Technical Self-Sufficiency, Pricing Independence: A Penrosean perspective on China's Emergence as a Major Oil Refiner since the 1960s

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Abstract

International embargos and the withdrawal of Soviet technical expertise had by the early 1960s effectively engrained China's approach to energy and technical self-sufficiency. Chinese officials cited reasons similar to those advanced by Edith Penrose in her critique of the international oil companies (IOCs) investments. Drawing on Penrose's approach this paper shows that although self-sufficiency led to significant progress in primary capacity, self-sufficiency had to be reconciled with increasing demand for more complex petrochemicals. Modernization increased China's reliance on the IOC's technology and reduced pricing independence, confirming a historical regularity in the market imperfections underpinning the power of the IOCs.

Keywords: Penrose, International Oil Firms, National Oil Companies, China, Petroleum Industry

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The international oil companies (IOCs) have long had a controversial relationship with the oil industries of the developing economies. The IOC's competitive and technical advantages meant that they were ideally positioned to finance oil industry modernisation, while National Oil Companies (NOCs) from developing economies have long struggled to attain similar capabilities.[1] The distributional effects of this were extensively described in Penrose's analysis of the oil industry.[2] Penrose showed that the dominance of the industry by seven major firms did not emerge as a result of perseverance in exploration but rather as a result of policies favouring the oligopolistic firm. Competitive markets allowed these integrated oil firms to use internal transfer pricing to capture welfare gains from falling prices. As converters of crude oil into a wide variety of finished and intermediate products, oil refineries play a crucial but under researched role in this process.[3] This raises an interesting question regarding whether state-owned refineries allow developing economies to capture a greater share of the gains that Penrose viewed as typically accruing to the IOCs. As a country that has long been reluctant to embrace markets or the IOCs as a solution to energy security, China offers a fascinating test of this.[4] Between 2000 and 2014, China increased its share of global refining capacity from 6.5% to 14.6% making it the world's second largest oil refiner.[5]

While many have expressed frustration regarding the pace of liberalisation in China's oil sector, the value of Penrose's approach is that it cautions against judging the policies of developing economies based on developed market assumptions regarding the benefits of foreign investment.[6] Instead Penrose argued that the focus should be on the vehicle for such investments, namely the large international firm. In the refining sector, of which this paper is concerned, large firms such as Exxon Mobil, Chevron and Total, and chemical producers like Lummus and Dow have had a longstanding influence on the price of feedstock for many domestic and industrial processes as well as the availability of technology. These firms have also resisted the gradual succumbing of the centralised management of vertically integrated production processes to specialisation.[7] Economies of scale in the sector have historically come from organisational and technological innovations that increased the speed of throughput rather than incremental additions of labour and machines.[8] This has helped the IOCs resist specialisation and divestment, allowing them instead to relocate capacity from slowing European markets to emerging markets in Asia.[9]

The development of China's oil refining sector is heavily intertwined with the above events. Following the outbreak of the Korean War in 1950, US and UK firms were instructed by their governments to suspend oil sales to China. In 1951, the PRC began the requisition of the properties of large British-American owned oil companies including the Shell Company of China, the Standard Vacuum Oil and the Texas Company (China), bringing them under local management.[10] Shell and British Petroleum (BP)) retained sales departments and offices, but by 1966 these were closed as the companies faced increasingly unfavourable trading terms.[11] China initially turned to the Soviet Union to provide technical expertise in refinery construction, a relationship which effectively ended following the Sino Soviet dispute. These events engrained a belief that China could outpace developed countries by self-reliance and "making foreign technologies serve China" (Peking Domestic Service, October 29, 1977). Chinese officials believed that the IOCs profited by plundering domestic oil resources and reselling them at inflated prices and openly sided with the Arab producers in their dispute with the developed economies.[12]

Ideological beliefs did not however obscure the demand for advanced refining technology in both primary and intermediate refining. A particularly important example of the latter is ethylene, which can be further refined into PVA (a key ingredient in polyester), fibres and resins, and propylene (a key input in the production of a range of plastics and rubbers). Unlike light-end products like diesel and gasoline; ethylene depends on the further refining of primary feedstocks using advanced steam cracking. Ethylene's usefulness in manufacturing meant that it featured prominently in planning targets. Although China possessed the coking and fluid catalytic crackers for primary distillation, the same was not the case for ethylene. By the 1980s China's ethylene capacity was less than 10% of US capacity and by 1996 this had barley increased to 13%.[13] Progress in ethylene capacity therefore provides an important benchmark of technical progress in intermediate refining. Primary refining also faced technical challenges. This was mostly due to the homogenous nature of domestic crude. This meant that refineries were configured to refine low sulphur and sweet domestic crude types, but not imported high sulphur sour crudes.[14] Increasing oil imports from the Middle East required the addition of desulphurization units.[15]

While plant imports in the 1970s addressed shortfalls in primary capacity, they did not address the shortage in intermediate capacity.[16] Neither did they anticipate the commercial and technical challenges associated with importing an increasing proportion of sour crudes after China became a net oil importer in 1993. The implication was that the technology for a modern refining industry could not be developed indigenously. It was not until 1999 that a reversal in policy resulted in the approval of six large ethylene joint ventures capable of dealing with sour crudes and involving many of the IOCs who had earlier withdrawn from China. By 2011 China had developed 3.3 million barrels per day of processing capacity for imported sour crudes or about 30.5% of total capacity.[17] By 2013 China's ethylene capacity had reached 48.9% of US capacity. The cost to the state was a loss of control with 47.9% of the ethylene capacity of China's largest state refiner Sinopec accounted for by refineries of which it had just partial ownership (Oil and Gas Journal, January 2013).

The objective of this article is to investigate whether China's emergence as a significant oil refiner has allowed it to capture the gains, which Penrose typically viewed as accruing to the IOCs? It examines whether China's historical reluctance to allow foreign ownership of refineries and its emphasis on indigenous innovation [*zhizhu chuangxin*], inadvertently created a distorted industry structure where state refineries had surplus primary capacity but were short on intermediary capacity for higher-end petrochemicals such as ethylene? These questions are motivated by a series of field visits to China's large state enterprises, and the particular distinction made in the petroleum sector between the technical intensity of oil refining (compared to exploration) and the effects of price regulation on output. Following Penrose's view that innovation cannot be understood as a chance mutation, the article adopts a dynamic combination of inductive and deductive analysis.[18] The latter is focused on integrating theory and industrial history to analyse the corporate economy, or what Lazonick describes as catching-up with the history of the firm.[19] Data are from a range of sources. Chinese and Japanese reports and archive material are used to show the relationship between ethylene capacity and technology transfer since the 1960s. A dataset of ex-refinery price changes is used to show how the historic preference for self-sufficiency continues to influence the relationship between international and domestic fuel prices. Refinery-level capacity data is used to examine the source of technical constraints.

