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From science to technology: The value of knowledge from different energy research institutions

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ABSTRACT

Expansion of public energy R & D budgets continues to be a key component of climate policy. Using an original data set of both scientific articles and patents pertaining to three alternative energy technologies (biofuels, solar and wind energy), this paper provides new evidence on the flows of knowledge between university, private sector, and government research. Better understanding of the value of knowledge from these institutions can help decision makers target R & D funds where they are most likely to be successful. I use citation data from both scientific articles and patents to answer two questions. First, what information is most useful to the development of new technology? Does high quality science lead to applied technology development? I find that this is the case, as those articles most highly cited by other scientific articles are also more likely to be cited by future patents. Second, which institutions produce the most valuable research? Are there differences across technologies? Research performed at government institutions appears to play an important translational role linking basic and applied research, as government articles are more likely to be cited by patents than any other institution, including universities. Universities play a less important role in wind research than for solar and biofuels, suggesting that wind energy research is at a more applied stage where commercialization and final product development is more important than basic research.

1. Introduction

Developing new and improved clean-energy technologies is an important part of any strategy to combat global climate change. For example, generation of electricity and heat is the largest source of carbon emissions, accounting for 42 percent of carbon emissions worldwide in 2012 (IEA, 2014). Meeting the climate policy goals currently under consideration, such as European Union discussions to reduce emissions by 40 percent below 1990 levels by 2030 or the U.S. Clean Power Plan goal of reducing emissions from the electricity sector by 32 percent by 2030, will not be possible without replacing much of the current fossil fuels-based electric generating capacity with alternative, carbon-free energy sources.

Because clean energy technologies are usually not competitive with fossil fuels without policy support (Greenstone and Looney, 2012), a large academic literature has emerged evaluating the role of environmental policy for fostering clean energy innovation. Much of this research focuses on the private sector, showing that both higher energy prices and targeted support for renewable energy, such as feed-in tariffs or renewable portfolio standards, lead to increases in clean energy patents.[2]

Even when environmental regulations encourage private sector innovation, firms will focus research efforts on technologies that are closest to market (Johnstone et al., 2010). Yet, one challenge facing many climate-friendly innovations is the long time frame from initial invention to successful market deployment. Consider, for instance, the case of solar energy. Despite research efforts that began during the energy crises of the 1970s, solar is still only cost competitive without policy support in niche markets, such as remote off-grid locations. This leaves a role for government-sponsored R & D to fill in the gaps, particularly in the case of climate change, where a diversified energy portfolio will be necessary to meet currently proposed emission reduction targets. Recognizing this need, during the December 2015 Paris climate meetings, a coalition of governments pledged to double their renewable energy R & D budgets to over $32 billion over the next five years (Sanchez and Sivaram 2017).

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[2] Examples include Johnstone et al. (2010), Verdolini and Galeotti (2011), Peters et al. (2012), Veugelers (2012), Dechezleprêtre and Glachant (2014), Nesta et al. (2014). Dechezleprêtre and Popp (2017) and Popp (2010) provide recent reviews.

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While many studies have looked at private sector energy R & D, fewer papers address the effectiveness of public sector funding for clean energy R & D. Those that do typically find a positive effect of publicly funded R & D on patenting (e.g. Johnstone et al., 2010; Verdolini and Galeotti, 2011; Dechezleprêtre and Glachant 2014; Nesta et al., 2014). However, these studies typically include just a single lagged value of energy R & D, raising questions about what is truly identified.[3]

To better ascertain the effectiveness of public energy research, Popp (2016) links data on scientific publications to public energy R & D funding. For evaluating public research funding efforts, publication data provide a more appropriate outcome measure than patents. By looking at the effect of public R & D funding on scientific articles, Popp (2016) isolates the effect of public R & D to shed light on the process through which public R & D helps develop scientific knowledge. As the ultimate goal of government energy R & D funding is not an article, but rather a new technology, Popp uses citations to link these articles to new energy patents. While public funding does lead to new articles, lags in both the creation of a new publication and the transfer of this knowledge to applied work mean that public R & D spending may take several years to go from new article to new patent.[4]

While Popp (2016) focuses on the time it takes for the results of publicly funded R & D to be cited by a new patent, this paper extends that work by providing more detail on the knowledge flows between published and patented clean energy research. Given recent calls for more publicly funded energy R & D efforts, such as the aforementioned pledges at the December 2015 Paris climate meetings, identifying the investments most valuable to further advancing energy research can help decision makers target R & D funds towards both the technologies and institutions where they are most likely to be successful. This paper uses citation data from both scientific articles and patents to answer two questions pertaining to the quality of energy research output:

