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Global entrepreneurship and the origin of an ecosystem root firm: The case of China?s solar PV industry

Wei Zhang
Tsinghua University, School of Economics & Management
Dept. of Innovation, Entrepreneurship & Strategy
zhangw3@sem.tsinghua.edu.cn

Jianxi Luo
Singapore University of Technology and Design
Engineering Product Development
luo@sutd.edu.sg

Steven White
Tsinghua University, School of Economics & Management
Dept. of Innovation, Entrepreneurship & Strategy
white.tsinghua@gmail.com

Abstract

In contrast to the extensive literature on the benefits, origins and evolution of existing industrial clusters and ecosystems, there is much less investigation of the foundational spark of their origins. To deepen our understanding of this critical stage, we have undertaken a study of the origin of the firm that became the most important root firm in China?s solar PV ecosystem to answer two related questions. First, how was this firm established in an environment that lacked nearly all of the factors representing necessary resources and opportunity? Second, how and why did this firm become a root in what eventually emerged as the most dynamic national ecosystem within the global solar PV industry? We find that the entrepreneur?s strategy?what we term ?global entrepreneurship??enabled him to found his firm before a supporting ecosystem existed in China. However, the emerging constraints of global entrepreneurship later motivated him to actively contribute to the development of a local ecosystem, in addition to the passive and involuntary role as a source of spin-offs as highlighted by studies of root firms in other industrial ecosystems such as Silicon Valley and Detroit. Our findings suggest that the geographic dimension of entrepreneurship could be important in understanding not only the founding of firms in seemingly incongruous locations, but also the motivation and process by which they may become root firms that actively, not just passively, help establish a new local ecosystem.

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Abstract

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Keywords: Ecosystem, root firm, global entrepreneurship, solar PV industry, China

INTRODUCTION

The benefits of ecosystems have attracted numerous researchers to seek an understanding of how ecosystems emerge. Klepper (2007, 2010) drew attention to the role of "root" firms in the emergence of ecosystems, drawing on his study of Silicon Valley and the role of Fairchild Semiconductor, and Detroit and Olds Motor Works. Roots are a critical "spark" (Bresnahan and Gambardella, 2004) when they actively cultivate a local supply base, attract investors, and contribute to supporting infrastructure in their local environment. They also contribute passively and often involuntarily as a source of spin-offs and skilled and mobile employees (Boeker, 1997; Klepper and Sleeper, 2005; Klepper, 2007, 2010; Marx et al, 2009; Lee, Lévesque and Minniti, 2012). As an increasing number of companies emerge and actively engage in exchange and collaboration networks and informal social networks (Buenstorf and Klepper, 2009; Evans and Garnsey, 2009; Simmie and Martin, 2010; Matthews, 2010), a complementary regional culture and institutional features (legal, financial, labor, educational, etc.) emerges and co-evolves (Saxenian, 1994; Florida, 2004). This is the basic model to understand the emergence of successful industrial ecosystems that generate "agglomeration economies" (Porter, 1990, 1998, 2003; Buenstorf and Klepper, 2009; Delgado et al, 2012).

The critical role played by an original founding firm as the necessary "spark" in the emergence of an ecosystem represents an under-studied but potentially rich opportunity for entrepreneurship research to inform studies of ecosystems. The entrepreneurship perspective reframes the phenomenon to focus on the founder's motivation and means of linking opportunity and resources, and how that impacts the founding of an ecosystem. The fundamental questions are two. First, how can an entrepreneur establish a firm in an environment that lacks most or all of the factors representing necessary resources and opportunity? Second, why and how would a firm become a root in what would eventually emerge as an ecosystem?

We address these two questions through a historical analysis of the emergence of China's solar PV ecosystem and the actions of the entrepreneur who founded Suntech, the firm that would become the most important root in that ecosystem. Zhenrong Shi founded

Suntech in Wuxi, China at a time when the necessary or supporting resources—raw materials, human capital and technology, government support, etc.—for solar PV manufacturing were either absent or woefully inadequate, and when the market was also nearly all outside of China. We find that Shi searched and integrated the necessary resources globally to serve international markets, a mode that we describe as "global entrepreneurship" and to be distinct from the concepts of "international entrepreneurship" and "born-global" in literature addressing the international dimension of entrepreneurship. However, the emerging constraints of global entrepreneurship vis-s-vis a growing and competitive global market soon motivated Shi to actively contribute to the development of a local ecosystem, in addition to passive and involuntary role as a source of spin-offs described in studies of root firms in other ecosystems such as Silicon Valley and Detroit (e.g., Klepper, 2007; 2010).

ROOT FIRMS: LINKING ECOSYSTEMS AND ENTREPRENEURSHIP

Our study of Suntech enables us to investigate the linkage between two phenomena that have so far been addressed by separate research streams. The stream investigating ecosystem emergence, rather than established structure and dynamics, highlights the role of "root" firms. The origins of these root firms, and how those origins may relate to a firm emerging as a root, have not been addressed. Another stream within the international entrepreneurship literature has focused on the rationale and challenges for an entrepreneur to establish a new firm in a location lacking supporting resources from a local ecosystem and, at the same time, to pursue opportunities abroad rather than in the home market. The following review of these literatures identifies key findings, and then we integrate them to clarify their linkage within a broader phenomenon. This also provides a clearer conceptualization of our empirical research question and how it may contribute to these two research streams.

Ecosystem origins: The role of root firms

While geographic proximity, networks and positive feedback loops explain the agglomeration benefits of ecosystems (Hanson, 1982; Song et al, 2001; Rogers and Larsen, 1984; Boeker, 1997; Marx et al, 2009; Saxenian, 1990; 1991; 1994), they do not provide insights into the antecedent emergence process. Ecosystems do not emerge in every region, and few of the many cities and governments around the world that have attempted to build their own "Silicon Valleys" have succeeded. Ecosystems are usually the result of path-dependent and evolutionary processes that unfold in real time (Locke, 1995; Feldman, 2001; Feldman et al., 2005; Simmie and Martin, 2010).