The remainder of the paper is structured as follows. The next section explores the contemporary relevance of Penrose's analysis of IOCs captive market. Section 3 traces the historical development of China's refining sector, highlighting the interplay between concerns over self-sufficiency and the demand for technical progress. An analysis of domestic and international ex-refinery prices in Section 4 shows that despite China's success in constructing surplus primary capacity and the presence of entry barriers, imbalances in production ensure that international prices continue to adversely affect the financial margins of state refineries, effectively reducing pricing independence. Drawing on the lessons of East Asia, the final substantive section argues that it is possible to orchestrate policies that maximise the net contribution of the IOCs investments, without rejecting the benefits of an international division of labour.

The IOC's Captive Market

Best known for *The Theory of the Growth of the Firm* published in 1959, Penrose's research is often regarded as being ahead of it time in the sense that it emerged before a comprehensive theory that accounted for the power and oligopolistic behaviour of multi-national enterprises had been developed.[20] In doing so Penrose identified the "very unstable combination of individualist competitive enterprise and co-ordinated planning" which underpinned the flexibility and adaptability of the large integrated firm.[21] In this sense her work on the large oil firm, was not unlike Hymer's analysis of the multinational enterprise or Chandler's history of the large firm. However, whereas Chandler showed how the integrated structure evolved as an efficient organisational form;[22] Penrose argued that vertical integration evolved after WWII to give the IOCs a captive market that was so strong it could only be broken by government pressure.[23]

In the refining sector the captive market meant that the location of oil refineries had often little to do with either market prices or a nation's comparative advantage. Oil refineries play a vital role in transforming crude oil into a variety of petroleum and petrochemical products. Hence, in countries with a shortage of oil resources, refinery construction represented a conscious import saving effort to ease balance of payment pressures.[24] Countries with oil resources also depended on the IOCs to supply technical know-how and capacity. The IOC's were content to supply this cheaply on the condition that they had the right to access and supply crude oil. Excluding the IOCs meant forgoing access to technology. This is because refining technology had large fixed costs of entry and relied on a "steady state technology of chemical processing".[25] Technologies such as Fluid Catalytic Cracking (FCC), which provide the basis for modern refining, were first pioneered in the 1920s but were not commercially adopted by the IOCs until the 1940s.

Penrose viewed this as creating a predicament for developing economies which involved alternating between the grateful acceptance of the IOC's technology and suspicion of their pricing policies. The price of market entry for the IOCs was often the construction of an oil refinery, giving the IOCs access to local production.[26] For developing economies this price was amplified by low-income levels and the ability of the IOCs to discriminate between markets. Penrose cited the experience of India during the 1950s as an example of how the technological benefits of allowing international firms to establish refineries during the 1950s was offset by the fact that oil could be imported from affiliates of the same companies.[27] The Indian government responded by setting limits on foreign ownership. It also expanded the activities of the national oil company believing that foreign control of refining capacity prevented India from shopping around for crude supplies.

While the oil industry has often been described as a cartel, the captive market differed in the sense that it was highly flexible. For Penrose it represented "an insistent attempt on the part of the international companies to maintain their international price structure in those markets where they had a complete monopoly while giving way elsewhere".[28] Its workings were strengthened by the comparatively few policy options available to developing economies. Oil nationalisations in the 1970s simply exposed differences between counties that had significant oil reserves and those who had not. The exclusion of the IOC's from countries that fell into the latter category meant forgoing future exploration. So poor was the IOC's reputation in much of the developing world that they had written off investment in these areas by virtue of exclusion.[29] The emergence of OPEC did not necessarily improve the plight of these countries. Instead the "have-nots" became dependent on transfers and trade with OPEC.[30] NOCs rarely benefited from the same level of integration as the IOCs. This had little to do with a public/private division, but rather the contrast in size and length and depth of experience between the two sorts of entities.[31]

A drawback of Penrose's approach is that although it argues for greater scrutiny and regulation of the IOC's investments via state intervention, in practice policies in developing economies have tended to favour price subsidies and liberalisation. A significant majority of developing economies continue to regulate the price of petroleum either at the retail or ex-refinery level as a form of social safety net.[32] Although China has long resisted giving the IOCs unfettered access, it also regulates ex-refinery prices and has faced pressure to remove entry barriers. A joint report by the World Bank and oil industry representatives in 2001 set out a road map for a structural transition from regulatory to market based discipline as part of the 10th Five Year Plan (2001-05).[33] This effectively repeated an agenda set out by the Bank in 1997.[34] The 2001 report specified the removal of investment restrictions on the IOCs in the wholesale and retail market. The Third Party Plenum in 2013 proposed lowering of entry barriers and breaking up monopolies in strategic sectors. In 2015 the National People's Congress emphasised energy conservation as part of accelerating market reforms (NCNA, March 16, 2015). Despite the frequency of these proposals, petroleum was excluded from a list of sectors where state prices will be phased out by 2017 (NCNA, October 15, 2015). A document released in 2015 restated the principle of nurturing internationally competitive NOCs.[35] The remainder of this paper is concerned with the historical, technical and commercial reasons for China's reluctance to fully open its refining sector to the IOCs.

China's Refining Sector

Historical conditions meant that by design, China's refineries lacked the integrated structures of the IOCs. Large refineries were typically located in coastal areas like Shanghai, Dalian and Guangzhou or in strategically safe locations like Yanshan. These were often long distances from producing assets, a problem amplified by bottlenecks in the rail network. A proliferation of small "teapot" refineries at the local level historically frustrated efforts to increase efficiency. The withdrawal of Russian assistance after 1960 amplified the already significant technical challenges faced by the industry. It also engrained the notion of energy self-sufficiency and saw the emergence of the 'petroleum faction,' a group of senior cadres who shared Mao's views on economic development.[36] Oil discoveries in *Daqing* and *Shengli* in the 1960s gave China's refineries a degree of oil self-sufficiency and provided the impetus for technical breakthroughs. This ensured immunity from the effects of transnational prices right up to the early 1990s. Consequently the inefficiencies of non-integrated and geographically dispersed refineries were initially less severe. Reorganisation of the industry in 1983 saw Sinopec inherit most of the downstream part of the industry while PetroChina inherited the bulk of upstream assets. The following section shows that despite the significant achievements during the era of self-sufficiency, progress in crucial areas of intermediate capacity such as ethylene, and later the addition of desulfurization units, have long depended on technology transfer. This resulted in the IOC's technology became embedded in state refineries. It also meant that small refineries were reliant on domestic demand for light-end products, making it harder to consolidate their activities.

