

MAKE THE FOREIGN SERVE CHINA

HOW FOREIGN SCIENCE AND TECHNOLOGY HELPED CHINA DOMINATE GLOBAL METALLURGICAL INDUSTRIES

BY MICHAEL KOMESAROFF | No. 2 | MARCH 2017

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EDITOR'S NOTE

In June 2016 the Freeman Chair in China Studies hosted a discussion on trends in China's resource-related sectors, and the rising concerns globally about overcapacity. A central area of the conversation was around the growth of Chinese production in metallurgical industries. To some, the source of the problem is Chinese industrial policy. Since state institutions provide low-cost financing and subsidies to companies that face limited penalties for commercial failure, especially state-owned enterprises (SOE), the incentive is to produce as much as possible regardless of demand. But to others, the real story is the surprising improvement in the efficiency of Chinese producers over the past two decades, which has left them more competitive than their Western competitors. Hence, Chinese companies have reasonably expanded production and exports.

We are delighted to welcome a participant in that initial discussion, Michael Komesaroff, to pick up the conversation with this contribution to our working paper series. With several decades of experience in the metallurgy industry, including an extended period at Rio Tinto, Michael is well positioned to weigh in on these issues. His paper explores the sources of growing efficiency, the effect of state intervention on the sector's performance, and the implications for Western businesses and governments. We hope that this working paper will generate further discussion about this critical topic in policy and business circles in the coming months.

INTRODUCTION

This paper seeks to demonstrate that China's massive investment in capacity to produce metals is not just the result of state support, but because the country is home to the world's largest and technically advanced metallurgical plants, its companies are able to produce metals at lower cost than most of their foreign competitors.

The first, larger part of the paper analyzes China's efforts to adopt a blended strategy of "buy and make" to advance its metallurgical industries. Using examples, primarily from the steel, magnesium, rare-earths, and aluminum sectors, the paper documents the steps taken by Chinese enterprises, both private and state-owned, to raise their capabilities in metals-processing technology. The examples in the paper also show how these enterprises have systematically been able to strengthen their domestic capabilities by leveraging international sources of know-how and technology. The section concludes that because of changed circumstances China needs to radically alter its industrial culture and reform its scientific institutions if it is to maintain its lead in the production of metals.

The second part of the paper explains how, in addition to the easy replication of metallurgical plants and its low-capital cost strength, China has benefited from continual government support so facilities have been built despite there being no economic justification. Such support includes preferential low-interest loans, which immunize enterprises from market signals that can warn against poor financial performance that can precipitate enterprise failure. Government support is a consequence of a policy of using state-owned enterprises to maintain social stability even at the expense of economic efficiency. Despite its financial support, Beijing has at times sought

to restrain expansion of its national metals industry; but rather than deter growth government regulations have had the unintended consequence of encouraging the replacement of small and technically inefficient plants with larger and more efficient facilities.

The final part of the paper briefly summarizes the findings and their implications for how the global industry and governments might most appropriately respond going forward to the rise of China's metallurgy industry. While trade remedies may be appropriate in some specific circumstances, Western industry would be better served by strengthening its advantages in downstream areas of metallurgical industries and cooperating with leading Chinese producers of primary materials.

The paper's title comes from a letter Mao Zedong wrote to students of the Central Conservatory of Music in February 1964 in which he said: "Make the foreign serve China," by which he meant to adopt the good qualities of foreign cultures to enrich Chinese culture.¹ The paper aims to demonstrate how in the post-Mao era China's leadership has applied this aphorism to the development of the country's metallurgical industries.

I. GROWTH AND TECHNOLOGICAL IMPROVEMENTS

THE EARLY YEARS

In 1978, on the eve of China's Reform and Opening period, its metallurgical industries were characterized by small-scale and inefficient facilities.² Some of these plants had been constructed by the Japanese when they occupied China in the 1930s, but most were based on obsolete technologies inherited from the Soviet Union. Support for Soviet technologies ceased abruptly in 1960 when the Soviets split with China and the Soviet Union's Premier Nikita Khrushchev withdrew the engineers who had been sent to help their Chinese counterparts develop the country's industrial base.

For reasons of state security, before 1978 China did not publish production details of its metallurgical industries, but later analysis has revealed that at the beginning of the Reform period, China's production of ferrous and nonferrous metals was very small. For example, the International Iron and Steel Institute (IISI) estimates that in 1977 China produced 23.4 million tons (mt) of crude steel, which accounted for less than 4 percent of global production.³ In aluminum, China's production of 350,000 tons was less than 2 percent of global output.⁴

The small scale of individual plants was a direct consequence of Mao Zedong's policy of regional self-sufficiency, which required each province to have a self-contained industry structure, with particular emphasis on the production of steel, cement, coal, fertilizer, and heavy machinery. This autarkic policy reached its peak during the Cultural Revolution (1966–1976) when some 300 sub-provincial governments invested in their own steel mills. With so many small and technically inferior plants, it was inevitable that Chinese mills were not able to exploit economies of scale.

Since 1978, China's metallurgical industries have undergone rapid modernization, and they are now characterized by facilities that are among the largest and most technically advanced in the world. For example, in 2015, China turned out 31.67 mt of primary aluminum, accounting for 54.7 percent of world production. In 1990, the average size of China's aluminum smelters was 22,000 tons per

1. Ravenel International Art Group, <http://ravenelart.com/artwork.php?id=2075&lan=en>.

2. The term "metallurgical industries" refers to the extraction of ores and the smelting and processing of ferrous metals (iron, steel, chrome, and manganese) and nonferrous metals (predominantly aluminum, copper, nickel, lead, and zinc). This paper concentrates on the smelting processes as they apply to ferrous and nonferrous metals.

3. International Iron and Steel Institute (IISI), *A handbook of World Steel Statistics* (Brussels: IISI, 1978), 3.

4. World Aluminium Institute, "Statistics, Primary Aluminium Smelting Intensity," <http://www.world-aluminium.org/statistics/primary-aluminium-smelting-energy-intensity/#data>.

annum (tpa), much smaller than the 190,000 tpa that was then the average for smelters outside China.⁵ In 2015, the average Chinese smelter was rated at 330,000 tpa, much larger than the rest of the world where the average was 260,000 tpa. Currently six of the world's 11 largest aluminum smelters, including the world's two biggest, are in China, and some of them are equipped with advanced technology that has yet to be used on a commercial scale outside the country.

China is now the world's largest producer of crude steel, and in 2015 its output of 804 mt was half of world production. As with aluminum, China's steel industry is now characterized by large modern facilities, which include the world's largest blast furnaces. In 2013, globally there were 12 blast furnaces larger than 2,500 cubic meters, of which three were in China. Not only are China's blast furnaces large, they are capable of efficiently producing a wider range of higher-quality steels such that the country is now virtually self-sufficient in steel and needs to import only a limited volume of very specialized steels.⁶

The examples of aluminum and steel are replicated in many other metallurgical sectors, including magnesium, gold, bismuth, cadmium, copper, lead, nickel, stainless steel, rare-earth elements, and zinc. In most cases the rapid transformation of China's metallurgical industries can be traced to technology acquired in the 1980s and 1990s when Chinese state-owned enterprises (SOEs) purchased obsolete plants from failing foreign peers. The plants were dismantled and transported to China for reassembly. The underlying technology for these facilities was more efficient than what was then being used in China, but from a foreign perspective the plants were small and the technology was usually relatively old and not rated as the world's best practice. However, for China, the purchase of transplanted foreign facilities was a cost-effective means of growing their understanding of more-advanced metallurgical technologies and this strategy contributed to the country's emergence as the global leader in the production of most metals.

The specific strategy adopted by China when rebuilding the transplanted facilities was to confine any modifications to those necessary to simplify the process and adapt them to Chinese conditions. Having adapted the imported plants, engineers set out to fully understand the technology before initiating a series of continual incremental enhancements that improved performance. The continual improvements were helped by a rapidly expanding economy with an almost insatiable demand for metals that supported a sustained construction program. Learning from each new project helped China's engineers make further small enhancements as well as lowering construction costs. The consequence of this strategy is that now China is able to build simple, low-cost metallurgical plants that they staff with abundant low-wage workers performing simple and repetitive tasks. This is the opposite to the West, where capital costs are high because there are few projects, each with a different technology that tends to be complex so it requires highly paid skilled workers.

OBSOLETE FOREIGN FACILITIES

The steel industry provides an interesting case study of how China has benefited from its strategy of purchasing obsolete foreign facilities. One of the first such transactions was the purchase in 1988 by the Shagang Group Co. Ltd. of an electric arc furnace from a UK producer. The furnace was dismantled and shipped to Shagang's mill in Jiangsu where it was put to work producing 250,000 tpa of steel reinforcing bar.⁷ Later the same year, Shagang purchased a furnace and casting machine from France's Société Métallurgique de Normandie. A similar transaction was the acquisition of an American finishing mill by Beijing-based Shougang Corporation. Located at Fontana in California, the 2.8-mtpa mill had been built by Kaiser Industries during World War II to provide steel for ships. During the 1980s the mill had been upgraded at a cost of \$287 million, but after three years of use

5. During the 1980s China's smallest aluminum smelter was the 1,200-tpa plant in Weibin, Shanxi, which was an order of magnitude smaller than the smallest plants in the rest of the world.

6. During the first decade of the Reform era, China spent as much as 20 percent of its merchandise imports on finished steel.

