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### **China Shifts Gears: Automakers, Oil, Pollution, and Development<sup>1</sup>**

This paper is about the rise of the automobile in China and the implications of the growth of passenger cars for oil consumption, emissions of conventional pollutants and greenhouse gases, and economic development. Determining how to contend with these competing pressures in China requires careful thought and attention. In order to resolve the seemingly incompatible goals of enhanced environmental protection, greater national security through fewer oil imports, and continued expansion of the manufacturing sector, China will be constantly “shifting gears” as it formulates new policies and economic development strategies in the years ahead. The development and deployment of cleaner and more energy-efficient automotive technologies will be essential to reconcile the needs for environmental protection, national security, and economic development in China.

The paper investigates the extent to which technology transfer through foreign direct investment is an effective mechanism for the deployment of cleaner and more energy-efficient technologies in developing countries. In particular, the international technology transfer from U.S. automotive firms to their Chinese joint-venture partners from 1984-2002 is evaluated through empirical case studies. There are three major Sino-U.S. joint ventures in the Chinese passenger car industry. In chronological order, these are Beijing Jeep, Shanghai GM, and Chang’An Ford.

A number of questions will be addressed in this paper. First, to what extent did U.S. firms transfer their cleanest automotive technologies to China from 1984-2002? Second, to what extent has the transfer of automotive technology contributed to Chinese economic development, including the development of more advanced Chinese capabilities in automotive technology? Third, how have the automotive technologies that were transferred affected human health and environmental quality in China? Fourth, what can be gleaned from the answers to these questions about the incentives for and barriers to further automotive-technology transfer? Finally, based on the research, what can be inferred about China’s ability to “leapfrog,” to advanced technologies with the help of technology transfer?

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## *Shifting Gears: Problems and Opportunities*

The Chinese automobile industry, perhaps surprisingly, is still young. As late as 1990, only 42,000 cars were being produced each year in China, compared with nine million in the United States. After the Cultural Revolution ended in the 1970s, Chinese firms lacked the technological capabilities to design and manufacture new cars, and so they turned to foreigners to acquire these advanced technologies, usually by forming joint ventures. The prospect of a thriving automobile industry in China was attractive to the Chinese government because such an industry could strongly contribute to economic development in China – and it was equally attractive to foreign investors because China appeared to be a new, untapped market with enormous potential for growth given China’s huge population.

As of 1980, there were some benefits to the scarcity of passenger cars in China. Cars were not major sources of urban air pollution in China. Also, Chinese cars did not consume huge quantities of imported oil, as they did in the United States. During the twenty years between 1980 and 2000, motor vehicles emerged as a leading source of urban air pollution in China. Partly because of the growth in automobiles, Chinese demand for oil soared, ultimately causing China to become a net importer of oil by 1993, the world’s fourth-largest importer as of 2004, and the second-largest consumer of oil in the world by 2005. The Chinese automobile industry took off economically, and in 2002, one million passenger cars were produced in China for the first time. China’s automobile industry (including autos, motorcycles, engine, and parts & component industries) employed 1.6 million workers, as of 2003 and accounted for about six percent of the total added value of manufacturing there that year (CATARC 2004). The one constant in the midst of this massive change is that Chinese firms continue to be very dependent on their foreign partners for advanced technology.

There is an exceptional opportunity in China to shift gears and alter the trajectory of automobile growth by transferring cleaner and more energy-efficient technologies to China. There are still relatively few passenger cars on the road in China – only about 16 million compared with 179 million in the United States as of 2004. Motor vehicle oil consumption in China is currently one-tenth that of the United States, greenhouse-gas emissions from automobiles are still relatively modest, and the increasingly severe urban air pollution could be reversed through pollution control measures.

During the 1990s, sales in new automobiles grew on average 27 percent annually, resulting in a doubling in the number of passenger vehicles on the road every two and a half years (see Figure 1). The opportunity lies in taking advantage of such growth by installing, in every new car that is sold in China, the cleanest and most energy-efficient of the automotive technologies that are already sold commercially in the United States, Japan, and Europe. If this were done, urban air pollution could be minimized, a substantial part of the projected emissions of long-lived climate-altering greenhouse gases from the Chinese automobile sector could be averted, national oil imports could be contained, and the Chinese automobile industry could continue to flourish, contributing to China’s steady economic development. Thus, this paper aims to determine how the chances of this outcome could be increased based on an understanding of the historical record.

