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14. ABSTRACT
This project studied firm-level capabilities in China for technology innovation in several energy-related domains: civilian nuclear power, wind turbine manufacturing, and solar photovoltaic panel fabrication. The research documented patterns of knowledge creation, transfer, and dissemination between Chinese and overseas firms, as well as among Chinese firms themselves. The research particularly aimed to understand the specific mechanisms and processes by which technological knowledge is generated and transferred within and among firms. The

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Report Title

Final Report: Emerging Energy Technology Innovation and Development Capabilities in China

ABSTRACT

This project studied firm-level capabilities in China for technology innovation in several energy-related domains: civilian nuclear power, wind turbine manufacturing, and solar photovoltaic panel fabrication. The research documented patterns of knowledge creation, transfer, and dissemination between Chinese and overseas firms, as well as among Chinese firms themselves. The research particularly aimed to understand the specific mechanisms and processes by which technological knowledge is generated and transferred within and among firms. The research also examined the interaction between Chinese firms engaged in energy-related innovation and Chinese governmental agencies conducting various aspects of industrial policy. The research identified unique product development and manufacturing capabilities within the Chinese business ecosystem -- including for some dual-use, civilian-military technologies -- that are not found elsewhere in the world.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received		Paper
06/30/2017	5	Jonas Nahm, Edward S. Steinfeld. Scale-up Nation: China?s Specialization in Innovative Manufacturing, World Development, ( ): 288. doi: 1,049,729.00
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Number of Papers published in peer-reviewed journals:

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Received	Paper
TOTAL:	

Number of Papers published in non peer-reviewed journals:

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Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

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Received Paper

TOTAL:

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(d) Manuscripts

Received		Paper
10/25/2015	2.00	Jonas Nahm. Renewable Futures and Industrial Legacies:Wind and Solar Sectors in China, Germany, and the U.S., The Watson Institute for International and Public Affairs atBrown UniversityWorking Paper No. 2015-27 (06 2015)

TOTAL: **1**

Number of Manuscripts:

Books

Received Book

TOTAL:

Received Book Chapter

TOTAL:

Patents Submitted

Patents Awarded

Awards

Graduate Students

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Names of Under Graduate students supported

NAME PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 5.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 1.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 2.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 5.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields: 0.00

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

This research has identified emerging capabilities for technology innovation among Chinese firms, particularly in the energy sector. Within the U.S. policy community, some experts believe China has developed world-class capabilities for energy technology innovation. Others counter that the nation is primarily duplicating technologies absorbed from abroad. Indisputable is that for domestic deployments and global exports alike, Chinese energy technology firms are immersed in tight R&D networks with international commercial partners. What is being learned in these relationships? Who is learning? In what directions do different types of knowledge flow? What are the ramifications of such flows for the development of innovative capacity in the firms and nations involved? And, to what extent are these networks moving into entirely new domains, such as data analytics, Internet of Things, and other developments associated with advanced manufacturing and "Industry 4.0"?

These questions relate to theoretical concerns about the role of innovation in industrial development more generally. Traditionally, late industrializers such as Japan and South Korea were seen as engaging primarily in technology mimicry rather than what is generally understood as innovation. Technology was believed to follow the global product cycle, with innovation and new product rollouts taking place in advanced economies, and only late-stage cost reduction and secondary technology deployments – once the technology was fully mature – in developing economies. China's recent experience with energy technology, however, suggests that we may be observing a new form of late industrialization, one in which developing economies play a much more central role in delivering the innovations needed to bring new-to-the-world technologies to the market. Indeed, with China's extensive experimentation with "Industry 4.0" – the coupling of traditional manufacturing with sensing, data analytics, and digital interconnectivity – we believe we are witnessing the participation of a developing economy at the cutting edge of global industrial change. Thus, at the very least, we are conceptually pushed to reconsider the role that actual innovation is playing in late industrialization. Moreover, given the types of knowledge that Chinese firms seem to be generating (and the demand for such knowledge by advanced industrial counterparts), we are pushed to reconsider the importance of late-stage innovation surrounding technology commercialization not just for developing economies, but for advanced industrial nations as well.

On a related note, many observers now recognize that Japan, during its phase of rapid industrial growth from the 1960s through 1980s, initiated major changes in the way traditional manufacturing is organized. That changes, what came to be termed "lean production," now represent best practice across a number of industrial sectors. At the time they were being developed, however, many observers failed to identify them correctly, instead ascribing Japan's gains at the time only to subsidization, unfair trade practices, and intellectual property rights violations. Many of the same accusations are being leveled at Chinese technology firms today. One major goal of this research is to determine whether Chinese firms are also developing news ways to structure production, ways that may differ substantially from Japanese-style lean production, but that are no less important for the long-term trajectory of global high-tech manufacturing.
This research has proceeded methodologically through firm-based, structured qualitative case comparisons across three energy technology domains: civilian nuclear power, solar photovoltaic cell/module fabrication, and wind turbine manufacturing. Each of these areas involves new technology development and extensive partnerships between overseas and Chinese domestic firms. The technology areas differ, however, in terms of their degree of standardization, the complexity of the systems integration tasks involved, and the degree to which China is their main global market. Interview-based qualitative data collected at the firm level is useful for explicating complex processes and extended mechanisms of causation. Through the first phase of research, we have sought to explicate subtle patterns of knowledge creation, transfer, and dissemination – phenomena that cannot easily be identified at arms length through measures such as patent filings, copyrights, or trademarks. This is particularly true for complex systems involving multiple firm-level participants. The most interesting data from our interviews have involved the nature of work flow, the division of labor, and the mechanisms through which coordination takes place. While we are open to and have indeed conducted large N survey work in our previous work, but we feel that this particular project -- with its emphasis on understanding the finer details of inter-firm coordination, capability building, and technology development processes – has been best served through in-depth qualitative interviewing.