Empirical research into the emergence of ecosystems has identified a number of conditions and processes that seem to be shared across ecosystems. One factor is the presence of an "anchor" or "root" firm, such as a large advanced R&D-intensive firm from which knowledge externalities can flow to the benefit of smaller firms and increase the overall innovative output in the region (Agrawal and Cockburn, 2003; Feldman, 2003). Other factors relate to the degree of "spin-offs" and "organizational reproduction" that research has highlighted as an important mechanism for the emergence and growth of regional ecosystems (e.g., Klepper, 2010; Aoki, 2010). Spinoffs may result from one or more employees leaving a firm to start a new venture, either because of a disagreement or with the support of their former employer. The likelihood and rate of spinoff formation has been linked to the region's entrepreneurial culture (Haunschild and Miner 1997; Saxenian, 1994; Florida, 2004; Senor and Singer, 2009), as well as related institutional features such as relaxed employment laws and use of non-compete employment contracts (Marx et al, 2009).

Research has shown that in most ecosystems, one or a few firms play a disproportionate role as a source of spinoffs. Several scholars have traced the origins of many of the major firms in today's Silicon Valley back, through spinoffs and their founders' backgrounds, to a few key roots; namely, Fairchild Semiconductors, William Shockley Semiconductors, and Hewlett-Packard (Klepper, 2010; Sturgeon, 2000; Blank, 2008). Similarly, Klepper (2010) traced firms in the Detroit automotive ecosystem to a single root, Olds Motor Works.

Origins of root firms: The geographic dimension of entrepreneurship

While ecosystem research has documented the role of one or more root firms in the emergence of an ecosystem, it has largely ignored the origins of the root firms themselves. It seems quite counterintuitive that entrepreneurs would choose to found a firm in a region that lacks both key resources and market opportunity. Pitelis and Teece (2010), in their study of corporate venturing by multinationals, suggest that those who select such an environment should recognize that establishing the basic elements of an ecosystem will be part of their entrepreneurial activities; namely, they must help set up relevant organizations locally, search and develop local resources, and form formal and informal local linkages. Such actions by the earliest ventures in a region could help establish an ecosystem over time (Klepper, 2007, 2010; Evans and Garnsey, 2009; Simmie and Martin, 2010; Matthews, 2010).

Others have drawn attention to the need and benefit, especially for such ventures lacking the support of a local ecosystem, to develop linkages to distant sources of key resources. Porter (1990) emphasizes the need for geographically distant search across different specialized regional clusters, and the importance of balancing the search for both local and distant resources. Illustrating this, Song et al (2001) describe how, in the early stage of Korea's semiconductor industry, Korean firms developed their capabilities by extensively recruiting U.S.-educated and -employed nationals to return home. Later, some of these successful firms become roots for the local ecosystem, whose development would allow more resources to be sourced locally.

This strategy and action of seeking resources outside a new venture's home country is the focus of scholars interested in the phenomenon of international entrepreneurship (Acs et al 2003; Dana et al 1999; Oviatt and McDougall, 1994; 2005; Keupp and Gassmann, 2009; Jone et al, 2011). "International new venture" is one term used in the literature to describe a firm that, from inception, seeks to derive competitive advantage from the use of resources and sale of outputs in multiple countries (Oviatt and McDougall, 1994). This conceptualization adds a geographic dimension to the fundamental definition of entrepreneurship as "the pursuit of opportunity beyond the resources you currently control" (Stevenson and Jarillo, 1991) and a specific empirical focus within the broader research

addressing the sources of opportunities, the discovery process, evaluation and exploitation of opportunities, and entrepreneurs' characteristics (Venkataraman, 1997; Shane and Venkataraman, 2000). This definition also distinguishes it from the stream of research on staged internationalization, a very different phenomenon in which a firm builds up capabilities and market shares at home before venturing abroad (Johanson and Wiedersheim-Paul, 1975; Johanson and Vahlne, 1977; 1990; Chang, 1995; Oviatt and McDougall, 2005), which does not explain international new ventures being founded with limited home market opportunity, limited domestic resources, or both (Knight and Cavusgil 1996).

Oviatt and McDougall (1994) originally distinguished among international new ventures based on the number of markets entered and distribution of value chain activities. We have adapted their categorization to directly reflect the current emphasis on entrepreneurship as an integration of resources and opportunities (Figure 1). This generates four ideal types defined by the location of resources (local, global) and opportunities (local, global). Local ventures operate entirely within their home country, linking local resources with local opportunities. Global outsourcing ventures draw on global resources to serve local markets, while international new ventures draw on local resources to serve distant markets. Finally, born-global ventures integrate resources internationally to pursue opportunities globally, in line with the definition of "born-globals" by previous researchers (e.g., Rennie 1993; Moen and Servais 2002; Rialp et al. 2005).

We find relatively few studies of truly born-global firms, perhaps because of the extreme difficulty in successfully integrating both resources from abroad and opportunities distant from the home market simultaneously, as suggested by Hashai (2011). We find the most studied, truly born-global ventures have been those in emerging economies where key knowledge, inputs and a local market either does not exist or is inadequate to support an entrepreneur's strategic objectives (Child and Rodrigues, 2005; Deng, 2009; Guillén and García-Canal, 2009). While a large number of scholars claim to be investigating born-global ventures, a critical review of their samples and measures reveals that nearly all are studying firms who from inception seek market opportunities abroad, what would be categorized as "international new ventures" in the typology of Oviatt and McDougall (1994) as well our

typology (Figure 1). This seems to be driven by a data constraint; it is much easier to gather large-scale data on firms' exports and sales compared to the resources they draw on. Their findings, however, do inform the logic for firms to seek markets abroad, and include domestic market size compared to the potential of foreign market(s) (Hedlund and Kverneland, 1985; Ganitsky, 1989; Knight and Cavusgil, 1996; Fan and Phan, 2007), relative attractiveness of first developing a foreign rather than home-country market (Anderson and Gatignon, 1986; Chen, 2010; Delios and Beamish, 1999; Erramilli and Rao, 1993); "cultural distance", i.e. the similarity in cultural and socio-institutional norms, between the home country and a foreign countries (Kogut and Singh, 1988), the international experience and social and professional networks of the entrepreneur prior to the start of the new venture (Oviatt and McDougall, 1994; Busenitz and Barney, 1997; Madsen and Servais, 1997; Harveston et al., 2000; Shrader et al., 2000; Bengtsson, 2004; Coviello and Munro, 1995; 1999; Coviello, 2006; Mort and Weerawardena, 2006), the entrepreneur's learning capacity (Zahra and George, 2002; Knight and Cavusgil, 2004); and the interplay of ambition and perceptions that define the global versus local scale of the identified opportunity (Westhead, et al., 2001).