Foreign Dependence to Self Sufficiency

The history of China's refining industry has long alternated between concerns over foreign dependence and the demand for technical convergence. Even before 1949, refineries in China's northwest including Fushun, Jinxi, Huadian, Siping and Dalian were built by the Japanese to supply the raw materials for Manchurian industrialisation. These were small in scale and produced synthetic crude using shale oil retorting and coal. Larger refineries such as those at Yumen and Dushanzi were constructed during the War with Japan.[37] A refinery at the Yumen oil field, which produced 1,500 barrels/day began construction in 1945, while a small refinery at the Yanchang oil field was built during the late Manchu Dynasty and had a capacity of 320 barrels/day mostly for purifying paraffin for candles. [38]

After 1949, an increase in oil production meant that the capacity to refine oil into useful products often lagged production. International embargoes meant that in order to rehabilitate older refineries including Dushanzi and Jinxi, China had to rely on Russian technical assistance and parts. Many other refineries were small and used primitive technologies. The origin of local "teapot" refineries can also be traced to this period. There were some 1,400 small production units in 1958.[39] Some of these were closed following the ending of the Great Leap Forward, but the impetus for local level refining units remained strong. Shanxi province was reported as having 400 small refineries for synthetic petroleum during the early 1960s, while another 128 small refineries were planned for Jiangxi province.[40] China also began building new larger refineries at Lenghu and Lanzhou. Lanzhou was China's first large scale refinery and was built during 1956-58 using Soviet specialists to train workers in refinery construction and 85% soviet equipment. Its size meant that it could take oil from the Yumen field via a 584 km pipe, thereby relieving pressure on the smaller Yumen refinery.[41] Lanzhou's construction also included a catalytic cracking unit for aviation fuel and a deasphalting unit for producing lubricants (China Reconstructs, November 8, 1959). By 1959 total output of refined products stood at around 2.29 million tons per year.[42]

The withdrawal of Soviet experts in 1960 following the Sino Soviet dispute exposed both a shortage of advanced capacity and the geographical dispersion of China's refineries. A lack of advanced refining capacity meant that partly refined oil was exported to Japan. China repurchased about 30% of the refined products.[43] This process was inefficient and placed a large demand on China transportation network. It also introduced commercial risk into the system of central planning. Oil was partly refined at oil fields in the North West and then transported to coastal refineries at Jinxi and Dalian for further processing. Soviet withdrawal also placed significant technical demands on Chinese engineers, as although they could manufacture the precision tools necessary for refinery construction, they lacked experience in practical application. A focus on imitation had retarded capabilities in design.[44] This meant that two conditions for refining progress, namely domestic equipment manufacturing and automation could not be achieved without foreign involvement. The construction of the Peking Petrochemical Complex illustrated this. Chinese engineers were able to build the carbide furnaces, electrolytic chloride cells, the equipment for acid synthesis and the refining of monomers, but needed to import from West Germany the polymerisation equipment that joined the monomers into the final product.[45]

Scaling Up, Daqing and the Reinterpretation of Self-Sufficiency

Despite their technical disadvantages, Chinese technicians were quick to adapt. The development of the Daqing oil field provided a particular impetus for accelerating refining capacity. Mao viewed Daqing as a showpiece for Maoist methods of development, emphasising self-reliance and political education over foreign technical dependence and material incentives.[46] Daqing's development derived considerable support from the Petroleum Faction. Work on the refinery began in April 1962 and it was operational by 1966 (China Reconstructs, December, 1968). Its construction coincided with a drive to scale up domestic refining technology. This included the construction of a FCC refinery with a throughput of 600,000 tons/year, followed by a FCC unit with a throughput of 1.2 million tons/year plant using domestic technology and technicians.[47] China also developed a fermentation process for dewaxing and platforms for extracting higher purity benzene using catalytic agents in 1966 (China Reconstructs, August 1966; Peking Review, 9th December 1966). It is unclear what role foreign technology played in scaling up. One account noted that China purchased a 300,000 tonne petroleum processing plant from Italy in 1964 and refining equipment from

Japan in 1965.[48] Another indicated that China's FCC technology was based on access to technical data from former Shell and Esso refineries in Cuba.[49]

The impact of scaling up on refining capacity and output were impressive and had a notable effect on the drive for self-sufficiency. From 1965 to 1970 refining capacity increased almost three fold (Table 1). Between 1968 and 1972 the Shanghai and Lanzhou refineries added 1.5 million and 1 million tons of primary capacity respectively.[50] China's dependence on Russian gasoline imports fell from 1.32 million tonnes in 1961 to 0.27 million tonnes in 1964.[51] By the end of the 1960s China claimed self-sufficiency in a variety of petroleum products and technical comparability with advanced economies in some areas (Peking Review, 26th September 1969). Despite these achievements, petrochemicals remained the Achilles Heel of China's raw material supply. While China had succeeded in producing all of the synthetic fibres that Japan could, production was small and often confined to trial plants, with aggregate production of 10,000-20,000 tonnes/year compared to Japanese output of 200,000-300,000 tonnes/year.[52] Refinery throughput was also variable and volumes suffered as a result of political campaigns especially between 1966 and 1970 (Table 1)

Table 1: Selected indicators of China's Refining Industry 1959-78

	1959	1965	1970	1975	1978
Crude Oil Refining Capacity (Mt/year)	5.79	14.23	44.02	67.64	92.91
Output of Refined Petroleum products	2.29	6.17	13.62	24.83	33.52
Throughput (%)*	68.3	76.1	62.9	75.2	76.1
Product types	309	494	577	636	656
Oil Product Exports	0	0.17	0.48	2.22	2.42
Self-sufficiency (%)	40.6	100	100	100	100

* calculated as volume refined over capacity

Source: China's Refining Industry [in Chinese], 73

The re-emergence of the Petroleum Faction in the early 1970s, which had been side-lined during the early part of the Cultural Revolution, and the visit of US President Nixon in

1971 saw a modification of views on self-reliance as the faction became advocates of importing technology.[53] It had become clear that without such technology, China could not meet its demand for petrochemical products. In order to ease supply pressures, in 1973 China signed its first contract with a US company since 1949 for a shipment of polypropylene (500 tons) and resin (2000 tons).[54] Policy switched from the importation of prototypes to complete plants.[55] China also entered into contracts with Lummus and Standard Oil for the supply of ethylene and polypropylene technology as part of turnkey plants with Japanese firms between 1972 and 1974 (US China Business Review 1974:10). Russian technical expertise was replaced by Japanese technical personnel of which about 40% were specialised in some aspect of refining or petrochemical production.[56] By 1978 China's leadership had interpreted Mao's views to imply that learning from other countries was a condition of self-reliance, "effectively reconciling self-reliance and open door policy in one stroke."[57]

Technical Self-sufficiency and the Case of Ethylene

Against a background of relatively fast growth in primary energy production, China achieved some significant progress during the 1960s and early 1970s.[58] Nevertheless the policy of self-sufficiency proved costly in terms of forgoing access to technology, especially for ethylene, and the rate of domestic innovation seems to stall. During the 1960s, Japanese experts estimated that China's refining technology had reached the same level of Japan's in the 1950s.[59] By the 1970s estimates indicated that refining technology was equivalent to Western technology in the 1950s.[60] Domestic assessments indicated that breakthroughs in the 1970s, including those in the area of catalysts for ethylene ploymerization, lacked the necessary scale for modernisation. (NCNA [Xinhua], February 15, 1975). China could build FCC units capable of refining basic fuels and lubricants, but not the hydrocrackers required for large scale ethylene refining, aromatics and PTAs (Purified Terephthalic Acids). The ethylene capacity of older refineries such as Lanzhou, Shanghai and Fushun were less than 150,000 tons at a time when international refineries had ethylene capacities of at least 500,000 tons.[61] Larger refineries suffered from supply problems (Kyodo, January 7, 1981). Political disruption from the "Gang of Four" meant that refinery construction was disrupted, while austere economic conditions led to the postponement of new plants. Even after the Open-Door policy, a prevailing fear of foreign exploitation resulted in contracts for petroleum investment being overly focused on trivial non-strategic issues.[62]