7. Dao Ying, "Steelmaker forges ahead," *China Daily*, September 8, 2007.

it was shut down, and in 1993 it was sold for less than \$20 million to Shougang, who dismantled and shipped the facility to Guangxi.⁸

It was the turndown of Germany's steel industry that provided the richest pickings for China's emerging steel producers. Germany's steel industry, which began to close down in 2001, operated with sophisticated technology, the result of a long history of sustained technical innovation. Among German steel producers, ThyssenKrupp was the undoubted technical leader, but ever-increasing labor costs combined with stricter European environmental standards forced the company to shutter its Dortmund-Höörde plant in 2001. Within a month of its closure the mill had been sold to China's Shagang Group for \$24 million—well below its value as scrap. Shagang sent 1,000 of its workers to Germany to begin the year-long task of dismantling the plant and packing it for the 10,000 km journey to Jiangsu. Compared with earlier purchases of obsolete foreign mills, the dismantling, transport, and re-erection of the Dortmund mill was a far more daunting task. Earlier purchases were smaller and involved simple steel-finishing equipment, but the Dortmund project was much larger and more complex, as it included a complete steel mill with blast furnaces. The dismantled plant comprised 250,000 tons of equipment and 40 tons of documents that explained the intricacies of the reassembly process.⁹

In 2003 the Yankuang Group also benefited from the demise of Germany's steel industry when it purchased a coke-making plant that had supplied the now-shuttered Dortmund steel mill. Four hundred Chinese workers dismantled the 2-mtpa plant, which had only been built a few years earlier, so it complied with exacting European environmental standards.¹⁰ The coke plant was re-erected in Shandong where it later formed the basis of a joint venture between Yankuang and two foreign companies: Japan's Itochu Corporation and Brazil's Vale SA.¹¹

China's aluminum industry provides another useful case study of how the acquisition of obsolete foreign metallurgical plants by Chinese companies propelled the country to leadership in metallurgical science and technology. As with the steel industry, the opportunity to purchase aluminum smelters arose as a result of global restructuring following a sustained rise in energy prices. After the global oil crises of the 1990s, Japanese companies began to withdraw from the smelting of aluminum. Most of the shuttered capacity had been built after World War II and was relatively modern. It was based around Prebake technology, which is more efficient and environmentally cleaner than the Söderberg technology the Soviets had provided China. In March 1986, Japan's Showa Light Metal Company ceased production at its 150,000 tpa Chiba smelter, and a portion of the smelter (believed to be 50,000 tpa) was sold to the state-owned China Nonferrous Metals Corporation (CNNC), which relocated the plant to Baiyin in Gansu.¹²

China also purchased a portion of a smelter from Germany's VAW Aluminum. This smelter, at Töging, which also used Prebake technology, was taken out of operation in 1994, dismantled, transported and re-erected in Danjiangkou, Hubei. The smelter, which included advanced features such as computerized control, was re-commissioned in 1999.¹³

As with its steel and aluminum sectors, China's magnesium industry has grown to be the world's largest after purchasing obsolete foreign facilities. Because of rising energy and labor costs, the Japanese firm Ube Industries Ltd. ceased production of magnesium at its Yamaguchi smelter in September 1994. Shortly after, the 9,500 tpa plant was dismantled and shipped to China, where

8. "Company News: China to buy Used Mill: A New Approach to Exporting Steel," *New York Times*, November 4, 1992, <http://www.nytimes.com/1992/11/04/business/company-news-china-to-buy-used-mill-a-new-approach-to-exporting-steel.html>; "China dismantles U.S. plant 22-storey steel facility headed for homeland," *Cincinnati Post*, October 7, 1993; and "U.S. Steel Firm Sells Equipment to Chinese Company," *Kyodo News*, February 20, 1992.

9. James Kynge, *China Shakes the World* (London: Weidenfeld & Nicholson, 2006), 1; and Ying, "Steelmaker forges ahead."

10. Joseph Kahn and Mark Landler, "Choking on Growth; China Grabs West's Smoke Spewing factories," *New York Times*, December 21, 2007.

11. U.S. Securities and Exchange Commission, *Form 6K*, Valley of the Rio Doce Company, July 2004.

12. John C. Wu, "The Mineral Industry of Japan," United States Geological Survey, 1986, 500.

13. Alton Tabareaux, "Prebake Cell Technology: A Global Review," *Journal of Metals* 52, no. 2 (2000): 22–28.

it was re-erected in Nanjing, Jiangsu. Having operated for 17 years, the Ube plant had used a relatively old pyrometallic technology called the Pidgeon process, which had all but been abandoned elsewhere in the world because it was so labor intensive. However, this was not a problem for China, where there was an abundance of cheap labor.¹⁴

As the Chinese engineers started to understand the Pidgeon process they began to improve on the technology of the transplanted Ube equipment. They made dramatic improvements to technical efficiency, such that, at the turn of the century Chinese producers had driven down their operating costs to become the world's largest producer of magnesium. Today, Chinese magnesium smelters account for 90 percent of world production, but an unintended consequence of their purchase of the Ube plant is that Chinese magnesium producers focused on perfecting the old Pidgeon process rather than pursuing newer, more efficient and environmentally cleaner processes based on electrolytic technology. Nevertheless, China's lack of understanding of electrolytic technology as applied to magnesium smelting was corrected in the same way as previous generations of Chinese engineers overcame their lack of knowledge in other metallurgical sectors; to understand the latest technology they purchased an obsolete electrolytic magnesium smelter from a financially stressed foreign producer.

Canada's 40,000 tpa Becancour smelter in Quebec, once the world's largest magnesium plants, ceased production in 2007 because the owner, Norway's Norsk Hydro ASA, was withdrawing from the industry. The decommissioned smelter, which had been in operation since 1989, was dismantled and shipped to Golmud in Qinghai. The new owners, Qinghai Salt Lake Industry Co. Ltd. (QSLIC), contracted the Canadian engineering consultancy Hatch Ltd. to advise on the re-erection of the plant and to adapt the process to the conditions of the province. Over the years Hatch had worked closely with Norsk Hydro to improve the performance of the Becancour smelter, so the company had an intimate knowledge of the plant's technology.¹⁵ Retaining Hatch marks the Qinghai project as different from most of the other instances where dismantled foreign plants were re-erected in China because the purchasers of other transplanted facilities usually did not enlist the help of foreign experts and certainly not on such a large scale as QSLIC.

With annual production of 105,000 tons, China accounts for 95 percent of the world's production of the rare-earth elements (REE), which are used in a diverse range of modern high-technology applications. Aside from leading the world in production China is number one for reserves, consumption, and exports of REEs. China's dominance of the REE sector was enhanced by its purchase in 1995 of a state-of-the-art American processing plant, which was subsequently dismantled and transported to China. Based in Indiana, the plant, known as Magnequench, had been built by General Motors (GM) using U.S. government grants. Magnequench owned a number of patents and possessed unique expertise in manufacturing high-powered neodymium-iron-boron (NdFeB) magnets. Because they are able to maintain their magnetic strength at elevated temperatures, NdFeB magnets are widely used in military applications including guided missiles and "smart" bombs. However, GM used NdFeB magnets in more prosaic applications such as airbags and mechanical sensors for their automotive products.

In 1995, GM decided to divest itself of subsidiaries that were not in its core competence and sold the Magnequench business to a Chinese consortium for \$70 million.¹⁶ At the time of the takeover, the new Chinese owners, which included two Chinese state-owned metals firms—San Huan New Material and China National Nonferrous Metals Import and Export Company—pledged that they had invested for the long-haul and were committed to keeping the production line going for at least

14. Michael Komesaroff, "Many hands make light metal," *Metal Bulletin Monthly*, September 2000, 58–61.

15. "Transferring Magnesium Technology from Canada to China," *Hatch Engineering* (n.d.), <http://www.hatch.ca/ar2013/qslic-primary-magnesium-plant.html>.

16. One industry source claimed that the Chinese had been pestering GM to sell Magnequench since 1993: Charles Child "GM to sell magnet unit to Chinese company," *Automotive News*, March 27, 1995, 46.

a decade.¹⁷ The U.S. government approved the sale only after the new Chinese owners agreed to keep the Magnequench plant operating in the United States for at least five years.¹⁸ The day after the five years expired in 2002 the Chinese owners closed the Indiana facility and shipped the equipment to China.¹⁹ With the closure and transshipment of the Magnequench plant, not only did the United States lose its REE production capability, but it also abdicated its technological lead.

Purchasing obsolete foreign metallurgical plants for transport and re-erection in China appears to have been a haphazard, though pragmatic practice that was not Beijing's official policy; however, the central government did readily give its support when an SOE sought approval for such projects. Beijing's position was consistent with its early Reform policies of incrementally restructuring its economy through experimenting with new policies, particularly relating to developing its antiquated basic industries. The country's policy options were limited because the government was confronted with the critical economic challenge of feeding its people after the horrors of the Cultural Revolution. However, for China the timing of these changes was fortuitous in that they followed the oil shocks of the 1970s when the price of oil shot up from \$3 to \$37 per barrel in a decade, forcing steel and other energy-intensive industries to close or relocate to countries where energy was much cheaper. It was this restructuring of heavy industry that was the prerequisite for successful implementation of China's policy. China's abundance of low-cost, relatively skilled labor was another fortuitous factor favoring China because it made the dismantling and re-erection process a viable and competitive option that other countries could not have emulated even if they had wanted the facilities.

The lucky coincidence of a global restructuring of basic industries and the availability of a cheap skilled workforce is unlikely to be repeated, making it highly unlikely that China's successful heavy-industry development model will be replicated anytime soon. It is also unlikely that China could successfully recycle the model for use with anything other than a basic industry that produces a standard product to an international specification. There are examples, such as kaolin and titanium dioxide, where China acquired Western plants or technology designed to produce consumer goods, but was not able to successfully operate their acquisition. Consumer goods have a wide variation in characteristics that are custom designed to appeal to final consumers.

ACQUIRED LEARNING

The foreign facilities purchased by China were more advanced than those developed within the country, so they provided Chinese engineers with the opportunity to quickly experiment with more advanced technology. A particular concern for the Chinese was to simplify the technology and make it more suitable for local conditions. For example, because of China's relatively expensive power tariffs, part of the simplification of the aluminum smelting technology was to lower power consumption by incorporating larger, shorter-life, and relatively cheaper carbon anodes. Outside of China power is cheaper and the anodes more expensive so designers accept the reverse tradeoff—lower anode consumption for increased power consumption.

