research beneficiaries. Thus, we propose:

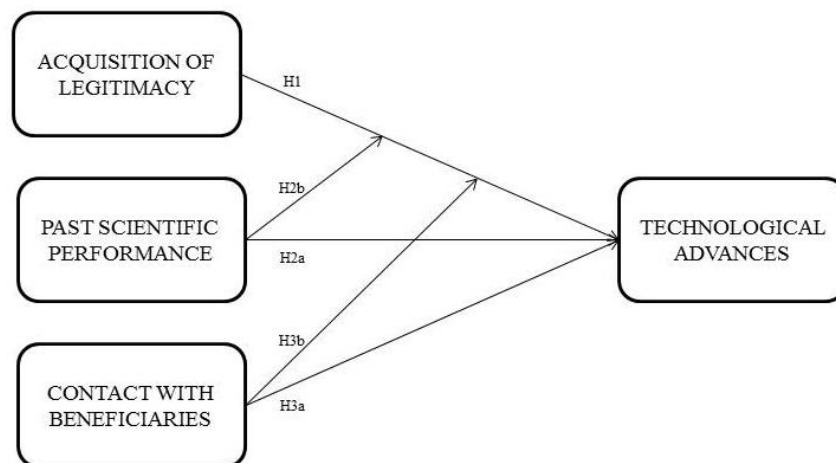
***Hypothesis 3a:** The greater the scientists’ contact with beneficiaries, the higher the likelihood that scientists will achieve technological advances from scientific research.*

Finally, we argue that direct interaction with beneficiaries provides an alternative path to gain research credibility, as compared to the formation of research networks rich in legitimacy ties. By drawing on research networks in which end-beneficiaries are central partners, scientists signal a focus on, and awareness about, the societal impact of scientific research. Thus, scientists who are embedded in research networks with a high proportion of direct beneficiaries of research are likely to gain a greater appreciation of the practical relevance of research findings, and achieve the necessary

credibility among potential users to facilitate acceptance of new applications from research activities. This achieved legitimacy increases the chances of a successful translation of scientific research into practical applications. In this sense, having research networks characterised by the direct interaction with beneficiaries creates an alternative path for obtaining legitimacy, potentially compensating for the absence of relational-based legitimacy ties to network partners.. Thus, we put forward the following hypothesis:

***Hypothesis 3b:** Scientists' contact with beneficiaries weakens the positive relationship between acquisition of legitimacy from their research network ties and achievement of technological advances from scientific research.*

Figure 1: Conceptual model



3 Context and data

The biomedical context

We test the ideas discussed above in the biomedical field. In the context of biomedicine, public funding has deliberately targeted support for research programmes on the basis of their expectation to deliver both fundamental understanding about the root causes of diseases (i.e. scientific discoveries), and innovative contributions to the development of new treatments, diagnostic methods and medical devices to improve healthcare (i.e. technological advances). The rationale for this support has been

based on the apparent gap between the success in biomedical scientific discoveries and the weak performance in terms of their transformation into commercial outputs: what has been called as “the blocks associated to the process of translation from bench to bedside” (Morgan et al., 2011, p. 946).

As a consequence, public research programmes to support biomedical research have abounded in many countries (US, UK, France, Germany, Canada ...), with the idea of strengthening the translatability of research - “taking the findings from basic or clinical research and using them to produce innovation in health care settings” (Cooksey, 2006, in Morgan et al. (2011)). Consistent with the definition of translational research in biomedicine - i.e. “the process of the bi-directional transfer of knowledge between basic work in the laboratory and elsewhere with that of the person, in health or disease” MRC, 2007, in Morgan et al., 2011), these policy initiatives have been driven to encourage the formation of diverse, heterogeneous research networks. These networks have been aimed at strengthening research collaborations between biomedical actors belonging to different institutional setting and professional spheres: in particular, bringing closer together basic scientists from universities and clinical scientists and medical practitioners from hospitals.

In this sense, biomedical research provides an ideal setting to investigate the impact of research networks for the generation of multiple types of novel knowledge outcomes. As we have argued, connecting scientists from different disciplines and actors from diverse communities of professional practice (e.g. basic and clinical scientists, medical practitioners or patient associations) involves huge challenges, since these heterogeneous actors are governed by different, often conflicting professional cultures and social norms. Adopting a relational dimension to the challenges outlined above allows us to explore the conditions under which such institutionally heterogeneous networks are actually conducive to higher knowledge-related outputs.