Founding mode and emergence as an ecosystem root: A linkage?

These separate literatures on the origins of ecosystems and the geographic dimension of entrepreneurship help us reframe our fundamental question and, at the same time, suggest how our findings may contribute to those streams of research. At a conceptual level, our study seeks to understand the linkage between a firm's initial founding mode (in this case, as a born-global venture) and its emergence as a root in a new ecosystem. This will allow us to address questions within the ecosystem and international entrepreneurship literatures that are linked by the common focus on a firm founded in a location lacking both enabling resources and market opportunity, and contribute to the broader concern with the geographic context of entrepreneurship (Romanelli and Schoonhoven, 2001).

METHODOLOGY

The objective of this study is to understand the relationship between global entrepreneurship—the founder of a born-global venture drawing on resources and seeking opportunities globally—and the emergence of that firm as a root of a new industrial ecosystem. We chose the Chinese solar PV industry as our empirical setting because several entrepreneurs established private solar PV firms in China at a time when it lacked essentially all of the key resources—knowledge, raw materials, human capital—needed in this industry, and whose domestic solar PV market was insignificant. Within less than six years, however, the firms in China's solar PV ecosystem rose from being internationally absent to capturing the largest share (29%) of the global market by 2007, displacing Japan, Germany and the USA. China also became home to arguably the most comprehensive and dynamic solar PV ecosystem in the world.

Among the industries, that Chinese firms have come to dominate globally, the solar PV industry has several features that make it an appropriate setting for our study. First, it is relatively more knowledge-intensive than most of China's successful export industries that are characterized by mature technologies and low technology intensity. Second, the Chinese firms are integrated global competitors rather than simply contract manufacturers involved in only the low value-added portions of the value chain.

We focus specifically on Suntech as it represents a born-global venture that emerged as an ecosystem root firm (Figure 2). Its founder, Zhengrong Shi, undertook what we term global entrepreneurship, searching, acquiring and integrating resources primarily outside of China to pursue market opportunities that were also outside of China. His firm later became the most important root in China's solar PV ecosystem.

Data, both archival and interview, were gathered from diverse sources to gain an in-depth understanding of the industry, the founding and development of key Chinese firms, and more extensive data on Suntech's development and relationship with other organizations in the emerging Chinese ecosystem. Media and analyst reports, IPO prospectuses, and annual reports and filings, and internal company documents were gathered for the industry and firms from 2002. Interviewees included the founders and senior executives of the major PV firms

in China (Suntech, Yingli, Trina, CSI and LDK), as well as industry analysts and government institute researchers. More extensive archival and interview data were gathered for Suntech, including visits and multiple interviews with the founder and senior executives in the headquarters, R&D facilities and manufacturing facilities.

We developed a timeline integrating the key events leading to Shi founding and growing Suntech and his actions that directly or indirectly contributed to the development of China's solar PV ecosystem. We communicated our basic findings with executives from Suntech and other key firms, and received extensive feedback that has helped us refine our understanding of the process, motivations and means. Helping us to further conceptualize the case of Suntech's founding and role in the emergence of China's solar PV ecosystem, we have been in extensive discussions comparing our findings with those of other researchers globally who have been studying this industry from technical, economic, managerial and policy perspectives.

Overview of the Chinese solar PV ecosystem

Global solar PV production and installation have experienced exponential growth since 2000, with installed capacity increasing almost 20-fold from 1,459MW in 2000 to 39,529MW in 2010. Market growth was primarily driven by the effective implementation of feed-in-tariffs, first in Germany in 2004, followed by similar renewable energy legislation in Spain and Italy. Since then, demand has continued to be primarily in Europe, and supply in Asia.

By 2007, China became the largest producer of solar PV cells in the world, with total production of 1,088MW surpassing both Japan and Europe. Of the top 20 PV cell manufacturers by production at that time, six were Chinese, including Suntech, Yingli, JA Solar, Solarfun and CEEG. Among them, Suntech was the largest Chinese producer (and in later years would be the largest globally). Nine of China's top-ten solar PV firms were publicly listed on foreign stock exchanges before the global financial crisis of 2008 (Table 1). By 2010 there would be more than 100 PV cell and 400 PV panel makers in China, with 16 listed abroad and another 16 listed domestically.

Over the same period, a complete solar PV ecosystem emerged, including firms in the production value chain and specialized suppliers of equipment and services (Tables 2 and 3), as well as industry associations and government agencies focused on the solar industry. As a result, aggregate production increased significantly and China became a major producer of key inputs and a global source of both cells and panels. Silicon manufacturers, for example, were insignificant as late as 2004, but by the end of 2008 their 4,000 tons of production accounted for 15% of global production. Venture capital and private equity (VC/PE) funds also entered the Chinese ecosystem, dramatically increasing after Suntech's successful debut on the NYSE made its founder one of the richest men in China. By 2010, approximately US$3.4 billion, or 66% of global equity investments in PV-related businesses, would be made in China.[1] This sustained presence of foreign and domestic VC/PE from the mid- to late-2000s supported the start-up and growth of domestic manufacturers and suppliers who constituted the world's leading solar PV manufacturing ecosystem.