## Terminology

A number of terms will be used in this paper that should be clearly defined at the beginning. First and foremost, the term “automobiles” is defined to include passenger cars such as sedans and hatchbacks, and light trucks such as sport-utility vehicles (SUVs), pick-up trucks, minibuses, and minivans. The term does not include large buses, heavy trucks, trains, or airplanes. Occasionally, the term

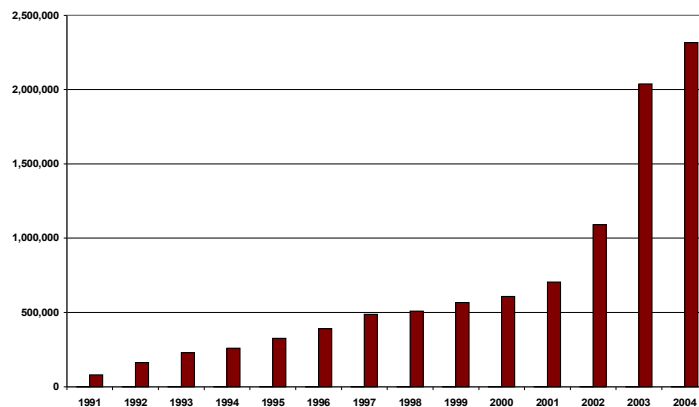
“motor vehicles” is used, and this term does include buses and trucks. Light trucks are not commonly used as passenger cars in China, but increasingly, minivans and sport-utility vehicles are being marketed to the Chinese consumer as passenger cars; two of the U.S. firms operating in China now produce sport-utility vehicles.

It is also important to clarify what is meant by “cleaner” technology. An automobile can be made cleaner and more energy-efficient through a combination of three measures: reducing tailpipe emissions of air pollutants, improving fuel efficiency, and using cleaner fuels. Tailpipe emissions of common air pollutants including nitrogen oxides (NO<sub>x</sub>), carbon monoxide (CO), and hydrocarbons (HC) are usually controlled through catalyst technology and on-board diagnostic (OBD) systems. Cleaner fuels – such as unleaded, low-sulfur, and compressed natural gas – can also contribute to reducing some of the harmful emissions of pollutants from an automobile. Emissions of the key greenhouse gas, carbon dioxide (CO<sub>2</sub>), can be reduced to some extent from switching from petroleum-based fuels to alternative fuels, and net carbon emissions can also be reduced by using alcohol fuels derived from biomass (which removes carbon dioxide from the atmosphere when the crops are growing). Electric vehicles and vehicles powered by fuel cells operated on hydrogen are sometimes described as being completely clean, but their overall cleanliness depends on how the electricity or hydrogen is obtained. Today, hydrogen is usually produced from natural gas (with an associated release of the greenhouse gases to the atmosphere), and most electricity in China is generated by burning coal. In China, hydrogen would also probably be produced from coal. Of course, whatever the origin of the primary energy for vehicle propulsion, increasing the energy efficiency of the automobile can not only reduce oil consumption, but also reduce greenhouse-gas and the release of conventional pollutants as well. Finally, the term, “technology transfer” must be defined. Technology is understood to encompass both tangible goods or products, such as machinery, and tacit information, such as skills and knowledge (Grubler 1998). International technology transfer is thus the transfer of hardware, such as tooling for factories, and also the transfer of intangible assets such as product design and the capability to manufacture a product. Brooks argues that technology transfer is “a way of linking knowledge to need,” and that it is a process of cumulative learning (Brooks 1995). This succinct definition of technology transfer illuminates several important characteristics of technology transfer. It affirms that

Figure 1

### Passenger Car Production in China (1991-2004)

Data Sources: CATARC, 2004 Auto Industry of China; China Auto (Jan. 2005)



technology should be conceived as knowledge (Kranzberg 1986), and that technology transfer is a process of communication and education on the part of all parties involved. Martinot, Sinton, and Haddad agree that “technology transfer is fundamentally a process of learning” (Martinot, Sinton et al. 1997).

### *Methodology*

Most of the empirical data were gathered through extensive interviews in the United States and China with government officials, firm representatives, and relevant experts. In total, from 1999-2003, 90 people were interviewed, occasionally multiple times. All but two of the interviews were conducted in person, and the exceptions were conducted by telephone. The majority of the interviews were conducted during the summer of 2002, at which time the relevant factories in China were visited. In China, interviews were conducted in Beijing, Tianjin, Shanghai, Chongqing, Ningbo, and Shantou. In the United States, interviews were conducted in Detroit, Ann Arbor, Cambridge, and Washington, DC. As a rule, interviewees with Chinese citizenship are not identified by name to protect confidentiality, but the date and location of the interview and affiliation of the source are usually provided. Numerical data about the automobile industry in China were obtained from the China Automotive Research and Technology Center (CATARC) in Tianjin. Government documents, newspaper and magazine articles, and scholarly books and articles are also referenced.