During our first phase of research from 2012 to 2015, we conducted 107 interviews in China in the wind power and solar PV industries. An additional 117 interviews were conducted with participants in the wind and solar power-related production networks in Europe and the United States. We conducted another 67 interviews in China in the civilian nuclear power sector, with respondents spread across both Chinese indigenous and multinational firms.

During 2016, we pushed forward with our field interviews, focusing particularly on eight solar and wind firms located in Beijing and in the industrial belt stretching from Shanghai to Nanjing (i.e., Wuxi, Suzhou, Changzhou, Nanjing). This more focused approach allowed us to hone in on our questions about the R&D process and inter-firm work flow.

In 2016, we also began to focus much more aggressively on efforts by firms to revolutionize manufacturing by coupling traditional fabrication with advanced sensing and data analytics. We are currently developing two case studies, one in the lithium ion battery manufacturing sector, and one in the optical sorting industry. While the latter diverges somewhat from our focus on energy-related industries, the sensing technologies being employed are similar to what we are witnessing in the energy sector, and in the actual case we are studying, the particular manufacturing firm we are working with spans the energy and optical sorting sectors.

During this past year, we have also moved aggressively to develop comparisons between Chinese firms on the one hand, and U.S. and European firms on the other. Our findings on sensing and data analytics uptake in China have proven particularly important for our comparisons with German and Swiss firms, since European partners – including several of the firms with whom we are working – are collaborating directly with Chinese entities to apply new sensing and data analytics solutions within China. Our research is suggesting that governmental policy efforts – "Industry 4.0" on the German side and "China Manufacturing 2025" on the Chinese side – are accelerating the rate at which Chinese and German firms engaged in traditional manufacturing are absorbing frontier technologies for sensing and data analytics, and doing so in a deeply networked manner with one another.

During the previous reporting year, we have accomplished three main sets of goals.

First, in our field work, we have moved aggressively to develop fine-grained, firm-level cases involving the coupling of advanced sensing and data analytics to traditional manufacturing processes, including the manufacturing of lithium ion batteries and optical sorting equipment. We now have active field work going on in Switzerland, Germany, and China. This work is critical because the Chinese government is now using industrial policy to mimic Germany's efforts to foster "Industrie 4.0," the coupling of advanced data and web- based capabilities with traditional manufacturing. We sensed this shift in our previous research efforts focusing on innovation surrounding product design and manufacturing scaling. In accord with shifts in Chinese (and German) governmental policy surrounding industrial upgrading and innovation, we too are shifting over research emphasis to capture several new loci of innovation in the digital domain surrounding traditional fabrication. We are clearly picking up this shift in our case-level examination of the production of lithium ion batteries in China (production that is using Swiss and Germany capital equipment). During the previous reporting year, PI Edward Steinfeld and postdoctoral fellow Jonas Nahm conducted six trips to China, one trip to Germany, two trips to Switzerland, and one trip to the United Kingdom to conduct field work consisting primarily of firm-level interviews and site visits to the firm-level cases we are developing for our larger book project. The field visits allowed us to achieve two main goals: to compare R&D-related innovation efforts by Chinese and non-Chinese firms operating in the same industrial domain, and in cases in which Chinese and European firms are collaborating in production networks, to understand how knowledge is moving in multiple directions across those firms. During this reporting period, we also coupled our firm-level interviews with with meetings and interviews with academics at Tsinghua University and Beijing Normal University in Beijing, and policy makers in the Chinese government's State Council, National Development and Reform Commission, and National Energy Commission. By deepening our data collection efforts on the governmental side, we have been able to gain better understanding of the policy aims of the Chinese government's 2015 landmark report "Made in China 2025).

Second, we are moving aggressively to publish findings from our earlier phases of research. During the past year, we had artlce-length manuscripts accepted for publication in Business and Politics, the China Quarterly, and in an edited volume to be published by Brookings Press. We also are currently working on two book- length manuscripts based on the research conducted through this grant.

Third, we have sought to bring increasing numbers of students into the research efforts. This grant, in addition to supporting the efforts of a principal investigator and a postdoctoral fellow during the previous year, also supported research assistantships for three PhD students and four undergraduate students.

Technology Transfer