Data

We situate our analysis within the biomedical research field in Spain. In the course of the last decade, the Spanish Government has launched a number of public policy initiatives and programs aimed to promote translational and cooperative research across different biomedical fields. A representative step towards this aim was the creation of the Spanish Biomedical Research Networking Centers (henceforth, CIBERs). In 2006, the Spanish Ministry of Health undertook an initiative to reorganize biomedical research in Spain as a mean to foster excellence in biomedical research as well as to improve the quality, value and effectiveness of the healthcare services delivered to the general population. A crucial part of the CIBER program was the development of a formal network structure to promote research cooperation among professional communities working on similar biomedical research areas, lending greater weight to hospitals and clinical research groups. Our research population comprises all scientists affiliated to all CIBER networks.

We collected data on scientists' participation in medical innovation, and the structure and content of their personal networks. Our main method for collecting primary data was a large-scale survey. We used administrative data and public databases to compile the names, affiliations, and e-mail addresses of all biomedical scientists in the CIBER networks (a total population of 4,758 individuals). Using an on-line survey platform, in April 2013 we sent a personalized invitation to each scientist, receiving questionnaire responses from 1,309 scientists, a response rate of 27.5 percent. The first part of the survey comprised the collection of network data at the individual level using a standard procedure for egocentric network surveys (e.g.: Levin and Cross, 2004).

Measures

Dependent variable. Our survey asked respondents to report the extent to which they had been involved in an extensive list of activities and outputs associated with medical innovation. A drop-down menu allowed them to indicate their frequency of participation in each activity, ranging from 0 (never) to more than 10 times in a particular year (we singled out 2012 as the year previous to the distribution

of the questionnaire). We conducted principal components factor analysis with varimax rotation to explore whether the proposed items were reflective of the different dimensions related to medical innovation. The results yielded four dimensions (as displayed in Table 1) showing that medical innovations are quite heterogeneous. We labelled the respective dimensions based on the nature of activities and outputs captured by each group.

Factor 1 (*Product generation: invention and commercialization*) is the first group of technological advances, capturing aspects related to drug discovery and commercialization. Factor 2 (*Drug development*) is the second group of advances and relates to participation in the design of clinical trials, oriented to demonstrating drug safety and efficacy. The group *Clinical guidelines* correspond to Factor 3 and captures advances related to the development of clinical practice protocols for medical practitioners. Factor 4 (*Diagnostics and prevention*) groups advances related to the development of medical devices for diagnostics and prevention, and health-related guidelines for the general public aimed at disease prevention.

Table 1: PCA Analyses of Technological Advances

	Product generation	Drug development	Clinical guidelines	Diagnostics/prevention
Patent applications for new drugs or therapeutic substances	0.763	0.055	-0.035	0.059
Licenses granted from patents	0.729	0.090	0.003	-0.053
Participation in spin-off companies	0.733	-0.001	-0.012	0.088
Clinical trials phases I, II, III, new drugs or therapeutic substances	0.188	0.620	0.363	-0.079
Clinical trials phase IV, new drugs or therapeutic substances	0.155	0.818	0.204	-0.046
Clinical trials phase IV, new diagnostic techniques	-0.120	0.730	-0.222	0.219
Development of guidelines for healthcare professionals	-0.048	0.204	0.772	0.237
Development of guidelines for patients	-0.025	0.018	0.811	0.067
Patent applications for new diagnostic techniques	0.216	-0.051	0.128	0.764
Clinical trials phases I, II, III, new diagnostic techniques	-0.062	0.276	-0.026	0.693
Development of guidelines for the general population	-0.041	-0.166	0.395	0.632

In short, these results suggest a division of technological advances in four broad categories which constitute the basis for our combined output indicator. To collapse all those activities into a unique indicator of *technological advances*, we created a categorical variable, ranging from 0 (if the respondent has not achieved any technological advance) to 3 (if the respondent has achieved technological advances that belong to three or four distinct categories). For instance, a scientist having achieved a patent application for a new drug and a clinical guideline for patients would be assigned a score of 2, since she has achieved two outcomes belonging to two distinct groups. The main advantage of this indicator is that it explicitly recognizes and captures the great variety of technological advances that a scientist can achieve.