### *The Energy and Environmental Dimensions of Cars in China*

#### Energy

Ask almost any urban Chinese citizen if he or she would like to own a car, and you will surely get an affirmative answer. In the last decade, the prospect of attracting millions of Chinese car buyers has propelled both foreign and domestic auto manufacturers to pour billions of dollars into developing a vibrant automobile industry in China. Yet, as automobile production surged upward during the 1990s, questions started to arise, both within China and internationally, about the implications of such explosive growth in the Chinese automobile industry (World Bank 1997; Shao and Zhang 2001; EIA 2001a). In particular, the connections and trade-offs among economic development, energy use, and environmental quality began to be discussed.

Today, with 20 percent of the world’s population, Chinese citizens still own just 1.5 percent of the total number of cars in the world. This is in stark contrast to the situation in the United States where with only 5 percent of the world’s population, U.S. citizens own 25 percent of the world’s cars. In other words, China currently has about the same number of cars per person as the United States did in 1913 (Davis and Diegel 2002).

Passenger cars do not currently consume very much energy in China because there are still relatively few cars on the road; most of the related energy concerns arise when one thinks of future automotive oil consumption. As of 2002, the entire transportation sector only consumed 7 percent of commercial energy supply (EIA 2002). In 2003, motor vehicles consumed 1.2 million barrels per day, about one-third of total Chinese crude oil production (CATARC 2002; EIA 2002). Rising oil consumption emerged as a major concern when China became a net oil importer after 1993. China only

holds 2 percent of world oil reserves (BP 2004), so traditionally oil was mainly used in industrial boilers. Partly because of the rising popularity of automobiles, both oil consumption and oil imports grew rapidly during the 1990s. By 2000, total Chinese automobile oil consumption equaled total oil imports at about 1.2 million barrels per day (Xu 2002).

As of 2004, imports had risen to 2.4 million barrels per day (compared with 10 million barrels per day for the USA) making China the fourth-largest oil importer in the world after the United States, Europe and Japan. China already imports a greater percentage of its oil from the Middle East than the United States. More than half of China's current oil imports come from the Persian Gulf region compared with just one-quarter of U.S. imports. Given its increasing dependence on the Middle East, China has predictably signed major oil exploration and production contracts worth billions of dollars with a number of foreign countries including Peru, Sudan, Iraq, Venezuela, and Kazakhstan during the past ten years to assure itself of oil supplies into the future (Xu 2000b).

### Environment

More people are killed and injured by automobiles in China than anywhere else in the world with 680 people killed and 45,000 injured daily (Economist 2005). Other than car accidents, the most immediate health and environmental problem related to automobiles in China is urban air pollution, although carbon emissions from automobiles in China will likely be a major source of global climate change in the future absent aggressive policy intervention. There is increasing evidence that motor vehicles are now a leading cause of urban air pollution in China, which was not the case even a decade ago (Pan 2004). Heating, cooking, power generation, and industrial coal consumption used to be the main contributors to urban air pollution, but during the 1990s, coal was replaced by natural gas in many urban buildings and homes. Power plants are still a significant source of urban air pollution as well, but many plants are being relocated outside of the cities. Seven of the ten most polluted cities in the world are located in China caused in great part by growing auto emissions. Monitoring data from 388 Chinese cities shows that only 31 percent can meet the Chinese standards for air quality (WHO 2004). Some city-specific data:

The high emissions from autos in China are mainly the result of inadequate emissions-control regulations. Prior to 2000, emission standards for automobiles did not exist, leaded fuel was still widely used, and catalytic converters were not installed on cars. Starting in 2000, China banned the use of leaded fuels, required the installation of catalytic converters, required that all automobiles contain electronic fuel-injection engines, and adopted the European system for controlling automobile emissions. Beginning in 2000, all new automobiles had to be able to meet EURO I standards, which were required of European automobile manufacturers in 1992. Automobiles sold in the big cities, such as Beijing and Shanghai, were required to meet EURO II standards. In 2004, China required automobiles to meet EURO II standards, which was the European level as of 1994. In 2005, automobiles sold in Beijing and Shanghai had to meet EURO III standards, and in 2007, the whole country is scheduled to go to EURO III levels. In 2010, EURO IV standards should take effect. Thus, Chinese air pollution standards generally lag European levels by ten years, although more rapid progress is being made in some large coastal cities. Chinese standards for gasoline and diesel passenger cars lag

U.S. levels even more, because air-pollution emission standards are still more stringent in the United States than in Europe, especially with respect to particulate emissions.

