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Fostering practice-oriented and use-inspired science in biomedical research

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ABSTRACT

In contexts where the abstract and predictive outcomes of theory-driven research from the lab provide little insight for solving practical problems, use-inspired research is argued to shape advances in science by leading more directly to practice-oriented outcomes. We show that in the biomedical sector, basic research conducted by clinical scientists is significantly more likely to exploit prior insights from the applied literature, and triggers relatively more applied and industrial follow-on research compared to a sample of randomly matched articles. However, clinical scientists' engagement in the development of this type of practice-oriented and use-inspired basic research is limited due to the intensity of their clinical obligations and patient care. The allocation of a unique fellowship that partly releases these clinical scientists from their clinical burden fosters the development of practice-oriented and use-inspired basic science. These clinical scientists tend to publish more and shift their focus towards the development of scientific basic research that integrates insights from bench and bedside.

1. Introduction

Scientific research in Pasteur's quadrant – use-inspired research driven by a quest for fundamental understanding – has been argued to directly foster technological development and innovation as the fundamental understanding of the basic scientific principles creates clear strategies to solve practical problems (Stokes, 1997; Amara et al., 2019). Incorporating use-inspired knowledge from the real-world environment into the scientific research process is particularly important when learning from the abstract and predictive outcomes of theory-driven research conducted in the lab does not provide much information about how the solution might fare in the real-world environment (Nelson et al., 2011).

This paper discusses the development of practice-oriented and use-inspired basic science in the biomedical sector. Many have argued that the theoretical and predictive insights from fundamental basic science in this sector, on their own, are limited in their ability to serve as a direct input for medical innovation and clinical practice due to the complexity of the human physiology and the heterogeneity of the human population (Gelijns et al., 1998, 2001; Chalmers, 2006; Mittra, 2009; Ali and Gittelman, 2016). In this context, we examine the role clinical scientists may play in the process of medical innovation by fulfilling a bridging role between research and clinical practice. These scientists, employed between lab and bedside at academic hospitals, bring a unique perspective to the medical research workforce which might foster the development of basic research with a more use-inspired and practice-oriented character (Mankoff et al., 2004; Ley and Rosenberg, 2005; Kyvik, 2005; Littman et al., 2007; VRWB, 2008; Norga, 2009; Mittra, 2009; Grady, 2010; Lander and Atkinson-Grosjean, 2011). However, the extent to which these clinical scientists are involved in the development of this type of basic research is in reality limited. More often they function as simple "translators" of discoveries from lab to bedside while being heavily involved in clinical care at the hospital.

In short, the present article aims to contribute to the existing literature on use-inspired and practice-oriented basic science by increasing our understanding of this phenomenon in two ways. First, we examine the role clinical scientists can play in the development of use-inspired and practice-oriented basic science in the biomedical sector. Second, we study which incentives might encourage the engagement of clinical scientists in the development of use-inspired and practice-oriented basic science.

To address these research questions, we first carefully identify a set of clinical scientists and analyze whether the involvement of these clinical scientists in the development of scientific basic research actually affects the practice-oriented and use-inspired character of the

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[1] The authors consider this manuscript a nice example of interdisciplinary collaboration and declare shared last authorship

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conducted basic science. We propose measures to assess the practice-oriented and use-inspired character of these researchers' basic publication records. Specifically, we examine the knowledge sources of clinical scientists' scientific work and evaluate its impact on applied and industrial follow-on research compared to other scientists' basic research. Next, we evaluate the impact of a unique fellowship that targets these clinical scientists and partly releases them from their clinical duties at the bedside to allow them to focus on their research activities. In addition, we run a complementary survey among the fellowship holders to examine how different factors affect the outcomes of the fellowship.

Whereas a multitude of studies have analyzed the relationship between the financial incentives of scientific research grants and scientific productivity (e.g. Stephan, 1996; Arora et al., 1998; Arora and Gambardella, 2005; Godin, 2003; Chudnovsky et al., 2008; Azoulay et al., 2011, Jacob and Lefgren, 2011), this study is - to the best of our knowledge – the first to evaluate the impact of the allocation of additional research *time* on the production of practice-oriented and use-inspired basic science by clinical scientists in this context. By studying how the involvement of clinical scientists, actively engaged in the clinic, affects the nature of basic scientific research developed by these scientists, we complement prior literature on bridging between science and innovation that has evaluated the opposite movement, i.e. how the involvement of (basic) scientists affects the development of applied technologies and firm performance (e.g. Toole and Czarnitzki, 2007; Cassiman et al., 2018; Kaiser et al., 2018). Moreover, we add to the ongoing debate and the literature that has shown how research in Pasteur's quadrant can play an important bridging role between academia and industry (Murray and Stern, 2007; Tushman and O'Reilly, 2007; Lacetera, 2009; Baba et al., 2009; Bikard et al., 2018), by proposing one way in which the development of this type of research could be fostered.

Our results indicate that basic research conducted by clinical scientists is more likely to exploit prior insights from the applied literature and triggers more applied and industrial follow-on research. Moreover, we find that clinical scientists partly released from their clinical burden by the Senior Clinical Investigator fellowship, granted by the Research Foundation Flanders (FWO), publish more subsequent to receiving this fellowship and more often fulfill the role of principal investigator, leading their own research projects. More importantly, we provide evidence that the allocation of this fellowship fosters the development of practice-oriented and use-inspired basic science. Rather than translating discoveries from the lab to bedside, the granted clinical scientists are found to publish more scientific basic research that brings together insights from bench and bedside. The outcomes of our survey indicate, not surprisingly, that granted researchers obtain better results when the proposed clinical release is effectively implemented, and additional sources of monetary funding are available to the researcher.

The rest of this paper proceeds as follows: In the next section, we discuss prior literature on the role of use-inspired and practice-oriented basic research in bridging between scientific discovery and innovation. Section 3 describes our data and sample construction, our variables, and, the methodology used in the empirical analysis. Section 4 presents the main results from our analysis. Finally, Section 5 concludes.

2. Theoretical background

2.1. Basic science & innovation

Prior research has pointed out the importance of basic scientific research as a driver for technology development, innovation and economic growth (e.g. Jaffe, 1989; Mansfield, 1991; Rosenberg and Nelson, 1994). However, not all scientific knowledge triggers the development of marketable products and applied technologies (Gittelman and Kogut, 2003; Nightingale and Martin, 2004; Bikard, 2018). Nightingale (1998) argues that the outcomes of basic scientific research cannot always be directly applied to produce technology because science answers the *wrong* question; Whereas innovation starts with a desired end-result and aims to discover the unknown starting conditions to achieve it, basic scientific research is typically defined as theory-driven research that follows a predictive and forward-looking logic, primarily conducted with the aim to understand phenomena without any specific application or end-use in mind (Partha and David, 1994; Nightingale, 1998; Gavetti and Levinthal, 2000; OECD, 2002; Rubio et al., 2010). Stokes (1997) classifies the type of basic research that is solely driven by a quest for a fundamental understanding into Bohr's quadrant, referring to the theoretical work on atomic structure and quantum theory by the Danish Nobel prize winner Niels Bohr. Accordingly, this type of pure basic research is characterized by a reductionist approach where real-world phenomena are simplified to their essential properties. Simulations, models and instruments are applied in search of cause-effect relationships in a strictly controlled and isolated environment (Arora and Gambardella, 1994; Gittelman, 2016). Therefore, pure basic science most often represents more abstract principles touching upon the fundamental relations between causes and effects. However, proof that these abstract principles can be embedded in practical applications is rarely provided (Cummings and Teng, 2003; Landry et al., 2006). Consequently, the abstract and predictive outcomes of theory-driven basic research carried out in an isolated lab environment, on their own, have little predictive power in case the distance between these laboratory conditions and the real environment is considerable (Nightingale, 1998; Nelson, 2003; Gittelman and Kogut, 2003; Gittelman, 2016). In this event, predictive theory on its own does not hold the key to solve practical problems. The incorporation of contextualized insights from the real environment is expected to be essential to foster technological advancements (Nelson et al., 2011; Gittelman, 2016). Evans (2010), for example, illustrates how industry expertise brought into academic collaborations by companies, enables these collaborations to perform more novel and *commercially* relevant research. Scientists engaged in industry activity advance technologically inspired ideas that can redirect scientific theory and eventually lead to discoveries that might not have been anticipated academically (Evans, 2010).