Independent variables. Our indicator of *legitimacy ties* is based on the original scale developed by Levin et al. (2011). Following standard ego-network survey procedures, scientists were invited to “write down the names of those persons (up to ten) from outside your research group that are particularly important for the advancement of your research activities”. The specific wording of the question was “how did the interaction with each of the contacts contributed to the advancement of your research activities?”. To assess the content of respondents’ network ties, respondents were presented a set of name interpreter questions where they had to indicate which of the following resources were obtained from each network member: i) it provided specific solutions to problems found in my research, ii) it contributed to identify new sources of information relevant for my research, iii) it provided new focus that contributed to the development of my research, iv) it contributed to increase my capacity to convince others about the scientific interest of my research (legitimacy), v) it provided research credibility on third parties (Levin et al., 2011; Walter et al., 2015). Thus, the content of each of the five resources was captured with dummy codes (1 if the specific form of resource was obtained from alter and 0 otherwise). It is important to note that resource types are by no means mutually exclusive (e.g.: the same alter may provide specific solutions and access to new sources of information). To correct for this possibility, we used a weighted indicator for each resource type.

Specifically, we divided each resource by the total number of distinct resources coming from each alter. Then, to aggregate the scores obtained for each network member into a unique score, we summed up all scores by resource type. We conducted a principal components factor analysis (varimax rotation, eigenbased), which suggested that respondents obtain two distinct types of network resources. The first group was composed by two resources: *legitimacy* and *credibility*. We averaged the scores that each respondent obtained in these two items to build our indicator of *legitimacy ties*. The second group was composed by three resources: *specific solutions*, *access to new sources of information*, and *new focus to problems*. We tagged this set of resources as *problem-solving ties*. As for legitimacy ties, we created a unique indicator by averaging the scores obtained in these three items, and employ this indicator as a control variable. Both variables are correlated at .320 ($p < .05$). This relatively low correlation suggests that each indicator is actually capturing a distinct network resource.

To build our proxy for *past scientific performance*, we collected bibliometric data for all survey respondents. The variable is built on all papers published by our respondents during the period 2000 – 2011. Specifically, we calculated the mean normalized citation score (MNCS) for each publication. The MNCS is known as the “crown indicator” among citation-based indicators (Waltman et al., 2011; Waltman and Eck, 2012). The indicator normalizes citations for field-differences and differences in citation window length. Thus, a paper having a MNCS value above (below) one means that on average the publication is cited more (less) frequently than would be expected based on its field and publication year. To build from paper-level to scientist-level, we averaged the MNCS values obtained by each scientist in each paper published during the period 2000 -2011.

Our indicator *contact with beneficiaries* was also built upon the data obtained through the ego-network survey. For each of the aforementioned network contacts, respondents had to indicate whether each contact was a: i) basic scientist, ii) clinical scientist, iii) medical practitioner, iv) patient or patient representative, v) private sector, vi) public administration and vii) others. Our indicator is the number of network contacts that were classified as “medical practitioner” or “patient/ patient representative”.

Therefore, the variable can range from 0 (none of the contacts belonged to the indicated categories) to 10 (all contacts are medical practitioners, patients or patient representatives).

Control variables. We accounted for a number of control variables. First, we control for two relational aspects of respondents' network. The first one was problem-solving ties. That is, the set of network resources conducive to obtain specific solutions, have access to new sources of information, or provide a new focus to problem. The second one is average contact frequency. That is, how often, on average, respondents interact with each of their network contacts. The variable ranges from 1 (one or few times per year), to 4 (one or more times per day). We also controlled for structural-based features of respondents' networks by computing an ego-network brokerage indicator. The survey asked respondents for information on each alter-alter relationships (Burt et al., 1998; Podolny and Baron, 1997). Although ego network data is based on individual perceptions, it has been shown that measures from ego-network data are highly correlated with measures collected from whole-network data (Everett and Borgatti, 2005) as well as from data collected from both members of the dyadic relationship (Battilana and Casciaro, 2013). Building on previous literature, we calculated ego-network brokerage by counting the number of structural holes for each ego-network (Everett and Borgatti, 2005). That is, the absence of alter-alter ties between each ego-network contact. This sum was then divided by the total number of possible alter-alter ties, $n(n - 1) / 2$. The maximum brokerage score occurs when there are no connections between alters in the scientist personal network (ego-network). For each individual, this ratio ranged from 0 to 1, with low values reflecting few structural holes and high values reflecting many structural holes and therefore, a higher score on ego-network brokerage.

We also control for respondents' academic position (principal investigator, postdoc with project, postdoc without project, predoctoral scientist, technician), as well as the respondents' number of academic papers that they published in the period 2000 - 2011. Additionally, we built on self-determination theory (Ryan and Deci, 2000) to ask respondents about their intrinsic and extrinsic motivations. At the group level, we added a series of dummies to indicate whether the research group

is located at a university, hospital, public research organization or other organization type. We also control for the research group size (group size), and the previous technological performance of the research group, proxied by the number of patent applications filled by the principal scientist.