In 2004, the Chinese government approved the country's first fuel-efficiency standards for passenger cars. Concern about rising oil imports and energy security was the main motivation for the government to pass these standards. These standards took effect in July 2005 for all new passenger cars, SUVs, and MPVs less than nine seats. There are separate standards for automatic and manual transmission vehicles. Unlike the Corporate Average Fuel Economy (CAFE) system in the United States, the Chinese issued maximum fuel consumption limits for 16 different weight classes. Standards will be tightened again in 2008, and at that point, it is estimated that most passenger cars weighing more than 3,500 pounds will not be able to meet the second phase of the standards without significant technological improvements (An 2003). In other words, the 2008 version of the standards will be considerably more stringent than the U.S. CAFE standards as of 2005, especially for sport-utility vehicles and light trucks. The goal of the Chinese government was to discourage the use of heavier, larger vehicles as individual passenger cars. On a fleet-wide average basis, China's fuel efficiency standards will be approximately 50 percent more stringent in 2008 than the U.S. CAFE standards in place in 2005, but less stringent than the equivalent Japanese or EU standards (An 2004).

The new fuel efficiency standards are also likely to provoke transfer of more fuel-efficient technologies from foreign car manufacturers to China, although the standards are not so strict that they will motivate transfer of truly advanced technologies such as hybrid-electric cars.

### *The Auto Industry and Economic Development*

The automobile industry that emerged during the 1990s in China has greatly contributed to economic growth there. Chinese government policy and foreign direct investment both played important roles in the transformation of a backwards, small, weak industry with few capabilities to today's industry which is was the third-largest in the world as of 2005. At this point, the main contributions of the auto industry to the Chinese economy are in terms of output and employment, but it was not clear that this industry has gained skills beyond manufacturing, parts localization, and limited design capabilities. Inconsistent and occasionally weak Chinese government policies, the lack of incentives for foreign manufacturers to teach their Chinese counterparts more about technology and design, and China's entry into the WTO have all combined to limit the potential of this industry. Still, the Chinese automobile market has proven itself to be the most dynamic and explosive in the world for the last decade and the potential exists for this growth to continue virtually unabated.

In 1994, the Chinese government designated the automobile industry one of the "pillar" industries of economic development. Undoubtedly, the Chinese government's decision to make the automobile sector a mainstay of the economy greatly contributed to economic development in China, especially with respect to employment and output. There were 1.6 million Chinese employed by this industry as of 2003. The value added by the Chinese auto industry represented six percent of the total value added of manufacturing in China in 2003, a near doubling of this percentage from its level in 1990 (CATARC 2004).

Foreign direct investment in the automobile sector has contributed to the economic success of this industry in China in a number of ways. First, it has created

desirable and stable jobs for Chinese workers in the joint-venture firms. Second, this investment has strongly benefited the wider economy because the Sino-foreign joint ventures have created a strong source of demand in China for raw materials and automotive parts and components. In 1994, the Chinese government imposed “localization” requirements on the Sino-foreign joint ventures, which forced them to use a certain percentage of Chinese-made parts in their automobiles. Many of the Chinese suppliers were initially unable to meet the standards of the foreign firms, so the foreigners worked with Chinese suppliers to improve the quality of their products. Once the suppliers learned how to enhance their products, they began to export them to other markets, which allowed them to expand production and lower unit costs. Overall, these “backward linkages” from the Sino-foreign joint ventures and the Chinese automobile industry in general are increasingly contributing to economic growth in China. By the mid-1990s, the Chinese auto industry was providing the demand for 5-6 percent of total steel production, 80-90 percent of petroleum products, 14-16 percent of machine tools production, 50 percent of tempered glass production, 45 percent of tire production, 15 percent of engineered plastics production, and 15 percent of paint production (CATARC 2001).

As of 2005, twelve foreign-invested joint ventures dominated the Chinese domestic passenger car market, with about a hundred small firms on the periphery. The foreign-invested joint ventures accounted for most of China’s passenger car production. There are currently twelve major Sino-Foreign joint ventures: Shanghai VW, FAW-Volkswagen, Shanghai GM, Dongfeng Citroen, Dongfeng Nissan, Dongfeng Kia, Guangzhou Honda, Chang’An Suzuki, Chang’An Ford, Beijing Jeep, Beijing Hyundai, and FAW-Tianjin-Toyota.

