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Article

How do researchers generate scientific and societal impacts? Toward an analytical and operational framework

Pablo D'Este[1], Irene Ramos-Vielba[1,*], Richard Woolley[1] and Nabil Amara[2]

[1]INGENIO (CSIC-UPV), Universitat Politècnica de València, Valencia, 46022, Spain and [2]Université Laval Quebec, Québec, G1V 0A6, Canada

*Corresponding author. Email: iramosvi@ingenio.upv.es

Abstract

Models of research systems increasingly emphasize collaborations between networks of heterogeneous actors, to both produce knowledge and formulate interdisciplinary responses to societal challenges and market needs. In this context, researchers' goals and practices are required to satisfy professional requirements for new scientific findings and societal demand for relevant knowledge. Researchers may need also to find ways to reconcile tensions between these two missions. This article proposes an analytical and operational framework that incorporates individual, organizational and process-context factors to explain distinct configurations of scientific and societal impacts from research. The framework emphasises the role of productive interactions with different nonacademic actors as a mechanism for reconciling the scientific and societal missions of research.

Key words: scientific impact; societal impact; research quality; analytical framework; productive interactions

1. Introduction

In recent decades, there has been an increased focus on the generation of both scientific and societal impacts from publicly-funded research and the demonstration of broader 'public value' to society from the funding of science that goes beyond the importance of scientific achievements or commercialization goals (Bozeman and Sarewitz 2011; Bornmann 2013). Broadly speaking, scientific impact is associated with achieving recognition within a professional community of knowledge producers, while societal impact refers to research contributions to addressing current and/or future social, environmental, economic, and other needs outside academia. In the interests of delivering both scientific and societal impacts, Higher Education Institutions (HEIs) are being called upon to be more entrepreneurial, more engaged and more responsive to nonacademic stakeholders' needs. Individual researchers are being asked to broaden the set of professional activities in which they engage and to deliver outcomes that are of interest to both the academic community and nonacademic stakeholders (Organ and Cunningham 2011).

In the context of these dual scientific and societal expectations related to research, evolutions in the scientific community's orientations and practices remain relatively poorly specified. Whilst many scientists are firmly wedded to the principles of curiosity-driven research and academic autonomy, others are oriented toward the provision of benefits to nonacademic communities. Between these two extremes are researchers with different mixes of capacities and willingness to connect the worlds of fundamental research and practical application, who potentially may play key roles in transforming scientific ideas into useful inventions (Subramanian et al. 2013). In some cases, scientific and societal impact can be achieved jointly. However, this is not automatic; greater scientific impact does not necessarily imply greater social impact (and/or vice versa) and may generate significant tensions (Halilem 2010).

This article introduces a framework for investigating the factors linked to the varied impacts of research. Our analytical framework proposes three types of factors that influence the generation of scientific and societal impacts. First, key characteristics of individual researchers which are considered antecedents to the generation of impact. Second, a set of organizational factors that might enable or limit the generation of impact. Third, a set of preconditions for the emergence of societal impacts, included as process-context variables. The inclusion of these process-context variables is inspired by the concept of 'productive interactions' (Molas-Gallart and Tang 2011; Spaapen and van Drooge 2011).

Our integrated examination of these three types of factors contributes to ongoing discussion on the generation of scientific and societal impacts from research. Scientists may be required to resolve tensions between diverging research goals and objectives in order to generate both scientific and societal impacts from their research. A fundamental contention of the proposed framework is that complementarities may arise from researchers' pursuit of scientific and societal impacts in collaboration with nonacademic stakeholders and partners. In this regard, we understand 'productive interactions' as a mechanism contributing to researchers' resolving of tensions between the scientific and societal goals of their research, through mutual learning, development of shared understandings and processes of goal adaptation with nonacademic partners. Thus, productive interactions, in certain contexts, may create the conditions that contribute to aligning the scientific and societal missions of research. Our analytical framework is thus designed for the investigation of research activities at the level of individual researchers working to produce research impact. Our propositions are expected to shed new light on the microlevel processes that contribute to research impact, in a system context where funders, evaluators, and other social stakeholders have explicit expectations that researchers will satisfy dual scientific and societal missions.

The article is structured as follows. Section 2 reviews the literature related to the development of our analytical framework. We summarize the major models of interaction between universities and other types of organizations, which provides a general heuristic regarding the institutional conditions under which individual researchers seek to generate research impact. We then present the arguments regarding the tension between professional requirements for scientific advances and societal demands for relevant knowledge. Section 3 draws on a specific literature to formulate some conceptual assumptions and empirical building blocks of our integrated framework. The section is organized in three parts, addressing the individual antecedents, organizational conditions, and process-context dimensions of our framework. Section 4 discusses the potential of our approach to provide support for the development of research policy and highlights some limitations.

2. Broadening the social scope of academic science

In this section, we review some prominent conceptual models for how the institutional arrangements of the broader research system influence the way scientific and societal impacts are generated. We identify the main arguments shaping the extent to which individual researchers' contributions are oriented toward scientific knowledge production for a professional audience or toward the generation of societal impacts, or both.