2.2. Use-inspired basic science & innovation

Referring to the research approach of Louis Pasteur, Stokes (1997) classifies the type of scientific research that seeks a fundamental understanding of scientific problems while at the same time having a clear and direct use for society into Pasteur's quadrant, and labels it *use-inspired basic science.* For Stokes, the research of Pasteur exemplifies how basic and applied research can coincide. In his early days as a laboratory assistant, Louis Pasteur studied how chemically identical crystals reflected light differently based on their shape. He hypothesized that optically active crystal was a sign of living material. Later, when searching for a solution for contamination in the fermentation process of wine, Pasteur realized that the crystals in wine were optically active and fermentation was thus an organic process. This applied observation led to the development of Pasteur's germ theory, which triggered further empirical studies and led to solutions for the production of beer and wine, and to pasteurization and antiseptics. The interplay between Pasteur's basic and applied insights led to the discovery of an analogy between fermentation and contagious disease, and eventually to the development of the vaccine (Stokes, 1997; Berche, 2012; Science History Institute, 2017). A more recent example illustrating how real-world insights might shape advances made in science can be found when looking into the discovery of the potential of CRISPR (clustered regularly interspaced short palindromic repeats). CRISPRs are specialized stretches of DNA found within the genomes of prokaryotic organisms such as bacteria. In the early 2000s, Rodolphe Barrangou and a team of researchers at Danisco, a Danish food ingredient

company, were introduced to CRISPR while sequencing streptococcus thermophiles bacteria, commonly found in yogurt and dairy cultures. Sequencing different strains of bacteria, the researchers discovered the eye-opening link between CRISPR sequencing content and phage resistance, confirming that CRISPRs play a role in regulating bacterial immunity (Barrangou et al., 2007; Kerry, 2015; Vidyasagar, 2018).

This type of use-inspired basic scientific research is not the norm. Amara et al. (2019) show that only 28% of scientists across different fields of research classify their research into Pasteur's quadrant. About 72% of these scientists performing basic research classify their basic scientific research into what Stokes (1997) named Bohr's quadrant where the research question was not inspired by use, but rather by making contributions to fundamental understanding. Scientists might be discouraged to engage in research that focuses on practitioners' needs due to (i) the reward and incentive system of the academy, (ii) insufficient resources, and (iii) the existing divide between researchers' and non-academic agents' interests (Evans, 2010; Amara et al., 2019).

Prior work has suggested that "boundary-spanners" active in both scientific research and technology development are critical to achieve this connection between fundamental understanding and practice (Gittelman and Kogut, 2003; Breschi and Catalini, 2010). The existing literature typically considers these individuals as "translators" of the fundamental understanding of the underlying theoretical mechanisms towards practical applications. Due to the localized, specialized, tacit and embedded nature of the relevant knowledge, transferring the information is complex. In the words of Polanyi (1966): "the portion of knowledge that one can express in speech and writing is only the tip of the iceberg". As a result, the actual mobility of individuals involved in basic scientific research has been shown to transfer this knowledge most effectively for practical use and technology development (e.g. Zucker et al., 2002; Subramanian et al., 2013; Cassiman et al., 2018).

However, as argued above, in contexts where the abstract and predictive outcomes of theory-driven basic research provide little information about how the solution might fare in the real-world environment, the uni-directional translation of the scientific knowledge for technology development might fail to foster technological advancements (Nightingale, 1998; Nelson, 2003; Gittelman and Kogut, 2003; Gittelman, 2016). Understanding the user-need and incorporating use-inspired knowledge from the real-world environment into the scientific research process becomes critical in this situation (Nelson et al., 2011). Not only the tacit dimension of *scientific* knowledge might hamper its transfer, but also the required *contextualized* knowledge and real-world insights might be "sticky" because of its localized, tacit and embedded character (von Hippel, 1994). Therefore, developing successful science-based technology in such a context requires access to the tacit and sticky *scientific* and *contextual* knowledge base at the same time. Hence, rather than being involved in transferring the fundamental principles from scientific research to the context, it might be optimal for "boundary-spanning" researchers to translate the specifications of a complex and tacit context into particular fundamental research questions. Use-inspired basic scientific research will therefore display a very different relation with applied research compared to predictive theory-driven basic scientific research. The former should draw more on applied sources while the latter will draw more on basic scientific research.

2.3. Use-inspired basic science & innovation in biomedicine

2.3.1. Research context

As introduced, our study discusses the development of practice-oriented and use-inspired basic science in the biomedical sector. The focus on this sector is especially relevant since many have argued that the theoretical and predictive insights from fundamental basic science, on their own, are limited in their ability to serve as a direct input for medical innovation and clinical practice due to the complexity of the human physiology and the heterogeneity of the human population (Gelijns et al., 1998, 2001; Chalmers, 2006; Mittra, 2009; Ali and Gittelman, 2016). Prior work stresses how the reduction of the remaining uncertainty, and thus technological progress, is dependent on the interplay between practice and the scientific research enterprise (Thomke et al., 1998; Gelijns et al., 2001; Nelson, 2003). Historical evidence even reveals how advances from clinical and patient-oriented research can lie at the origin of the development of important new treatments (Rees, 2004; DeMonaco et al., 2006; LeFanu, 2012). For example, Williams (2004) describes how findings in pediatric patients before developing sickle cell anemia and differences between Middle Eastern and Sub-Saharan patient populations with similar blood conditions but very different symptoms, led to the discovery of successful treatments of the disease and resulting in a flurry of basic scientific research clarifying the pathways of the disease (Gittelman, 2016). The solution developed was very different from the pathways that were analyzed in basic scientific research devoted to the disease before the discovery of these clinical insights.

In this setting, we analyze the role clinical scientists, scientists employed between lab and bedside at academic hospitals, can play in the development of use-inspired basic science by fulfilling the role of "boundary-spanners" between clinical practice and basic scientific research. Shaped by their insights from clinical care at the bedside, these scientists speak the language of both scientific research and clinical practice and bring a unique perspective to the medical research workforce (Ley and Rosenberg, 2005; Lander and Atkinson-Grosjean, 2011). DeMonaco et al. (2006) illustrate the importance of practicing clinicians in the development of new, off-label drug therapies through field discovery. Llopis and D'Este (2016) found evidence for the fact that contact with patients is especially positive for those researchers involved in basic scientific research. These findings confirm research in the field of the sociology of science that stresses how innovations are generally rooted in boundary-spanners involved at both the bench and the bedside, typically in the context of (academic) hospitals (Ben-David, 1960; Metcalfe et al., 2005; Mina et al., 2007; Morlacchi and Nelson, 2011). The work of Assmus and Haeussler (2015) and Ali and Gittelman (2016) similarly emphasizes how basic and applied research skills should interact within a single individual in order to successfully turn inventions into innovations.

Despite this positive evidence, clinical scientists are often too distracted by the amount of clinical care at the bedside to actually conduct scientific basic research (Butler, 2008). Lack of resources and different incentives have put the boundary-spanning role of clinical scientists between research and clinical practice at risk and has limited their engagement in the development of use-inspired, patient-centric and innovative research (Bassand et al., 2002; Sung et al., 2003; Rees, 2004; Ley and Rosenberg, 2005; Mittra, 2009). Mittra (2009) argues that young potential clinical innovators turn away from this type of research career as they feel that their clinical expertise is no longer required for modern medicine's forward march that heavily relies on the "bench-to-bedside" research path. Nevertheless, the "bench-to-bedside" search paradigm has failed to deliver the expected medical progress and tangible human benefit once hoped for (e.g. Gelijns et al., 1998, 2001; Chalmers, 2006; Hopkins et al., 2007; Mittra, 2009; Ali and Gittelman, 2016). Swinney and Anthony (2011) show that the phenotypic screening approaches for small-molecule drug discoveries associated with a clinical research approach have been more successful in coming up with new molecular entities that are first-in-class. In contrast, the target-based approaches driven by the mechanisms of action at the molecular level coming out of the lab have been more successful in follow-on drug discovery (Gittelman, 2016). As a result of this discussion in the medical sector, efforts have been undertaken to (re)engage clinical scientists in research activities by revitalizing the clinical-scientists' career through providing these researchers with ample funding and opportunities (e.g. Sung et al., 2003; Ley and Rosenberg, 2005; NIH Roadmap, 2005; Sheridan, 2006; Butler, 2008).