4 Results

Table 2 shows the descriptive statistics of all our variables, and Table 3 reports correlations. It is important to note that, although our two relational network indicators (legitimacy ties and problem solving ties) are correlated at 0.320 ($p < .05$), this correlation is not particularly high, thus suggesting that each indicator is capturing a different network resource. Table 4 presents the regression results employing an ordered probit model. Ordered probit analysis is suited for qualitative dependent variables that have more than two ordinal categories, as it is the case of our dependent variable¹. In Model 1 we entered only the control variables; Model 2 adds the effect of legitimacy ties. Results shows that legitimacy ties are positively associated to technological achievements ($b = 0.187$, $p < .01$), thus supporting Hypothesis 1. Model 3 explores the effect of past scientific performance. Hypothesis 2a is not supported, since there is no significant relationship between past scientific performance and technological achievements ($b = 0.017$, n.s.). Hypothesis 3a proposes that contact with beneficiaries is positively associated with technological achievements. The results from Model 4 support this hypothesis ($b=0.311$, $p < 0.01$).

Hypothesis 2b proposes that past scientific performance exerts a reinforcing effect on the positive relation between acquisition of legitimacy and technological advances. The results support this hypothesis (Model 6), as the interaction between legitimacy ties and past scientific performance is positive and significant ($b = 0.114$, $p < .01$). Hypothesis 3b suggests a substitution effect between legitimacy ties and contact with beneficiaries with regards to technological advances. Model 7

¹ We performed a likelihood ratio test to confirm that the parallel regression assumption has not been violated. That is, to confirm that the relationship between each pair of outcome groups is the same ($\chi^2(28) = 32.57$).

indicates that this hypotheses is also supported ($b=-0.071$, $p <.05$). Finally, Model 8 reports results when adding all linear and interactive effects in the same model. As model shows, all coefficients remain significant, thus reinforcing the robustness of our findings.

Table 2: Descriptive statistics

	Mean	Sd	Min	Max
Technological advances	0.79	0.95	0.00	3.00
Legitimacy ties	0.50	0.51	0.00	2.63
Past scientific performance	0.99	1.41	0.00	28.63
Contact with beneficiaries	1.56	1.87	0.00	10.00
Problem-solving ties	1.06	0.66	0.00	3.33
Average contact frequency	1.82	0.70	1.00	4.00
Ego-network brokerage	0.55	0.37	0.00	1.00
PI tech performance	1.00	2.29	0.00	21.00
Group size	17.79	10.36	2.00	79.00
Extrinsic motivation	3.70	1.18	1.00	7.00
Intrinsic motivation	6.18	0.81	1.00	7.00
#Past Publications	19.76	29.26	0.00	301.00
Principal investigator	0.12	0.32	0.00	1.00
Postdoc w/project as PI	0.32	0.47	0.00	1.00
Postdoc w/o project as PI	0.28	0.45	0.00	1.00
Predoctoral researcher	0.16	0.37	0.00	1.00
Technician	0.07	0.26	0.00	1.00
Other positions	0.05	0.21	0.00	1.00
University	0.32	0.47	0.00	1.00
Hospital	0.33	0.47	0.00	1.00
Public Research Org.	0.25	0.44	0.00	1.00
Other institution types	0.10	0.30	0.00	1.00
N. Observations	993			

Table 3: Correlations

	1	2	3	4	5	6	7	8	9	10	11	12
1 Technological advances	1.000											
2 Legitimacy ties	0.217*	1.000										
3 Past scientific perf	0.060	-0.001	1.000									
4 Contact w/ beneficiaries	0.368*	0.419*	0.011	1.000								
5 Problem-solving ties	0.072*	0.320*	0.014	0.430*	1.000							
6 Avg. contact frequency	0.099*	0.051	0.009	-0.019	-0.090*	1.000						
7 Ego-network brokerage	0.030	0.230*	0.051	0.146*	0.409*	-0.221*	1.000					
8 PI tech. perf	-0.029	0.040	-0.001	-0.100*	0.045	0.012	0.016	1.000				
9 Group size	0.009	0.003	-0.047	-0.013	-0.036	0.003	-0.016	0.129*	1.000			
10 Extrinsic motivation	0.161*	0.092*	0.078*	0.058	-0.076*	0.052	-0.040	0.004	-0.014	1.000		
11 Intrinsic motivation	0.010	0.095*	0.017	-0.001	0.030	0.044	0.021	0.019	-0.068*	0.233*	1.000	
12 Past publications	0.224*	0.135*	0.133*	0.142*	0.154*	0.004	0.112*	0.036	-0.090*	0.121*	-0.007	1.000