2.1 The production of knowledge and the generation of impacts from research

There are several models that describe and theorize transformations in the way knowledge is produced and used to create impact outside of academia. A common underlying theme in these models is a shift toward multiactor networked processes and activities in research. For example, post-academic or postindustrial science (Ziman 1996) is characterized as collective, constrained by limited resources, focused more on applied research, and shaped reflexively by a specific branch of the social sciences—science and technology policy. Post-academic science is characterized by a set of norms (proprietary, localized, authority, commissioned, expert) that contrast with the classic Mertonian formulation of the normative basis of academic science (communalism, universality, disinterestedness, originality, skepticism). The potential for the generation of impacts from research can be understood as being configured in different ways depending on the combination of resource restrictions and the degree of policy direction. Academic capitalism (Slaughter and Leslie 1997), argues that academic researchers faced with cut-throat competition for funding, are amenable to targeting their research toward potentially-profit-making developments, particularly in collaborations with private sector partners. This strategy is seen as allowing researchers to escape from competition for limited public funding and to expand university research budgets. This work highlights the importance of government and policy support for a more entrepreneurial form of academic subjectivity, common to UK, USA, Canadian, and Australian research systems (Slaughter and Leslie 1997).

The formulation of postnormal science (Funtowicz and Ravetz 1993) sought to radically redraw the boundaries between research, stakeholders, and citizens—and, therefore, the contours of impact generation. The key argument related to postnormal science is that the seriousness of the challenges faced by science, technology, and society requires a more inclusive, interdisciplinary, and perspectival approach to research and its impacts. Thus, postnormal science elevates participatory processes to a position of irreducible importance in the production and use of knowledge. There are some evident commonalities with the 'new production of knowledge' (Gibbons et al. 1994), which proposes an emerging mode for generating research results and outcomes (Mode 2), which operates in parallel with the traditional academic (Mertonian) mode of research (Mode 1). Compared to autonomous public research organization centered Mode 1 science, Mode 2 science is more socially distributed and takes place closer to the context of knowledge use. Mode 2 science is also more interdisciplinary and is networked in its organizational forms, and its results are evaluated by a range of interested stakeholders, not just other academics. Mode 2 science involves closer alignment of research with social, industrial, environmental, and other goals and objectives. Thus, generation of impact from research is understood to start from a much more contextualized and problem-oriented perspective.

The triple helix model (Etzkowitz and Leydesdorff 2000) develops an innovation systems approach to the interdependent university, government, and industry spheres, into more properly institutional (Etzkowitz et al. 2000) and evolutionary (Leydesdorff 2000) formulations. Triple helix dynamics lead to the formation of an 'overlay of reflexive communication' among agencies in the three spheres, including policies and programs designed to stimulate interactions and to support mutual collaboration. A range of hybrid entities and intermediaries emerge and evolve, embedding a nonlinear model of impact generation from research. Activities that increase the modes, motivations and effectiveness of academic engagement (D'Este and Patel 2007; Landry et al. 2010; Lam 2011) are commonly described as 'third mission activities' or 'the entrepreneurial university' (Etzkowitz et al. 2000; Molas-Gallart et al. 2002; Gulbrandsen and Slipersaeter 2007). Recent work has extended the triple helix model to the quadruple helix through the addition of a fourth actor—the 'media-based and culture-based public' (Carayannis and Campbell 2009). Through its culture and values and its construction of 'public reality', the media-based and culture-based public influences research systems and 'innovation culture'. This extension of the triple helix model allocates an important role to the public in research processes, and foresees the ability of research systems to adapt and evolve responsively—with a recursive positive effect on the generation of societal impact.

In the main, these models offer consistent descriptions of the major elements involved in transforming systems of knowledge production

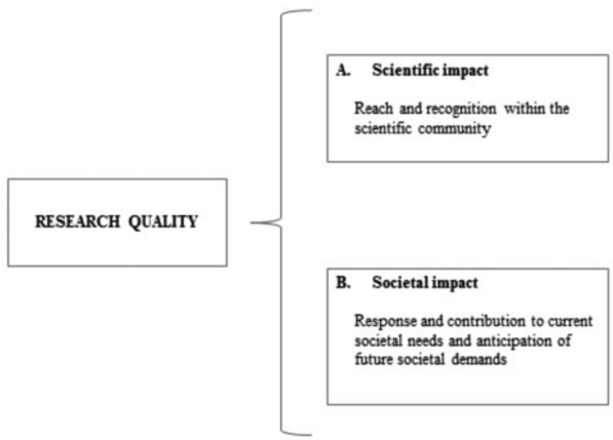

Figure 1. Two dimensions of research quality.

and use. First, knowledge is seen as the outcome of processes involving a more heterogeneous set of actors than previously was the case. Second, the objective of knowledge production increasingly is shaped by stakeholder needs or societal challenges that transcend individual disciplinary approaches. Third, the importance of science and research policy, including incentives, priorities, and other forms of 'directing' research, is a significant dynamic affecting the evolution of the research system. According to these propositions, individual researchers are called on to work collaboratively to address both scientific and societal challenges. The degree to which scientific and societal missions are relatively aligned or diverge, is likely to vary considerably between scientific fields. How individual scientists, under these prevailing institutional conditions and within their specific scientific fields, resolve the tensions between professional demands for new knowledge outputs and heightened societal demands for relevant knowledge remains an unresolved empirical question that provided the rationale for the development of our analytical framework. Whilst these models emphasize various forms of institutional integration, the impact of these conditions at the level of individual researcher's agendas and activities remains unclear.