2.3.2. Research question

The aim of this study is twofold. First, we analyze to what extent basic scientific research conducted by a carefully defined group of clinical scientists differs from a sample of randomly matched basic scientific research articles. Specifically, we assess how the involvement of these clinical scientists in the development of basic scientific articles influences the practice-oriented and use-inspired character of these articles. In a second step, we examine which incentives affect the actual engagement of clinical scientists in the development of basic scientific research. More precisely, we evaluate the impact of a unique fellowship, provided by Research Foundation Flanders (FWO), which targets these clinical scientists and partly releases them from their clinical duties at the bedside to allow them to focus on their research projects.

As argued, we expect that the involvement of clinical scientists in the development of basic scientific research results in the development of basic scientific research with a higher practice-oriented and use-inspired character. Due to their leading role in the clinical activities carried out at the bedside, clinical scientists are confronted with applied and real-world insights on a regular basis. Thus, we predict that basic scientific research carried out by clinical scientists is infused with patient insights and is more likely to reference applied science compared to a sample of randomly matched basic scientific research articles. Moreover, we expect that basic scientific research conducted by clinical scientists is relatively more likely to spur follow-on applied science and is more likely to connect directly to the work of industry scientists within this context.

However, the involvement of clinical scientists in the development of (practice-oriented and use-inspired) basic scientific research is not self-evident as in practice these researchers might be too distracted by the amount of clinical care at the bedside to actively engage in basic scientific research activities. Consequently, we expect that clinical scientists granted with an effective release from their clinical duties, as offered by the Senior Clinical Investigator FWO fellowship, will partly move away from the bedside and increase their involvement in basic scientific research activities with a relatively high practice-oriented and use-inspired character.

3. Data, variables & methods

3.1. Database construction

In order to address the proposed research questions, our samples are constructed as follows: (1) First, we precisely define a sample of 168 clinical scientists based on the selection criteria put forward by the Research Foundation Flanders (FWO) and its Senior Clinical Investigator fellowship (84 treated and 84 controls). (2) Next, each scientific basic research article published by one of the identified clinical scientists is randomly matched with an article published in the same issue of the journal as the article published by the clinical researcher. This section explains the construction of the sample of clinical scientists in greater detail and discusses how we identify the set of scientific basic research articles and their corresponding matched controls.

3.1.1. Clinical scientists: FWO versus no FWO fellowship

FWO is an independent government agency that supports fundamental research in all disciplines in Flanders (Belgium) with scientific excellence as the only selection criterion. The Senior Clinical FWO investigator fellowship was brought into existence to support medical doctors and researchers who want to pursue a full-fledged clinical scientist career. To serve this purpose, the beneficiaries of this grant are offered the chance to obtain a part-time leave from their clinical position for 5 years, with two possible 5 year extensions. This research grant reimburses the university hospital and has to be entirely devoted to the clinical replacement of the FWO candidate. To be eligible, the candidate must be a medical specialist, general practitioner or pharmacist specialist in clinical biology, younger than 46 and holding a Ph.D., with a full-time clinical role and a permanent employment contract at a university hospital in the Flemish Community.[2]

In total, our sample contains 84 clinical scientists that were granted the Senior Clinical FWO investigator fellowship over the period from 2000 to 2014. Based on the same selection criteria we select 84 additional clinical scientists that did not receive the FWO grant as control group, resulting in an overall sample of 168 clinical scientists. In the absence of information on the runner-ups to the recipients of this fellowship, we rely on observable characteristics to create a viable control group where we match each FWO granted researcher with the single closest non-granted researcher or "nearest neighbor" of our control group. To do this, we first construct a sample containing all potential controls for the FWO granted researchers by selecting those researchers that were not granted a Senior Clinical Investigator FWO fellowship, but have very similar characteristics; Out of a list containing all researchers holding a full-time clinical role at a Flemish university hospital, with a Ph.D. and educational duties at that university (568 researchers), we select all corresponding non-granted researchers with respect to academic-age,[3] gender, specialization,[4] department and university. Next, the sample of potential controls is validated by field experts with regard to these researchers' scientific activity and academic profile, narrowing down the potential control sample to 119 researchers. All these potential controls have been eligible for the FWO Senior Clinical Investigator fellowship at one point in their career. Finally, we collect the entire publication record of both the FWO granted clinical scientists and the potential control group in order to take the researchers' academic performance into account when conducting nearest neighbor propensity score matching to construct the ultimate control group. This matching model does not only take gender, specialization and university into account, but also includes the number of publications and the average quality of these publications before the allocation of the grant as a matching criteria, aiming to pair each FWO granted researcher with the single closest non-granted researcher of our control group. A detailed description of the nearest neighbor propensity score matching procedure can be found in Appendix. Our final sample contains all publication data from the Web of Science for the 84 treated and 84 non-treated clinical scientists over the analyzed time frame, going from 5 years before the FWO fellowship was granted until 3 years after.[5,6]

3.1.2. Identifying basic publications & matched controls

Subsequently, each basic research article published by one of these 168 clinical scientists (pooled sample: 84 treated and 84 controls) is randomly matched with an article published in the same issue of the journal as the article authored by the clinical scientist. Specifically, we match 1633 distinct basic research articles published by one of these clinical scientists with a random article published in the same issue of that journal, resulting in 1633 additional articles.

To identify the "basic" or "applied" nature of a scientific publication, we rely on the CHI Journal classification system. Based on expert assessments, the CHI Journal classification system assigns each biomedical journal to one of four mutually exclusive research levels, according to a journal's degree of "appliedness" as reflected in its content

[2] University hospitals in the Flemish Community include the KU Leuven, UGent, UHasselt, UAntwerpen & VUB campus (http://www.fwo.be/Fundamenteel-klinisch-mandaat.aspx).

[3] Based on year of first publication.

[4] We distinguish between three specialty groups: diagnostic specialties (pathology, radiology, lab medicine,…), surgical specialties and non-surgical specialties (internists, pediatricians, …).

[5] We exclude review articles, editorials, and letters from the set when computing these measures.

[6] As a robustness check we focus on the early FWO fellowship cohort in order to account for a longer follow-up period.

(Noma, 1986; Hamilton, 2003). More specifically, the journals are categorized as "clinical observation" (level 1), "clinical mix" (level 2), "clinical investigation" (level 3) and "basic biomedical research" (level 4)[7,8]. While this classification system has been used across a wide range of empirical studies (e.g. Narin and Rozek, 1988; Hicks and Hamilton, 1999, Brusoni and Geuna 2003; Della Malva et al., 2013; Assmus and Haeussler, 2015; NSF Science Indicators), this method has not been uncontested due to a lack of documentation providing the theoretical notions, methodological rigor or practical considerations employed by CHI Research to design this classification scheme (Tijssen, 2010). Despite these concerns, studies applying alternative classification methods based on the SCI Journal Citation Report (Lim, 2004), using a text-mining approach based on title words (Lewison and Paraje, 2004), or applying a "knowledge utilization" typology (Tijssen, 2010) find remarkable consistent results when using the CHI Journal Classification.[9]

We classify each publication that can be matched to the CHI Journal classification data, as being "basic" or "applied". We apply both a strict and a broad definition for the "basic" and "applied" categories. The strict definition only uses publications in journals from level 1 as "applied" and from level 4 as "basic". The broader definition classifies publications in journals from level 1 and 2 as "applied", and from level 3 and 4 as "basic".

3.2. Dependent variables

3.2.1. Bibliometric indicators of practice-oriented and use-inspired science

In order to compare the practice-oriented and use-inspired character of scientific basic articles, an indicator that aims to capture the practice-oriented and use-inspired nature of each individual publication is constructed. The *Applied Backward Citations* variable reflects the use-inspired nature of basic research articles by measuring the extent to which articles published in journals classified as basic by the CHI Journal classification method, cite publications published in journals classified as applied by analyzing the ratio of backward applied citations. The *Applied Forward Citations* variable similarly reflects the practice-oriented nature of each of the basic research articles by using the ratio of forward citations of the article that result from journals classified as applied by the CHI Journal classification method. In addition, the *Industrial Relevance* of basic science is identified by examining the ratio of forward citations stemming from scientific articles authored by scientists affiliated to business enterprises or other types of private sector organizations.