1) What information is most useful to the development of new technology? That is, are scientific articles cited frequently by other articles also more likely to be cited by patents, or are the types of articles cited by patents different from those cited by articles? Popp (2016) argues that there is room to expand public R & D budgets, as there is little change in either the quantity of published research or the quality, measured by citations, after large increases in public energy R & D. However, are citations within the published literature an appropriate measure of the relevance of this published research for applied work? In Section 4, I show that highly cited journal articles do receive more citations by patents, suggesting that counts of journal-to-journal citations are a good indicator of the ultimate value of an article for technology development.
2) Which institutions produce the most valuable research? Are there differences across technologies? Using patent and article citations as a measure of knowledge flows, in Section 5 I ask which institutions provide the most useful building blocks for future researchers. Do collaborations between public and private research organizations increase flows of knowledge among groups? Government funded research is performed by a variety of institutions, including universities, government laboratories, and the private sector. As governments prepare to expand renewable energy R & D funding, such evidence can inform where public research funds can best be targeted. While government research efforts are often criticized as wasteful, I find that government patents are cited more frequently by researchers than other patents, and that government research articles are more likely to be cited by future patents. Thus, research not only funded but also performed by the government does appear to play an important translational role linking basic and applied research. Universities play a less important role in wind research than for solar and biofuels, suggesting that wind energy research is at a more applied stage where commercialization and final product development is more important than basic research.

2. Literature review

While the research in this paper most directly builds on the aforementioned Popp (2016), this study also contributes to two strands of related literature. The first strand includes papers using patent citation data to study flows of knowledge across sectors. In the broader science and research policy literature, several papers study links between academia and industry. Many of these papers look at the tradeoffs between patents and publishing without specifically examining how links between academia and industry affect research output (e.g. Murray 2002; Bonaccorsi and Thoma, 2007; Breschi et al., 2007; Magerman et al., 2015). Focusing specifically on the flows of knowledge across institutions, early evidence comes from the patent citation studies of Adam Jaffe and co-authors. Jaffe and Trajtenberg (1996) find that university patents were cited more frequently, and government patents less frequently, than corporate patents. Trajtenberg et al. (1997) find both that university patents receive more forward citations than other patents, suggesting they are more important, and make fewer backwards citations to previous research, suggesting these patents are also more basic. Bacchiocchi and Montobbio (2009) extend this work to a multi-country setting. While they also find university and public research patents are cited more frequently, this is mainly driven by US universities. In Europe and Japan, patents from public research typically are assigned to public research organizations (such as Centre National de la Recherche Scientifique in France), but these are not more likely to be cited. Finally, providing some evidence of technology transfer, Dornbusch and Neuhäusler (2015) find that mixed teams (e.g. academia and private sector inventors) have the largest impact on future technology (e.g. more citations).

Fewer papers look specifically at knowledge flows related to renewable energy. Both Jaffe and Lerner (2001) and Popp (2006) show that passage of laws to promote technology transfer increased flows of knowledge from government labs to the private sector. More recently, Wu and Matthews (2012) examine citations in USPTO patents for solar PV cells by Korean, Taiwanese and Chinese applicants from 1984 to 2008. The importance of the private and public sector varies by country. Taiwanese patents initially cited mostly public institutions, but switched to almost all private sector citations by 2000. In Korea, most citations are to the private sector, while in China, the public sector is the main driver of innovation. Canter et al. (2016) study wind and solar PV inventor networks in Germany. While they do not explicitly link network size and collaboration to research outcomes, they cite existing research identifying knowledge transfer networks as important drivers of innovation (Dosi, 1988; Powell et al., 1996; Ahuja 2000). This paper contributes to this body of work by providing evidence both on the value of collaboration in energy research and on which institutions are most effective for renewable energy research across a wider range of countries.

The second strand of literature uses non-patent literature (NPL) references to link patents and publications. One of the first papers to use NPL citations is Branstetter (2005). He uses a random sample of 30,000 U.S. patents form 1983-86. About 4300 of these cite academic science. Patent citations to scientific articles increase over time, and the modal lag between article publication and the application year of a citing patent is three years. 65% of papers cited by patents come from university authors, while papers from private firms represent 24% and papers from nonprofits receiving 11%. Interviews with inventors in the biotech field confirm that spillovers were increasing over time and that increased citations reflected those spillovers.

Reinforcing the claim that non-patent references are a better

[3] A partial exception is Peters et al. (2012), who state that they test multiple lags and stocks of public R & D in unreported results.

[4] Note that it not need be the case that all publicly funded research take several years to yield results. For instance, some public funding may lead directly to new patents, as well as publications. While some patents may emerge quickly, Popp (2016) shows that it may take 10 year or more until the full effect of additional R & D spending on patenting activity is observed.