2.2 Research quality tensions: the joint pursuit of scientific and societal impacts

The dual missions to produce new scientific findings and societally relevant knowledge that characterize the prevailing institutional conditions of research systems are tied increasingly to assessment criteria in formal evaluation systems. Research quality at the individual or research group level is no longer considered equivalent simply to the volume of scientific outputs (primarily journal articles) and their citations counts. Rather, in systems such as the UK Research Excellence Framework, research quality is conceived as three dimensional and comprising scientific outputs, societal impacts, and the research environment (REF 2011). Research quality is viewed (and assessed) more and more as a function of scientific and societal outcomes and impacts, in keeping with the kinds of scientific research system models described in Section 2.1. Under these systemic conditions, the researcher's range of interactions is likely to expand in both types of partners and types of activities involved (Felt et al. 2013). Drawing on this discussion, the analytical framework we propose conceives scientific and societal impacts of research as the two components that shape the diverse configurations of 'research quality' (Fig. 1).

This broader definition of what constitutes research quality, coupled to an expanded set of expected activities, can raise various problems at the level of the individual researcher's plans and goals. The literature proposes several intertwined arguments related to the difficulties faced by researchers seeking to reconcile the tensions between the pursuit of new scientific knowledge and societal relevance of their research activities. One argument refers to the existence of different (sometimes contradictory) logics behind the achievement of scientific impact and societal relevance. According to this thinking, processes characterizing the creation of relevant scientific knowledge, on the one hand, and the production of usable results or the translation of scientific discoveries to commercial innovations, on the other hand, diverge (Dasgupta and David 1994; Gittelman and Kogut 2003). The public funding of research is based on its general contribution to the advancement of science (fundamental understanding) and to the pool of knowledge available to society (businesses and nonacademic communities) (Salter and Martin 2001). University academics increasingly are being required to respond to a broader set of market and societal expectations (Organ and Cunningham 2011). Primarily research-oriented scientists must combine their inherent 'taste' or preference for science and publication with the translation of discoveries into product development inspired by the possibility of obtaining additional benefits (Stern 2004). A mix of new funding opportunities, broader institutional mandates for universities, and novel research technologies are shaping the patterns of faculty responses to these dual logics (Owen-Smith and Powell 2001).

The second argument is that the incentive structures governing the reward system in science have led systematically to the prioritizing of peer recognition and academic reputation within the scientific community (Stephan 2010), making the generation of societal impact from research a secondary consideration from the individual perspective of career progression in academia. If public sector scientists' decisions essentially reflect and are shaped by a reputation-based scientific reward system (Merton 1973), then a fundamental tension exists between maintaining an individually-directed scientific career trajectory and seeking, in addition, to contribute to the social relevance and (in some cases) the resource base of a public research organization. If the scientist's decision to engage actively in Knowledge and technology transfer (KTT) is viewed as a sign of deviance from the dominant reward system in science, then the likelihood that researchers will seek fully to exploit the societal impact of their research findings could be reduced (Hessels and Van Lente 2008). Following this reasoning, the separation between the criteria guiding what is considered by scientific peers to be outstanding research (reputation) and what is considered by societal actors to be useful research (relevance), will create significant tensions and potential conflicts related to individual scientific careers (Hessels et al. 2009).

The combination of these arguments (contradictory logics and scientific ouput/impact-based reward systems) highlights the difficulties scientists can face in seeking to generate scientific and societal impacts from their research. Reconciling high-level academic performance and exploitation of the societal relevance of research is likely to be contingent on a broad set of factors. These include factors linked to the institutional and organizational setting in which research activities are conducted, and to the distinct characteristics and attitudes of individual scientists. Scientists' experience is likely also to contribute to how they shape their research activity to respond to scientific and societal objectives (Cummings and Kiesler 2005). In the following section, we propose a set of factors, integrated in an explanatory framework, to improve our understanding

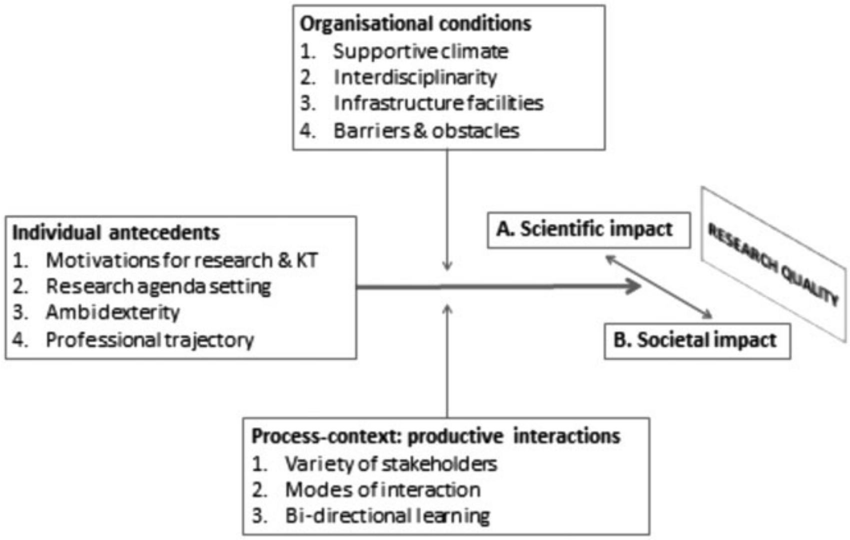

Figure 2. An analytical and operational framework.

of the configurations of scientific impact and societal relevance that an individual scientist's work produces.

3. Explaining the diverse balance among scientific and societal impacts

Research quality may be driven by outstanding scientific contributions, by timely responses to societal demands, or by idiosyncratic combinations of both drivers. Here, we specify a range of factors that likely influence the particular configuration of scientific and societal impacts generated by individual research activity. We build on works that focus, in particular, on empirically tested factors, which facilitate the operationalization of our analytical framework. We group these factors into three types: (1) individual antecedents; (2) organizational conditions; and (3) process-context factors.