3.2.2. Bibliometric indicators of scientific performance

To examine how the allocation of FWO's Senior Clinical Investigator fellowship affects these clinical scientists' scientific productivity in general, we construct two bibliometric indicators :[10] (i) the number of (basic and applied) publications per researcher per year, and, (ii) the number of last author publications per researcher per year.[11]

3.3. Independent variables

In the first part of our analysis, where we evaluate the practice-oriented and use-inspired character of scientific basic research carried out by clinical scientists, the main independent variable is the treatment dummy *Clinical Scientist Publication*. This variable is one when a basic research article is authored by one of the clinical scientists included in our sample, and zero if the article serves as a randomly matched control.

When addressing the second research question, studying how the allocation of the FWO fellowship affects these clinical scientists' scientific productivity in general and their engagement in the development of basic research, our main independent variable in the different analyses conducted, is the treatment dummy *FWO Fellowship*. This variable is one during the years a clinical researcher received the FWO fellowship, and zero otherwise. Additionally, a dummy variable *FWO* is included to correct for any unobserved ability that has been taken into account by the FWO selection procedure but not by the construction of the control group and matching process. The *FWO* dummy variable is 1 for all researchers that receive the FWO fellowship at a certain point in time, and zero for those researchers who are not granted a FWO fellowship at any point in time. Ergo, this dummy variable is constant over time. Furthermore, we include *Year* dummies to take temporal effects into account. As a robustness check we include a control variable that accounts for the *Monetary Sources of Funding* granted to the treated and non-treated clinical scientists over the analyzed time frame.[12]

3.4. Complementary survey

In order to analyze the heterogeneity within the scientific performance of those clinical scientists that obtained the Senior Clinical FWO Investigator fellowship, we ran a complementary survey. Our survey gathered information on 5 dimensions: the research dimension, the time-budget dimension, the research-support dimension, the funding-dimension and the social dimension of each researcher and its environment. The survey was carefully constructed and tested with the help of 8 clinical scientists. We sent out the survey to 78 researchers that were granted the FWO fellowship and got a response rate of about 55%, or 43 researchers. Additionally, we interviewed several of the granted researchers. The Senior Clinical FWO investigator fellowship offers a part-time leave from the researchers' clinical position in order to focus on their research activities. We measure the effective replacement subsequent to the allocation of the FWO grant,[13] time spent

[7] For example, the CHI Journal classification system proposes that Level 1 is typified by the *Journal of the American Medical Association*, Level 2, by *The New England Journal of Medicine*, Level 3, by the *Journal of Clinical Investigation*, and Level 4, by the *Journal of Biological Chemistry*.

[8] The CHI Journal classification system identifies *Science* and *Nature* as scientific *basic* journals. Despite the fact that articles published in these journals might have important practical implications due to their outstanding quality and relevance, the core of the medical articles published in these journals typically have a compelling *basic* character. Moreover, it is important to realize that only 0.002% of all articles included in our sample were published in the aforementioned journals.

[9] As a robustness check, we identify each article's research level (1-4) based on text analysis of articles' titles, abstracts and cited references following the model developed by Boyack et al. (2014) instead of relying on the CHI journal-level classification method. All results are robust to using an article research level classification.

[10] An earlier version of the paper also examined the impact of the FWO Senior (*footnote continued*) Clinical Investigator fellowship on scientific publications through the number of citations per paper per research per year with a fixed two-year citation window. We found that the FWO fellowship does not have a robust significant impact on the number of citations per paper and the number of citations per last author paper received during the post-grant time-span. Other studies examining the impact of competitive grant funding on scientific quality also did not find evidence of a robust significant increase (or decrease) in subsequent academic quality (e.g. Godin, 2003; Jacob and Lefgren, 2011). We therefore did not pursue this line of investigation further.

[11] A robust social norm in the life sciences assigns first authorship to the junior author who was responsible for actually conducting the investigation, last authorship to the principal investigator, and divides the remaining credit to authors in the middle of the authorship list (Azoulay et al., 2011).

[12] Due to data and privacy limitations, we were only able to obtain precise and detailed additional funding information on the individual researcher level for a set of researchers employed at the KU Leuven, a total of 99 researchers: 49 granted individuals and 50 controls.

[13] The promised part-time clinical leave subsequent to the allocation of the FWO fellowship is in practice often not granted as skilled replacement is not

on research, additional sources of financial funding, the number of Ph.D. students and the number of research assistants.

3.5. Methodology

As a result of our careful one-to-one matching of scientific articles (see Section 3.1.2), we can simply calculate the difference in means for the *Applied Citation* and *Industrial Relevance* indicators when analyzing to what extent the practice-oriented and use-inspired character of basic research conducted by clinical scientists differs from the control sample of randomly matched articles.

To examine the impact of the FWO fellowship, we need to address an important identification issue: the appointment of FWO fellowships is typically driven by certain expectations about the potential of researchers, and thus not random. As a consequence, granted researchers might have experienced similar outcomes in case they had not been appointed (Azoulay et al., 2011). In an attempt to overcome this issue, we aim to construct a viable control group of clinical researchers via a matching exercise on observable characteristics (see Section 3.1.1) and conduct difference-in-difference analyses to rely on within-scientist variation to evaluate the FWO fellowship's impact. Let SP_{it} be one of the dependent variables that measures the scientific performance of the clinical researcher i at time t (see Section 3.2.2). We estimate regressions of the following form, where u(t) = time dummies.

$$SP_{it} = \beta_1 FWO_i + \beta_2 FWO\ Fellowship_{it} + u_t + \varepsilon_{it}$$

Due to the nature of the constructed bibliometric indicators of scientific productivity, which are positive integer variables, we estimate count data models by running a pooled Poisson quasi-maximum likelihood (QML) estimator as well as a fixed-effect panel Poisson QML estimator.[14] Conducting QML Poisson regressions instead of standard Poisson regressions, we control for the issue of over-dispersion encountered in our dataset (i.e. the variance of the dependent count variables is larger than the mean). The advantage of the pooled Poisson model is that it does not impose the strict exogeneity assumption. By clustering standard errors at the individual researcher level, dependence over time is accounted for. Estimating a panel fixed-effect model, we correct for potential (unobserved) individual research ability. All individual-specific characteristics of the different researchers, such as gender, specialization, etc., are not included in the specification as these characteristics are absorbed by the individual-specific effect (Czarnitzki and Toole, 2010).

Despite our intensive matching efforts on observable characteristics, unobserved research ability and time varying unobserved heterogeneity might still affect our results related to the impact of the FWO fellowship. To address this issue, we also constructed a weighted control group by means of Kernel matching (Heckman et al., 1998). Kernel matching is a non-parametric matching estimator that makes use of weighted averages of all individuals in the control group in order to construct the counterfactual outcome (Caliendo and Kopeinig, 2005). Our results are robust to using this control group.

4. Results

In this section, we first analyze to what extent the practice-oriented and use-inspired character of basic research conducted by clinical scientists differs from a sample of randomly matched scientific basic articles. Next, we examine how a partial clinical release, provided by FWO's Senior Clinical Investigator fellowship, affects these clinical scientists' scientific productivity in general and their engagement in the development of basic research. Finally, we explain the heterogeneity of the scientific performance of the FWO granted clinical scientists by focusing on differences in these researchers' time-budget, research support, clinical obligations, access to sources of monetary funding and an effective clinical replacement.

4.1. Clinical scientists and use-inspired basic research

In Table 1, we examine the practice-oriented and use-inspired character of all scientific basic articles published by our pooled group of clinical scientists and compare these articles with the sample of randomly matched articles. Interestingly, the set of 1633 basic articles published by the clinical scientists accounts for about 30% of their total scientific output over the analyzed time window. Even before a clinical release is granted to half our sample of clinical scientists, we find the pooled group of clinical scientists to publish on average one basic research publication per year. This indicates that clinical scientists not only work on more applied research projects, but also publish basic research.