Learning from the simplification process spread throughout China and was the basis for the subsequent rapid expansion of the national metals industry. This learning also helped Chinese

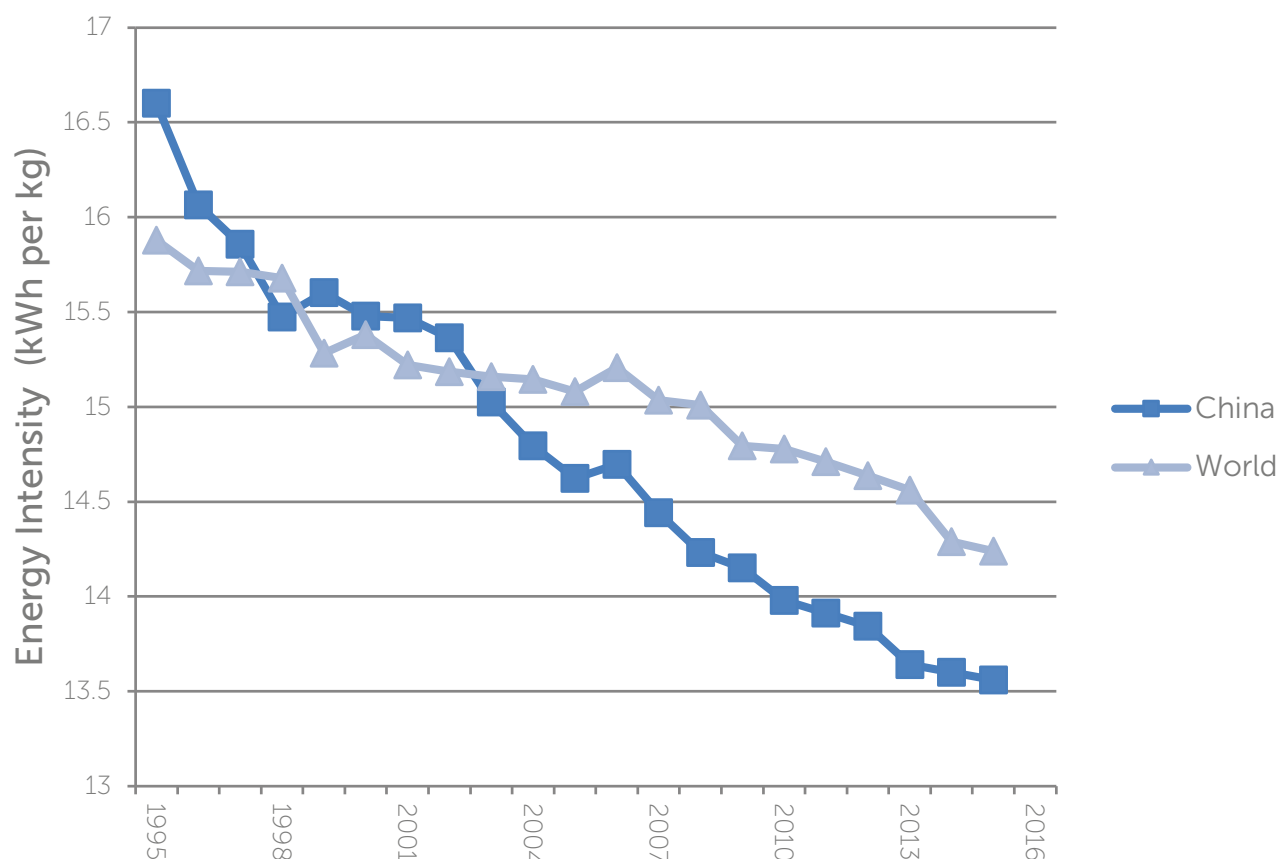
17. Prior to bidding for Magnequench, San Huan New Material had appeared before the U.S. International Trade Commission for violating a U.S. patent for NdFeB magnets. Subsequently, the company was fined \$1.6 million. See "In the Matter of Certain Neodymium-Iron-Boron Magnets, Magnet Alloys and Materials Containing Same, Investigation NO 337-TA-372 Enforcement Proceeding," U.S. International Trade Commission, November 1997, <http://www.usitc.gov/publications/337/pub3073.pdf>.

18. San Huan is owned by the Chinese Academy of Sciences, which is under the jurisdiction of China's central government. The chairman of San Huan, Zhang Hong, was a son-in-law of former Chinese "paramount leader" Deng Xiaoping. The other Chinese investor in Magnequench, China National Nonferrous Metals Import and Export Company, was led by Wu Jianchang, another Deng Xiaoping son-in-law.

19. One report claimed that immediately after purchasing the plant the Chinese owners duplicated the production line at a facility in China and that the U.S. operation was closed only after the duplicated production line had been confirmed to work correctly. See Scott Wheeler, "U.S. Missile Technology Plant Moved to China," *Insight on the News*, <http://www.rense.com/general35/sdfg.htm>.

engineers improve on the initial technology. In the aluminum sector, knowledge gained from the operation of the Bayin and Danjiangkou smelters formed the basis of indigenously developed computer models that Chinese engineers used to progressively increase the scale and efficiency of a later generation of locally designed and built smelters. For example, the cell rating of Chinese smelters was progressively increased from the 160 kiloAmperes (kA) rating of the Nippon Light Metal KK (NLM)-supplied Guizhou plant to the more productive 640 kA, now the world's largest.²⁰ Along the way the average energy consumed in the production of aluminum in China fell from 17.0 to 13.5 kiloWatt hour per kg (kWh/kg). As a comparison, smelters outside of China consume an average of 15.0 kWh/kg.²¹ These improvements in technology were incremental and not a consequence of any systematic basic research by local engineers. Also, apart from the purchase of the original plant, the improvements usually did not involve any direct or planned foreign collaboration.²²

FIGURE 1. SMELTER TECHNOLOGY



That China purchased only part of the Chiba and Töging smelters suggests that the national strategy was to treat the acquisition as a large pilot plant on which to learn and improve the technology. This strategy is mainly applicable to metals such as aluminum, where the technology is basically a series of discrete batch processes. It is less applicable to the production of crude steel, which is essentially a single continuous process.

In the steel sector Chinese engineers were also able to improve the performance of the facilities

20. Outside of China, aside from small demonstration plants, there are no other smelters operating at more than 450 ka.

21. World Aluminium Institute, "Statistics, Primary Aluminium Smelting Intensity."

22. The Becancour magnesium smelter is one such exception.

they had purchased from foreign companies. Shagang engineers made several significant improvements to the Dortmund blast furnaces, including increasing the output from 5,000 to 6,000 tons per day by incrementally expanding the diameter of the vessel. Additional competitive advantage was achieved by extending the life of the blast furnace to 15 years, a significant improvement over the normal 7 to 10 years.²³ The performance gains with the transplanted Dortmund mill were the basis for significant improvements at other Chinese iron-making plants, such that over the subsequent 20 years blast furnace productivity improved from 1.80 to 2.46 tons per cubic meters per day, with consumption of coke falling from 537 to 362 kg per ton of metal.²⁴ Comprehensive energy consumption dropped from 0.9 ton of standard coal equivalent (sce) in 2000 to 0.6 ton of sce in 2015. Over the same period, freshwater consumption also dropped sharply, from 30 to 3.3 m³ per ton of steel, while sulphur dioxide emissions fell from 4.5 to 0.9 kg per ton of steel.²⁵ Improvements in the magnesium sector were no less impressive. Chinese engineers were able to reduce the consumption of magnesium ore (dolomite) used in the Pidgeon process from 16 to 10 kg per kg of magnesium, while they extended the life of furnace retorts from 150 to 250 cycles. Coal consumption fell from 12.1 to 5.4 kg per kg of magnesium metal. Waste heat from the process was harnessed to drive steam-driven vacuum pumps, which reduced consumption of electricity and more efficiently evacuated the retorts that are at the heart of the process (Komesaroff, 2006).²⁶

In addition to providing the opportunity for immediate learning, China's acquisition of obsolete foreign metallurgical plants early in the Reform era was a cost-effective means of progressing up the industry knowledge curve at a time that the country's purchase of foreign goods and services was constrained by limited reserves of foreign currency. Plants that were surplus to the needs of foreign companies could be purchased at a fraction of the cost of original or green-field equivalents. After paying ThyssenKrupp \$24 million for the Dortmund steel mill, Shagang coughed up a further \$12 million to transport the dismantled plant to China, where its reconstruction cost a further \$1.2 million with only a small proportion—probably less than 3 percent—of the total cost involving foreign currency. All told, the cost was 60 percent of the investment required to build a new plant.²⁷

There are no published costs for the other obsolete plants purchased by Chinese metallurgical companies, but it is likely that the savings relative to a green-field facility are of the same order as those for Shagang's steel project. Apart from the direct cost savings gained by purchasing obsolete plants, significant secondary savings were achieved through a faster route to market. It took Shagang three years to transplant the Dortmund mill to China and begin production. This is half the time it would have taken to commission a green-field mill.

China's earliest metallurgical plants were notorious for the poor quality of their products, a direct consequence of their use of inferior technology and poor-quality indigenous raw materials. In aluminum smelting the molten metal absorbed contaminants from the Soviet supplied Söderberg cells to a much higher level than occurs with the more modern Prebake cells. Similarly, the small indigenous blast furnaces that were a feature of China's earliest steel mills were not able to produce high-quality metal suitable for rolling into the flat sheets that are essential for modern value-adding manufacturing industry. However, the transported blast furnaces with their computerized control were able to produce the required quality.

23. Ray Hudson and Don Swanton, "Global shifts in contemporary times: the changing trajectories of steel towns in China, Germany and the United Kingdom," *European Urban and Regional Studies* 19, no. 1 (2012): 6–19.

24. I. F. Kurunov, "Current State of Blast Furnace Smelting in China, Japan, South Korea, Western Europe, and North and South America," *Metallurgist* 59, no. 7–8 (November 2015), 563; and Yoshio Okuno, "Prospects of Iron and Steel Production and Progress of Blast Furnace Route in China," Nippon Steel Technical Report No 94, July 2006, 19.

25. Haiman Liu and Ligang Song, "Issues and Prospects for the Restructuring of China's Steel Industry," *China's New Sources of Economic Growth, Vol 1: Reform, Resources, and Climate Change* (Australian University Press, 2016), 342.

26. Michael Komesaroff, "Technological adoption and adaptation in an 'open' market: the case of China's magnesium industry," Council on Foreign Relations, Industrial Innovation in China Conference, New York, July 24, 2006.

27. Kyngé, *China Shakes the World*, 11–12.

The modern metallurgical capacity sourced from foreign suppliers during the early years of the Reform period was built around high-productivity technology that was dependent on higher-quality, coarser, and stronger ores than had previously been used in China. For example, the fine magnetite ores that are characteristic of China's indigenous iron ore are unsuitable for use in large blast furnaces of the type China purchased from Japan and as a result of learning from foreign blast furnaces imported iron ore is now the preferred feed for most of the country's steel mills. When the fine Chinese magnetite is used in these furnaces it yields a fine weak sinter that breaks down to affect the porosity of the feed, which can lower productivity by as much as 40 percent. Similarly, much of China's bauxite is diasporic, and apart from being costly and difficult to refine, it produces an alkaline alumina that taints metal quality and because it has fine particles, much of it is blown away so there is a reduction in productivity.