The proposed analytical framework (Fig. 2) is an individual-level approach to understanding the distinct configurations of scientific and social impacts emerging from research activities. We consider scientists' research agendas to be conditioned by their perception of the synergies and tensions between scientific and societal missions. Thus, the framework is based on a set of individual characteristics likely to influence the particular balance between research goals, in scientists' research activities. Our analytical framework also suggests that organizational conditions and process-context factors influence the particular scientific and societal goal mix pursued in individual research activities. On the one hand, organizational-level factors—that is, the institutional and organizational setting in which the research is conducted—are both enabling and constraining in relation to the scientist's choice and pursuit of distinct research goal configurations. On the other hand, process-context factors—such as, productive interactions with nonacademic actors—might contribute to enhancing the scientist's capacity to reconcile the tensions between scientific and societal goals through the bilateral learning opportunities these interactions produce. The following subsections provide an extended discussion on and justification for the proposed three sets of factors.

3.1 Individual antecedents

It has been argued that research behavior is influenced strongly by individual differences (Halilem et al. 2011). A focus on the individual researcher sheds light on the interplay between the formal and informal activities undertaken by researchers (Landry et al. 2010) and the influence of the scientist's allocation of time and other physical and human resources, to different activities including research, teaching, management, and entrepreneurial activities, among others (Gulbrandsen and Smeby 2005; Link et al. 2008; Teichler 2010). Researchers' decisions affect multiple types of activities and their personal attributes are likely to play an important role in shaping how they meet personal goals and satisfy institutional demands for scientific and societal impacts. Scientists embody various beliefs and behaviors which will continuously redefine the orientation of and boundaries to their work. While the individual characteristics identified below are not comprehensive, they include individual-level variables that have been operationalized and validated in prior empirical research (Table 1) and which contribute to the analytical and operational features of our analytical framework.

A first set of factors concerns scientist's motivations for conducting research and interacting with academic and nonacademic actors. These factors are highlighted in the literature as relevant antecedents to the researcher's disposition to achieve both scientific and societal impact from research (D'Este and Perkmann 2011). Scientists' motivations are configured according to the extent to which they focus on the pursuit of intrinsic satisfaction or extrinsic goals such as solving social problems and contribute to society (Roach and Sauermann 2010; Lam 2011).

Second, a positive attitude toward setting the scientific research agenda in cooperation with nonacademic actors is likely to influence awareness of the types of societal demands to which scientists can contribute and the mechanisms for achieving these objectives (Grant 2008; Olmos-Peñuela et al. 2015). Recent evidence supports the importance of individual prosocial motivations among scientists for the adoption of conduct that includes social relevance as a critical research goal and to explain the engagement of scientists in a broad range of knowledge transfer activities (D'Este et al. 2016; Iorio et al. 2017).

Third, diverse sets of skills (technical, procedural, managerial) and intellectual capital (organizational, social, and human capital) can endow the individual scientist with the capacity required to address the academic and nonacademic communities simultaneously (Fini et al. 2012; Turner et al. 2013). This blend of skills and capabilities can provide scientists with the ambidexterity required to reconcile conflicting research goals among research partners from different institutional settings, for example, academic and nonacademic environments (Ambos et al. 2008).

Finally, scientists' professional trajectories regarding formal training within specific disciplinary domains and their patterns of sectoral and international mobility, have been shown to be important for a favorable disposition to achieving multiple goals in research activities. For instance, access to extended social capital networks from experience of working in different sectors, can strengthen scientists' ties with nonacademic organizations and promote differentiated careers patterns (Dietz and Bozeman 2005). Similarly, international mobility provides access to diverse sources of funding and types of networks (Cañibano et al. 2008). The link between varied research background and researcher productivity remains inconclusive, although some studies find a return to productivity (Franzoni et al. 2014) and social engagement (Lawson et al. 2017) from migration.

In summary, certain individual characteristics are likely to contribute to the ways in which scientists reconcile the multiple demands to which they often are subject, including institutional conflicts emerging from the combination of science, societal challenges, and market logics within research endeavors (Pache and Santos 2013; Sauermann and Stephan 2013). The degree and form of the tensions associated to the joint satisfaction of scientific and societal impact goals may depend also on the type of research (i.e. upstream oriented or close to the end user).

3.2 Organizational conditions

Organizational level characteristics are important for influencing how individual researchers achieve a scientific and social goals mix in their research activities, and for shaping the balance between scientific and societal impact. Individual motivations for and attitudes toward scientific and societal achievements are likely to be moderated by the institutional and organizational setting in which research activities are conducted, including both the university and the departmental environments. The proposed framework suggests a number of organizational conditions that positively and/or negatively influence the achievement of a balanced mix of scientific and societal impacts.

First, organizational conditions include the existence of a climate within the scientists' working environment that is supportive of more socially-oriented research activities. Peer community practices, related to public engagement, technology transfer, and commercialization, for example, vary across specializations and disciplines (Becher and Trowler 2001). Workplace peers are likely to have a strong influence on the scientist's behavior based on prevailing norms regarding the appreciation and esteem attached to engagement with nonacademic audiences (Stuart and Ding 2006; Bercovitz and Feldman 2008; Clarysse et al. 2011). Faculty who are socially embedded in departments that support and place value on achieving societal impact from research (e.g. entrepreneurial activities) can more easily withstand existing and potential disincentives (Kenney and Goe 2004; Tartari et al. 2014).