The results of the comparison presented in Table 1, show that (1) basic research published by our set of clinical scientists is significantly more likely to exploit prior insights from the applied literature (*Applied Backward Citations*) while at the same time it triggers relatively more applied follow-on research (*Applied Forward Citations*) compared to the sample of randomly matched basic articles. In addition, we find that basic science published by clinical scientists is significantly more likely to serve as an input for follow-on research by scientists affiliated to business enterprises compared to the articles serving as control sample (*Industrial Relevance*). Moreover, (2) we provide evidence that these findings are robust when only comparing these articles where the identified clinical scientists hold the last author position. In order to even further guarantee that we compare similar articles, (3) we narrow down our sample of 1633 publication-pairs and only consider the 25% publication-pairs with the highest topic overlap. To obtain a text-based measure of topic similarity between each scientific basic article published by a clinical researcher and its randomly matched article published in the same journal, we perform text analysis on the publication abstracts. As a robustness check, a similar exercise is done by using the medical subject headings (MeSH-terms) assigned to these publications provided by the National Library of Medicine. The obtained results are robust.

Together these statistics suggest that basic science conducted by clinical scientists has a significantly higher practice-oriented and use-inspired character as compared to a sample of very similar randomly matched articles. Nonetheless, as discusses before, clinical scientists' engagement in this type of research, and their scientific productivity overall, is limited due to these researchers' clinical obligations at the bedside and a lack of incentives and resources to engage in research activities. Therefore, we now analyze to what extent, and under which circumstances, releasing clinical scientists from their clinical duties affects their scientific productivity, impacts their involvement in scientific basic research and strengthens their boundary-spanning position between research and clinical practice.

4.2. Clinical scientists & the senior clinical investigator FWO fellowship

4.2.1. Bibliometric indicators of scientific performance

We compare the scientific productivity of the granted clinical scientists and their non-granted clinical controls by examining the number of publications per year. Fig. 1[15], plots this indicator over time and suggests an increase in the number of publications subsequent to the

(*footnote continued*)
always readily available or effective replacement is not adequately organized within the clinical service.

[14] To estimate this model, we use the QML Poisson fixed-effect Stata routine developed by Tim Simcoe, Boston University.

[15] This graph presents the estimated coefficients stemming from a dynamic difference-in-difference analysis that estimates these differences distributed over time.

Table 1
The use-inspired and practice-oriented character of scientific basic research.

			Basic science by clinical scientists		Random control sample	
			Mean	Std. Dev.	Mean	Std. Dev.
(1)	All scientific basic articles	Applied Backward Cit.	0.49***	0.35	0.38	0.36
		Applied Forward Cit.	0.58***	0.35	0.45	0.37
		Industrial Relevance (Dum. var.)	0.45***	0.50	0.36	0.48
		N	1,633		1,633	
(2)	If last author publ. = 1	Applied Backward Cit.	0.54***	0.35	0.43	0.35
		Applied Forward Cit.	0.60***	0.34	0.49	0.37
		Industrial Relevance (Dum. var.)	0.43***	0.49	0.33	0.47
		N	359		359	
(3)	If topic similarity publ.-pair top 25%	Applied Backward Cit.	0.54***	0.34	0.44	0.35
		Applied Forward Cit.	0.58***	0.36	0.50	0.36
		Industrial Relevance (Dum. var.)	0.42**	0.50	0.34	0.48
		N	395		395	

*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

allocation of the fellowship. The parallel pre-treatment trend assumption for the total number of publications of treated and non-treated authors holds (see also Fig. 1A).[16] In our regression analysis (Table 2) we control for some of the observed and unobserved factors that might be driving divergence in pre-treatment levels between treated and non-treated observations for the number of publications. Moreover, the presented results are robust when a kernel-weighted control group is constructed and applied to address any remaining concern regarding the parallel pre-trend assumption (see Fig. 1A and B.). The outcomes of the regression analysis suggest that the number of publications increases substantially after the FWO fellowship is actually awarded (Table 2, column 1). Yet, a difference exists between selected and non-selected researchers as indicated by the positive and significant effect of the *FWO* dummy variable in the pooled Poisson QML estimation. This provides evidence of a successful selection process by the Research Foundation Flanders (FWO). The positive impact of the allocation of this grant on the number of subsequent publications is confirmed by the results of the fixed-effect QML Poisson estimation (Table 2, column 2). The outcomes of the fixed-effect Poisson model suggests that the FWO fellowship has a marginal effect of 24% [=exp(0.216)−1] on publication output, or one additional publication per researcher per year.

Maybe more importantly, we examine the impact of the FWO fellowship on the evolution of the researcher as principal investigator by analyzing the fellowship's impact on the number of last author publications. The graph plotting this indicator (Fig. 2[17]) indicates a strong increase in the number of last author publications after the allocation of the FWO fellowship.[18] This expectation gets confirmed by the different Poisson regressions conducted (Table 2, columns 3 and 4): we find an increase of around 50% [=exp(0.400) - 1] in the number of last author publications per researcher as a result of the Senior Clinical FWO fellowship, or roughly 0.4 extra last author publications per researcher per year. As opposed to the total number of publications"-estimation, the *FWO* dummy in the pooled Poisson QML estimation (Table 2, column 3) does not present evidence that selection into the FWO-sample has an impact on the number of last author publications. Thus, the increase in the number of last author publications appears to be solely driven by the allocation of the FWO fellowship.

4.2.2. Basic versus applied science

To analyze what drives the presented increase in scientific productivity, we run similar fixed-effect Poisson QML regressions on the total number of basic and applied publications (Table 3). We find that the increase in the total number of publications triggered by the allocation of the FWO fellowship, is driven by an increase in the number of basic publications rather than by the number of applied publications. This holds both for the strictly and broadly defined basic and applied categories.[19] The results presented in Table 3 suggest that the allocation of the FWO fellowship is related to a marginal effect of 63% [=exp(0.487)−1] in the number of basic publications according to the broad definition (1), and even 95% [=exp(0.669)−1] applying the strict definition (2). Hence, it appears that the allocation of the fellowship effectively increases clinical scientists' involvement in the development of basic research, while applied research output remains relatively stable.

Summarized, the outcomes of these analyses suggest that by providing research-time to clinical scientists, the allocation of the FWO fellowship shifts these researchers' focus towards the development of practice-oriented and use-inspired basic science that integrates insights from bench and bedside.[20]

4.2.3. Robustness checks

4.2.3.1. Use-inspired and practice-oriented basic research. Granted versus *non-granted clinical scientists*. While we provided evidence that basic science conducted by the pooled group of clinical scientists has a significant higher use-inspired and practice-oriented character as compared to a sample of very similar randomly matched articles (see Section 4.1), a potential concern could be that differences exist between the use-inspired and practice-oriented character of scientific basic research published by granted and non-granted clinical scientists. In

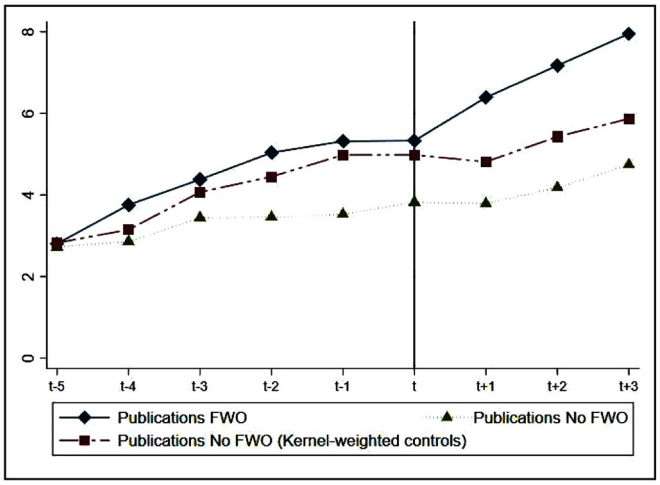
[16] The interaction coefficient of the FWO group is not significantly different from the control group at each point in time before treatment at a 95% confidence interval (the most significant difference is at t-1 with a p-value of 0.079, all other coefficients have a p-value higher than 0.10). Note also that Figs. 1A and B report a one-standard-error interval and not the 95% confidence interval.