The problem of inferior raw materials can also be attributed to deficiencies in China's pre-Reform planned economy where autarkic policies and scarce foreign currency forced plants to process locally sourced, poor-quality raw materials, a situation that was aggravated because there were no incentives for local suppliers to provide more suitable ore. Furthermore, plants could not select alternative suppliers that could provide better-quality ore, and the limited availability of foreign currency precluded the purchase of imported substitutes. However, all this changed when China began to acquire foreign technology, which was designed to process high-quality raw materials not widely available in China.

Improved product quality with the reassembled Dortmund mill enabled Shagang to service high-value quality-sensitive markets that had been previously closed to the company. Prior to its transshipment to China the mill had supplied Volkswagen with high-quality hot and cold rolled sheet steel as well as stainless steel and zinc-coated steel, all of which are critical materials for pressing automobile bodies.²⁸ Acquisition of the Dortmund mill enabled Shagang to supply Volkswagen, then China's largest producer of automobiles, with the high-value and technically advanced steels that previously it was not capable of producing.

CONTINUOUS LEARNING

While the purchase of obsolete foreign plants was a key driver behind the growth of China's metallurgical industries, it was not the only means by which metallurgical companies advanced their understanding of key processes. Two other routes—technology provided by suppliers of raw materials and continuous learning through sustained incremental growth—also have long been important sources of learning for China's metallurgical industries. International suppliers of raw materials such as iron ore and coke (steel industry), as well as bauxite and alumina (aluminum industry), often differentiate their ores by offering free technical assistance to potential customers. Generally, supplier support does not involve patented technology, but it is more than rudimentary, and during the early years of China's Reform period this knowledge gave Chinese engineers the confidence to test different ore blends. Such experimentation contributed to a more practical understanding of fundamental metallurgical processes that resulted in a blending of foreign and domestic ores that optimized the mills' performance.²⁹

The purchase of obsolete foreign facilities is the key to the technical strength that characterizes China's contemporary metallurgical industries, but this novel approach was not China's first choice for acquiring the technology it needed to modernize and expand its metallurgical facilities. Shortly

28. Hudson and Swanton, "Global shifts in contemporary times: the changing trajectories of steel towns in China, Germany and the United Kingdom," 15.

29. One forward-thinking Australian minerals company provided a secondment for a young Chinese engineer who later rose to head his country's nonferrous metals industry. The future leader would later recall the warmth of the reception he received from Australians and his envy of the quality of the mines he saw on his secondment. His admiration for the Australian mines encouraged the young engineer to pursue foreign technology when he was appointed to his leadership role.

after Deng Xiaoping initiated the reform process, Beijing began to purchase selected technologies from the world's leading metals companies. In 1979, NLM, then an affiliate of Canada's Alcan Aluminum Limited, was awarded a contract to supply the technology and most of the equipment to construct an 80,000 tpa aluminum smelter in Guizhou. With the completion of the Guizhou project, NLM offered to build a 100,000 tpa smelter in Guangxi, but because of a shortage of foreign currency Beijing did not take up the offer.³⁰

Around the time that NLM was building the Guizhou smelter, Nippon Steel Corporation, then the world's largest steel producer, was contracted to build an integrated steel works on the south bank of the Yangtze River, some 20 km from Shanghai at Baoshan.³¹ With a crude steel capacity of 6.7 mtpa the facility was to be built in two phases. The first phase was initiated in 1978 and completed seven years later, while the second phase, which commenced operation in 1989, included steel casting and rolling facilities. With the exception of a seamless pipe mill sourced from Germany, all the main facilities for the steel works were imported from Japan. The Baoshan complex was modeled on Nippon Steel's Kimitsu facility and introduced Chinese engineers to the then-most-advanced steel-making technologies. Baoshan's 4,000 m³ blast furnace was at the time one of the largest in the world, far larger than the 2,580 m³ furnace at the Anshan mill in Liaoning, which was then the largest in China.³² The Baoshan furnace was not only much bigger than the one at Anshan, but it also operated entirely under computer control and was far more energy-efficient because it recovered waste gas for use elsewhere in the process.³³

Not only did the Baoshan project incorporate advanced technology it was also, for its time, one of the largest international technology-transfer projects. With an investment of \$2.9 billion, the facilities and materials supplied from Japan totaled 520,000 tons; in addition, there were 200 tons of technical documents. China sent 786 engineers to Japan for technical training, while 335 Japanese specialists went to China to offer technical guidance.³⁴ The gigantic scale of the technical transfer prompted Nippon Steel's chairman (Yoshihiro Inayama) to publicly voice concerns over China's ability to absorb and assimilate the advanced technology.³⁵ This was not to be the last time that foreigners were to underestimate the ability of Chinese engineers.³⁶

The Guizhou aluminum smelter and the Baoshan steel works were successful projects, though they were not without their problems. First, China's limited infrastructure, especially that associated with the generation and distribution of electricity, delayed the commissioning of large, complex, and energy-intensive plants. For example, in 1975 the iron and steel works in Wuhan, Hubei purchased sophisticated rolling and casting technologies from Germany and Japan, but because of local electricity shortages the facilities could not operate continuously at full capacity, and it was not until 1980 that they were finally commissioned.³⁷

The biggest problem, however, was that metallurgical projects contracted to foreign companies required the outlay of a large amount of hard currency that China lacked, and the purchase of imported metallurgical plants was seen as a big money-eater, with Vice-Premier Bo Yibo labeling the Baoshan project "a burden for the Chinese people."³⁸

30. Pui-Kwan Tse, "The Mineral Industry of China," United States Geological Survey, 1990, 78

31. Prior to the Baoshan project, Nippon Steel had assisted in building a \$440 million mill to produce electrical sheet steel near Wuhan in Hubei.

32. Anshan steel mill was built in the 1950s with Soviet assistance.

33. Prior to the Baoshan mill, China's steel mills had used computers, but this was confined to manipulating process data, whereas the computers at Baoshan controlled the blast furnace process.

34. Takashi Sugimoto, "The Chinese Steel Industry," *Resources Policy*, December 1993, 264–86.

35. Henry Scott-Stokes, "Talking Business with Inayama of Nippon Steel," *New York Times*, November 30, 1978.

36. Nippon Steel's Inayama was a strong supporter of Sino-Japanese trade, but in 1978, when China produced 31.7 mt of steel, even he doubted that the country would achieve its declared goal of producing 180 mtpa of steel compared with just over 100 mtpa for Japan: Scott-Stokes, "Talking Business with Inayama of Nippon Steel." In 1996 China overtook Japan to be the world's biggest steel producer, and in 2002 the country reached its 180 mtpa target. In the same year, Japan produced a mere 81 mt. In 2014, China's steel mills produced 823 mt, compared with Japan's mills, which produced 111 mt of steel.

37. Sugimoto, "The Chinese Steel Industry," 270.

38. Janice M. Hinton, "China's Steel Industry: The Policy Implications for Technology Transfer to the People's Republic of China," Ph.D. disserta-

The acquisition of surplus plants from foreign companies did not require large outlays of foreign currency, because the sellers were usually under financial pressure and were desperate to close their loss-making businesses. The foreign companies also underestimated the ability of the Chinese to meet the challenge of dismantling complex processing plants and package them for shipment to China, where they were quickly and cheaply reassembled. Desperate to dispose of any liability for their shuttered plants, the foreign companies were happy to sell them to Chinese enterprises for nothing more than scrap value and sometimes even less.

REVERSE ENGINEERING

Licensing of technology has been a feature of other Chinese industries, but it was not a common practice in the metallurgical industries. An incident with France's Pechiney SA contributed to the reluctance of foreign metallurgical companies to collaborate with Chinese counterparts. In the early 1990s Pechiney partnered with the Chinese National Non-Ferrous Metals Corporation (CNNC) to build an integrated aluminum complex at Pingguo in Guangxi. At the time, Pechiney was arguably the world leader in aluminum-smelting technology, and for this reason it was invited to work with CNNC after NLM had passed up the opportunity to partner with the SOE. Pechiney conducted a two-year feasibility study for a 100,000 tpa smelter, together with associated bauxite mine and alumina refinery, to which the State Council readily gave approval.³⁹ The project stalled when the proponents could not raise the necessary finance, but this did not stop CNNC, which, having being exposed to Pechiney's latest technology and having learned from a similar plant, proceeded alone with the project based on technology developed through its own design development.

The design for Pingguo, which was undertaken by Guiyang Aluminum and Magnesium Design Institute, a CNNC subsidiary, was a remarkable example of reverse engineering. However, CNNC had little time to savor the achievement because almost as soon as the smelter had been built and the technology proved to be an advance on other Chinese technologies, many of the engineers who had worked on the project resigned from CNNC to join private Chinese companies that wanted to enter the lucrative aluminum industry. Paid handsomely by CNNC's competitors for their technical knowledge and CNNC's designs, these engineers remained with their new employers until the smelters had been commissioned, at which time they usually resigned to work on the next development. It was through this sequence of former CNNC engineers moving from one new entrant to the next that modern aluminum smelting technology spread through China and was not confined to one company or institute. This practice also demonstrates that the Chinese do not discriminate in their lack of respect for intellectual property; Chinese companies will infringe the proprietary technology of national champions as readily as they do to foreign competitors and the absence of an enforced intellectual property law accelerates diffusion of any new technology.

A dispute between Germany's Chenco GmbH and Do-Fluoride Chemicals Co. Ltd. of Henan illustrates how a Chinese company escaped bankruptcy to become a major player in its field (fluoride chemicals) after it illegally misused foreign proprietary technology. Chenco, a chemical engineering and consulting company with proprietary technology for producing inorganic fluoride chemicals, sold three licenses for its technology to Do-Fluoride Chemicals Co. Ltd., also known as DFD, which went on to build a number of other plants based on the unauthorized use of the original three licenses. Prior to purchasing the licenses from Chenco, DFD had operated with inferior Soviet-era technology, and its product quality had found little acceptance, even with price-sensitive Chinese consumers. Riding on the back of the Chenco technology, DFD has grown to become the global leader of fluoride chemicals and it is now the largest supplier of aluminum fluoride to the global aluminum industry.

tion, Rand Graduate Institute, 1985, 86.

39. Jasper Becker, "China Puts Aluminum on Highest Priority," *Journal of Commerce*, November 6, 1986.

Chenco took its concerns with DFD's misuse of its proprietary technology to the International Chamber of Commerce (ICC), where arbitrators found in the German company's favor and ordered DFD to pay €6.5 million for misuse of the license, as well as damages of €320,000. DFD, which argued its case before the ICC, has refused to make the payments to Chenco.⁴⁰ Listed on the Shenzhen stock exchange, DSD describes itself "as a company with advanced technical innovation," which the Ministry of Industry and Information Technology has accredited "as a first group of National Technical Innovation Demonstration Enterprises."⁴¹ It would seem that the ICC's adverse ruling has not damaged DSD's standing with China's government.