The implication of the above is that from the start, China's refineries lacked the plant scale that business historians viewed as a necessary precondition for innovation.[63] Correcting this required foreign participation in plant construction.[64] Table 2 documents the link between the change in policy towards technology transfers and ethylene output. Initially Japan offered the most readily available source of plant and technology. From 1972 onwards China signed contracts for the purchase of whole ethylene plants from such firms as the Mitsubishi and Toyo. It also signed contracts for the purchase of control valves and measuring instruments required for running these plants (Nikkei Sangyo Shimbun, February 26, 1974). A thaw in diplomatic relations with the US allowed China purchase plant from Lummus, a US company that continues to feature prominently in the construction of Chinese refineries. During the early 1980s plant imports from the US especially hydrocrackers, formed the basis for significant capacity expansions in such major refineries as Tianjin, Maoming, Nanjing, Shanghai, Guangzhou, and Zhenhai.[65] These imports involved adding secondary capacity to existing plants.[66]

Table 2: Significant technology transfers, capacity and ethylene production

Planning Period	Avg. Primary Refining Capacity	Ethylene Output	Significant Technology Transfers and Events
1966-70	20.4	0.007	Domestically pioneered FCC and distillation
1971-75	47.6	0.051	1972: Shanghai refinery begins work on 300,000 ton ethylene facility using Japanese & West German technology 1973: Yanshan 300,000 ton ethylene plant from Lummus
1976-80	80.0	0.348	1977: Yanshan ethylene plant fully operational 1979: Shanghai & Liaoyang ethylene plants fully operational Contracts for 300,000 ton ethylene plants (Liaoyang, Qilu, Nanjing (2), Beijing, & Shengli) using Japanese & W. German technology**
1981-85	100.2	0.650	1982: hydrocracking technology (US) Maoming, Shengli 1985: Catalytic reformers (US & France): Guangzhou 1985: Alky unit and heavy oil processing tech (US): Shengli
1986-90	120.5	1.16	1986: Hydrocracking tech (US): Nanjing 1987: Catalytic Cracking (US): Guangzhou, Zhenhai, Changling, Nanjing 1987-88: Alkyl Units from US to Tianjin, Shanghai, Nanjing, Shijiazhuang, Maoming, Anqing, Guangzhou, Daqing, Zhenhai 1988: Olefin tech (France): Shijiazhuang
1991-95	167.8	2.06	1994: Zhenhai plans doubling of capacity
1996-00	240.9	3.89	1999: ABB Lummus & Sinopec J.V. to design & market 12 ethylene furnaces (1.2 million tons) 1999-2001 Approval of six ethylene J.Vs with Royal Dutch Shell, BASF, ExxonMobil, Saudi Aramco, BP, and Philips
2001-05	315.1	6.04	2005: SEECO JV comes on stream 2005: DuPont establishes R&D facilities in China
2006-10	445.9	10.89	2010: Fujian JV Sinopec & BP comes on stream
2011-14	624.6	15.78	Expansions to Maoming, Changling and Jinling come on stream

* Refinery capacities refer to the planning period average. Original data were in barrels per day and are converted to tonnes per year using the standard conversion rate of 49.8. Ethylene output data refer to planning period averages.

** The Qilu and Nanjing ethylene facilities did not come on-stream unit 1986, while the Liaoyang facility came on stream in 1987

Sources: China's Refining Industry, 214-15; China Statistical Yearbook, 2015; 1991; 1985; BP, Statistical Review; NCNA, January 15, 1977; Kyodo, January 8, 1979. NCNA, June 25 1979

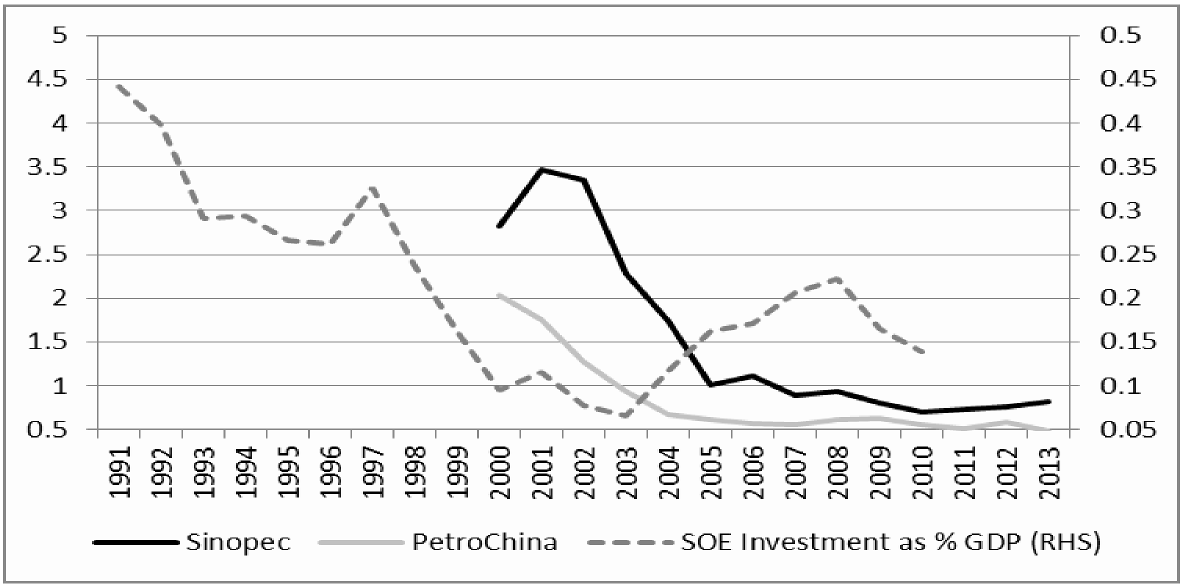
A significant drawback of this approach was that it did not involve the construction of new ethylene units. In the early 1990s this was less problematic as annual ethylene production averaged around 2 million tons per year, easily meeting domestic consumption of 1.57 million tons (Table 2). Both the Eight Five-Year Plan (1991-95) and the Ten Year Strategic Plan (1991-2000) set targets for expanding ethylene capacity to 3 million tons by 2000.[67] By 2000 domestic ethylene production had reached 4.7 million tons annually, significantly exceeding planned output, but meeting less than two-thirds of domestic demand (China Daily, September 11, 2001). The ethylene capacity of China's largest refineries was still less than 500,000 tons a year. An increasing proportion of domestic consumption, especially in non-price regulated heavy distillates, therefore had to be met through imports. Import dependence reflected an underlying imbalance in the product mix of domestic refineries favouring and their focus on the "light end" of the barrel. This imbalance meant that less than two per cent of gasoline consumption is met by imports and refineries had an incentive to export surplus gasoline production.[68] In 2010 gasoline exports stood at 7.5% of domestic consumption. The high rate of gasoline exports versus and low rate of imports has led to mismatches in supply and frequent bouts of fuel shortage.