A second organizational feature refers to skill diversity in the composition of research groups (Wuchty et al. 2007). Interdisciplinary research groups and organizational environments are likely to exert a cognitive influence on their researchers' ability to process information and knowledge that contributes to original scientific insights, and to grasp scientific opportunities to contribute to societal demands. However, interdisciplinary research involves the integration of multiple forms of expertise through a process which needs to be carefully managed and balanced, if 'new epistemic communities must be constructed and new cultures of evidence produced' (Klein 2008: S116). Successful interdisciplinary assimilation requires high levels of flexibility, negotiation, and compromise among participants, to favor integration and collaboration along multiple pathways.

A third organizational feature refers to the existence of a supportive infrastructure regarding physical and human resources to help identify suitable nonacademic research partners and assist in the management of intellectual property rights and contracts. The existence of specialized support units, such as university Technology Transfer Offices (TTOs), may indirectly influence academics to start new ventures (Clarysse et al. 2011) and enable links with nonacademic audiences (Landry et al. 2013). Such facilitator and intermediary roles foster the connection between university scientists and societal actors who potentially could participate in and benefit from knowledge exchange processes (Siegel and Wright 2015b).

Finally, organizational-level barriers to interactions with stakeholders can limit the capacity of scientists to achieve an appropriate balance between scientific and societal impacts. These barriers are generally cognitive (due to the different cultures of academics and nonacademics) or transaction-related (due to administrative obstacles and negotiation conflicts) (Bruneel et al. 2010; Tartari et al. 2012; Ramos-Vielba et al. 2016). The organizational conditions are likely to influence the extent to which scientists perceive these barriers as insurmountable obstacles. Scientists' perceptions of barriers will differ depending on the support provided by their organizational setting, among other factors.

In summary, the set of organizational conditions identified here are likely to act either as enabling or limiting for academic researchers seeking to generate both scientific outputs and societal impacts. This set of conditions is not exhaustive; rather, it identifies a range of factors derived from the literature for which there is substantial empirical evidence (Table 1).

3.3 Process-context factors: productive interactions

There is increasing consensus among scholars in the fields of sociology of science and research evaluation that research projects that generate significant societal impact require an iterative process of interaction between scientists and stakeholders, involving bidirectional flows of knowledge and expertise (Nowotny et al. 2001; Smits and Kuhlmann 2004). We draw on the concept of 'productive interactions' (Molas-Gallart and Tang 2011; Spaapen and van Drooge 2011; de Jong et al. 2014) to argue that interactions between researchers and stakeholders are vital not only to achieve societal impacts from research activities, but also to resolve tensions between scientific and societal goals in research activities.

In this sense, interactions between science and society may be a precondition for future societal impact, which it is impossible to grasp or anticipate in a precise manner at a particular point in time, since the effects are remote from the initial phase of research and only weakly attributable to specific actions. Thus, while the attribution of societal impact from specific research activities represents a phenomenal challenge for research evaluation, the focus on 'productive interactions' provides a workable approach to appreciative foresight: that is, interactions between researchers and stakeholders, which 'can be seen as necessary interim steps in the process that leads to societal impact' (Spaapen and van Drooge 2011: 214).

However, not every type of interaction between scientific researchers and stakeholders will be equally likely to produce societal

Table 1. Individual antecedents and organizational conditions.

(I) Individual antecedents					
Components	Description	Methods	Selected criteria	Areas of research	Sources
1. Motivations for research and knowledge transfer	Reputational *(ribbon)* and intrinsic *(puzzle)* rather than financial *(gold)*	Mixed (interviews and survey)	Motivating factors to engage in industrial links activities	Biosciences, Computer science, Physical sciences	Lam (2011: 1360)
	Range of incentives for different channels of engagement with industry	Quantitative (survey and public records)	Ranking incentive items for interactions with industry	Engineering and Physical sciences	D'Este and Perkmann (2011: 323)
	List of nine *motives* for entering a training program that aims to foster knowledge transfer into practice	Quantitative (survey)	Ranking motive items for entering the training program	Young researchers from all fields	Arzenšek et al. (2014: 192)
	Recognition within the scientific community, personal financial gain, additional funding for graduate students and laboratory equipment	Qualitative (semi-structured, in-person interviews)	Categories of stakeholders: (1) TTO directors and university administrators, (2) academic scientists, (3) managers/entrepreneurs	Five major public and private research universities in Arizona and North Carolina	Siegel et al. (2003: 116–17)
2. Research agenda setting	Inspired by *prosocial* motivation as the desire to benefit other people	Quantitative (survey)	Items for prosocial motivation as a personality trait	Firefighting and fundraising	Grant (2008: 51)
	Openness to nonacademics' inputs along stages of research process	Quantitative (survey)	Researchers' open behavior during research processes	All fields	Olmos-Peñuela et al. (2015: 392)
3. Ambidexterity	*Diverse skills* contribute to develop a favorable entrepreneurial attitude	Mixed (structural equation modelling)	Technical / procedural / managerial skills	New technology-based firms	Fini et al. (2012: 394)
	Intellectual capital resources: organizational/social/human	Literature review	Initiative, cooperation, multitasking, brokering	–	Turner et al. (2013: 327)
	The *ability* to which academic scientists can *simultaneously* achieve research publication and research commercialization at the individual level	Quantitative (survey)	Multiplicative interaction of publication and commercialization involvement at the individual level	Life, science, engineering, and medical research	Chang et al. (2016: 9)
4. Professional trajectory	*Intersectoral jobs* relates to publication and patent productivity	Quantitative (curriculum vitae (CV) analysis and patents)	Diverse work experience in a career and new social networks	A wide range of fields	Dietz and Bozeman (2005: 353)
	Links between *mobility* and research performance	Quantitative (CV analysis)	Researchers' stays in a different organization	Physics, biology, philosophy and philology	Cañibano et al. (2008: 21)
	High share of senior researchers: predominance of more experienced researchers with an established university career over young researchers at the beginning of a university career	Quantitative (two distinct surveys)	Factors that enhance/inhibit the establishment of university–firm interactions	Researchers from all fields and manufacturing firms	Schartinger et al. (2001: 262)

