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Star scientists in PV technology and the limits of academic entrepreneurship☆

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ABSTRACT

This study analyzes the contributions of star scientists to the development of the most promising renewable technologies in solar photovoltaic. The process of development involves agents discovering the new technologies and large user companies, as well as individual efforts from universities and academic stars maintaining momentum with major investments. In contrast to the situation for biotechnology, star scientists, regardless of their contribution, are comparatively minor players in solar photovoltaic technology.

1. Introduction

Numerous scholars study the technological competencies of new technology-based spin-offs. Zucker, Brewer, Darby, and Peng (1994) and Zucker and Darby (1996) launch a small but influential addition to this line of thought, arguing that the biotechnology revolution is mainly the result of star scientists' efforts. Zucker et al. (1994) find that star scientists transfer their advanced knowledge to new technology firms through different channels, including participating in the scientific committees of these firms and even serving as founders or advisors. According to them, a star scientist is someone who discovers 40 or more genetic sequences and publishes at least 20 articles reporting these discoveries.

In subsequent years, some authors studying biotechnology decide to adopt this notion of star scientists and not produce original definitions (Sapsalis, Van Pottelsberghe, & Navon, 2006; Tzabbar & Kehoe, 2014). Others turn to patents and publications (see Table 1). For example, Niosi and Queenton (2010), studying Canadian biotechnology firms, define biotech superstars as those who appear as inventors in more than five patents and author more than one major publication per year.

Although the vast majority of articles on star scientists focus on biotechnology, the concept migrated, albeit modestly so, to other high-technology disciplines such as nanotechnology, chemistry, computer and electrical engineering, and materials (Lowe & Gonzalez-Brambila, 2007; Trippl, 2011; Tartari, Perkmann, & Salter, in press).

This study finds only one scholarly work on star scientists in the solar photovoltaic (PV) sector, but the author of that work (a thesis) does not build a definition (Colalat, 2009). Fuller and Rothaermel (2012) define star scientists as faculty founders of new technology ventures and apply this definition to several industries, including the photovoltaic sector. Fuller and Rothaermel (2012) mention SunPower, a photovoltaic spin-off from Stanford University in California that Dr. Richard Swanson, a professor of electrical engineering founded, as a case in point. Table 1 summarizes the definitions and key bibliographies on star scientists.

University spin-offs (USOs) are one of the important channels through which star scientist can contribute to the growth of high-tech firms. Pirnay, Surlemont, and Nlemvo (2000)define USOs as follows:

> "…/new firms created to exploit commercially some knowledge, technology or research results developed within a university".

The scientific domain itself does make sense for the performance of USOs. A large percentage of academic spin-offs relate to biotechnology and health sciences. Mowery, Nelson, and Ziedonis (2001) calculate that some 75% of the patenting and licensing at three of the most research-active universities in the United States (US), namely, the network of the University of California, Columbia and Stanford, are in biomedical research, particularly biotechnology. The second most important sector is computer software. The article does not mention solar technology. Similarly, in an annual survey of intellectual property generated in Canadian universities, health sciences appear as number one, although not as prominently as in the US. Again, the survey does

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Table 1
Star scientist definitions.