Investment, capacity and scale

The reasons underpinning the product imbalances in refineries are both technical and commercial and have their roots in the historical evolution of the industry. Modern refining requires large-scale plants and steady rates of investment. There are long time lags in bringing on-stream new capacity. Retrenchment in the 1980s saw the postponement of several important refinery projects.[69] Despite recovering during the 1990s, by 2003 investment in petroleum processing had fallen to 8.97 billion yuan compared with 10.2 billion yuan in 1993, while investment in petroleum processing as a proportion to GDP showed a steady fall during this period (Figure 1). The introduction of market-based criteria for new projects including minimum investment returns and a reluctance to sanction new ethylene plants below a certain capacity further dampened investment.[70] It was not until 2005 that significant increases in nominal investment were recorded and in 2007 China invested some 69.8 billion yuan in petroleum processing.

A similar trend was evident following the restructuring and stock market listings of China's two major refiners, Sinopec and PetroChina in 2000. This transformed the debt positions of both enterprises but did not reverse a long-term relative decline in investment.[71] Although both NOCs increased their aggregate capital expenditure, their ratio of investment to retained earnings became increasingly conservative, reflecting international industry trends (Figure 3). These data reflect the fact that research and development spending at China's NOCs is now equivalent to the IOCs.[72] This was consistent with Penrose's contention that a high degree of self-financing had not only been a longstanding characteristic of the IOCs, but it was also a position that undermined claims that price falls and taxation jeopardised investment.[73] In this sense commercialisation has taken China's NOCs closer to IOC investment norms, but without similar technical capabilities.

Figure 1: Capital Expenditure in Listed NOCs and State-Owned Units



Sources: Data for listed firms from Sinopec and PetroChina Annual Reports 2000-2014; Data for State-Owned Units from *Zhongguo neng yuan nianjian* 2011; 2006; 2002-2000; 1997-1999; 1991-96.

A second reason for the imbalance relates to refinery scale. Faster throughput and technology innovations in the sector have historically been driven by scale.[74] The data in Table 3 indicates that during the 1970s and 1980s most of China's refineries were small by international standards. For example in 1970, the average US refinery had an operable capacity of about 2.3 million tons/year (or 15.9 million barrels/year). One estimate indicated that in 1972, of China's 23 refineries, only 12 had primary capacities greater than 1 million tons/year and these accounted 91% of the country's total capacity.[75] Table 3 also shows that despite significant capacity growth in some of the larger refining units, much of China's primary capacity continues to be accounted for by smaller "teapot" refineries. These tend to be less complex and more vulnerable to lower margins. This highlights two persistent problems. The first is a lack of new refining units of significant scale and complexity; the second is the problem of variable rates of throughput.

To appreciate the problem of a lack of new capacity, it is necessary to understand the nature of capacity additions. Table 3 shows that additions to capacity tend to come from existing plants. Refineries at Maoming, Qilu, Yanshan, Shanghai and Guangdong have since the 1960s and 1970s been the main drivers of capacity growth. These refineries were also the main beneficiaries of plant and technology imports during the 1970s and 1980s enabling them to increase capacity and complexity of refined products (Table 2). Other refineries such as Daqing and Qilu are capable of complex refining but were initially constructed to refine domestic crude oil from nearby oil fields. Recent large capacity additions, such as that at Dushanzi refinery involve upgrading existing primary capacity to accommodate imported sour crudes as well as improving complexity via a one million ton ethylene unit using technology from the US firm Lummus. Sinopec's new Fujian refinery is an interesting exception. It was configured to handle imported sour crudes from the Middle East as part of a joint venture with ExxonMobil and Saudi Aramco using technology from Lummus.

A second aspect of this problem is the slow rate at which small units are eliminated. Based on the data in Table 3, around 30% of Sinopec's refining capacity is accounted for by small refineries. For PetroChina the proportion is around 47%. Although publically available data makes it difficult to calculate the individual capacities of these refineries, available data suggest there are around 45 "other" refineries with annual average capacities of approximately 29 million barrels per year. A majority of these "other" refineries have capacities significantly less than the level considered economically viable. This trend contrasts with the US where the number of operable refineries fell from 279 in 1970 to 148 in 2010, while their average output increased from 15.9 million barrels per year to 43.3 million barrels per year.[76]

Table 3: Primary Distillation Capacity of China's Major refineries (mill barrels /year)

Refinery	**1963[a]**	**1966[b]**	**1968[c]**	**1972[c]**	**1988[d]**	**1998**	**2000**	**2010**	**2013**	**Throughput (%)**
Sinopec										
Maoming	2.1	2.1	2.2	7.3	44.1	99.2	99.2	99.2	172.7	96.3
Zhenhai						69.8	88.2	169.0	174.9	80.3
Qilu*				4.4	47.8	77.2	77.2	102.9	102.9	96.2
Yanshan*				22.0	55.1	69.8	58.8	99.2	99.2	83.1
Guangzhou					19.8	56.6	56.6	97.0	97.0	84.8
Gaoqiao						53.6	53.6	95.5	95.5	95.5
Jinling		2.1			40.4	51.4	77.2	95.5	154.3	95.4
Tianjin					18.4	36.7	36.7	91.9	101.4	34.4
Shanghai*	2.1	14.2	14.2	25.7	41.1	38.9	46.3	102.9	117.6	62.9
Changling						36.7	36.7	-	84.5	-
Fujian								88.2	102.9	58.3
Qingdao								73.5	88.2	90.0
Others						341.8	327.1	683.5	682.8	-
PetroChina										
Fushun*	0.2	8.5	8.5	14.7	55.1	67.9	59.1	86.5	81.3	75.3
Dalian	2.1	5.0	5.1	25.7	41.2	55.4	55.4	151.5	151.5	67.9
Daqing		4.3	4.4	40.4	35.3	44.3	44.3	44.3	44.3	-
Jilin					20.6	44.3	44.3	72.4	72.4	87.4
Lanzhou	7.1	16.3	16.9	24.3	22.0	40.6	77.6	77.6	77.6	100.0
Jinzhou	0.7	0.7	2.3	7.35	55.8	41.4	36.9	49.7	49.7	-
Jinxi	1.4	5.0				40.6	41.3	48.0	48.0	-
Urumqi						36.9	36.9	44.3	44.3	-
Guangxi								73.9	73.9	67.8
Dushanzi*	5.7	7.1	7.3	7.3				73.9	73.9	90.6
Others						361.4	332.6	528.9	643.6	88.6

Notes: Capacities converted using 7.35 barrels per ton rounded to one decimal place. Typical conversion rates used are 7.1 barrels per tonne for domestically produced oil and 7.35 barrels per tonne for international crude. All figures rounded to one decimal place.