### *Three Case Studies: Beijing Jeep, Shanghai GM, and Chang’An Ford*

To explore the stated research questions empirically, three case studies of foreign investment into the Chinese auto sector were conducted primarily through the use of interviews. The cases examined were the three main joint ventures between U.S. and Chinese firms: Beijing Jeep, Shanghai GM, and Chang’An Ford. It is not possible to examine these case studies in detail here, but a brief description of each case follows.

Beijing Jeep was the very first joint venture of any kind between an American firm and a Chinese one, and it was the very first automotive joint venture in China. The agreement was originally signed in 1983 between American Motors Corporation (AMC) and Beijing Auto Works (BAW), but Chrysler took over the joint venture when it merged with AMC, and then DaimlerChrysler took over the venture when Daimler merged with Chrysler. The two main products of Beijing Jeep for many years were the BJ212 (later the BJ2020) and the Jeep Cherokee. The BJ212 technology was donated to China by the Soviets back in the 1950s and transferred to Beijing Auto Works after the Cultural Revolution. The Cherokee was transferred to BAW by AMC.

Beijing Jeep was a troubled joint venture throughout the period studied (1984-2002), in large part because it was the pioneering joint venture, the first of its kind. Many lessons were learned on both sides of the Pacific from this company. In terms of technology transfer, AMC initially transferred the Cherokee to China in complete knock-down kits for assembly. The Chinese were dissatisfied because they did not learn much through the assembly process, and also because they had hoped a new vehicle would be designed to meet Chinese needs. Given that they were sport-utility vehicles, the products

were not very fuel-efficient, and the Americans did not transfer pollution-control technology until required to do so by the Chinese government in 2000.

Shanghai GM is a joint venture between GM China and the Shanghai Automotive Industry Corporation (SAIC). Among the three big U.S. investments in China's auto industry, it has been by far the most successful – attaining the position of third-largest passenger car producer in China in 2005. The joint venture was signed in 1997, not long after the Chinese government issued its first automotive industry policy. The first product that GM transferred to China was a version of the Buick New Century (or Regal) sedan, soon followed by a second, more affordable, small car called the Buick Sail (a version of the Opel Corsa). GM brought significantly more advanced technology to the Chinese market, and thus spurred significant competition within the Chinese auto industry as other foreign firms were then compelled to do the same. GM improved the fuel efficiency of the Buick Regal sedan to meet the consumer preferences in China, and also transferred pollution-control technology to meet the Chinese emissions standards, but GM did not go beyond the standards required. Since 2002, Shanghai GM has introduced a number of new models and established new factories.

The final joint venture examined by this study is Chang'An Ford. This joint venture was signed after China had signed the agreement with the United States for Permanent Normal Trading Relations (PNTR), which paved the way for China's entry into the WTO. PNTR removed many of the restrictions that the Chinese government had formerly imposed on foreign investors, a critical factor in Ford's decision to sign the joint venture agreement. Ford originally decided to transfer a version of the Ford Fiesta, a rather dated technology that was in production in India as the Ikon. This was the only model that was in the works during the period studied. Since 2002, Ford has built a second plant to produce the Ford Focus in light of the fact that the Fiesta did not sell well in the Chinese market.

### *Findings*

If the Chinese wish to deploy substantially cleaner and more efficient automobiles in China, they face a fundamental choice about the extent to which they “make” or the extent to which they “buy” the cleaner technologies. Historically, the Chinese were forced to buy conventional automotive technologies from abroad because their own technological capabilities were limited. The idea was that they would learn through technology transfer and gradually acquire their own technological capabilities, eventually attaining some self-sufficiency (Harwit 1995). China finds itself in a similar predicament today because it lacks the advanced technological capabilities needed for advanced and energy-efficient clean-vehicle development and deployment. Based on its past experience, is it wise for China to rely on a strategy of technology transfer to acquire cleaner automotive technologies from abroad? If so, which cleaner technologies should China purchase from abroad, and which ones should China try to make domestically? To answer these questions, lessons can be derived from analyzing the three U.S.-China automobile joint ventures from 1984-2002: Beijing Jeep, Shanghai GM, and Chang'An Ford.

Based on the empirical evidence from these cases, there are three main findings that emerge from this research:

- U.S. firms transferred outdated automotive pollution-control technologies during the 1980s and 1990s to China because no Chinese policies were in place to require cleaner or more energy-efficient technologies.

- To some extent, U.S. foreign direct investment helped to deploy cleaner automotive technologies in China than those that were in use before, but the potential environmental benefit of the newer technologies is being offset by the growth in the number of cars on the road.

- Automotive technologies that were transferred were not necessarily updated in tandem with updates made to equivalent foreign models, again due to lack of incentives (policy or otherwise) to do so.