Author	Industry or technology	Definitions
Zucker & Darby, (1996)	Biotechnology	"Those discovering more than 40 genetic sequences and/or authoring 20 or more articles reporting such discoveries up through early 1990. There are 327 of these stars worldwide, of whom 207 worked in the U.S. and 52 in Japan, with the U.K. next largest with 30 stars. A star scientist has written three or more articles in this and the two preceding years with location determined by the last affiliation given for the star."
Sapsalis et al., (2006)	Biotechnology	There is no definition of stars
Lowe & Gonzalez-Brambila, (2007)	Six disciplines from biology and chemistry to computer and electrical engineering, and materials	Stars are highly productive scholars that become entrepreneurs. There is no mention of patents or the discovery of genetic sequences in the definition
Groysberg, lee, & Nanda, (2008)	Wall Street research analysts	"/…/disproportionately productive and valuable" people (p. 1213)
Niosi & Queenton, (2010)	Biotechnology firms and academics	Biotech superstars are those with more than five patents and more than one major publication per year
Trippl, (2011)	All scientific disciplines in university	"Stars scientists are defined here as authors of highly cited research papers, identified by the number of citations they generated in journals in the ISI databases in the period 1981–2002". (P. 1654)
Fuller & Rothaermel, (2012)	All high-tech scientific academic disciplines	Faculty founders of new tech ventures are star scientists
Oettl, (2012)	Immunology	Stars are people with high levels of scientific productivity (publications) and helpfulness. Highly productive individuals who do not help colleagues are "lone wolfs", not "stars"
Moretti & Wilson, (2013)	Biotechnology	"…those patent assignees whose patent count over the previous ten years is in the top 5% of patent assignees nationally."(ibid, p. 3)
Tzabbar & Kehoe, (2014)	Biotechnology (industrial organizations)	"Star employees have been defined as individuals who demonstrate disproportionately high levels of productivity" (P. 452). There is no definition of what high productivity may be.
Hoser, (2013)	Nanotechnology	Those academics with the maximum number of citations
Tartari et al. (in press)	All scientific disciplines in university	"We define star scientists as academics in our sample in the top 1% of the distribution of citations in their discipline, and the top 25% of the distribution for grants received from the EPSRC"

not mention the solar photovoltaic (PV) sector (Statistics Canada, annual).

Local venture capital also appears to be a determinant of growth. Using a large sample of US academic spin-offs supported by venture capital, Zhang (2009) finds that most of them focus on two areas: biotechnology and information technologies. In addition these spin-offs tend to remain close to their alma mater.

USOs from different US universities perform very differently. More entrepreneurial universities have much better scores as licensors of technology to academic spin-offs. Walter, Auer, and Ritter (2006) argue that network capabilities and entrepreneurial orientation are key variables explaining the performance of these USOs. Further, Powers and McDougall (2005) find that universities with experienced (older) technology transfer office (TTOs) incubate more successful spin-offs. More productive faculty members (in terms of articles and citations) also contribute to more successful spin-offs. Early collaboration with industry also contributes to spin-off growth.

2. Hypotheses

On the basis of literature reviews, the article draws the following hypotheses:

H1. Technological content (i.e., the relevant industrial sector) is a major determinant of the likelihood of creation of a USO. More specifically, the likelihood of creation of a solar PV USO is lower than that of biomedical and information technology USOs.

H2. Venture capital has a strong industrial sector component. Venture capital supports much more often biomedical and information and communication technologies (ICT) spin-offs than solar PV ones.

H3. More experienced universities and TTOs will produce more successful USOs.

H4. Star scientists will engage in more successful solar PV USOs.

3. The solar PV sector

The solar photovoltaic sector started modestly in Bell Labs in the 1950s when three researchers developed the silicon transistor. Today, the silicon cell is still the main component of solar PV technology (Perlin, 2002). The first application was in space, in the late 1950 and 1960s, with satellites requiring a reliable long-term source of electricity, even if the cost of that solar energy was high. A second major application, in the 1970s, was in sea buoys and sea oil and gas exploration and exploitation, far from conventional sources of electricity. At this time, large hydrocarbon companies, such as ARCO, BP and Shell, started investing in solar PV R&D. As the cost of solar PV energy started to decline following technological advances, the sector began to interest companies such as Telecom Australia, as a mean to provide telephone connections in a country close to 8 million square kilometer in area and with lots of sunshine but with a population of only 12 million in the early 1970s. At the same time, Japanese companies such as Canon, Sharp, and Sanyo invested in solar technology to power their hand calculators and similar devices.

Universities joined the solar bandwagon later. In the 1980s, the University of New South Wales (UNSW), under the guidance of Dr Martin Green, started conducting research on solar cells to improve their efficiency. At the same time, Dr Allen Bennett at the University of Delaware (UD) provided an impetus to academic research on PV technologies. Soon, these two pioneers launched the first academic spin-offs, Pacific Solar in Sydney Australia and AstroPower in Glasgow, Delaware, in 1995. AstroPower sold its assets to GE in 2004, and GE handed these assets to Taiwan's Motech in 2009. The main UNSW spin-off, Pacific Solar, experienced ups and downs and finally closed its doors in the late 1990s.