ORIGINS OF A FUTURE ROOT ABSENT A SUPPORTING ECOSYSTEM

Zhengrong Shi founded Suntech in 2001, and it was the first private solar PV cell manufacturer in China. Shi had grown up in China, but left in 1988 after receiving his master's degree to be a visiting scholar at the University of New South Wales in Sydney, Australia. He later entered the Ph.D. program, working under Professor Martin Green, a leading scholar in the field of solar PV technologies. There he met Stuart Wenham, also a student of Green's and who would be the first Chief Technology Officer of Suntech. After completing his Ph.D. in 1992, Shi continued his career as a research scientist in the Solar Photovoltaics Research Group of UNSW, led by Green. He then moved to Pacific Solar, a spin-off from Green's lab focused on solar technologies, where he eventually became Director of Research. During those years he was granted a number of patents in addition to publishing extensively in the solar PV technology field.

[1] Source: Mercon Capital Group, LLC.

Frustrated that Pacific Solar was focused solely on R&D and not commercialization, from 2000 Shi began to explore external opportunities to produce PV cells and modules in China. He explained his focusing on China as being driven by a sense of opportunity, given his own technical knowledge and the labor and other cost advantages that China could offer. In 2001, he co-founded Suntech Power in Wuxi, Jiangsu Province, with two of his colleagues, Fengming Zhang and Ted Szpitalk from Pacific Solar, and two other hometown friends in China. Even after leaving, Shi maintained a very good relationship with Pacific Solar and the R&D activities at UNSW through technological collaboration and the movement of several key technical personnel from UNSW to Suntech, and Green, his Ph.D. supervisor and founder of Pacific Solar, became one of Suntech's advisors.

Suntech's challenges vis-à-vis an absent ecosystem

In 2001 when Suntech was founded, the Chinese solar PV ecosystem could at best be described as "rudimentary" and offered few of the necessary resources and institutional support for Shi to establish an international-standard solar PV manufacturing firm. He could not source from an existing domestic equipment and related supply base, and the only experienced technical manager he could attract from a domestic state-owned firm was a year away from retirement.

At that time, there were only seven small solar PV producers in China, including four state-owned monocrystaline silicon PV producers (Yunnan Semiconductors, Ningbo Solar Power, Qinhuangdao Huamei Solar Equipment, and Kaifeng Solar Cell Factory), and three Sino-foreign joint venture non-silicon solar cell producers (Harbin Chronar Solar Energy Electricity, Shenzhen Trony Solar, and Shenzhen Sumoncle Solar Energy). These firms shared several features: 1) reliance on imported turn-key production lines and critical equipment; 2) small production capacity and output, 3) customer base of state-owned manufacturers for government and military use, and 4) internationally uncompetitive products due to inferior technical and quality levels. Furthermore, China's semiconductor industry, which uses similar production technologies as those for crystalline silicon and thin-

film cells and in other countries complements the solar manufacturing sector, was weak and so provided no spill-over benefits.

Sufficient key raw materials were also not available in China when Shi founded Suntech. Before 2004, there were only two domestic polysilicon suppliers. Both were state-owned enterprises established to supply silicon to the (also) state-owned semiconductor firms, not PV firms. Their production of 60 tons in 2004 was hardly sufficient to support the semiconductor industry, much less a new solar PV firm aiming for large-scale manufacturing capacity. In fact, both silicon producers struggled for survival as government subsidies declined, with one of them halting production and restructuring in 2003-2004.

In addition, China was not a major market for solar PV cells and modules when Shi founded Suntech, nor would it become one. In 2001, China accounted for only 3.3% of global solar PV installment. Over the following years, as global markets grew exponentially, China's share of global demand actually declined to 0.3% in 2005 (the year of Suntech's IPO). It only grew slightly to 2.2% in 2009 due to two central government incentive programs aimed at boosting domestic demand to support the manufacturers who were beginning to feel the effects of a dramatic drop in global demand in the post-financial crisis period.

Not surprisingly, China was also not a source of relevant technology. Based on patent filings, for example, no international patents with potential relevance for solar PV production (under the category "Batteries: Thermoelectric and photo electric") were granted to inventors based in China for the period 1990-2000 (author's patent search). This contrasts with the three leading countries in this category—the USA (449 patents), Japan (365 patents) and Germany (58 patents)—who were also the leading producers of solar PV in 2000.

In summary, when Shi founded Suntech in 2001, the environment was hardly supportive. Key raw materials, intermediary inputs and equipment could not be sourced locally. Related industries were weak, and the labor market for those with relevant technical expertise was nearly non-existent. Domestic demand for PV cells and modules did not represent an attractive market opportunity, and international demand was being met by incumbents abroad. Finally, both institutional support and R&D were insignificant. In spite

of these unattractive conditions, Suntech survived and emerged as a leading global solar PV firm, and China's solar PV ecosystem became the most dynamic in the world.

Global entrepreneurship as Suntech's founding mode (2001-2002)

We bracket Suntech's founding stage as the period from 2001, when Suntech was registered in Wuxi, Jiangsu Province, to September 2002, when the first solar cell production line began operation. As already described, Shi established his firm in a country that had no solar PV ecosystem and little to offer in the way of support for his new venture, either in terms of resources or opportunity. Accordingly, he had to source most of these factors outside of China, or supplement and adapt those that he found in China, a founding mode that corresponds most closely with "global entrepreneurship" as described earlier in this paper.

To launch the first production line, Shi needed production technology and management know-how, raw materials (silicon wafers), and manufacturing equipment. Essentially all of these were sourced from abroad. Some of that he himself brought from his experience in Australia, including his managerial experience at Pacific Solar in Sydney and the core technical know-how for producing PV cells meeting the international market's technical and quality standards. He also recruited Fengming Zhang, another Chinese based at UNSW, as Director of R&D. There were, however, no experienced production engineers or factory workers to recruit in Wuxi, and few of those in the few state-owned firms would take the risk of moving to a new, private and unproven start-up. In the early years, he was only able to attract Yichuan Wang, a senior engineer from Yunnan Semiconductor with whom he had been in contact over the years on his visits to China, and who was a year away from retiring. Accordingly, Shi, Zhang, with some assistance from Wang, had to oversee all aspects of production line design and operation as well as train the inexperienced employees they were able to recruit. They were, however, able to achieve international ISO9001:2000 certification for their line before launching full production, benefiting from the advice of a senior VP of the state-owned, Wuxi-based home appliance maker Little Swan Group, one of the original corporate investors in Suntech.