(continued)

Table 1. (continued)

(II) Organizational conditions					
Components	Description	Methods	Selected criteria	Areas of research	Sources
1. Supportive climate	Influence of *university departments* on entrepreneurial competencies	Quantitative (archive, survey and start-ups)	View on importance attached by departments	Electrical engineering, computer science	Kenney and Goe (2004: 701)
	Work context effects on transition to for-profit science	Quantitative (case–cohort data)	Coworker transitions/entrepreneur coauthors	Life sciences/biotech firms	Stuart and Ding (2006: 116–19)
	Absorption of *localized social norms in work environments*	Quantitative (administration records)	Institution patents/chair and cohort prior disclosures	Medical schools departments	Bercovitz and Feldman (2008: 77)
	Social environment: proximity to other academics who started spin-offs	Quantitative (survey and public records)	Spin-offs created by a university in the same year	Engineering and physical sciences	Clarysse et al. (2011: 1089)
2. Interdisciplinarity	Higher productivity of *team work* in knowledge creation	Quantitative (Web of Science papers and patents)	Citations: team- versus solo-authored work	Sciences a engineering, SS, arts and humanities	Wuchty et al. (2007: 1037)
	Principles for interdisciplinary research *performance and evaluation*	Literature review (quantitative and qualitative studies)	Engaging in mutual learning and joint activities	–	Klein (2008: S122)
	Integration of disciplines within a research environment	Quantitative (survey)	Collaboration between scientists from different disciplines with the goal of producing new knowledge	All fields	van Rijnsoever and Hessels (2011)
3. Infrastructure facilities	*Knowledge and technology transfer organizations as crucial nodes* connecting suppliers and users of knowledge	Quantitative (websites and survey)	Help firms to specify their needs related to research	–	Landry et al. (2013: 437)
	Department support is decisive to develop nonacademic competences	Qualitative case studies (longitudinal)	Departments with critical mass of industry networks	Biotechnology and engineering	Rasmussen et al. (2014: 100)
	Intermediary role of university TTOs between suppliers of innovation and societal actors	Literature review (theoretical/empirical)	Proper incentives scheme in place/sufficient rewards	–	Siegel and Wright (2015a: 5 and 11)
	Supportive infrastructure available for the researcher that wishes to move research findings into the commercial realm	Qualitative (longitudinal multiple case studies)	TTOs, education in patenting or help in evaluating business plans, support structures located outside the academic organization	Life sciences (stem cell research projects)	Nilsson et al. (2010: 619)
4. Barriers and obstacles	Collaboration mitigates *orientation-related and transaction-related* barriers	Quantitative (survey and public records)	Working on collaborative projects with universities	Engineering & Physical sciences / firms partners	Bruneel et al. (2010: 863)
	Experiences shape perceptions of barriers to industry collaboration	Quantitative (survey and public records)	Academic's industrial collaborators/channels	Engineering and Physical sciences	Tartari et al. (2012: 664)
	Interactions between *risk to scientific autonomy and risk to scientific credibility*	Quantitative (survey)	Cooperation with nonacademic public organizations	All fields	Ramos-Vielba et al. (2016: 565)
	Obstacles reflecting costs of realizing KTT activities from an institute's point of view	Quantitative (survey)	KTT activities with private enterprises	Engineering, natural sciences, mathematics and physics, medicine, and economics and business administration	Arvanitis et al. (2008: 1872–73)

Table 2. Process-context factors: productive interactions as preconditions.

Components	Description	Sources
1. Variety of stakeholders	**Knowledge exchanges with a wide range of end users:** small and medium-sized enterprises, big firms, government agencies, nonprofit organizations, hospitals, civic societies, patient groups, international organizations, and others	Abreu et al. (2009) Hughes et al. (2011) Hughes and Kitson (2012)
2. Modes of interaction	**a. Formal interactions** (signed contract): Consultancy, contracted/joint research, teaching/training, personnel exchanges, creative/cultural products, guidelines/protocols/norms, renting equipment/materials, testing prototypes **Commercialization activities:** IPRs, patents, licensing, utility models, know-how, spin-offs **b. Informal interactions** (no-signed contract): Advisory work, dissemination activities, lectures for the community, specific training, nonacademic professional networks, presentations at nonacademic fora, nonacademic actors in both teaching and curriculum design. **Communication activities:** use of both analog and digital social media) means to disseminate research results to nonacademic actors	Molas-Gallart et al. (2002) D'Este and Patel (2007) Landry et al. (2010) Olmos-Peñuela et al. (2013) Lupton (2014) Perkmann et al. (2015) Sugimoto et al. (2017)
3. Bidirectional learning	**a. Flows of knowledge and expertise** **a.1. Benefits from interactions (formal and informal) to research activities:** specific inputs, relevant information sources, external resources, new ideas, approaches and perspectives, validation, legitimacy, recognition **a.2. Benefits from interactions (formal and informal) to nonacademic actors:** concrete improvements (organizational practices, problems solutions, products and services), new chances (better understanding, business opportunities, training, networks), confirmation of choices (reputation, support, validation) **b. Transmission** (processing for final use): Facilitating practices (formats, language, ways and manners) specifically for end users	Amara et al. (2004) Gulbrandsen and Smeby (2005) Perkmann and Walsh (2008) Landry and Amara (2009) Spaapen and van Drooge (2011) Levin et al. (2011) Dowling (2015)

impact in the short, medium, or long run. Similarly, not every scientist who interacts with stakeholders will generate research outcomes with societal impact. Drawing on studies by Abreu et al.(2009), Spaapen and van Drooge (2011), Perkmann et al. (2015) and others, we suggest that there are three components of interactions between scientists and stakeholders that are particularly critical for generating societal impact: (1) variety of the stakeholders; (2) breadth and depth of the interaction modes; and (3) presence of interactive learning.