* These refineries benefited from Lummus ABB technology

Sources: a) Chang, Petroleum Resources China, 22-26; b) Ho, Peking's Petroleum Industry; 29-27 c) Bartke, Oil Peoples Republic, 31; d) China's Refining Industry*,* 17 Table 1-3; Sinopec and PetroChina Annual Reports Form 20-F

In larger refineries, improved techniques and higher yields have meant that efficiency is not a barrier to improved throughput. Most large refineries achieve unitisation rates in excess of 80% (Final Colum, Table 3). However utilisation varies considerably across refineries and over time. A detailed look at Sinopec's utilisation ratio (throughput to primary distillation capacity) shows that it declined from 0.85 in 2007 to 0.80 in 2009. This cannot be explained by declining efficiency. During this period refinery yield increased from 93.9% to 94.5%. A more likely explanation is that during 2008 the domestic ex-refinery prices were set below international prices, a move that led refineries to reduce their utilisation rates. From 2010 to 2011, Sinopec's refining margins dropped dramatically from US$5.83 to US$0.73. Its capacity utilisation ratio subsequently dropped from a peak of 0.88 in 2011 to 0.82 in 2013. This coincided with a rare "triple drop" in ex-refinery prices between May and July 2012 sparking optimism about a return to an era of six yuan pump prices. Instead refineries responded by holding gasoline pump prices at the maximum retail benchmark level of 7.31 yuan/litre.[77] The NDRC subsequently raised gasoline and diesel prices (NCNA, September 10, 2012). By 2013 refinery margins had recovered. These events highlight the vulnerability of the smaller less complex teapot refineries to pump prices. The effect of adjustments in regulated prices in explored in greater detail in Section 4.

Embedded technology and Joint Ventures

The above highlights the importance of understanding the source and complexity of the post-2000 capacity additions in China's refineries. From this perspective the dramatic increase in ethylene production achieved since 2000, which include a near trebling of average output from just over 6 million tons during 2001-05 to 15.8 million tons in during 2011-14, was a direct result the approvals of six ethylene joint ventures after 1999. This included projects involving Royal Dutch Shell Group and CNOOC (800,000 ton capacity); a BASF and Sinopec in Yangtse (650,000 ton capacity); Sinopec, ExxonMobil and Saudi Aramco in Fujian (650,000 ton capacity); a BP/Sinopec/SPC in Shanghai (900,000); Dow Chemicals and Sinopec in Tainjin (600,000 ton); and Philips and CNPC in Lanzhou (600,000). These offered a politically

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acceptable balance between the urgent need for additional capacity with concerns over foreign dependence.

The joint-venture between SPC, BP and Sinopec (*Shanghai SEECO Petrochemical*) to construct a 900,000 ton ethylene plant offers an example of this. The plant was completed in 2005 with SPC owning 20%, Sinopec 30% and BP 50%. SPC's capital contribution was US$180.2 million (out of a total US$901.4 million). The ethylene refining technology was supplied by the US firm ABB Lummus. Lummus first supplied China with ethylene technology for its Yanshan refinery in 1973 (Table 2). Lummus's critical role in supplying the complex technology for ethylene production is illustrated by the fact that approximately 60% of China's ethylene production is based on its technology.[78] By 2010 SEECO produced 1.294 million tons of ethylene.[79] SECCO's ability to expand capacity rapidly had obvious attractions in meeting state production targets. SEECO added 1.09 million tons of ethylene capacity in less than a decade. It had taken two decades for SPC to add 400,000 tons to its own ethylene capacity.

The success of the SEECO venture illustrates the speed at which IJVs could increase intermediate capacity. It also reflected the fact that foreign technology was already well embedded in China's more advanced refineries. This is illustrated in the Shanghai refinery's history. The refinery was founded on 18 units, nine of which were imported from Japan and West Germany during the 1970s, with the remainder Chinese made (NCNA, June 25, 1979). While Shanghai's distillation units are designed and built in the PRC, its hydrocracker units are based on US technology. Ethylene units were built with technology from Japan (Mitsubishi) and the US (Lummus); aromatic units were built with Japanese (Toray) and US (Universal Oil Products) technology; and PTA units built using Japanese (Mitsui Petrochemical Corporation) technology. For the production of fibres such as polyesters SPC relied on technology from Toray (Japan), Kanebo (Japan) and Dupont (US). This carries a number of drawbacks. Operationalising imported technology has not always been seamless and there were difficulties in operating imported polyester units at design specification.[80] Technology imports also tied refineries into licensing and servicing agreements.