Raw materials and key equipment were also nearly exclusively sourced from abroad. While he designed his first production line to be able to use mono- or polysilicon wafers to give him some flexibility, neither were substantially available domestically. Although he was able to source a small portion of monosilicon domestically, approximately 98% of this key input was sourced from foreign suppliers, Germany's Solar World being the largest among them. Similarly, essentially all of the equipment specific to solar PV cell production had to be imported, including the PECVD machine (the most expensive equipment in the production line) from Centrotherm (Germany), screed printer from Baccini (Italy), and etching machine from Applied Materials (USA).

Shi was more successful at securing a large portion of the initial start-up financing locally as a result of fortuitous timing. Having recognized the potential of venture capital (VC) to encourage and support new, especially technology-based start-ups, China's central government had just begun to encourage local governments to establish government-backed venture capital funds. The Wuxi municipal government had recently established its own VC firm. Shi was able to secure an investment of US$6 million from a syndicate of two Wuxi government VC firms and another six local enterprises. Shi himself invested in the venture, contributing US$400 thousand in cash and US$1.6 million in the form of IP (including rights to all of Shi's 13 patents, although none were directly related to the type of PV cells that Suntech would initially produce).

In terms of opportunity, Shi's first and primary focus was on international markets. However, as a newcomer to the international market, compounded by being the first private Chinese firm to enter, he could not secure orders before he began production. Accordingly, and rather luckily as it brought in a much-needed revenues, his first customer was part of the Chinese government-sponsored Village Lighting Project targeting off-grid villages in seven less-developed provinces. From his initial plans to establish a start-up, however, he saw the greatest growth opportunity in the established, developed-country markets, especially Europe and the USA. This had motivated his emphasis on reaching global standards for both technical level (the primary measure being conversion ratio) and quality. With the launch of the first production line, he began preparations to lead his sales team to international expos

and trade shows in the USA, Japan, The Netherlands and Germany, with the expectation that those would eventually account for 95% of his revenues, a level that was required by the Board of Directors and included in the original company formation document.

Suntech's growth and the Chinese ecosystem's development (2003-2007)

Suntech's growth and the development of China's solar PV ecosystem were inextricably linked in the period 2003 to 2007. As Suntech grew to become a global competitor, the Chinese solar PV ecosystem also emerged to become arguably the most productive and dynamic in that global industry. Our study reveals Shi and Suntech's role in that emergence. Even as he successfully established his firm and commenced initial production by integrating resources sourced from abroad, illustrative of a mode we describe as global entrepreneurship, he began to focus considerable attention on developing supportive ecosystem locally. Our study reveals Shi's active nurturing of related firms as a source of capital, orders and technology upgrading, as well as his passive role as a source of spin-off entrepreneurs and legitimacy benefiting new firms vis-à-vis VC and PE investors.

Shi's first deliberate actions focused on inputs that represented bottlenecks and a high percentage of his total cost structure. In the early stage, silicon wafers were not only critical to his making cells, the few Chinese state-owned manufacturers did not have existing capacity nor financial strength to provide him an adequate supply. Although he was able to source from Germany, foreign suppliers did not see him as an important customer, and transportation represented a huge added cost. To address this, he worked with two of the state-owned enterprises to dramatically increase their technology and manufacturing capacity. With Luoyang Silicon he formed a joint venture in which Suntech was a majority shareholder, and the joint venture would make wafers from monosilicon supplied by Luoyang and guarantee Suntech an annual supply of 30MW. He also formed a non-equity strategic alliance with Emei Semiconductor Materials that included technical collaboration and Suntech's pre-payment for wafer supplies. He also encouraged another materials firm, Daquan Corporation, to join him in an alliance and diversify into polysilicon production by

guaranteeing purchases. Later, in 2006, a top manager left Suntech on friendly terms and established Asia Silicon, and Suntech became his first key customer.

Silicon ingot, the precursor to wafers also used by the IC and semiconductor industries, was also in short supply locally. Shi worked with three domestic ingot producers who otherwise did not have the capacity to supply Suntech. He helped them source silicon, the critical raw material, from the major international suppliers, and also provided them capital to increase capacity and begin production for the solar PV industry.

Shi also focused on the cropping process, a highly technical step in wafer production for which there was no firm capable in China. Chinese suppliers of monosilicon wafers had to ship their ingots to Japan for cropping into thin wafer slices, a costly and time-consuming process. To address this, Shi encouraged a new friend, who had a traditional business in Zhengjiang and was searching for an opportunity in the solar PV industry, to focus on this part of the value chain. He helped him negotiate a quite unusual terms with Meyer Burger of Switzerland, the leading global supplier of the critical wire sawing equipment. His firm, Huantai, became the first Chinese firm to import such equipment (2 machines in 2003, and 8 more in 2005), at a cost of Euro850,000 each, but with a one-year payment terms. In 2007, Suntech and Huantai would form a joint venture to further increase wafer processing capacity to match the boom in demand. Not only did this create a new local supplier, but this also drew Meyer Burger into the Chinese market for the first time. As China grew into a major market for Meyer Burgers, they also began to locate more sales and service activities in China.

Besides silicon, a number of other metals such as aluminum and silver are used in the production of solar cells. To increase his access to a steady supply of these inputs, Shi encouraged the Guangzhou-based materials firm Luxing Technology to diversify into applications for the solar PV industry. Suntech and Luxing collaborated to help qualify the new products, and Suntech was Luxing's first customer for them. In later years, Luxing would establish a subsidiary in Wuxi and become the dominant supplier with an 80% share of the Chinese market, but its CEO recognized Suntech's critical role, saying "Without Suntech there wouldn't be a Luxing."