First, regarding the variety of stakeholders, there are likely to be as many different interpretations of what constitutes valid societal impact as there are potential beneficiaries. Businesses, government agencies, nonprofit organizations, civic societies, hospitals, patient groups, will have distinct expectations about what constitutes relevant societal impact from scientific research. Thus, the variety of stakeholders with whom researchers interact is likely to enhance awareness and understanding of the distinct expectations of scientific research and to increase the potential to address a wider range of unmet societal needs. Moreover, greater awareness and understanding of stakeholders' views of what constitutes valid and legitimate research goals will increase the scientist's capacity to reconcile conflicting institutional logics among partners in the context of research activities.

The second component refers to the conduits or mechanisms of interaction. Interactions between scientists and stakeholders can take multiple forms. They can be formal or informal, depending on whether the interactions are meditated through contractual arrangements; they can be transactional (e.g. one-off, market-based interactions) or relational (frequent and personal-based interactions); they can be targeted or open-ended depending on the specific terms of the research agenda, etc. Understanding the range of interaction modes between scientists and nonacademic actors is critical since they will affect the type of societal impact. For instance, while technology transfer may require some form of market-based formalized contract, responding to highly-contextualized demands from potential beneficiaries may involve only informal and interpersonal interactions. We consider that it is essential to account for the specificities of the different modes of interaction and their complementarities to understand the potential for societal impact from research.

Finally, productive interactions can enhance the learning opportunities for the parties involved. Scientists are likely to acquire a better understanding of the potential applications of the findings from their research activities and improved capacity to identify new puzzles to inspire blue-sky and applied research. Similarly, stakeholders can learn how to participate in and influence the definition of research targets to ensure that their demands are met while obtaining a better understanding of whether a particular piece of scientific research will achieve their objectives. If interactions set in motion bidirectional flows of knowledge and lead to learning opportunities for the parties involved, the capacity of the scientist to resolve the tensions between the scientific and societal goals of their research activities are likely to be greatly enhanced. Table 2 presents a broad set of items which we suggest could be tools to capture these three process-context components to conduct empirical research and contribute to the operationalization of the concept of productive interactions.

Our proposed analytical framework (Fig. 2) suggests that the three components of productive interactions potentially contribute to resolving critical tensions faced by individual scientists when seeking to meet demands for scientific and societal impact from their research activities. We argue that these three components of productive interactions can shape scientists' cognition, skills, and attitudes and, potentially, contribute to reducing the tension associated with reconciling scientific and societal demands.

In relation to cognition, we argue that productive interactions can enhance scientists' awareness about the potential practical applications of their research activity and their capacity to identify previously undetected research problems. This helps them to overcome conflicts associated with the need or desire to satisfy scientific and societal goals through their research activities. On the one hand, it allows the scientist a better understanding of what nonacademic actors believe constitutes valuable and relevant research (Olmos-Peñuela et al. 2015). On the other hand, productive interactions can help scientists to weigh the knowledge benefits for the advance of their research activities, which will attenuate their concern that interaction with stakeholders might undermine scientific achievement or damage career progression (Perkmann and Walsh 2009).

Regarding skills, we consider participation in productive interactions as helping scientists to develop coordination and networking capabilities. On the one hand, it increases their capacity to manage and coordinate research portfolios to realize the synergies between research projects addressing different goals and with different beliefs about desirable research outcomes (Wallace and Rafols 2015). On the other hand, productive interactions contribute to a better appreciation of the priorities and incentives of other actors in setting the terms and objectives of research activities and enable networking and brokerage capabilities to align different institutional logics (e.g. science and market logics) (Pache and Santos 2013).

Finally, in relation to attitudes, productive interactions can contribute to the formation and shaping of scientists' motivations to assume certain research roles and academic identities. In particular, productive interactions may be conducive to prosocial research behavior, since scientists may derive intrinsic satisfaction from research activities that show a positive impact on the wellbeing of a third party (D'Este et al. 2016). Productive interactions also can be conducive to the formation of hybrid identities in academic settings; the scientist might assume a role that reconciles inherent contradictions between the practices and norms of an academic identity and the active participation in technology transfer activities (Jain et al. 2009). According to Felt et al. (2013), many researchers engage in a range of interactions, including governance and valorization activities, which are insufficiently recognized by the existing academic reward system. We suggest that it is precisely these 'productive' types of interactions that enable researchers to resolve the tensions between demands to produce scientific and societal impact from their work and to accommodate these, sometimes divergent, goals within their overall research portfolio.

To summarize, the capacity of individual scientists to generate both scientific and societal impact is enhanced in the presence of interactions which involve potential beneficiaries of research, and which exhibit bilateral learning opportunities. In this sense, we suggest that productive interactions are likely to play a moderating role in our analytical framework, by enhancing the connection between the individual level characteristics (discussed previously) and the capacity to balancing scientific and societal impacts from research activities.