Some foreign companies seem to have enjoyed successful collaboration with counterparts in China only to find later that their technology has been compromised. One such company, Finland's Outotec Oyj (formerly a division of Outokumpu Oyj), was a sequential supplier of technology to China's infant metallurgical industries, but more recently the company initiated legal action against a Chinese company that it believed had violated its patented technical know-how. Outotec's introduction to China came in 2000 when it undertook a collaborative program with the Zhuzhou Smelter Group Co. Ltd., which operated a zinc smelter in Hunan. Zhuzhou wanted to expand its operation based on the latest technology, and it worked with Outotec on a series of laboratory tests of Hunan's unique zinc ore, which has traces of indium, which is deleterious to the smelting process. These tests demonstrated the technical and economic feasibility of expanding the smelter using Outotec's proprietary technology.

Subsequently, in 2006, the parties signed agreements to implement Outotec's technology at Zhuzhou. For the Chinese side, environmental issues were an important element in their choice of the Finnish technology, as was the fact that the technology could extract the indium, which could then be sold as a valuable by-product.⁴²

The Zhuzhou expansion was completed in 2008, and both sides seem to have been more than satisfied with the outcome of their collaboration. Encouraged by their Zhuzhou experience Outotec subsequently sold other proprietary technologies to Chinese companies in the copper, aluminum, tin, ferrochrome, and nickel sectors. Most of these contracts were relatively small, typically in the range of \$30 to \$80 million, and involved the supply of discrete equipment modules. However, despite its earlier successes, Outotec began to encounter problems with protecting its technology so it launched arbitration proceedings against one of its clients, Yanggu Xiangguang Copper Co. Ltd., in the ICC.⁴³ Based in Shandong, Yanggu had purchased a license to Outotec's copper-smelting technology in 2005, and the Finnish company then alleged that its Chinese counterparty had violated this agreement. Yanggu denied any infringement and petitioned China's National Development and Reform Commission to investigate Outotec for abusing its market power. In September 2015 the parties reached a confidential agreement to settle their differences.⁴⁴

A common theme of the Pechiney, Chenco, and Outotec experiences is the shift in market power from the foreign technology owner to the Chinese collaborator. In the three cases China was seeking foreign suppliers of modern, technically efficient, and environmentally clean technologies to develop its core metallurgical industries, but as Chinese engineers began to understand the basic processes, they appear to have abrogated their contractual arrangements to pursue their own independent research.

China's attitude to partnering foreign suppliers of technology is likely to have been influenced by the government's autarkic mentality and limited reserves of foreign currency. During the early years

40. PR Newswire, August 22, 2011, <http://www.prnewswire.com/bloggers/news-releases/?nrId=128175358>.

41. Do-Fluoride Chemicals Co., Ltd., Chairman (sic) Address, <http://www.dfdchem.com/eabout.aspx>.

42. "Expanding Zinc Capacity at Zhuzhou, China," *Engineering & Mining Journal*, December 2008, 56–60.

43. "Xiangguang denies breaching licence agreements with Outotec," *Metal Bulletin*, April 9, 2014.

44. Coincidentally Outotec's action came shortly after Yanggu was granted a U.S. patent for a copper-smelting process (Application Number U.S. 13/696,728).

of Reform the limited availability of foreign currency constrained planned developments such as the replication of the Japanese-designed Baoshan steel mill and the Guizhou aluminum smelter. Domestic critics of foreign-purchased technology believed that China had committed to too many expensive projects that were a waste of both capital and material resources.⁴⁵ The critics believed that these projects could be replicated in China at a fraction of the cost charged by foreign companies, and this view was reflected in Beijing's policy of preferring imported technology that could be reverse engineered so that subsequent requirements could be manufactured domestically. Indeed, the rigorous approval process required to purchase foreign technology, while intended to conserve foreign currency, was also designed to promote self-sufficiency.

The gold sector provides another example of China initially pursuing technical collaboration with foreign companies, but renouncing the practice once its engineers had an understanding of how their technical partners operated, in this case smelting gold. Until recently China's gold industry followed the standard Chinese pattern of a fragmented industry operating with small-scale, inefficient, and environmentally dirty plants. A partial explanation for the gold industry's adherence to this pattern of collaboration is that China's reserves of gold ore are mineralogically complex and hard to process. For this reason initially China allowed foreign participation only in the sector where the foreign partner could provide advanced technology to mine, process, and smelt gold. However, as Chinese engineers began to understand their complex ore, production grew—China's is now the world's largest producer of gold—so foreign participation was no longer encouraged.⁴⁶

China's use of technology transfer agreements to advance indigenous designs is not unique to the metallurgical industries, and the practice appears to mirror similar developments in China's automotive, high-speed railway and nuclear sectors, where foreign suppliers have been required to share technology with local companies in order to access the vast Chinese market. These technology transfers have come "at the cost of reduced competitiveness and the establishment of domestic competitors."⁴⁷

The paper will return to the issue of intellectual property later, but the Pechiney, Chenco, and Outotec experiences were valuable warnings to foreign companies wanting to sell technology to China. These experiences are also a practical demonstration of China's attitude to the licensing of technology: most Chinese companies are loath to pay for intangibles like technology. The lesson seems to be that with an endless supply of smart engineers and scientists, why pay for technology, something that you cannot touch, see, taste, or smell. It was this philosophy, typified in the Pechiney experience, that rapidly and widely promulgated China's understanding of the aluminum-smelting process such that technology is no longer a barrier to entering the industry as new participants usually have ready access to relatively modern and cost-competitive technology by copying drawings and contracting with their competitors and former employees. Unrestricted access to technology combined with rapid urbanization, driving the demand for metals has underpinned the proliferation of new Chinese metallurgical capacity.

CAPITAL LEARNING

The rapid expansion in metals production has given Chinese metal companies another technical advantage—capital learning—that is not normally available to their foreign competitors. Metallurgical industries are characterized by capital-intensive facilities that convert a heterogeneous mineral (ore) into a homogeneous product (metal) sold to a standard specification. Because there is basically no difference between their finished products, metallurgical companies compete on cost, and because they are inherently capital intensive, the key to success revolves around capital management, or whether project developers can build new plants more quickly and cheaply than their competitors.

45. Hinton, "China's Steel Industry: The Policy Implications for Technology Transfer to the People's Republic of China," 3.

46. Pui-Kwan Tse, "The Mineral Industry of China," United States Geological Survey 2007, 9.1–9.24.

47. Clark Edward Barrett, "Chinese 3rd Generation Nuclear Technology Development," *China Brief XIV*, issue 8 (April 24, 2014): 8–11.

Because of the large investment and its lumpy nature, decades can elapse between the time that companies that operate in capital-intensive industries build green-field facilities. For example, although the world's largest non-Chinese aluminum-producing company, Russia's United Company (Rusal), accounts for 7 percent of the world's production of primary aluminum, the company has not built a new smelter in close to two decades. Increased production has come from productivity improvements and small incremental expansions at existing operations. A similar situation exists in the steel industry, where, outside of China, no new blast furnace capacity has been built for at least a decade. Because of the sporadic nature of their capital programs, metallurgical companies are usually not able to retain the learning gained from individual investments. When the facility is completed the project team is disbanded because there is no immediate work for them. Some of the team members work on other capital undertakings, but the collective learning of specific project-management systems is lost.

Collective learning or experience curves are common in manufacturing, where learning through repetition results in falling costs with each unit of production. Because there is less repetition, experience curves are rare in capital undertakings, but China's record of relentless construction of new capacity has revolutionized capital management practices and has given China the skill to execute capital works much faster and cheaper than Western companies.

There is probably no better example of this principle than China's aluminum industry. Over the 15 years ending in 2015, world production of aluminum increased from 24.7 to 57.9 mtpa. Of the increased 33.2 mtpa China contributed 28.9 mtpa or 87 percent, an increase that, over the decade, meant China's expanded production was nearly four times the aluminum output of Russia, the world's second-largest producer of primary aluminum.⁴⁸ Or more spectacularly, in five years (2011 to 2015) China built more aluminum-smelting capacity than the rest of the world did in 25 years. With such a large and sustained increase in production, China's smelter project teams were fully committed to a series of new smelters where they were able to capitalize on the learning of previous projects. This learning was combined with minor variations in design that resulted in a significant reduction in construction costs. Outside of China new capacity costs over \$7,000 as against \$2,000 per ton for smelters constructed in China. The rapid growth of China's aluminum industry demonstrates that in capital-intensive industries skills in project delivery can more than compensate for higher operating costs.⁴⁹ Some of China's capital cost advantage is the result of lower labor costs, but the learning derived from a sustained two-decade-long expansion program should not be underestimated.

Aluminum is not a unique example, as over the past decade or more, growth in Chinese output has dominated the global production of most metals. In nickel, over the 10 years to 2014, China accounted for 90 percent of increased world production and in magnesium, the rest of the world contracted while China's production grew by 37 percent. In ferrous metals, China accounted for 90 percent of the growth in the output of crude steel, and over a decade China added four times as much steel capacity as Japan (which needed 60 years to achieve the same growth). Such huge increases in output have meant that Chinese engineers have the accumulated learning to build a wide range of low-cost, metal-producing capacity.

PROGRESS THROUGH ESPIONAGE AND INTELLECTUAL PROPERTY THEFT

Intelligence experts claim that Beijing manages a systematic and relentless campaign to acquire technology through its spy agencies and Chinese companies, scientists, and students abroad. Reported to be on an industrial scale, China's intelligence gathering does not distinguish between traditional national-state spying and theft of commercial secrets. Because a large part of its

48. World Aluminium Institute, "Statistics, Primary Aluminium Smelting Intensity."

49. Outside of China, capital costs for aluminum smelting equate to more than 40 percent of the cash cost of production.

economic activity is undertaken by its SOEs, China's theft of commercial and industrial intelligence provides its companies with a huge advantage.