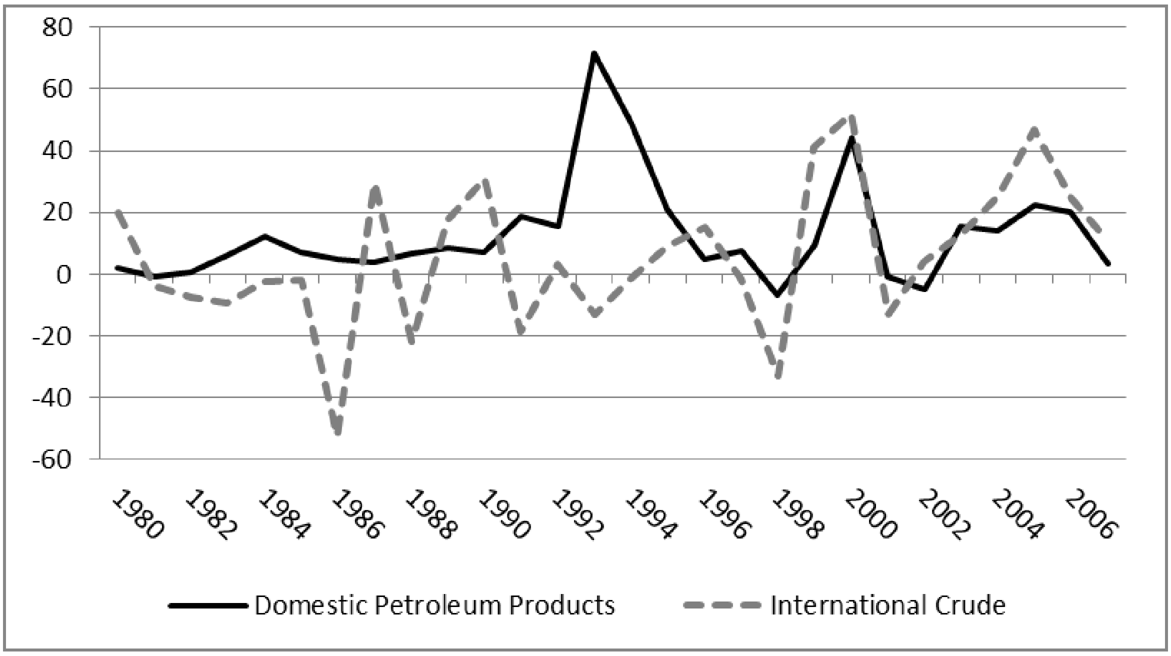
Pricing Independence and Welfare Gains

The drive for energy and technical self-sufficiency since the 1960s was designed to ensure that China would not be subject to the predatory pricing practices outlined in Penrose's work. Whereas foreign technology had become embedded in the production of intermediate petrochemicals, ample primary capacity, regulated prices, storage capacity thresholds and transport contract requirements gave China greater scope to protect the petroleum products market.[81] However increasing oil imports meant that petroleum prices could not be indefinitely subsidized. This section examines whether this has threatened the ability of state refineries to capture the benefits that Penrose viewed as otherwise accruing to the IOCs, or simply amplified historical production imbalances outlined in the previous section? An analysis of international and domestic ex-refinery diesel and gasoline prices in this section shows that although domestic prices have increasingly reflected international prices, this is less about price liberalisation and more to do with mitigating their effects on refinery margins. An analysis of Beijing's pump-prices shows that upgrading fuel standards reduces the ability to subsidise fuel prices indefinitely, further reducing pricing independence.

Reforms to the Pricing Mechanism

The global nature of the oil price alongside increasing domestic demand effectively forced the early reform of domestic prices. Figure 2 shows that during the 1980s and early 1990s, domestic prices for petroleum products remained stable and largely immune from the volatility in international crude prices. After 1993, China's first year as a net importer of oil, the pricing system was reformed such that all crude was priced at the state high price. This replaced a pervious system based on state high and low prices. The new system was updated on a monthly basis using Singaporean prices as a reference. Its effect in more closely aligning domestic and international prices was almost immediate (Figure 2). A further reform in October 2001 introduced guidance prices based on three international markets (SCMP, October 18, 2001). Between 2003 and 2015, China made four further major reforms to the oil pricing mechanism. In December 2015, China suspended the adjustment mechanism over fears that falling international prices would undermine efforts to reduce fuel consumption.

Figure 2: Yearly Change Domestic Petroleum Products vs. International Crude (%)



Source: China Urban Price Life and Price Yearbook

Concealed in this were important product differences, reflecting a shortage of intermediate refining capacity and a surplus of capacity at the light-end. Early pricing reforms allowed China offset cost pressures in domestic oil exploration. From 1993 to 2007, ex-factory prices for domestic petroleum extraction showed an average annual increase of 24.8%.

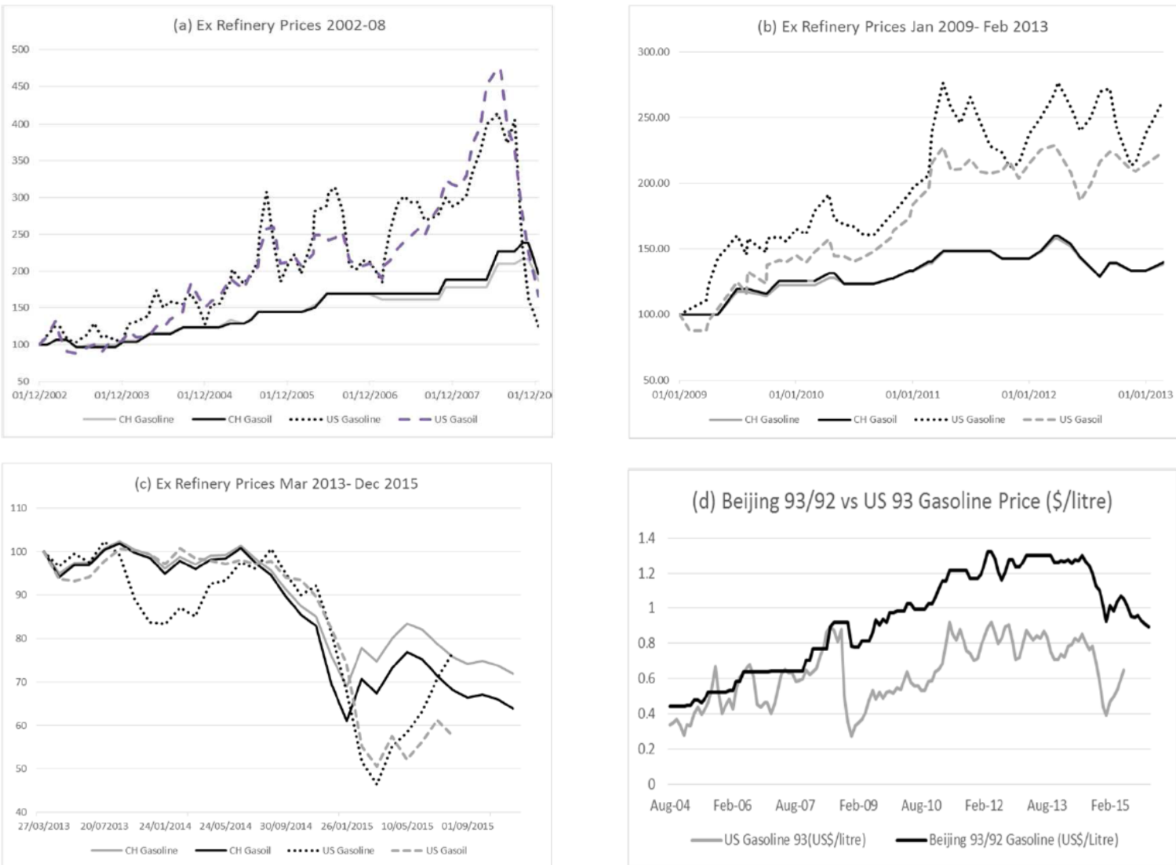
However, it was not until December 2007 that the wholesale oil and refined petroleum markets were opened to new entrants.[82] On the other hand, the shortage of intermediate refining capacity meant that by 1996 import tariffs on petrochemicals were reduced from a range of 9% – 40%, to 5% - 22%.[83] Under WTO membership tariffs on ethylene, synthetic resins and fibres were scheduled to fall further after 2003, 2008 and 2004 respectively.