N = 993

*p > 0.05

Table 4. Results: Ordered Probit

	M1	M2	M3	M4	M5	M6	M7	M8
	b/se	b/se	b/se	b/se	b/se	b/se	b/se	b/se
Legitimacy ties		0.187*** (0.04)			0.114*** (0.04)	0.110** (0.04)	0.151*** (0.04)	0.148*** (0.04)
Past scient. perf			0.017 (0.03)		0.026 (0.03)	0.072** (0.04)	0.025 (0.03)	0.073** (0.03)
Contact with beneficiaries				0.311*** (0.05)	0.274*** (0.05)	0.278*** (0.05)	0.321*** (0.05)	0.327*** (0.05)
Legitimacy ties*Past scient.perf						0.114** (0.05)		0.118** (0.05)
Legitimacy ties*Contact w/beneficiaries							-0.071** (0.03)	-0.073** (0.03)
Problem-solving ties	0.060 (0.04)	0.010 (0.04)	0.061 (0.04)	-0.086* (0.05)	-0.099** (0.05)	-0.100** (0.05)	-0.119** (0.05)	-0.121** (0.05)
Avg. contact frequency	0.107*** (0.04)	0.091** (0.04)	0.106*** (0.04)	0.116*** (0.04)	0.105*** (0.04)	0.110*** (0.04)	0.100*** (0.04)	0.105*** (0.04)
Ego-network brokerage	0.035 (0.04)	0.009 (0.04)	0.034 (0.04)	0.045 (0.05)	0.027 (0.04)	0.030 (0.05)	0.021 (0.05)	0.024 (0.05)
PI tech. perf	0.056 (0.04)	0.046 (0.04)	0.056 (0.04)	0.068 (0.04)	0.061 (0.05)	0.062 (0.05)	0.067 (0.05)	0.068 (0.05)
Group size	0.079 (0.06)	0.070 (0.06)	0.079 (0.06)	0.062 (0.06)	0.058 (0.06)	0.053 (0.06)	0.057 (0.06)	0.053 (0.06)
Extrinsic motivation	0.139*** (0.04)	0.131*** (0.04)	0.138*** (0.04)	0.125*** (0.04)	0.119*** (0.04)	0.121*** (0.04)	0.119*** (0.04)	0.121*** (0.04)
Intrinsic motivation	0.021 (0.04)	0.004 (0.04)	0.021 (0.04)	0.020 (0.04)	0.009 (0.04)	0.008 (0.04)	0.011 (0.04)	0.010 (0.04)
#published papers	0.131*** (0.05)	0.131*** (0.05)	0.130*** (0.05)	0.130*** (0.05)	0.129*** (0.05)	0.124*** (0.05)	0.124*** (0.05)	0.119** (0.05)
cut1_cons	-0.054 (0.23)	-0.057 (0.24)	-0.056 (0.23)	-0.123 (0.25)	-0.120 (0.25)	-0.120 (0.25)	-0.130 (0.25)	-0.130 (0.25)
cut2_cons	0.808*** (0.23)	0.815*** (0.24)	0.807*** (0.24)	0.769*** (0.25)	0.774*** (0.25)	0.776*** (0.25)	0.769*** (0.25)	0.771*** (0.25)
cut3_cons	1.661*** (0.23)	1.684*** (0.23)	1.659*** (0.23)	1.667*** (0.25)	1.676*** (0.25)	1.684*** (0.25)	1.673*** (0.25)	1.680*** (0.25)
CIBER dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Institution type	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Academic position	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	993	993	993	993	993	993	993	993
Log pseudolikelihood	-1043.4	-1032.8	-1043.2	-1019.4	-1015.7	-1013.6	-1013.1	-1010.9
R2 McKelvey & Zavoina	0.267	0.286	0.267	0.308	0.314	0.318	0.321	0.324

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Robust standard errors are clustered by CIBER
Coefficients for all continuous variables have been standardized

5 Conclusions

This study aims to advance research on the underlying factors that drive the relationship between publicly funded science and technological advances, by taking a relational approach to knowledge networks. Although extensive research has examined the role that scientific collaboration networks play in knowledge creation processes, we contribute to this stream of research by investigating whether, and the extent to which, the specific types of resources exchanged in research networks influences innovation performance. In particular, we focus on social exchanges enhancing scientists' legitimacy. Our interpretation is that legitimacy is a critical resource conducive to innovation performance from scientific research activities. This study contributes both conceptually and empirically to existing research as discussed below.