4. Discussion

The nature of the relationship between the scientific and societal impacts of research is an open research question and an item on science and research policy agendas. To date, there is little understanding of the complementary or substitutive effects that might exist between the generation of scientific and societal impacts. This limits the basis for informed policy discussion. In this article, we proposed an analytical and operational basis for understanding how scientific/societal impacts emerge from research and suggested a set of factors that might contribute to the reconciling of potential tensions between these two types of research impact at the individual researcher level.

The proposed framework aims to capture a range of interrelated aspects conducive to the generation of scientific and societal impacts, in the coproduction of diverse configurations of 'research quality'. The proposed framework is designed to provide insights into the three types of factors affecting joint pursuit of the scientific and societal impacts of academic research at the individual level: individual antecedents, organizational conditions, and process-context factors. We consider the process-context factors as crucial for investigating and understanding the inclusion of societal demands in research outcomes. We argue that 'productive' types of interactions with nonacademic partners and organizations may enable researchers to resolve potential tensions between pursuit of the scientific and societal impacts from their work, or to accommodate these dual missions within their research portfolios.

Our proposed analytical framework offers two advantages. First, the development of a conceptual and structured approach to individual researcher's involvement in the generation of scientific and societal impacts advances our micro-level understanding of how both types of impact emerge from research systems. Second, in starting from the individual level, the framework is designed to gather data that can be analyzed and interpreted at various levels and aggregations. The different levels of aggregation—scientific field, coauthorship network, research group, department or research center—provide multiple lenses of varying granularity to study the configuration of the scientific and societal impacts generated by research activity.

The framework allows identification of conditions likely to generate socially relevant research, as the precursor to its societal impact. Societal impact is more likely in a context of interactions with potential beneficiaries, which elicit learning opportunities for all the parties involved in the research activities. The three components of productive interactions—variety of stakeholders, modes of interactions, and bilateral learning—can shape scientists' cognition, skills, and attitudes, potentially contributing to a better reconciliation of scientific and societal goals in scientific research.

It is important to recognize that engaging in interactions with nonacademic actors does not lead necessarily to positive (or any) effects or impacts. There is some research that finds a negative impact of university external engagement on academic research activities (e.g. Louis et al. 2001; Czarnitzki and Toole 2010). However, our emphasis on a particular type of interactions (i.e. productive interactions) and its interplay with individual and organizational level characteristics in our framework, allows us to identify factors linked to a diversity of scenarios, where interactions with nonacademic actors may contribute in different degrees to the balancing of scientific and societal goals from research activities.

Our operational framework captures the heterogeneous configurations of individual characteristics and organizational factors that appear to lead to scientific and societal impacts. Scientific and societal impacts can be analyzed also as outcomes of a portfolio of more or less diverse activities undertaken by researchers (Cruickshank 2013), since scientific research leads to major contributions that can be beneficial for society through many different pathways. The acknowledgment of multiple forms of knowledge mobilization/translation may be not properly captured through a single 'impact builds on research' formula (Smith et al. 2011; Mounier 2015). A wide range of science–society interactions, for example, complex societal valuation processes or social responsibility as a form of engagement can influence scientists' motivations and their awareness of other stakeholders' expectations. Therefore, the production of high quality research should be understood as achieved through a variety of combinations of actors, motivations, and ingredients, which may be oriented toward scientific or societal missions or both.

From a policy point of view, our framework is designed to provide new insights into what constitutes research quality. This is important not least for improving the framing of assessment processes, in order to take full account of research impact. Assessment should avoid a simplistic dichotomy between scientific impact and societal impact, which does not correspond to diverse configurations of research process outcomes. Funding priorities in science have become contingent upon the production of demonstrable socioeconomic benefits, particularly in a political environment shaped by the global financial crisis, budget 'austerity', and concerns over reducing the public deficit (Holmwood 2011; Bornmann 2013). Evaluation criteria increasingly are being linked to societal benefits such an intended research product or final outcome, in specific use contexts (Carew and Wickson 2010). However, the diversity of research makes it difficult to evaluate different types of impact in a rigorous, objective, consistent and complete way, across disciplines and science institutions (Martin 2011). We would prefer a versatile and comprehensive approach to research activity, which integrates the generation of scientific outputs and societal impacts as interrelated and potentially mutually reinforcing dimensions of research quality, as elaborated in this article. We believe better information regarding the configurations of scientific and societal impacts generated by individual researcher's activities is particularly timely in the current policy context. The assumption that all researchers should pursue a uniform strategy in relation to the production of scientific and societal impact from their research would be based on weak or false impressions that such impacts are *necessarily* linked. This would have potentially destructive implications for research system diversity.

Our approach has three main limitations. First, the selection of literature and empirical factors addressed in the framework is limited, and it risks missing or underplaying certain factors in the literature. Second, there is a possible bias toward the literature on entrepreneurship and toward quantitative methods and the UK and US research contexts. Our framework may be biased to a degree by the expectations about researchers and research systems contained in this literature. Finally, the explanatory capacity of the proposed analytical framework will depend, among other factors, on how well we can operationalize the concept of 'productive interactions' to capture the process-context factor included. This raises the issue of measurement theory and other technical challenges, which will have a significant impact on the effectiveness of the framework.

Future research should focus on operationalizing and using the framework for empirical studies of research impact. It is envisaged that empirical results highlighting extant heterogeneity in the configurations of scientific and societal impacts generated by research activities, which also capture the specific combinations of factors that influence these diverse outcomes, would be a useful contribution to work on the outcomes and impacts of scientific research.

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