While most of the theft by China of intellectual property involves high-technology manufacturing industries, the metallurgical sector has not been immune from attack by the Chinese. In 2014, the United States charged five members of a Shanghai-based military unit for hacking the computer systems of six American entities, of which four—Alcoa Inc., Allegheny Technologies Incorporated, United States Steel Corporation, and the United States Steelworkers Union—were involved in the metals industry. Breaching these companies' cyber security cordons came at an opportune time for the Chinese: Alcoa's computers were hacked after the company partnered with an aluminum-producing SOE, China Power Investment Corporation, while the steel workers union's emails were accessed during a trade dispute with China.

The attack on Alcoa involved a simple email masquerading as a message from Carlos Goshan, chief executive of Nissan Motor Co. and at the time a member of Alcoa's board of directors. Despite a spelling error in Goshan's name, at least one of the 19 Alcoa employees to whom the communication was directed downloaded an attachment to the e-mail, which allowed the hackers to access 2,900 emails and 860 attachments.⁵⁰

Based on a 2016 complaint by U.S. Steel, American regulators began an investigation into a 2011 incident where cyber spies, alleged to be agents of the Chinese government, stole proprietary methods for making a lightweight steel alloy for use in the automotive industry. Details such as the alloy's chemistry, the temperature for heating and cooling the metal, and the layout of the production lines were said to have been stolen and subsequently passed on to Chinese state-owned steel giant Baosteel. Adding insult to their injury, U.S. Steel alleges that Baosteel used the illegally sourced technology to build a line to produce the alloy, which it then exported to American consumers.⁵¹

In 2014, Walter Liew, a 56-year-old naturalized U.S. citizen from Malaysia, was sentenced to 15 years in prison and fined \$28 million for stealing a U.S.-developed process for producing titanium dioxide—a product used as a white pigment in high-quality paper and plastics. Over a decade, Liew conspired with a group, including his Chinese-born wife (Christine Liew), to steal intellectual property from the American chemicals giant DuPont, which they then sold for \$30 million to a Chinese SOE.⁵² Some of the conspirators were retired DuPont scientists who had helped the company develop the chloride process for manufacturing titanium dioxide pigments, which is more efficient and cleaner than the sulphate technology prevalent in China. The world market for titanium dioxide is valued at over \$17 billion, with DuPont holding a 20 percent market share. Until it purloined DuPont's proprietary technology, China imported more of the chemical than it produced.

There should not be any surprise at China's actions in copying the proprietary technology it has purchased or stolen from foreign companies. From the first days of China's Reform period, the country's leadership has explicitly stated that it expected that collaboration with foreign companies "would provide the technology and training for China's engineers and technicians to catch up with modern developments which [would] . . . thereby stimulate domestic innovation." The leadership expected that their engineers and technicians would "study the imported technology with the purpose of copying and creating new designs for use throughout the country."⁵³

Theft of proprietary technology is clearly contrary to international law, but the practice is not unusual for emerging economic powers. China's stated policy of copying foreign technology

50. Danny Yadron, "Alleged Chinese Hacking: Alcoa Breach Relied on Simple Phishing Scam," *Wall Street Journal*, May 19, 2014.

51. John W. Miller, "U.S. Steel Accuses China of Hacking," *Wall Street Journal*, April 28, 2016.

52. Joe McDonald, "Investigators track technology theft to China, hit a dead end; scale of possible losses grows," *Associated Press*, August 9, 2013.

53. Hinton, "China's Steel Industry: The Policy Implications for Technology Transfer to the People's Republic of China," 16–17.

is reminiscent of how “[t]he United States emerged as the world’s industrial leader by illicitly appropriating mechanical and scientific innovations from Europe.”⁵⁴ During the eighteenth century, the American government encouraged industrial spies who scoured Europe seeking new machines and the workers who could run them. Indeed, Samuel Slater, who President Andrew Jackson described as the “Father of the American Industrial Revolution,” was known as “Slater the Traitor” in Britain because he illegally transferred to the United States his intimate knowledge of the British cotton-spinning technology that had transformed textile production in that country.⁵⁵

History is replete with examples like the United States and China, where a rising industrial power stole intellectual property from more-dominant competitors. In 1719, Thomas Lombe established the first silk mill in the United Kingdom after his brother made illicit diagrams of an Italian mill. Later, in 1728 a grateful British monarch rewarded Lombe with a knighthood. Britain was also involved in one of the most successful acts of industrial espionage ever, when, in 1848, the British East India Company sent a botanist, Robert Fortune, to China, where he stole both the technique for processing tea leaves and a vast collection of tea plants. The examples of Britain and America show that as they acquired the technical knowledge to modernize their economies, rising industrial powers transform into staunch advocates for enforcing stringent intellectual-property rules. The recent \$43 billion acquisition by China National Chemical Organization (ChemChina), a huge Chinese SOE, of the Swiss-based Syngenta AG has raised the prospect that China is approaching a stage where it is beginning to realize that its level of integration with the global economy is such that it needs to raise its standard of corporate governance, including its respect for intellectual-property rights. Syngenta, China’s largest foreign acquisition, is a leading global agribusiness that holds many patents, so its intellectual property is a core business asset that demands protection and should encourage its new Chinese owners to realize that its interests are best served by participating in the global system that respects and protects the intellectual property. Committing to agreed basic rules of conflict in the intellectual-property world is akin to nuclear arms control, where international agreements limit the spread of self-destructing nuclear weapons.⁵⁶

II. CONSTRAINTS ON FURTHER SUCCESS

TOWARD TECHNOLOGICAL STAGNATION

While China’s understanding of global metallurgical processes has benefited the rapid expansion of its local mineral-processing industries, this growth potentially contains the seeds of China’s own technological stagnation. Low barriers to entry and very competitive construction costs coupled with generous local-government subsidies have resulted in Chinese companies investing in excess metal-producing capacity, which has flooded the market and depressed global prices. Figure 1 shows that since 2000 the prices for aluminum and magnesium have hardly changed, while nickel and steel prices have increased only marginally. Copper, whose price has increased by a factor of four, is the only exception to this picture of relatively flat long-term metal prices.

A long and sustained period of depressed prices has resulted in low industry profitability with many producers, Chinese and foreign, losing money. Under such circumstances foreign companies are reducing their costs by eliminating nonessential expenditure, especially the funding of research and development activities. These cutbacks have seen spending by the increasingly cost conscious non-Chinese mining and metals industry fall relative to other sectors. For example, the metals industry spends around 0.5 percent of gross revenue on research and development, which is low compared

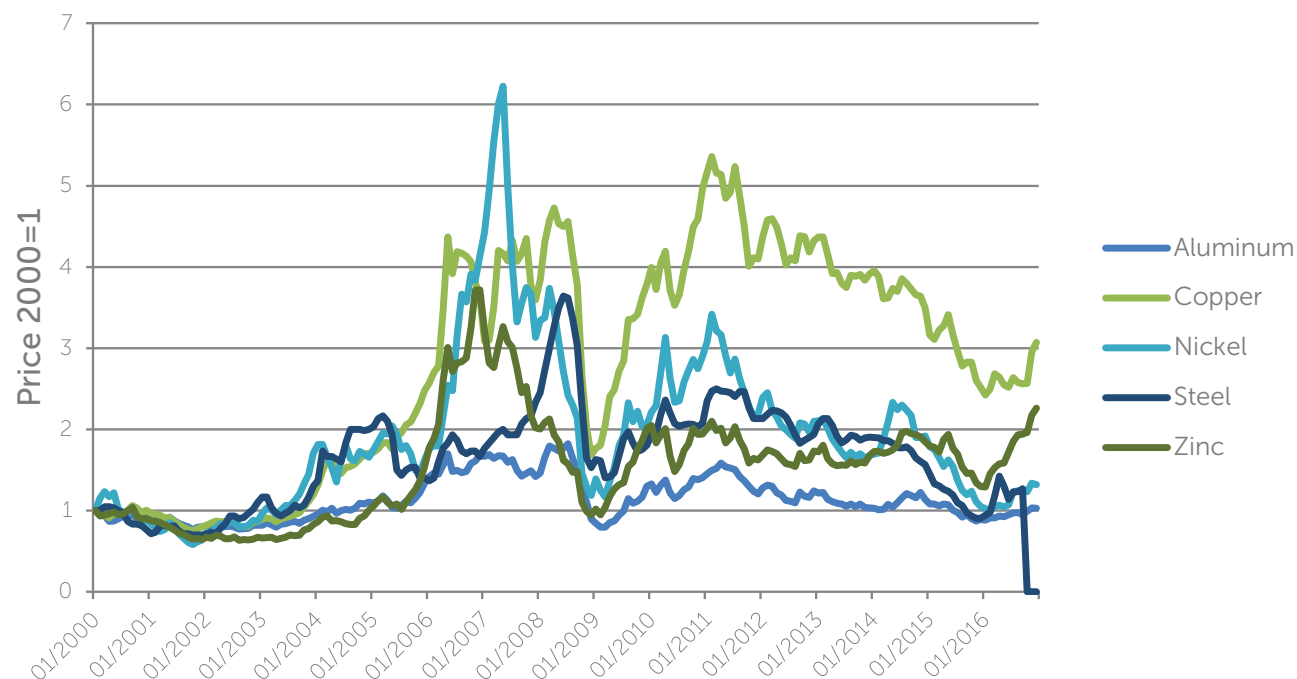
54. Doron S. Ben-Atar, *Trade Secrets: Intellectual Piracy and the Origins of the American Industrial Power* (New Haven, CT: Yale University Press, 2004), xxi.

55. James Surowiecki, “Spy Vs. Spy,” *New Yorker*, June 9, 2014; and Neil Heath, “Samuel Slater: American Hero or British Traitor?,” *BBC News*, September 22, 2011, <http://www.bbc.co.uk/news/uk-england-derbyshire-15002318>.

56. Jose Pagliery, “China’s president is here. Will U.S. call out China on hacking?,” *CNN Money*, September 22, 2015.

with comparable industries such as the chemical industry, which spends three times as much—1.5 percent of gross revenue—on research and development.

FIGURE 2. PRICES OF SELECTED METALS



Source: Urandaline Investments.