By that time, several other universities, mostly in the United States but also in Europe (Germany, Switzerland), started conducting R&D on solar PV technologies in a multi-agent race to increase solar cell efficiencies. Today, the University of Konstanz in Germany and the École Polytechnique Fédérale de Lausanne (EPFL) in Switzerland stand among the top contributors. Star Professor Michael Graetzel at EPFL is the Chairman of the Technical Advisory Board at an Australian spin-off company, Dyesol, which acquired one of EPFL's spin-off companies, GreatCell, a firm that made use of Dr Graetzel's discoveries in the field of dye solar cells.

Germany has lost some interest in the solar PV sector due to a reduction in government feed-in tariffs and Chinese competition. In 2009, the largest German start-up, Solon Technologies, went bankrupt, and soon the two largest German companies involved in the area, Robert Bosch and Siemens, sold or closed their solar PV facilities. However, government R&D laboratories remained active, with the Fraunhofer Institute in Freiburg being Europe's number one public research institute in the area. The Fraunhofer Institute created close to 15 spin-off companies, some of which are still alive.

Since 2000, Asian competitors have become more involved. Japan has developed a policy to foster the creation of university spin-offs, a phenomenon that seldom occurs in that country. However, as of 2015, there are few spin-offs from Japanese universities in the solar PV sector. All of them are working on niche products.

In Taiwan, the Industrial Technology Research Institute's (ITRI) policy is to import and develop advanced technology and spinoff technology-based firms concentrating on solar PV, after focusing on semiconductor products and processes. DelSolar, located in the Hsinchu Science Park, is ITRI's first and only PV spin-off. In 2005 DelSolar merged with NSP, another Taiwanese company, to become the largest solar PV technology firm in Taiwan.

Whereas South Korea seems almost impenetrable to solar academic spin-offs, China's Academy of Science and some Chinese universities are very active, TsingHua University stands over the others.

Asian and US governments are increasing their investment in solar PV R&D, but venture capital is historically fairly reluctant to engage in a sector that promises returns only in the long term and is plagued by high volatility. Only in the last few years did some VC investment return to the sector, mainly in the United States, and mostly in the downstream segments of the industry, such as companies that assemble and install rooftop modules. Upstream companies, with strong R&D capabilities and patents, in which star scientists are usually involved, are struggling to obtain private sector funds and only survive due to public funds, such as those from the US Department of Energy, the Advanced Research Project Agency (ARPA), and the Small Business Innovation Research Program (SBIR) programs. The decline in the price of oil and gas since late 2014 is doing nothing to reverse the trend.

4. Methodology

This work focuses mainly on patents, publications and venture capital, as well as on the construction of lists of new spin-offs and start-ups in the solar cell sector.

The authors use the United States Patent and Trademark Office (USPTO) database and the keywords “solar cells”, “solar cell”, “solar glass”, “photovoltaic cells” and “photovoltaic cell”. Removing the overlaps, the authors find some 4400 granted solar PV patents between 1976 and December 2013. The use of the USPTO database is because close to 50% of the solar PV patents originate in the United States and competitors in Japan, Germany, Taiwan and the People's Republic of China also apply for patents in the United States to protect their inventions from potential infringers.

Following the most widely used definition of a star scientist, the authors first analyze the articles of star scientists. There are 105,484 articles on solar technologies in Scopus as of 17 February 2015. Within this group, there are 109 stars with more than 100 articles with “solar cell” as the search query for the “Article title, abstract, and keywords”.

For venture capital, the authors use the secondary venture capital association reports as proof.