Perhaps the earliest example of Suntech's actively nurturing the development of a local supplier who would emerge as a key firm in China's emerging solar PV ecosystem was Institute 48 under the Ministry of Electronics. The diffusion furnace is one of the three most expensive and critical pieces of equipment in the PV cell production process. Shi first identified Institute 48 as it was supplying related equipment to the IC industry. As with other suppliers originally focused on other industry applications, in 2001 Institute 48 began R&D related to equipment for the solar PV industry. When Shi wanted to make the second PV cell production line but was severely constrained financially, he found the diffusion furnace developed by Institute 48 was of acceptable standards and the price was only one-third that of imported furnaces. Suntech became Institute 48's first customer in the solar PV industry. Institute 48 also began a collaborative relationship in which Suntech supplied technical input as a lead. Institute 48 also developed other key equipment, like the core PEVCD and etching machines. By July 2008, it had developed almost all of the key equipment, except for the screed printer, and could provide a turn-key PV cell production line for domestic PV cell producers. As the domestic industry boomed, this institute would grow into one of the largest suppliers of this critical equipment, and by 2008 had a 95% domestic market share and significant exports.

Shi and Suntech's impact on the domestic ecosystem extended beyond the industrial value chain of suppliers. Suntech's R&D activities went beyond its own specific needs and made it a significant actor in the development of human capital and technological upgrading by other solar PV firms. Shi had established an internal R&D lab from Suntech's founding. Its activities were key to Suntech's achieving industry-leading conversion rates for its cells at a production scale, ISO9001:2000 certification with its first production line, and CE and IEC certifications for the international markets it was targeting. In 2005, Suntech's lab later became the Jiangsu Provincial Solar PV Engineering Technology Center with the role of providing training for industry personnel (not just its own employees) as well as product testing and qualification for other firms. By 2005, Shi had established deep collaborations with five regional universities (Jiangnan, Zhongshan, Shanghai Jiaotong, Zhengzhou and

Nanjing Aeronautic Universities), generating joint research papers, supervising students and providing internship opportunities.

In line with what may be described as an inherent part of the definition of a root firm, Suntech was a major source of spin-off entrepreneurs and experienced personnel, to the extent that it earned the nickname of the "West Point" of China's solar PV industry. Many of these first- and second-generation spin-offs would emerge as key players in the global solar PV industry. The first to leave were part of Suntech's founding team, who left just after Suntech launched its first production line and later started Sunergy (Figure 3). Some of them subsequently quit Sunergy to found or join other new start-ups, some competing and others not, including JA Solar, Tianwei and Hareon. Wang Hanfei, the first professional manager hired by Suntech, moved to Solarfun and used his experience to help that firm launch its competing PV cell production line in seven months and list on NASDAQ just a year after Suntech. These spin-off entrepreneurs and their firms further benefited from the large pool of mid-level engineers and managers who gained training, experience and technical know-how at Suntech.

Suntech also played an indirect and passive, but extremely critical role in bringing foreign VC/PE funds to China, shifting domestic funds' attention to the solar PV industry, and providing an opportunity for new domestic investors and funds to be established. Suntech's initial founding was not the key factor. Rather, once Suntech became the first Chinese solar PV firm to list on the New York Stock Exchange in December 2005, it had a huge impact on foreign and domestic investors. Some of Suntech's earlier investors expanded their investments into other Chinese firms in the solar PV industry, many of them focused on other parts of the value chain. Natexis, for example, invested in three rounds of financing for LDK, a startup focused on wafer production. The approach of Wuxi's government-backed VC firm, Shi's original investor, became known as the "Wuxi Model" that other local governments imitated as they established their own locally-focused VC funds. More foreign funds entered China and made investments, and some employees of these firms quit to start their own funds; for example, VCs in DragonTech Ventures quit to form DT

Ventures to invest locally. The availability of early-stage investment funds, in turn, stimulated a dramatic increase in new start-ups in the industry.

Shi also played a role in the development and activities of industry associations. He was a key participant in symposia and policy discussions led by China's Renewable Energy Agency. He was also one of three Executive Directors of the New Energy Committee under the All-China Federation of Industry and Commerce, the leading corporate association including primarily private firms. From 2008 he helped establish and served as head of the Suzhou Solar PV Association.

By the late 2000s, China had become home to the largest solar PV ecosystem in the world, far surpassing Germany and Japan who had led for decades. As Shi described it, "In a 3-hour driving radius, Suntech can find all the raw materials and equipment it needs." That local ecosystem has been part of the dramatic advantages to China's solar PV industry in terms of cost, quality, collective learning and the other benefits of agglomeration economies.

BORN-GLOBAL AND THE EMERGENCE OF AN ECOSYSTEM ROOT FIRM

The Suntech case enables us to trace the evolutionary process by which a firm is founded as born-global venture—drawing on resources from abroad to address a market opportunity that is also abroad—but then becomes the root of a new local ecosystem. This, in turn, enables us to address issues specific to the ecosystem and international entrepreneurship literatures, as well as highlight a linkage between these otherwise separate research streams.

Global entrepreneurship: From enabling mode to motivation for ecosystem-building

As we came to understand the process by which Shi founded and grew Suntech—the entrepreneurial process that we have termed "global entrepreneurship"—we also identified its role in his deliberately undertaking activities that would result in Suntech's emerging as the earliest and main root in China's solar PV ecosystem (Figure 2). First, integrating resources sourced primarily from abroad enabled Shi to found a company with international standards

of technology, product quality and scale in an environment that otherwise had no basis for such a firm to be established, and to pioneer private Chinese firms' entrance into international markets. This was possible through a combination of his extensive experience working abroad, combined with dedication and personal ambition, that gave him an ability to identify and access resources globally and also understand and access international markets.