One further important implication can be drawn from this study: leapfrogging to substantially cleaner automotive technologies through technology transfer from foreign firms is likely to be quite challenging for the Chinese automobile industry without serious effort to align incentives to provoke cleaner and more efficient automotive production and consumption.

### *Policy Implications*

There is no single best practice that the Chinese government and firms could employ to enable China to leapfrog to the technological frontier of clean automobiles; a combination of government policies, regulations, and non-governmental initiatives is required. The main lesson from this study is that it would take a coherent, concerted, consistent, and long-term effort of government, industry, and civil society cooperation to achieve such a goal. China's failure to "catch up" with the world level in conventional automotive technological capabilities is not a result of some inherent inability to do so. When China tries hard to become a world leader in a given sector, it has shown that it is capable of achieving that goal. Consider that China launched a manned rocket into space in 2003 and that China has developed its own domestic nuclear power designs. China's failure to develop the capabilities to design and produce world-class automobiles, much less leapfrog to hybrid-electric cars, can only be attributed to a lack of effort. In the short to medium-term, a case might be made that China should concentrate on providing conventional but good alternative transportation options such as rapid bus transit while working to leapfrog to the most efficient, cost-effective, low-polluting commercially-viable automotive technologies available (such as hybrid-electric vehicles). In a best-case scenario, total vehicular Chinese oil consumption could readily be contained to less than one million barrels per day of oil consumption in 2020 through such measures, with related environmental and fuel-efficiency benefits. There is no reason that China needs to follow the practice of the United States with respect to fuel efficiency, which is essentially to delay the adoption of even more stringent fuel efficiency standards in hope that a big technological "breakthrough" will eventually provide a magical solution. Although initial fuel efficiency standards in the United States were passed, these Corporate Average Fuel Economy standards have not been tightened since the 1980s, but billions of dollars have been spent on public-private partnerships like the Partnership for a New Generation of vehicles and the current FreedomCAR program, with no widespread deployment of more efficient automobiles. Meanwhile, the U.S.

automobile manufacturers association claims that the fuel-efficiency of automobiles has improved, on average, about two-percent each year. Automakers have not used those fuel savings to improve fuel-efficiency. Instead, they have used the savings to increase vehicle weight, power, and the number of accessories. In contrast, the U.S. government continuously required automakers to reduce tailpipe emissions, and as a result, automobiles currently sold on the U.S. market emit remarkably few criteria air pollutants.

If China decides to go for the full leapfrogging strategy, it must approach the task comprehensively. China would need to improve its education system generally, and specifically the education of its automotive engineers. It would have to send its most promising workers overseas to study, and devise a strategy for luring those experts back to China to work in the industry. The Chinese government would have to promulgate policies to help foster a market demand for cleaner automobiles, such as raising the price of gasoline and implementing performance standards for air pollution and fuel efficiency that are continuously made more stringent over time. The Chinese government would have to force its domestic manufacturers to “learn by doing” increasingly on their own, without relying so heavily on the foreign manufacturers. And, China would probably have to start developing capabilities in clean vehicle components, such as automobile-scale fuel cells, until the Chinese producers acquire good enough system integration capabilities to fully participate in the innovation process – from invention to deployment – extracting “first mover” profits from their brilliant innovations. Specific policy recommendations are provided next.

Chinese government policies and regulations are the most direct incentive for eliciting cleaner and more energy-efficient technology transfer to China. This study documented that when the Chinese government passed the first tailpipe emissions standards for automobiles in China, the U.S. joint-venture partners immediately transferred the requisite pollution-control technologies to bring their products into compliance with Chinese regulations. Representatives from all three of the U.S. manufacturers said in interviews that if the Chinese government passed a more stringent environmental law, the joint venture would certainly find a way to comply. Current Chinese environmental laws are not providing sufficiently strong incentives to provoke the transfer of the most appropriate, cost-effective, and cleaner automotive technologies. Not only are more aggressive Chinese emission and fuel-efficiency standards needed to elicit cleaner technology transfer, but these standards must also be implemented consistently and enforced vigorously. The lack of a strong inspection and maintenance regime in China will permit non-compliance with automotive emission standards. Another reason why performance standards need to be set, maintained, and scheduled into the future, is that they provide a rationale for Chinese firms to bargain for cleaner technologies from their foreign partners.