5. Results: stars scientists in the photovoltaic industries

5.1. Definition of star scientist for solar PV industry

Analyzing the correlation between the number of articles in Scopus and the number of patents by academic scientists in USPTO and Espacenet, the correlation coefficients are just 0.043 and 0.22, respectively. The reason for this high-tech “anomaly” is that at least in North America, solar technology receives enormous knowledge externalities from several other industries, including semi-conductor firms and large glass producers investing in the specialty technical glass used in PV equipment. Thus, for the solar PV industry, unlike biotechnology or other disciplines, most of the research activity takes place in firms, with not so much occurring in universities. In photovoltaic cells, universities have just 589 US patents, whereas companies have more than 3800. There are almost 41,800 articles in SCOPUS on photovoltaic cells. Just over 55% of them include authors from universities. For photovoltaic glass, of the 3600 articles in Scopus, some 2073 (or 57%) include academics among the authors. In addition, photovoltaic glass requires large manufacturing plants and R&D activity. The four main patentees are very large American, European and Japanese companies (Guardian Industries and Corning, both from the United States, the French Saint-Gobain and Nippon Sheet Glass, with its British Pilkington PLC subsidiary). In Germany, some universities conduct solar technology research, particularly Albert Ludwig, Konstanz and Martin Luther universities. However, the number of German academic patents is very low. Only seven appear in the USPTO database, all granted after 2004. The assignees are the Universities of Konstanz and Albert Ludwig Freiburg. A few other academic patents appear in ESPACENET, making a total of 15.

To reflect academic expertise, our definition utilizes articles and patents, and our definition is as follows:

In the solar photovoltaic sector, academic star scientists are university or institutional researchers with at least four photovoltaic industry patents in the USPTO and/or over 100 SCOPUS publications.

5.2. The difference between solar PV and other high-tech disciplines

The solar PV sector produces far fewer patents than the biomedical and ICT industries. A simple perusal of the Organization for Economic Cooperation and Development (OECD) patents database shows that, between 1976 and 2011, OECD countries requested some 175,720 PCT priority patents in biotechnology, compared to 13,984 in solar PV technology. The difference, which is more than 12 times, is staggering, even when adding approximately 500 patents from China, Singapore, and Taiwan not granted in the USA.

Academic patents in solar PV technologies are fairly scarce. There are 589 university or institute patents. Removing overlaps, this figure amounts to barely more than 10% of the 4400 solar cell patents. In comparison, there are some 90,000 USPTO patents granted to assignees with the word “university”. One half of 1% of them were solar PV patents.

5.3. Venture capital in solar PV technologies

In the USA, which hosts 50% of the world's venture capital, biomedical and ICT technologies relegate solar PV technologies to the bottom of the list by a wide margin. US National Venture Capital Association (NVCA) who published the figures in 2014 puts software at the top, with 41% of the total investment of 48 billion, followed by biomedical and life sciences, with 18%, and other sectors. The figures do not even mention energy or clean energy, let alone solar PV technology. A Mercom Capital Group (2015), estimating figures for investments in solar PV technology, put the global total at US$1.3 billion for venture capital (most of this amount goes to downstream activities such as solar roof panel installation for residences in the United States, corresponding to two companies) and US$26.5 billion for corporate investment. In 2013, global investment figures for solar PV were only US$643 million from US$9.6 billion = for clean technology.

5.4. University patents

The US universities and public laboratories dominate in terms of academic solar technology patents, with 292. MIT, the University of Delaware, North Carolina State, the University of California, Caltech, Princeton and Stanford appear at the top of the list.

In Taiwan, where assignees have 136 US patents, ITRI tops the list with 57, followed by the Atomic Energy Council (22) and National TsingHua University (13).

In South Korea, with 82 patents, Dongguk University, the Korean Institute for Science and Technology (KIST), the Korean Research Institute for Science and Technology and Sungkyunkwan University have more than 50% of the public sector solar PV patents.

There are few academic patents in other countries. Australia would be a contender, but UNSW has only two patents under its name. Private firms and the University intellectual property arm presented several of its novelties. China (9), Canada (8), Germany (7), and a few other countries follow. The distribution of academic papers is much greater in other technologies than in solar PV.