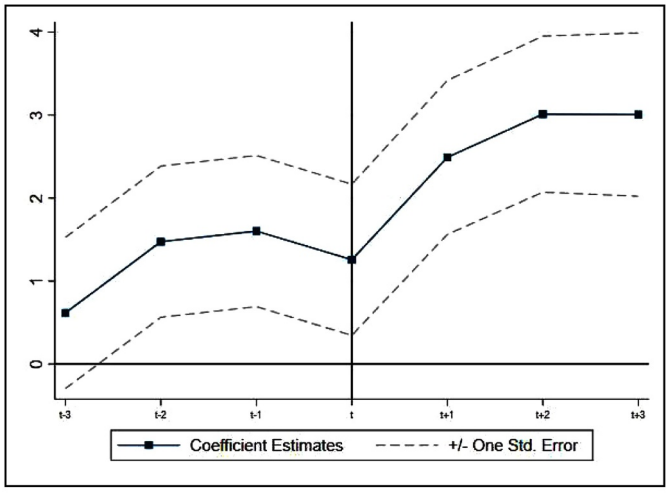
[17] This graph presents the estimated coefficients stemming from a dynamic difference-in-difference analysis that estimates these differences distributed over time.

[18] The parallel pre-treatment trend assumption is satisfied (see Fig. 2A). Moreover, we find that all our results are robust when testing for an "(inverted) Ashenfelter's Dip" and when including pre-grant publication performance indicators as a proxy for unobserved heterogeneity in a Pooled Poisson regression on post-grant publication performance.

[19] These results are confirmed when only considering publications where the researcher is last author. Results not provided but available upon request.

[20] The FWO grant itself does not increase the average use-inspired and practice-oriented character of these publications. After receiving the FWO grant, grant holders publish more basic research that is subsequently more likely to cite/be cited by applied research and, hence, overall the development of use-inspired and practice-oriented science increases.





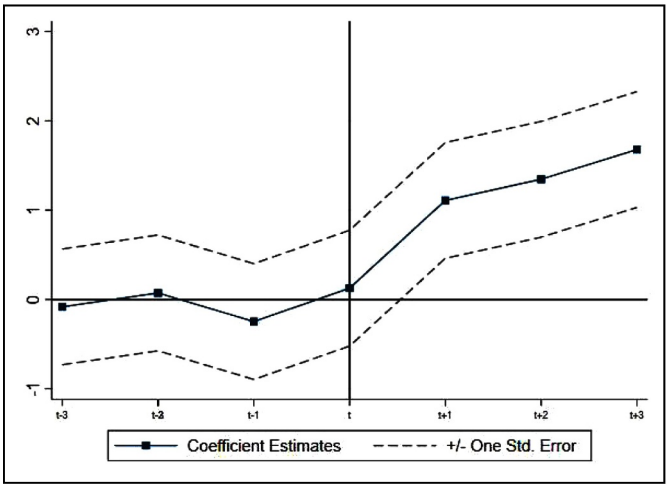


Fig. 1. Average number of publications per researcher per year. (A) Difference between treated and non-treated - average number of publications. (B) Difference between treated and kernel-weighted controls - average number of publications.

this robustness check we estimate whether such differences exist at the researcher level by conducting a simple regression analysis on the ratio of applied backward, applied forward and corporate forward citations to basic science published by clinical scientists during the 5 years before the allocation of the fellowship. Fig. 3 plots the estimated regression coefficients corresponding to the dummy variable *FWO*, which is one for all clinical scientists that receive the FWO fellowship at a certain point in time, and zero for those clinical scientists who are not granted a FWO fellowship at any point in time, serving as the reference category in this analysis. The graphical presentation of the *FWO* dummy variable coefficient estimates and their 95%-confidence intervals indicates that no significant differences between the practice-oriented and use-inspired character of scientific basic research conducted by both groups exist.[21]

4.2.3.2. Additional funding. The FWO fellowship itself does not provide monetary funding for the researcher, but the clinical scientists in our sample might have access to additional sources of funding. Due to data issues and privacy limitations, we were only able to obtain precise and detailed additional funding information at the individual researcher level for a set of researchers employed at the KU Leuven, a total of 99 researchers: 49 granted individuals and 50 controls. Table 4 presents the outcomes of the fixed-effect panel Poisson QML estimation, with the inclusion of the control variable *Additional Sources of Funding*. This control variable accounts for the total number of additional sources of monetary funding granted to each researcher per year. We find our results to be highly robust. Moreover, the outcomes of this estimation suggest that additional sources of funding have a significant positive impact on the number of last author publications.

4.2.3.3. Follow-up window. An additional concern regarding our analysis could be the limited 3 year follow-up period subsequent to the allocation of the grant. One might argue that the impact of the FWO fellowship on scientific productivity can only be truly analyzed using a longer follow-up window. In Table 5 we re-estimate our fixed-effect Poisson QML regression for those researchers that were granted the FWO fellowship between 2000 and 2003. Focusing on the early FWO fellowship cohort,[22] and its corresponding control group, allows us to examine a 10 year follow-up period, instead of the earlier presented 3 year follow-up period. The results are consistent with our findings: granted researchers publish more subsequent to the allocation of the FWO fellowship and are more likely to act as principal investigator, as measured by the increase in the number of last author publications.

4.3. Releasing clinical scientists as the precondition for scientific impact

Finally, the survey data on the granted researchers' timetables, clinical obligations and research support, provides us a better insight into the factors influencing the scientific performance of the grant holders of a Senior Clinical FWO Investigator fellowship.

The descriptive statistics presented in Table 6 suggest that large differences regarding these researchers' time-budgets, clinical obligations, research support and effective replacement after the grant allocation exist. To take the effective clinical replacement into account, we identified the group of researchers that indicated a higher than average clinical replacement (>7.63 h/week) after the grant allocation and generated the dummy variable *Replacement Above Mean*.[23] The collected data allows us to estimate the impact of a clinical *replacement above mean, the number of Ph.D. students* and *research assistants* surrounding the granted researcher and whether the granted researcher has access to *additional sources of funding* to finance his/her experiments subsequent to the allocation of the grant, while we control for *total work* (h/week),

[21] Additional robustness checks show that the parallel pre-treatment trend assumption for the total number of basic publications of treated and non-treated authors holds, and that no significant differences exist between the share of basic publications in treated and non-treated authors' publication portfolios prior to the allocation of the FWO fellowship.

[22] 23 researchers were granted the FWO fellowship between 2000 and 2003.

[23] Note that this is substantially less than the indicated part-time leave from the researchers' clinical position by the FWO. Defining a standard workweek as 5 working days of each 9 h (9.00–18.00), a part-time leave should equal 22.5 h.

Table 2
Poisson quasi maximum likelihood estimations.

	Publications (Pooled Poisson)	Publications (Fixed-Effect Panel Poisson)	Last author publications (Pooled Poisson)	Last author publications (Fixed-Effect Panel Poisson)
FWO	0.341***	–	0.144	–
	(2.91)		(0.61)	
FWO Fellowship	0.216***	0.216***	0.400**	0.400**
	(2.63)	(2.64)	(2.38)	(2.38)
Joint significance of 9 time dummies	χ^2 = 71.92	χ^2 = 72.35	χ^2 = 51.59	χ^2= 51.90
Log-likelihood	−4778.6	−2708.9	−2228.3	−1136.3
N	1,512	1,512	1,512	1,512

T statistics in parentheses; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

university, specialization, FWO allocation year and *time effects*. Table 7 presents the results of the Pooled Poisson QML estimation on our post-grant bibliometric indicators[24] for the within FWO fellowship analysis.

Not surprisingly, we find that a clinical *replacement above mean* subsequent to the allocation of the FWO fellowship is strongly related to the total number of publications (Table 7, column 1), number of last author publications (Table 7, column 2), and, the number of basic research publications (Table 7, column 3). The significance of this dummy variable points to the importance of an *effective* clinical replacement for a researcher to maximally benefit from the allocation of the Senior Clinical Investigator FWO fellowship as also stated by clinical scientists in our interviews. The interviewed clinical scientists emphasized that an effective clinical replacement is even more essential to increase the development of basic publications, as they argued that publishing an impactful basic article is significantly more time consuming compared to producing an impactful clinical study. Additionally, we show that the number of Ph.D. students and research assistants surrounding the FWO granted researcher, is positively related to the total number of publications and last author publications.