Metals companies that have a long, proud, and successful history of innovation have cut back or closed their research facilities and are now no longer supporting fundamental research. Rio Tinto, the world's second-largest mining company, has shuttered most of its research and development laboratories and now concentrates its technical efforts on operational improvements. In terminating its fundamental research activities, Rio Tinto abandoned a unique technology, called HIs melt (high-intensity smelting), used for making pig iron directly from iron ore. The technology offers significant financial and environmental benefits because it directly smelts low-quality iron ore fines using noncoking coals. The company had spent 20 years and more than \$1 billion developing this revolutionary technology. With assistance of Australian taxpayers, Rio Tinto built a commercial-scale (800 ktpa) demonstration plant in Western Australia to prove the technology, but when the financial crisis hit in 2008, the company decided to abandon the development of HIs melt and, reminiscent of an earlier period when China acquired new technology by purchasing loss-making plants for dismantling and re-erection in China, the HIs melt plant was dismantled and shipped off to Shandong for re-erection by Molong Petroleum Machinery in Co. Ltd.⁵⁷ Molong plans to expand the original Rio Tinto plant to 1.5 mtpa, with the expanded operation supplying Molong's steel pipe-making plant that produces high-quality specialized pipe for the global oil and gas industry.

In the rare-earths sector, global over-capacity and the relocation of the industry to China forced the closure in 2002 of the Rare-earth Information Center (RIC) based at Iowa State University (United States). The RIC had provided scientific and technical information concerning rare earths to industry and government for more than 36 years, but withdrawal of support from industry and the university forced the center to close.⁵⁸ The decline in industry funding, which caused the closure

57. Rio Tinto, "Next Phase in Developing HIs melt Technology," <http://www.riotinto.com/ironore/hismelt-4724.aspx>.

58. Brian J. Ficarek, Francisco M. Veloso, and Cliff I. Davidson, "Offshoring Technology Innovation: A Case Study of the Rare-earth Technology,"

of the RIC and the sale of the Magnequench facility to China, meant the United States went from self-sufficiency in rare-earth processing and manufacturing applications to importing more than 90 percent of its needs from China.⁵⁹

In Australia, the mining sector represents 8.7 percent of national GDP and accounts for half of total export earnings; however, despite its importance to the economy, the nation's premier research organization, the Commonwealth Scientific and Industrial Research Organization (CSIRO), has reduced its commitment to research on upstream mineral processing and metal production to confine its focus to essential support services. CSIRO has a long history of innovation in mineral processing, but in recent times contraction of its mineral activities has been dictated by declining industry demand for its services.⁶⁰

Without continued research, industry productivity will stagnate, and as the largest producer of most metals, China will be affected more than its foreign competitors. The disproportionate impact on Chinese companies is accentuated by two additional factors. First, having perfected technology sourced from overseas competitors, China will no longer be able to benefit by acquiring more advanced foreign technologies. Second, most of the easy technology improvements have already been made, and the law of diminishing returns will apply, so further advances will be more difficult. Unfortunately, without radical changes to its industrial culture and reform of its scientific institutions, it is unlikely that China's metallurgical sector will be able to adapt to the new environment. As a result, it is doubtful that it will grow as rapidly as it has in the past.

Often the closure of research and development activities is not sufficient to arrest the decline in profitability induced by excess capacity and in such cases profit-driven companies are forced to shutter their loss-making operations. This is particularly true of the aluminum industry and especially for producers operating in the United States. In 1999, U.S. aluminum producers turned out 3.8 mt of aluminum from 23 smelters, but by 2016, brutal competition from Chinese companies resulted in the total closure of 18 smelters. Of the five operating smelters, only two were producing at full capacity and production from the five operations was less than 0.8 mt. Sustained and intense competition from China has forced Alcoa, once the world leader in all things aluminum, to separate into two companies, effectively exiting the smelting business to allow its value-adding downstream fabricating operations to remain competitive by buying-in cheaper imported aluminum.⁶¹

SUPPORT FOR STATE-OWNED ENTERPRISES

The Aluminum Association (AA), a U.S. trade group that promotes the interests of the country's aluminum industry, claims that the financial health of its members is threatened by subsidized Chinese production, which leads to unfair and illegal trade practices. The association argues that the rapid expansion of China's aluminum industry is driven by artificial incentives, subsidies, and central planning by the Chinese government so that smelters are built despite there being no economic or environmental sense.⁶² The AA also makes much of the fraudulent gaming by Chinese producers of their country's export incentives, where aluminum exports are misclassified as semi-fabricated products rather than primary aluminum. In China, exported semi-fabricated aluminum products attract a 13 percent value-added tax export rebate, while primary aluminum exports incur a 15 percent tax, so there are significant financial incentives for exporters to misrepresent aluminum ingot as fabricated metal.

Journal of Operations Management 26 no. 2 (2007): 222–38. In 1985 the Chinese Society of Rare Earths established an information center modeled on Iowa's RIC.

59. Eileen Applebaum and Dean Baker, "A Strategy for Balanced Trade and Economic Revitalization," Center for Economic and Policy Research, Washington, DC, May 2007, 15.

60. CSIRO Annual Directions Statement 2014, 10, <https://csirostaffassociation.files.wordpress.com/2014/07/csiro-annual-directions-statement-2014-15.pdf>.

61. Geoffrey Smith, "Chinese Imports Just Doomed Another 1,200 Jobs at Alcoa," *Fortune*, January 8, 2016.

62. Aluminum Association, "China & Trade: Working to Ensure a Level Playing Field," <http://www.aluminum.org/china-trade>.

The AA and other international trade associations that protest unfair competition from Chinese producers rarely mention the technical level of China's metallurgical facilities. Notwithstanding the failure to acknowledge the technical efficiency of China's metals industries, Chinese companies and especially its SOEs receive wide-ranging support from Beijing that enables them to continue producing for extended periods while operating at a financial loss. Such support usually includes subsidies, particularly cheap loans from state-owned banks that immunize the enterprise against market signals such as poor financial performance. Liu and Song cite the steel industry to demonstrate that because of their bloated, highly paid, and inefficient workforces, SOEs are the main beneficiaries of government largesse.⁶³ The average steel output per worker in private steel mills is 514 tons as against 270 tons for state-owned mills. In addition to their poor productivity, SOEs in the steel sector are more generous to their workers than their private-sector competitors. State-owned mills pay their employees an average of Rmb5,094, which is 34 percent more than the Rmb3,807 private-sector mills pay their workers.

The steel industry is not an isolated example as an examination of the aluminum industry reveals. The state-owned Aluminum Corporation of China Limited (Chalco), once China's dominant aluminum producer, has been overtaken by more-nimble and profitable private players who are not saddled with outdated and costly labor responsibilities or counterproductive political obligations. For example, productivity at the Hongqiao Group, Chalco's largest private-sector domestic rival, is 69 tons as against Chalco's 43 tons per employee. Hongqiao also operates with a proportionally much tighter senior-management group—63 compared with Chalco's 10 workers per executive.

The management of state-owned metallurgical facilities is well aware that the facilities' profitability is burdened by an inflated and overpaid workforce. For example, at a February 2016 conference, the president of Taiyuan Steel Co. Ltd. reported to Chinese Premier Li Keqiang that his enterprise operated with 50,000 workers, but only 20,000 were needed. Wuhan Steel Group has announced that it will slash its workforce from 80,000 to 30,000 employees while maintaining its level of production. Anshan Steel Group, China's oldest steel enterprise, also plans to maintain its production while trimming its workforce from 160,000 to about 100,000 employees.⁶⁴

A reluctance to retrench surplus workers has long been a feature of China's economy, where the Communist Party seeks to maintain its privileged one-party status by trading economic growth for social stability. The tradeoff is particularly noticeable in remote areas where there are few employment opportunities and governments, both local and central, use their ownership of SOEs to preserve jobs. The reluctance to lay off workers suggests that they prefer to continue incurring financial losses rather than risk protests by dismissed surplus workers.

Fiscal decentralization further complicates the government's intrusion into the operation of business, particularly that of SOEs, and this has the effect of encouraging excess capacity. Under China's fiscally decentralized economy, local cadres are rewarded for the economic and social performance of their regions, but their task is made more difficult because local governments, which have no direct taxing powers, are required to fund essential social services from the tax revenue they are allocated by the central government in Beijing. Such a system is an incentive for local governments to protect established enterprises and invest in new capital-intensive prestige projects that spur economic growth. A strong local economy means more tax revenue with which to fund social welfare budgets as well as pet projects that are hoped will create jobs, reduce welfare payments, and promote social stability. As Arthur Kroeber has pointed out, large capital-intensive projects, particularly those involved in the production of metals, are a good way to impress visiting officials who can influence promotion prospects. And while the capital works are under construction, they make an immediate and hefty contribution to the local gross domestic product, which is a key indicator for evaluating the performance of cadres.⁶⁵

63. Liu and Song, "Issues and Prospects for the Restructuring of China's Steel Industry," 350.

64. *Ibid.*, 350.

65. Arthur Kroeber, *China's Economy: What Everyone Needs to Know* (Oxford University Press, 2016), 114.

At the height of the commodity boom and before the onset of the 2008 financial crisis, local governments piled into new metal-producing capacity, which they judged to be a long-term and stable source of tax revenue. This rapid expansion in capacity, which had little business logic, was funded by low-interest preferential loans from state-owned banks. In many instances provincially owned SOEs never expected to repay the loans and with today's stagnant economic growth and the reluctance to turn down loss-making capacity, what was expected to be an economic bonanza has degenerated into a prolonged drag on metal prices, wiping out profits. But despite their ownership of loss-making enterprises, local governments are averse to closing their disastrous investments.

State-owned companies also benefit from government support when they run out of cash. When they are no longer able to pay their banks, suppliers, and employees, SOEs are propped up with subsidized low-interest loans from state-owned banks. Often, as in the case of Dongbei Special Steel Group Company (DSS), a Liaoning government-owned enterprise, the SOE is resurrected to become a serial loan defaulter—DSS has defaulted on seven bonds totaling Rmb4.8 billion. For many years bonds issued by SOEs were assumed to have implicit state backing, which would prevent formal defaults; however, as the case of DSS illustrates, SOEs are beginning to miss bond repayments. Between 2014 and 2016, there were 18 notable defaults, of which seven (all of them private companies) have made full recovery, while none of the SOE defaults has been resolved.⁶⁶

Financial support is important, but it is not the only backing that SOEs receive from their government owners. Most, if not all, SOEs owe their existence to privileged access to key resources controlled by a government, and in the metallurgical industries this can involve monopoly access to ore bodies as well as priority right to use scarce transport capacity. Much of China's government-owned aluminum-smelting capacity was founded on privileged access to stranded blocks of electric power. For many years, state-owned coal mines prospered because their government owners did not enforce nationally promulgated occupational, health, and safety regulations. All of these privileges give SOEs a huge competitive advantage.