While global entrepreneurship may enable an entrepreneur to found and grow a firm in a local environment that offers little in terms of resources or opportunity, it does not necessarily lead to that firm emerging as an important root and promoter of a new ecosystem. Explicating this linkage generates the second role that global entrepreneurship may play in the emergence of a root firm in an ecosystem. Specifically, that mode also has some relative disadvantages and costs, especially when scale must be increased rapidly and competition is based on speed and cost structure. From our study, we find that while sourcing key resources internationally enabled Shi to found his firm, global sourcing also became a constraint and competitive disadvantage. Shi felt this disadvantage when he faced dramatically increasing demand (such as during the global market boom of July 2004-2008) coupled with a competitive imperative of ever-decreasing time-to-market and cost structure. Greater geographic proximity to these resources at lower cost became critical, and this explains why he proactively helped nurture new entrants, diversification by existing firms, and direct investment by foreign firms to create a competitive domestic Chinese solar PV ecosystem.

This highlights the two different potential roles—passive and active—that a root firm may play in an ecosystem's emergence and development. Much of the prior research based in the USA has highlighted what may be termed a passive, or even involuntary, role that a root firm may play. Klepper (2007), for example, describes the disagreements and opportunity-seeking that led many employees to quit firms and establish new competitors or ventures focused on an opportunity that the original firm would not or could not pursue, with the source firm thus becoming a root. Other roots have emerged as a result of an active, strategic decision to nurture supporting firms. Some firms may take this active role quite far, becoming what could be called "ecosystem architects", especially those who see such action as both strategically valuable and as part of a broader mission.

Further research could identify variances among ecosystem roots in terms of both role (active and passive) and motivation (strategic, mission), and relate those features to indicators of root firm-level and ecosystem performance. A further extension of the focus on roles could compare the process and implications for different types of actors in the emergence and performance of ecosystems. For example, what are the relative advantages and disadvantages of ecosystems driven by root firms, whether active or passive, compared to those driven by local or national governments? This debate is particularly salient in emerging market countries and regions where governments hope to jump-start a target industry's development and see a need and opportunity for government to play an active role, at least in the initial stage, in establishing and nurturing an ecosystem's development. Research with important policy implications could extend this line of inquiry to answer how does or should the role of government evolve once an ecosystem is in place.

Geographic dimensions of entrepreneurship

This study also draws our attention to the locational dimension of both opportunity and resources and highlights a conceptual ambiguity that hinders research and the integration of findings from different studies. Specifically, prior research has not converged on a consistent basis for differentiating among very different variations of "international entrepreneurship". As highlighted in the review of related literature, one stream of research has focused on "staged internationalization", with firms first integrating local resources and serving home markets before venturing into foreign markets. A very different stream has focused on what are called "born global" ventures that are somehow "international" from their inception.

While the case of Suntech at first seems a clear case of the latter, we find it highlights a further ambiguity within the literature addressing "born global" ventures. Specifically, some studies consider a firm that is founded locally but whose market is outside of its home country to be a born-global venture. Others, however, apply the same term to a new venture if the entrepreneur is relying on key resources that are sourced internationally.

While both variations involve an international dimension, we feel that these two types

of born-global ventures differ in ways that have significant conceptual and practical implications. To clarify among these variations, we have proposed a typology (Figure 1) defined by the location of the new venture's targeted opportunity (home or abroad), and where the resources to do so are concentrated (home or abroad). This defines four ideal types, and specific ventures can be located within the space they define and in intermediary levels between "global" and "local". Distinctions could have been very important for research design and interpreting findings, as we would expect firms that differ significantly on these dimensions could have very different motivations, corollaries of success and failure, and development processes, for example.

Furthermore, geography could provide an additional dimension to describe a ventures growth and alternative trajectories. For example, a venture founded as one type may transition to another as it modifies its business model or other factors drive it to make substantive changes in the opportunities it seeks and the source of resources it requires to do so. Indeed, Suntech's growth represents such a transition, as it shifted to increasing domestic sourcing of key resources as a domestic ecosystem emerged, with Suntech playing both an active and passive role in that emergence. Further research could explicate those factors that drive transitions, the performance of such transitions, and other development patterns that involve geographic changes.

CONCLUSIONS

We see global entrepreneurship as a strategic mode with some important prerequisites. For example, it may be difficult for entrepreneurs without extensive international experience, knowledge and relevant capabilities (such as language ability) to recognize global opportunities or identify and bring together globally dispersed resources to pursue those opportunities. Our study of Suntech shows the vital importance of these characteristics in enabling Shi to found and rapidly grow his firm. This mode may not as successful for other entrepreneurs with only single-region experience, personal networks, knowledge, and understanding of culture.

More generally, we see our study contributing to the area where research on

international entrepreneurship and ecosystems meet, with two broader implications regarding the value of global entrepreneurship in an increasingly global economy. First, global entrepreneurship may provide a means for entrepreneurs to start and grow new ventures without ecosystem benefits. Second, as a new firm so founded grows, it may become a root firm and proactively nurture a local ecosystem if that has some strategic value to the firm, such as significantly lowering costs, enabling faster response or facilitating more effective inter-organizational collaboration. These findings suggest further areas for research in the strategy and entrepreneurship field, as well as linkages with related debates related to economic development and public policy.

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Table 1

Leading PV firms in China

Firm	Time of first production	Rounds of VC/PE investments	IPO Time
Suntech	September 2002	4	December 2005 (NYSE)
LDK Solar	June 2006	3	June 2007 (NYSE)
Yingli	October 2003	5	June 2007 (NYSE)
Trina	May 2004	1	December 2006 (NYSE)
JA Solar	April 2006	2	February 2007 (NASDAQ)
CSI (Canadian Solar Inc)	June 2006	3	November 2006 (NASDAQ)
ReneSolar	November 2005	0	August 2006 (LSE) January 2008 (NYSE)
Solarfun	November 2005	2	December 2006 (NASDAQ)
Jinko	January 2007	2	May 2010 (NYSE)
China Sunergy	May 2005	1	May 2007 (NASDAQ)

Source: Consolidated by authors from company reports, Solarbuzz and market reports.