Furthermore, access to (additional) sources of monetary funding is positively related to the bibliometric quantity indicators. As we found before, this positive relation is most pronounced for the number of last author publications by the granted researchers, but loses significance in the case of basic research publications where research assistance seems more important. In interviews with different FWO fellowship-holders the positive effect of these additional sources of monetary funding was explained as follows: the FWO fellowship grants its beneficiaries “time” to conduct research, but the granted researchers do not necessarily have the required research budget to run their (expensive) experiments. Therefore, additional sources of monetary funding positively relate to the researchers’ scientific productivity and research independence. Besides, a larger research budget allows the granted researchers to hire more Ph.D. students and research assistants, and thus increases the size of their personal research group.

Summarized, these results suggest that an effective clinical replacement is indispensable to fully leverage the FWO Senior Clinical Investigator fellowship. As biomedical faculty members are typically expected to perform a multitude of tasks to fulfill their obligations, an effective clinical replacement is often the only way to allow this group of well-educated and clinical experienced researchers to focus on their research projects, act more as principal investigator and develop a full-fledged research career, including publishing more practice-oriented and use-inspired basic research.

[24] The results are robust when we run this Poisson estimations on the sum of the post-grant bibliometric indicators rather than on the individual year observations as presented in Table 7.

5. Discussion & conclusion

The outcomes of this study highlight that basic research published by clinical scientists is significantly more likely to exploit prior insights from the applied literature and triggers relatively more applied and industrial follow-on research compared to a sample of randomly matched articles. Moreover, we find that clinical scientists partly released from their clinical burden by FWO's Senior Clinical Investigator fellowship, publish more after the allocation of this fellowship and more often act as principal investigator, leading their own research projects. More importantly, we show that the boost in the clinical scientists’ scientific productivity is largely driven by an increased participation in the development of basic science. Given that basic research published by these clinical scientists is more likely to bring together insights from bench and bedside, the allocation of this fellowship fosters the development of practice-oriented and use-inspired basic-science.

From our survey data and evidence obtained from in-depth interviews, we find that the promised effective clinical replacement is important to fully leverage the FWO fellowship. Interestingly, it turns out that in reality some of the granted researchers are still too distracted by the intensity of clinical care to truly benefit from the FWO fellowship as an experienced and skilled replacement is not always readily available or effective replacement is not adequately organized within these researchers’ clinical service. Besides, we show that monetary funding sources are positively related to the researcher's scientific performance as they increase their ability to effectively run experiments. Not surprisingly, the size of the personal research group surrounding the granted researcher has a positive impact on this researcher's scientific productivity. In short, partly releasing clinical scientists from their clinical duties is a successful initiative to foster the development of practice-oriented and use-inspired basic research when these researchers are effectively replaced and have access to an adequate research budget to finance their staff and research projects.

Our study does not question the importance and relevance of advances made in “pure” basic science, basic science conducted with the aim to understand phenomena but without any specific application or end-use in mind. Rather, we argue that the direct transformation of the abstract outcomes of fundamental basic science into marketable products or applied technologies might be hindered in case the distance between the laboratory conditions and the real-world environment is considerable. Based on prior literature, we reason that in those cases, use-inspired and practice-oriented basic science, bringing together outcomes from theoretical basic science and insights from the real world environment, will foster this transformation more naturally and show under which circumstances clinical scientists can play a significant role in its development.

From a policy perspective our results suggest that increasing the involvement of clinical researchers in the basic scientific process is a worthwhile endeavor. Recent efforts such as the National Institutes of

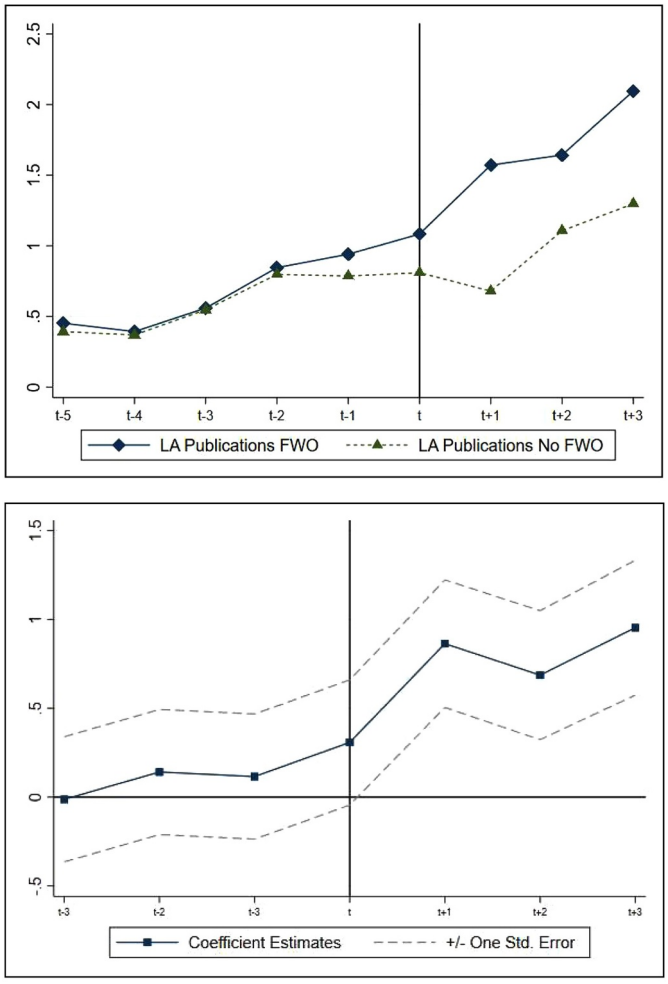


Fig. 2. Average number of last author publications per researcher per year. (A) Difference between treated and non-treated - average number of LA publications.

Table 3
Fixed-effect panel quasi maximum likelihood Poisson estimations.

	Basic Publ. – Broad Def. (1)	Appl. Publ. – Broad Def. (1)	Basic Publ. – Strict Def. (2)	Appl. Publ. – Strict Def. (2)
FWO Fellowship	0.487***	0.107	0.669***	0.0170
	(3.41)	(1.01)	(2.66)	(0.09)
Joint significance of 9 time dummies	$\chi^2 = 38.23$	$\chi^2 = 58.57$	$\chi^2 = 8.51$	$\chi^2 = 15.30$
Log-likelihood	−1377.5	−2093.7	−565.1	−1063.6
N	1,512	1,512	1,512	1,512

T statistics in parentheses; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Health Roadmap for Medical Research and the creation of Clinical and Translational Science awards which focus on translating scientific advances into medical practice, are a step in the right direction (Gelijns and Gabriel, 2012). However, rather than considering clinical researchers as simple "translators" from the scientific outcomes at the bench to patients' bedside, we argue that involving these clinical scientists at the initial steps of the research process might be especially relevant to encourage the production of use-inspired and practice-oriented science in this sector. An important open question remains as to how much involvement clinical scientists need without losing touch with clinical practice. Our results suggest that the FWO fellowship causes the clinical scientists to act more as PI (last author). This might have more impact on the direction of the research, but future research will need to confirm the eventual impact of clinical scientists as PIs on medical innovation. Ali and Gittelman (2016) do argue that the role of the MD-PhD as PI has an important influence on research results being

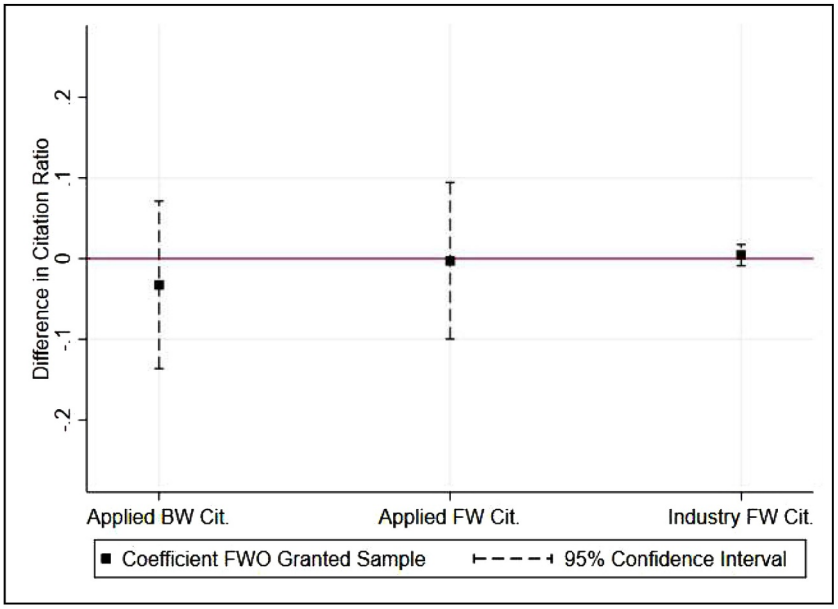


Fig. 3. Use-inspired and practice-oriented character of basic science published by granted versus non-granted clinical scientists.