Theoretical implications

The factors underlying how scientific activities can be translated into technological advances are subject to active academic discussion. Our contribution builds on a relational network approach to contribute to this debate. Previous studies indicate that the patterns of connections surrounding a focal individual are important to predict a number of knowledge-related outcomes (Kilduff and Brass, 2010; Tortoriello and Krackhardt, 2010). However, network research has dominantly taken a structural approach by looking at density, brokerage or composition properties of networks (Fleming et al., 2007; Gargiulo et al., 2009; Rodan and Galunic, 2004).

Instead, our study adopts a relational approach to social capital by looking at the properties of the dyadic linkages between network partners (Chua et al., 2008; Levin et al., 2011; Levin and Cross, 2004; Moran, 2005). In this way, we challenge the notion that network performance can be directly inferred from structural features. One aspect we have

investigated relates to the types of social exchanges occurring in such network. Drawing on Levin and Cross (2004), we have focused on the content of the dyadic ties among social parties. In particular, we place our attention on the scientists' acquisition of legitimacy through their social exchanges within their set of contacts. Our findings provide consistent evidence that support the claim that greater acquisition of legitimacy from network partners is strongly associated with technological advances from scientific research activities. These findings are robust to the influence of network density, both in terms of closure and strengths of linkages, providing further reassurance about the importance of the relational approach, and the focus on network content, in order to explain the relationship between science and innovation.

A second aspect we have investigated is on the contingency factors that moderate the relationship between network-based legitimacy and innovation performance. More specifically, the scientific standing and reputation of highly performing scientists act as a complement of acquiring legitimacy, by reinforcing the positive relationship between perceived legitimacy and innovation performance from scientific research networks. On the other hand, we identify network attributes associated with network composition that further advance a contingent approach. More specifically, we find that the direct interaction with particular partners - i.e. research beneficiaries - acts as a substitute of network-based legitimacy by weakening, and potentially replacing, the effect of network-based legitimacy on innovation performance.

Managerial and practitioner implications

The increasing societal pressure to demonstrate the practical results from scientific research has nowhere been more prevalent than in the case of biomedicine, where there is a strong social expectation that scientific collaboration networks should deliver both fundamental scientific discoveries and innovative contributions to develop new treatments

and improved healthcare. However, the social and economic benefits associated with public spending on biomedical research are not easy to realise. The formation of research networks that bring together basic and clinical scientists, jointly with medical practitioners and patients, have proved to be a necessary but not a sufficient condition for innovation performance.

The findings from this study provide new light on crucial mechanisms that are likely to facilitate the realisation of useful applications from scientific research in biomedicine. Furthermore, they contribute to the nascent stream of research employing social network analysis theories and methods to assess translational research in the biomedical field (e.g.: Leischow et al., 2008; Lurie et al., 2009).

In particular, our results highlight that, although the main focus of translational initiatives has been placed in creating a dense set of connections among distinct biomedical actors, the substance flowing through dyadic connections seems to be at least equally important. For example, if a scientist occupies a (structurally) prominent position within a research network but fails to engage in legitimacy-based social exchanges, it is possible that this position per se will not confer significant advantages in reaching more technological advances from research. Since the great majority of our sample of scientists is affiliated either to a university (i.e. mostly basic scientists) or to a hospital (i.e. clinical scientists), our findings reflect that this effect works in both sides of the translational continuum: from bench to bedside and vice versa.

Furthermore, by bringing on board relational network approaches we can help policymakers to craft more tailored translational policy initiatives. Thus, an interesting avenue for further research might be to advance on the combination of structural and relational network approaches to better understand how certain network configurations help to translate scientific findings into applications. For instance, exploring whether the

endorsement of network legitimacy is more abundant in networks formed by heterogeneous actors, or analysing if basic scientists acquire legitimacy through their clinical counterparts (and vice versa) seems fascinating avenues for further analysis.

Furthermore, the finding that contact with patients is more relevant for scientists with lower levels of network-based legitimacy points to important implications as well. An intense focus on the relational architecture of scientists' jobs (Grant, 2007) - that is, shaping their opportunities to connect and interact with potential research beneficiaries - may be viewed as a useful conduit to enhance scientists' downstream knowledge and pro-social motivation and thus, placing them in a better position to achieve technological advances.

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