Even though Beijing's support for its state-owned metal producers has contributed to the massive over capacity in the production of most metals, the government has sought to use its regulatory powers to constrain investment in new capacity. Though these regulations have been well intentioned, they ironically have had the unintended consequence of encouraging additional capacity. For example, at the turn of the century Beijing decreed that all Söderberg smelters and those with prebake technology rated at less than 160 kA were required to cease production. Rather than shut down, these small and highly polluting smelters invested in more-modern and larger capacity based on prebake technology. Another regulation required blast furnaces smaller than 400 m³ to close down; but rather than close, the reaction of iron makers was to invest in newer and larger blast furnaces to become compliant with the new regulations. Aggravating this unanticipated reaction was a decision by many of the smaller iron producers to convert their furnaces from the production of iron to producing nickel pig iron, tipping the market for that product into surplus, which in turn led prices to collapse and many plants to lose money.

III. POLICY IMPLICATIONS

China is now equipped with very large metallurgical plants that incorporate the world's most efficient technology. Much of this plant capacity was built at costs that Western competitors would find difficult to replicate. This caveat is important because industry associations, especially those that represent domestic steel and aluminum companies, have long protested against what they see as unfair competition from their Chinese rivals; but rarely, if ever, do they acknowledge the superiority of China's more modern and efficient metal-producing technologies. Often their

66. Anthony Chan, Jenny Zeng, and Brad Gibson, "China's economic policy risk becomes acute," <http://blogs.ft.com/beyond-brics/2016/08/17/chinas-economic-policy-risk-becomes-acute>.

complaints refer to an earlier period when China's industry was dominated by small energy-guzzling facilities that spewed toxic fumes that polluted the local environment. While such dangerous practices should be challenged, this paper has shown that they represent a small and declining proportion of China's metal-producing capacity.

The post-1978 restructuring of China's metallurgical industries is a prime example that competitive advantage is rarely enduring. A consequence of industrial development is that early entrants are replaced by new companies that have competitive advantages that enable them to outperform incumbents. Indeed, the basis for much of China's metal-producing capacity are plants that were transshipped from more-developed countries at very low cost precisely because the foreign owners realized they no longer had a competitive advantage.

The transient nature of competitive advantage also explains why many foreign companies have been reluctant to pursue legal remedies from Chinese rivals who have stolen or misused their proprietary technology. For example, Pechiney, the French aluminum company that is now part of Rio Tinto, has never taken action against its former Chinese partner for "reverse engineering" its world-leading proprietary technology. Other industries, particularly nuclear power and high-speed rail, provide further examples of large and reputable foreign companies that have willingly transferred their technology or else have not pursued equally large, but less-reputable Chinese partners that have misappropriated their technology. In almost all of these cases, evolving industrial structures driven by China's market dominance have deterred the foreign company from adopting a more aggressive defense of its technology.

The rapid growth of China's aluminum sector demonstrates that foreign timidity only hastens the growth of Chinese rivals. If foreign companies want to retain their competitive strengths, then they need to be more assertive in protecting their technical secrets. However, companies need to consider whether the costs of defending their technology exceed the benefits. In many cases the best strategy could be collaborating with rivals so as to take advantage of any complementary strengths. This policy has been embraced by several international companies that are now partnering with Chinese counterparts in emerging markets.

Much of the criticism leveled against Chinese metals producers is that as a result of Beijing's support they have built new capacity even when there is no economic justification and that such nonmarket forces have encouraged an enormous increase in new capacity. Because of the global nature of most metallurgical industries, critics argue that excess capacity in China has displaced production in other regions, resulting in localized job losses and even bankruptcies. While the logic of this argument is sound, the facts that justify the argument are questionable on at least two counts: first, China is not alone in subsidizing its metal producers, and second, irrespective of any government support, Chinese capacity is generally newer, more efficient, and cheaper to build than comparable foreign facilities.

Because of its detrimental effect on the U.S. aluminum industry, the Aluminum Association has long campaigned against China's wide-ranging support for its local smelting industry. However, for the past 30 years Alcoa, a prominent member of the association, has been able to keep its Australian smelters afloat by virtue of being a beneficiary of billions of dollars of Australian taxpayers' money. As with their Chinese rivals, Alcoa's Australian smelters have been propped up by governments, which fear the political consequences of closure. The similarity with China extends to siting of one Alcoa smelters, in Portland, which is remote and not a location normally associated with the energy-intensive aluminum industry. However, in the early 1980s when the smelter was built the government perceived an electoral advantage if it was constructed in Portland, so it funded a 500 km high-voltage power line that transmits electricity from remote power stations to the smelter. Furthermore, during the early years of its operation the smelter was seen to be a poor investment and the government saved the project by taking a small shareholding in the operation. The state

investing in an aluminum smelter is a characteristic of China's aluminum industry and something of which the Aluminum Association is particularly critical.

Government support for Alcoa's Australian smelters is not confined to Alcoa; Rio Tinto Alcan, another prominent member of the Aluminum Association, has long received government support for its smelters, particularly its Bell Bay operation in Tasmania. Similarly, in the United States, Alcoa has received hefty government grants to keep producing at its Massena and Ferndale smelters.⁶⁷

This brief study of Alcoa's Australian smelters suggests that China's support for its metal producers emulates long-standing Western practices that, though in decline, are more pervasive than China's critics would like to admit. Apart from being hypocritical, criticism of China's industry policies ignores the fact that after many years of sustained investment, China's metal producers are far more efficient than their foreign competitors, which operate with older and more-expensive plants. It is likely, therefore, that should China accede to foreign pressure that it no longer subsidize its metallurgical industry, Chinese plants would continue to produce quality metal at total costs (i.e., capital and operations) that are below most of its foreign competitors. It is for this reason that that much of the criticism of China's metallurgical industry is ill conceived and focuses on the wrong issues. In any event, such lobbying has been ineffective because it fails to acknowledge the difference between China's political economy and that of many of its Western critics. The growing strength of China's economy relative to that of its industrial rivals is another reason that China's critics need to reconsider their policies.

Business leaders, like army generals, usually fight the last war, and this is particularly evident in how foreign companies and their trade associations have reacted to the astonishing and rapid expansion of China's metal production. As a consequence of decades of rapid Chinese expansion, the demise of metal production outside of China, especially in the developed economies of Europe and North America, is now almost complete. There is no better example of this than the production of aluminum where, as recently as 1980, the United States was the world's largest producer; however, today the country is no longer competitive, with annual output tumbling from 4.64 mt (1980) to less than 0.8 mt. In 2001 there were 23 smelters in the United States, but currently there are five and only two of them are fully operational. Despite this massive contraction, the Aluminum Association has petitioned the U.S. government to penalize imports of primary aluminum from China.

The near death of aluminum production in the United States is symptomatic of many industries where a once-sophisticated production process has evolved into a low-entry barrier commodity business where more-competitive rivals challenge early entrants. In such situations, the usual response of incumbents is to withdraw to sectors where they have superior skills and other advantages that enable them to remain viable. Again, the aluminum industry provides a useful example. While production of primary aluminum in the United States has declined, consumption has increased as demand has grown for a new generation of value-added aluminum products, especially in the construction and transport sectors. In North America, downstream aluminum fabricators have experienced solid growth, more than offsetting the precipitous decline in aluminum production. The shift in market structure is illustrated by the recent separation of Alcoa into two independent companies—one an upstream company involved in the production of aluminum and the other a downstream company producing value-added rolled and engineered products. The downstream company—Arconic—is a member of the Aluminum Association; because its biggest cost is the aluminum it uses to make its high-value products, the company would be hurt if Washington agreed to the association's demands to penalize the entry of low-cost Chinese aluminum. Clearly this is a policy response that is no longer appropriate for the times.

67. Jessie McKinley, "Cuomo Reaches Deal to Keep Open Alcoa Plant in Upstate New York," *New York Times*, November 24, 2015; and Dave Gallagher, "Ferndale Intalco's smelter to stay open into 2018," *The Bellingham Herald*, May 2, 2016.

With the battle for upstream smelting having been lost to China, metal companies and their trade associations now need to develop strategies that reflect this changed situation. As with all business plans, the new strategy should seek to compensate for internal weaknesses by complementing the strengths of potential partners. The opportunity here is for downstream metal companies to form alliances with upstream Chinese metal producers. Again, aluminum provides a useful case study. Downstream fabricators such as Arconic might benefit from an alliance with a reliable Chinese supplier of competitively priced aluminum, while the Chinese supplier would benefit from a regular and reliable customer.

With the current global oversupply of aluminum, market power is with the fabricator and not the Chinese metal supplier. However, as in many other industries the downstream metal consumer's competitive advantage could quickly erode if the technology and "know-how" associated with the fabrication process and its product is shared with the Chinese metal supplier. This is more a matter of individual corporate discipline and less one of broad industry policy.

All this being said, trade remedies may be appropriate in certain circumstances. Downstream manufacturers and their industry associations need to be aggressive toward Chinese companies, especially when they dump product at below the cost of production, which is in breach of world trade rules. Similarly, industry associations need to publicly highlight and protest to government where Chinese metal products violate quality and safety standards or arrive with fraudulent labels and certificates. The resurgence of the U.S. aluminum extrusion industry is a response to such actions, which have resulted in duties averaging 33 percent but ranging as high as 400 percent on Chinese products. By 2009, China managed to capture 20 percent of the U.S. market, but duties imposed since 2010 have reduced their share to less than 1 percent.⁶⁸

IV. CONCLUSION

This paper has shown that in addition to strong support from the government, China's metallurgical industries have benefited by absorbing foreign technologies and then using indigenous development capabilities to improve operating performance. China's dominance of most metallurgical sectors provides ample evidence of the success of this approach. However, if China is to sustain its technical leadership it will need to adjust this model to one that encourages breakthrough technologies as against the incremental improvements that characterize the current model. Making this change will not be easy because China's current business culture punishes failure more than it rewards success, which is an environment not conducive to the judicious risk-taking that is essential for developing disruptive technologies. Further, China's obsession with secrecy and its reputation for the widespread theft of intellectual property constrain transnational collaboration. These factors will make it difficult for China to adjust its innovation model to one that can provide the technical solutions essential for sustained improvement. But even if the model can be changed it is doubtful whether it will be any longer possible to "make the foreign serve China."

Western industry and the policies of their governments need to adapt to this reality. Although trade remedies may be appropriate in some circumstances, more generally Western industry should focus on their evolving technological comparative advantages and cooperating with Chinese producers where appropriate.

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68. Chris Ray, "Why Australian Factories Are on Their Knees," *Sydney Morning Herald*, February 28, 2015.

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