5.5. Star scientist performance

Stars in the solar PV sectors do not focus solely on PV technology; nearly half of their academic work is in the other related fields. The average percentage of articles with the title or abstract containing “solar cell” is just 56% of their total papers, and the correlation coefficient between the number of articles with the title or abstract containing “solar cell” and the total number of articles is 0.32. For star scientists, the correlation coefficient between the percentage of papers with “solar cell” and the total number of patents in USPTO and Espacenet are 0.051 and 0.022, respectively, which indicates that the stars with more papers are not very active in solar PV entrepreneurship.

Among the 109 star scientists, the authors remove nine employed by companies because this work focuses on academic entrepreneurship. This procedure leaves just 100 stars belonging to 22 countries. Stars in different countries have different forms of entrepreneurship. Most of the stars outside of US are not high on USPTO patent lists but have several patents in their own countries, especially the stars in Asian nations, such as Japan and China. Among the 22 stars in the US universities, 8 of them have experience setting up a business or working experience in companies, with their academic expertise directly serving in the commercialization of the technology. In contrast in Japan, finding entrepreneurial activity among stars is difficult, except in terms of local patenting. Considering that very huge companies dominate the PV sector in Japan, large companies employ in one way or another most of the academic Japanese stars, and stars do not so much engage in entrepreneurial activity by themselves.

6. Conclusions and policy implications

Star academic entrepreneurship and relative venture capital are most active in biotechnology, other human health sectors and ICT, including software. Solar PV is another situation. Since the inception of the technology in the 1950s and 1960s, several factors restrict the creation of solar USOs, including the scarcity of research funds (in comparison with biomedical technologies), niche markets and the modest interest of academic researchers on the subject, with only a few active universities outside the US, such as UNSW in Australia and EPFL in Switzerland. Comparatively, there are few university patents on solar PV technologies. In addition, venture capital is fairly reluctant to invest in the field, except in Silicon Valley. New solar PV technologies do not attract much interest, and there are few start-ups. Thus, the authors find moderate evidence of support for hypotheses 1 & 2: both academia and venture capital privilege life sciences and ICT at the expense of renewable energy technologies. Only a few countries, such as Australia, China, Japan, Taiwan, and the US, are fueling innovation in this sector, most often with public monies.

Being comparatively new, the PV sector requires the accumulation of knowledge in related fields, such as semiconductors and glass technologies, advanced batteries and mechatronics. Under these conditions, scientists have greater potential to become star scientists in life sciences, ICT and nanotechnologies than in PV technologies. Today, the distribution of solar PV star scientists is global, but they are seldom entrepreneurs.

The authors cannot accept hypotheses 3 and 4. Universities surrounded with venture capital (mainly Silicon Valley but also Greater Boston and Los Angeles) may produce more successful spin-offs. Conversely, prestigious academic institutions in the area of solar PV technology, such as EPFL and UNSW, do not produce similar numbers and successful spin-offs. The findings do not justify extending the idea that successful stars engage in more successful spin-offs in the field of solar PV technologies.

Academic entrepreneurship is not widespread in the PV sector, even in US universities where academic entrepreneurship in bio- and nanotechnologies and ICTs is very active. Furthermore, most of the successful firms that are established directly or use knowledge produced by star PV scientists in PV are being acquired or shut down. To make the scientific and technological achievements of star scientists well commercialized, the corresponding mechanism for technological transfer between academic units and firms should be well designed and operated. Venture capital and a good regional economic landscape may also be necessary conditions for the development of successful new ventures.

From a theoretical point of view, we argue that the concept of a star scientist has to be integrated in the resource-based and competence theories of the firm to which the star scientist approach belongs. In many high-tech companies, star scientists are one of the key resources for growth.

From a public policy point of view, the overwhelming presence of large firms compared to spin-offs from academic institutions makes us think, similar to Mowery et al. (2001), that academic entrepreneurialism applies to a reduced set of technological domains. Solar PV technologies are not a central part of this set. The conditions of these technologies, namely their high risk, long-term payoffs and strong competition from huge corporations, may doom any policy aiming to create academic spin-offs from the start.

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