Table 2

Participants in China's PV value chain segments

	2003	2007
Monocrystalline silicon makers	5	10
Multicrystalline silicon makers	1	6
Wafer makers	7	24
Cell makers	6	>50*
Panel makers	19	>200
Listed firms	0	10 overseas
Industry revenues (USD$ million)	28	11,097
Employment (1,000)	2	83

Sources: Figures consolidated by authors from multiple sources.

Table 3

Major domestic suppliers

Equipment and Materials	Sub-categories		Key Domestic Suppliers
Raw materials		Silicon	GCL-Poly Energy, Xinguang Silicon, LDK, Fine Silicon
Equipment	Polysilicon	SiHCl3 Synthesis	Emei Simiconductor Material Institute, China Silicon Corp
		Distilling and Separation	Emei Semiconductor Material Institute, China Silicon Corp
	Ingot and Wafer	Multicrystalline Silicon Ingot Furnace	Jinggong Tech, Shanghai Hanhong, Jingyuntong, CETC Institute 48
		Monocrystalline Silicon Ingot Furnace	Jinggong, Shanghai Hanhong, Jingyuntong, Changzhou Tianlong Photoelectric, Beijing Jingyi, Xi'An Jingke, Xi'An Huade, Xi'An Lijing, CETC Institute 48
		Wire Cutting Machine	Shanghai Nissin, Inlon Tech
	Cell	Cleaning machine	Shenzhen Jiejiachuang, Sevenstar Electronics
		Diffusion Furnace	Sevenstar Electronics; CETC Institute 48
		Plasma etching machine	Sevenstar Electronics; CETC Institute 48
		Thin-firm Solar Production Equipment	Apollosolar
		PECVD (Plasma-Enhanced Chemical Vapor Deposition)	Kejing Tech, Huaqi Tech, Tanlong Photoelectric
		Screen printing	CETC Institute 45
		Oven	CETC Institute 45
		Sorting machine	SJTU Solar Energy Institute, XJTU Solar Energy Institute, Qinhuangdao Bosuo
	Packaging	Laser scribing machine	Wuhan Sangong, Shenzhen Dazhu, Zhuhai Aomao
		Automatic light welder	None
		Laminating machine	Qinghuangdao Aoruite, Qinghuangdao Boshuo, Shanghai Shenke
		Module testing	SJTU Solar Energy Institute, XJTU Solar Energy Institute,
Consumables		Quartz crucible	Beijing Crystal Institute
		Silicon Cutting Fluids and Materials	Oxirenchem, Xindaxin Materials
		Cutter Wire	Hengxing Sci & Tech, Xingda International
		Ag, Al and Ag/Al paste	Guangzhou Luxing
		PV Glass	CSG, Sanxin Glass, Xinyi Glass, Caihong Electronics, Jinjing Tech

FIGURE 1

Typology of entrepreneurial ventures incorporating the geographic dimension

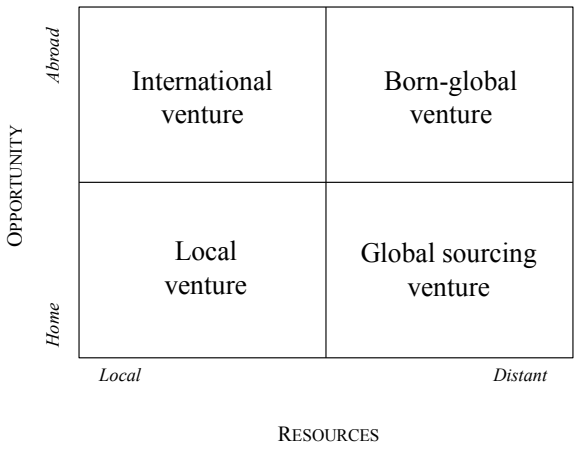

FIGURE 2

Global entrepreneurship as a founding mode of an ecosystem's root firm

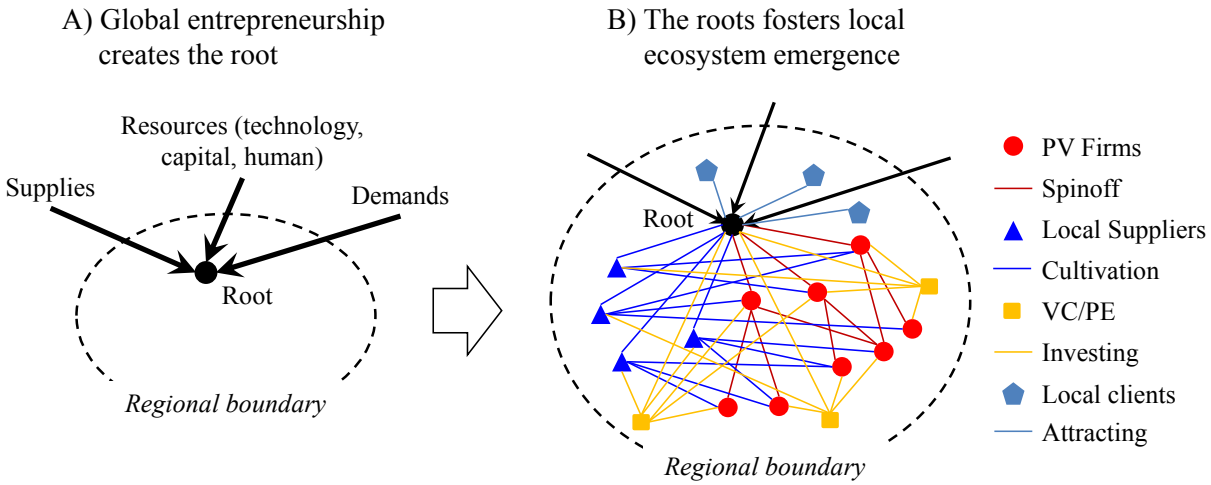

FIGURE 3

Movement of top managers from Suntech