Table 4
Robustness check - fixed-effect panel quasi maximum likelihood Poisson estimations.

	Publications	Last author publications
FWO Fellowship	0.287***	0.467**
	(2.68)	(2.47)
Additional Sources of Funding	0.020	0.070**
	(0.94)	(2.32)
Joint significance of 9 time dummies	χ^2 = 32.31	χ^2= 85.70
Log-likelihood	−1511.1	−598.6
N	891	891

T statistics in parentheses; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 5
Robustness check - fixed-effect panel quasi maximum likelihood Poisson estimations.

	Publications	Last author publications
FWO Fellowship	0.220**	0.471**
	(1.90)	(1.94)
Joint significance of 16 time dummies	χ^2 = 208.38	χ^2= 150.06
Log-likelihood	−1512.2	−883.1
N	690	690

T statistics in parentheses; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 6
FWO within sample analysis – descriptive statistics.

	FWO granted researchers				
	Obs.	Mean	Std. Dev.	Min	Max
Total working (h/week)	43	67.59	11.51	49	102
Research (h/week)	43	26.46	10.48	7	44
Clinical work (h/week)	43	30.27	11.84	8	60
Extra tasks (h/week)	43	8.47	6.55	1	32
Replacement post FWO grant (h/week)	43	7.63	8.45	0	25
Additional Sources of Funding (binary)	43	0.39	0.49	0	1
# of Ph.D. Students	43	2.14	1.79	0	7.5
# of Research Assistants	43	1.88	2.45	0	10

licensed to companies.

Our results match well with the arguments of Arora et al. (2019). They claim that the demise of the large corporate labs might be leading to a disconnection between scientific research and technology development and, as a consequence, to lower productivity growth. Corporate labs connected their scientists more closely to practical problems and engaged them in a more multidisciplinary approach to solving complex practical problems through scientific research. As a result, the scientific research coming from these corporate labs was more useful to inventors compared to scientific research performed at universities (Arora et al., 2019). We argue that in our context, clinical scientists, provided with the right incentives, could perform this bridging role by developing more use-inspired and practice-oriented basic research. This could compensate for the decrease in scientific research performed within corporations (Arora et al., 2018), while better connecting with the complex practical problems faced in the corporate R&D units.

To conclude, we would like to indicate the main limitations of our study. First, a possible concern could be the limited size of our sample. Nevertheless, our sample is equal to the population. Therefore, a straightforward extension of this research design to a larger sample of clinical scientists is not possible. Despite the limited size of our sample and the specific focus on the Senior Clinical Investigator FWO fellowship, we believe that the findings and insights from our study can be generalized to other clinical scientists employed at university hospitals. The difficulty is in carefully identifying these clinical scientists as many medical researchers active in clinical research did not follow a scientist PhD training in addition to their medical degree. Second, by exploiting the heterogeneity of the collected publications and their references in terms of basic and applied science, we identify practice-oriented and use-inspired basic science. However, we do not observe whether this basic science is effectively more likely to trigger successful product development and medical innovation, except for the fact that basic research published by these clinical scientists has a higher uptake by researchers in companies.

CRediT authorship contribution statement

Paul-Emmanuel Anckaert: Conceptualization, Methodology,

Table 7
FWO within sample analysis – pooled poisson quasi maximum likelihood estimations.

	Publications	LA Publications	Basic publications (Strict)
# of Ph.D. Students	0.099***	0.197***	0.373***
	(3.10)	(4.51)	(4.71)
# of Research Assistants	0.160***	0.118**	0.305***
	(3.93)	(2.41)	(4.89)
Replacement Above Mean	0.841***	0.981***	1.017**
	(2.78)	(3.51)	(2.71)
Total Work	−0.012	−0.021*	−0.0975***
	(−0.81)	(−1.80)	(−4.59)
Additional Sources of Funding	0.403*	0.669***	0.228
	(1.78)	(3.00)	(0.64)
Specialization	Incl.	Incl.	Incl.
University	Incl.	Incl.	Incl.
FWO Year	Incl.	Incl.	Incl.
Time Dummy	Incl.	Incl.	Incl.
Log-likelihood	−407.7	−204.6	−115.2
N	129	129	129

T statistics in parentheses; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Standard errors are clustered at the individual level.

Formal analysis, Investigation, Writing - original draft, Project administration. **David Cassiman:** Conceptualization, Methodology, Investigation, Writing - original draft, Supervision. **Bruno Cassiman:** Conceptualization, Methodology, Investigation, Writing - original draft, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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Appendix

Nearest Neighbor Matching

As described in the data-section of this paper, in total our sample contains 84 clinical scientists that were granted the Senior Clinical FWO investigator fellowship over the period from 2000 to 2014. In the absence of information on the runners-up to the recipients of the grant, we rely on observable characteristics to create a viable control group. Therefore, next to constructing a list with all potential controls with the help of field experts, we use nearest neighbor matching (without replacement) to pair each FWO granted researcher with the single closest non-granted researcher.

Pairs are chosen based on the similarity in the estimated probability of receiving the FWO fellowship, meaning the propensity score stemming from a Probit estimation on the dummy indicating the receipt of the FWO fellowship. Table A.1 presents the selection of variables taken into account for the matching process.

To test the success of our matched data we have conducted a Probit regression with outcome whether or not the researcher obtained an FWO fellowship. The results of this Probit regression (Table A.2) and the descriptive statistics (Table A.3) related to the granted and non-granted researchers suggest that, despite our best matching efforts, more productive researchers are more likely to be selected into the FWO fellowship. Nevertheless, the p-value of the LR test, 0.1063, cannot firmly reject the null hypothesis that all of the regression coefficients in the model are equal to zero. We will carefully control for some of the observed and unobserved factors that might be driving the divergence in pre-treatment levels between treated and non-treated observations and where possible utilize a diff-in-diff specification to mitigate potential biases in our results. Moreover, as a robustness check we also construct a kernel-weighted control group to address this issue. Our results are robust to using this control group (see Fig. 1A and B.).

Table A.1
Matched variables.

Matched variables	
Publications	Average number of publications per year before the allocation of the FWO grant
Publications Quality	Average number of citations per publication before the allocation of the FWO grant
Gender	Equals 1 if the researcher is male, 0 if the researcher is female
Specialization	Categorical variable: diagnostic, surgical or non-surgical specialty
University	Categorical variable: KU Leuven, UGent, UAntwerpen, VUB or UHasselt

Table A.2
Probit regression on receiving FWO fellowship.

	FWO (=1)
Publications	0.093**
Publications Quality	0.007
Gender	−0.054
FWO year (cohort)	Incl.
Specialization	Incl.
University	Incl.
N	168
LR	chi2 (9) = 14.48 Prob > chi2 = 0.1063

*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

Table A.3
Descriptive statistics granted versus non-granted clinical scientists before allocation of FWO fellowship.

	FWO		No FWO	
	Mean	Std. Dev.	Mean	Std. Dev.
Publications	4.19	3.47	3.12	2.25
- Basic	1.17	1.50	0.73	1.22
Publication Quality	3.61	3.13	3.44	5.52
Gender (Male = 1)	0.76	0.43	0.78	0.41
Specialization				
- Diagnostic	0.09	0.28	0.09	0.29
- Surgical	0.21	0.41	0.24	0.43
- Non-surgical	0.70	0.46	0.67	0.47
University				
- KU Leuven	0.65	0.48	0.66	0.47
- UGent	0.32	0.47	0.33	0.47
- VU Brussel	0.03	0.17	0	0
FWO year (based on academic age for control group)	2006.44	4.25	2006.60	4.19
N	84		84	

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