The absence of any Chinese fuel-efficiency policies or standards caused China’s oil imports for motor vehicle consumption to increase rapidly until 2005 when the first fuel-efficiency standards for automobiles were set. The standards set for 2005 and 2008, while good first steps, will not provoke the transfer of significantly more fuel-efficient technologies such as hybrid cars because the standards are not that stringent. Indeed, although the 2005 and 2008 standards are tighter than the 2005 U.S. corporate average fuel economy standards, they are not nearly as stringent as the 2005 fuel economy standards in Japan and the European Union (An 2004). Aside from further tightening the fuel economy standards, the Chinese government could spur more demand for fuel-efficient automobiles among consumers by using fiscal tools such as tax incentives or

increasing the price of gasoline in China (perhaps through a carbon tax, which would have the added benefit of targeting greenhouse-gas emissions), another initiative that the U.S. government has failed to undertake thus far. The Chinese government has approved the imposition of a fuel tax in principle, but it has never implemented this tax (People's Daily 2003b). It is almost inconceivable that U.S. firms would flout such regulations because it would be so embarrassing for the U.S. companies to fail to meet Chinese laws. Such regulations would create clear incentives to transfer cleaner and more efficient automotive technologies to China.

Other performance standards besides fuel efficiency standards that are still needed to provoke the transfer of substantially cleaner vehicle technologies include standards for lower sulfur fuels so that emissions-control equipment will work properly in passenger cars. The lack of cleaner fuel was cited by U.S. manufacturers as a key reason why they did not transfer more advanced pollution control equipment to China. In 2005, the Chinese government set a schedule for future pollution control regulations from automobiles, so the focus for pollution control must now shift to cleaner fuels, enforcement of all these standards, and improving enforcement, inspection, and maintenance programs.

A second method for creating incentives for cleaner technology transfer is through the Chinese government's education policies and government-sponsored R&D programs. It has been confirmed that comprehensive educational systems play major roles in the assimilation of industrial knowledge (Rosenberg and Frischtak 1985; Sharif 1989). Innovative, capable workers need to be fostered through the education system generally, and then specialized workers need to be given the opportunity to learn-by-doing. The most promising automotive engineers need to be sent overseas for training, and then lured back to China to work in the industry. In the case of Korea, for example, it was the government's large investments in human resource development that facilitated Korea's ability to acquire technological capabilities rapidly (Kim and Dahlman 1992). As one analyst notes, "Without adequate human capital or investments in R&D, spillovers from FDI may simply be infeasible" (Saggi 2002, 229). Such public investments would not only strengthen Chinese capabilities, but would also increase the bargaining power of Chinese firms at the negotiating table with their foreign partners.

If Chinese automotive engineers are innovative and capable of automotive design, the need of the Chinese automobile firms for their foreign partners will slacken. The Chinese Ministry of Science & Technology (MOST) has demonstrated vision and determination to develop and deploy cleaner vehicles in China with its "863" high-tech research program on electric, hybrid-electric, and fuel cell vehicles. Enhancing the resources of this program (and continually working to improve it) will only fortify Chinese capabilities for cleaner automotive production in the future. Along with government-sponsored R&D, the Chinese government could also create incentives for the Chinese firms to become less reliant on foreign technology, and more innovative in their own right.

So far, market competition is proving to be a "double-edged sword" for China in the automobile sector. In many respects, the Chinese government's decision to lower trade barriers and foster increased competition in the domestic market should be credited with helping to modernize the industry. As demand for better automobiles soared in the 1990s, certain foreign manufacturers such as General Motors began to introduce newer, more attractive, models into China, and this provoked the other foreign manufacturers to do the same. None of the newer models, however, came with the best-available,

advanced, pollution-control technology for the reasons discussed in this study. Purely domestic Chinese manufacturers have been severely challenged by this competition. Some, like Chery and Geely, have responded to the competitive challenge, and are beginning to produce automobiles that are competitive within the Chinese market (but are not yet export-quality). Other Chinese firms are failing, and when they fail, jobs are lost, with all the related social repercussions.

Aside from issuing better performance standards for emissions control and fuel efficiency, the Chinese government should also re-assess its industrial policy for the auto sector. Because of China's many concessions to gain entry to the WTO, it is now prohibited from using many of its former tools for industrial development. During the 1980s, the lack of a well-defined policy for the automotive sector caused continued Chinese reliance on foreign technology. Once the Chinese government articulated an industrial policy in 1994, much more progress was made in acquiring better technological capabilities. Now that China has become a member of the WTO, it must consider which policy tools remain at its disposal for the cultivation of knowledge-based assets that will contribute to the future development of the industry. Such assets – the skills necessary to create new products or processes (Amsden 2001) – are essential for the further development of China's automobile industry.

### *Implications for Theory*

The findings of this study have several implications for theory. These implications are summarized here:

- (1) There is little evidence in the case of U.S. technology transfer to the Chinese automobile industry for many of the leading hypotheses about the relationships between environmental policy, international trade, and foreign direct investment (including the pollution-haven, pollution-halo, race-to-the-bottom, and stuck-in-the-mud hypotheses).
- (2) There appear to be some practical “limits to leapfrogging” to substantially cleaner vehicle technologies through technology transfer from foreign firms in joint-venture arrangements. These barriers can be overcome through international investment rules, U.S. and Chinese policy, and the goodwill of foreign firms, but probably most effectively by Chinese regulations.
- (3) If technology is defined to include knowledge, foreign direct investment is not automatically an effective mechanism for technology transfer. Although many discrete technologies were transferred, Chinese firms acquired little “how-to” tacit knowledge from their U.S. joint-venture partners. If Chinese firms are not acquiring more advanced technological capabilities through their partnerships with foreign firms, they are not accumulating knowledge-based assets, which are considered to be fundamental for strong economic development.
- (4) Foreign direct investment is also not automatically an effective mechanism for transferring cleaner technologies to developing countries. Proponents of FDI argue that along with the actual investment, FDI brings modern technologies, and cleaner products and practices. The evidence in the case of the Chinese auto industry is that U.S. FDI did not bring substantially cleaner automotive technologies to China until they were required

by Chinese pollution-control regulations. As of 2005, none of the U.S. firms had transferred pollution-control technology to China comparable to what they produce and use in the United States.

(5) Although U.S. firms transferred slightly cleaner technologies to China, the huge growth in the number of automobiles on the road vastly outweighs the potential technological benefit of these cleaner technologies. This means that the “scale” effect of producing so many more cars outweighs the “technique” effect of transferring slightly cleaner technologies.

(6) The role of the state in technology transfer for industrial development appears to be very important. Chinese policy (or at times, its lack thereof) strongly affected the nature and extent of technology transferred to China from U.S. firms.

(7) The most important incentives for cleaner automotive technology transfer in these cases were market competition and Chinese government regulations. The most inhibitory barriers to cleaner automotive technology transfer were the lack of Chinese pollution-control and fuel-efficiency regulations, poor fuel quality, weak bargaining from Chinese firms, a vicious circle related to domestic competitiveness (or a marriage of convenience between the Chinese government and foreign auto companies), and a politically-powerless environmental movement.

### *Implications for Future Research*

This paper provides an analysis of firm-level technology transfer from the United States to China in the automobile industry from 1984-2002. Aside from updating this study in future years, there are two obvious comparative studies that would complement this research. First, it would be interesting to compare U.S. automotive technology transfer to China with U.S. automotive technology transfer to other developing countries with relatively large automobile markets, such as India, Mexico, and Brazil. This comparative analysis would allow the barriers and incentives to cleaner automobile technology transfer that were identified by this study to be tested in other developing country contexts. Alternatively, U.S. automotive technology transfer to China could be compared with Japanese and European automotive technology transfer to China to test whether other foreign firms have transferred cleaner technologies to China than the U.S. firms, and why (or why not).

Although not a big focus in this research, the apparent success of the Chinese automotive parts and components industry is intriguing because these Chinese supplier firms appear to have acquired more advanced capabilities than total-manufacturers in China. Why have the parts and components firms become more innovative than the big auto firms? My hypothesis is that Chinese government local content policies caused foreign firms to work with Chinese suppliers to bring their products up to specification, and so the foreign firms were forced to teach these suppliers.

Another tantalizing question that arose during the course of this research was why U.S. firms were more interested in funding R&D activities at the Chinese universities rather than within their own joint ventures in China. Are the universities more innovative than firms in China? Does this practice indicate that U.S. firms trust university researchers more than they trust their manufacturing partners? What are the connections between Chinese universities and firms for technological innovation, and how could they be improved?

Finally, this study provides a preliminary analysis about the barriers and incentives for China to leapfrog to cleaner technologies, such as hybrid-electric or fuel-cell vehicles using a strategy of acquiring these technologies from foreign firms through technology transfer. A more detailed and comprehensive analysis of this topic is still warranted, especially to support the creation of policies that will facilitate this leapfrogging.

### *Conclusion*

This paper has documented that even though cleaner alternatives existed in the United States, relatively dirty automotive technologies were transferred to China during the 1980s and 1990s. In order for leapfrogging to significantly cleaner technologies in China to become a reality, either the foreign firms have to be compelled to transfer their cleaner technologies, or the Chinese firms have to develop their own capabilities for clean automobile development and production. There is little evidence that either alternative will happen soon unless policies are formulated and implemented to create the necessary incentives for the foreign and Chinese firms to change their past behavior.

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