Pricing Reforms, Consumer Welfare and Refinery Margins

The data in Figure 2 indicates that after 1993 domestic price movements increasingly mirrored international prices, especially after the 2001 pricing reforms. To examine the effect of this, Figure 3 plots the relationship between international spot prices and domestic ex-refinery prices using data collected by the author for the period 2003 to 2015. The data is separated and rebased following each reform to the pricing mechanism. Ex-refinery prices are set by the state and effectively reflect a trade-off between consumer welfare and refinery margins. As such the rate of price pass through from international markets offers a useful proxy for the distribution of the gains, if any, of market restrictions. While this does not allow for taxation differences or pump price manipulation, the spread between pump and ex-refinery prices should be constant. Fuel tax in China remains comparatively low, accounting for around 14 per cent of the cost of a litre of gasoline, though falling international prices have increased the frequency of adjustments.[84]

The data show that while price regulation has shielded consumers from international price increases, price controls have been used to protect state refineries from international price falls. An increase in international prices in 2007 and early 2008 did not feed through to domestic prices (Figure 3(a)). In late 2008 a fall in international prices was not passed on as refinery margins came under pressure. The frequency of adjustments increased following the adoption of a new pricing mechanism in 2009. This resulted in a change in the benchmark retail price of oil products when the international price changed by a daily average of 4% over 22 working days. This cushioned domestic prices against international price increases from the second half of 2010 (Figure 3b). A further change in March 2013 saw domestic prices adjusted when international crude costs changed by more than 50 yuan per tonne over a period of 10 working days. The shorter time period increased the frequency of adjustment and reduced the opportunities for fuel hoarding (Figure 3c). However, by 2015 the reduction in international spot prices far exceeded the reduction in domestic prices and the adjustment mechanism was suspended in December 2015.

Figure 3: Domestic vs International Prices Changes



Notes: * Beijing introduced a new fuel standard effective from May 31st 2012 which replaced 90, 93, and 97 octane fuels with 89, 92 and 95 octane fuels

Sources: China data from NDRC price announcements [in Chinese]; IEA, Energy Prices

Variations between domestic and international oil price movements indicate that the NDRC has had to balance commercial and welfare implications when deciding the pass through of oil price changes. The data in Table 4 show the variation in Pass-through Coefficients (PTC) over the three pricing regimes. A PTC of 1 implies a direct pass through of increases in international spot prices. Since China's fuel pricing mechanism has an inbuilt policy lag, two time lags representing a one-month lag (t_{-1}) and a two-month lag (t_{-2}) are presented. Under the first pricing mechanism to end-2008, the rate of pass through even after two months is low, indicating that on average international price changes were not fully passed through. The rate of pass through increased, especially with a one-month lag after reforms in 2009. The correlation between domestic and international spot prices also increased. Conversely reforms in March 2013, which reduced the time period for adjustment to 10 days, lessened both the correlation and pass through between domestic and international prices. This coincided with a period of falling international prices, highlighting the commitment problem oil importers face in implementing price-smoothing regimes.

Table 4: Pass Through (PTC) and Correlation Coefficients, Monthly Prices 2003-15

Gasoline PTC	Jan 2003-Dec 08	Jan 2009-Feb 13	Mar 2013-Jun 15
T	0.242	0.520	0.567
t_{-1}	0.117	3.054	-0.356
t_{-2}	0.436	0.079	-0.136
Correlation Coefficient	0.815	0.915	0.789
Diesel PTC	**Jan 2003-Dec 08**	**Jan 2009-Feb 13**	**Mar 2013-Jun 15**
T	-0.394	0.874	0.685
t_{-1}	0.160	0.518	0.197
t_{-2}	0.045	-0.007	0.742
Correlation Coefficient	0.862	0.912	0.878
Beijing 93/92 Gasoline PTC	**Jan 2003-Dec 08**	**Jan 2009-Feb 13**	**Mar 2013-Jun 15**
T	0.303	0.467	0.088
t_{-1}	-0.094	3.092	-0.099
t_{-2}	0.293	0.195	0.178
Correlation Coefficient	0.664	0.954	0.947

Notes: PTC= Δ retail domestic price / Δ international benchmark price. Beijing pump monthly prices are converted to US$ using average IMF exchange rates.

Sources: Source: NDRC (see Table 3); Price announcements from Beijing Municipal Commission of Development and Reform [in Chinese]; IEA, Energy Prices (2015)

The Cost of Cleaner Fuel

Although Penrose did not look specifically at the question of who pays for cleaner fuels, the history of the refining sector shows that reducing lead and sulphur content requires refineries to implement more advanced and costly refining techniques. The question has become particularly pressing for China given ongoing problems with air quality. The NDRC has said that it expects refineries and consumers to contribute equally to funding upgrades to fuel standards (NCNA, September 23, 2013). As part of the first phase of fuel upgrading, the State Council has mandated that the sulphur content for gasoline and diesel will be no more than 10 ppm (parts per million) by 2017.

As the first Chinese city to adopt European fuel standards, Beijing offers an insight into the distributional effects of this. Figure 3(d) shows that Beijing's pump prices in dollar terms did not drop in line with international spot prices in 2008, a fact reflected in the negative PTC (Table 4). Increases in the spot price from 2009 onwards were passed on with a magnitude of three, with a one-month time lag (Table 4). It was reported that the introduction of the fourth standard in 2010 resulted in Beijing's gasoline prices increasing by an additional 0.2-0.3 Yuan per litre. (Peoples Daily, February 2, 2014). Effective from May 31 2012, Beijing became the first city to replace 90, 93, and 97 octane fuels with 89, 92 and 95 octane fuels. It was the first city to adopt the fifth standard in 2013, with most Chinese cites adopting the third phase of 150 ppm (NCNA, September 23, 2013). A negative PCT for the period 2013-15 indicates that international spot price reductions were not passed through, but Beijing's fuel price marginally increased. Part of this can be explained by the gradual depreciation of the RMB against the dollar. However the magnitude of the depreciation is not enough to explain the overall increase.

Catching up: the lessons of East Asia

This analysis has shown that China's efforts to achieve technical self-sufficiency have failed to break the historical link between progress in refining capacity and technology transfer. It also showed that technical and commercial challenges are inherently linked. While entry barriers has prevented the IOCs exploiting falling oil prices via a captive market, they have also distorted the domestic market by incentivising the export rather than further refining of surplus production. This has prolonged a historical mismatch between the output structure of refineries and the more sophisticated intermediate petrochemicals demanded by the market.[85] These mismatches, which had their historical roots in policies favouring the substitution of coal for oil in industrial burners, now imply that domestic refineries are overly concentrated in light end products and have limited incentives to supply the feedstock for more complex refining.[86]

Penrose's solution to this was not so much to do with rejecting the benefits of an international division of labour, but rather one focusing on the regulation of the large firm. In particular she argued that if "there is not a reasonably large gain to be had from direct foreign investment, the (developing) country may well consider that the investment is not worth the cost of the adjustments required to pay for it".[87] This reflected Penrose's concern for the theoretical issues arising from real world observations and their implications for international firms as investors in developing economies.[88] Theoretically it indicates a need for find a better allignment between domestic conditions and the ownership advantages of FDI. It is also consistent with the lessons from other Asian economies, which show that upgrading is dependent on well-orchestrated cooperation with the global value chain.[89]

One interesting lesson on this comes from the Japanese experience. An under researched feature of China's early industrial modernisation is the role of Japan. During the 1970s Japanese conglomerates such as Mitsubishi, Toray and Mitsui sold advanced refining technology to China (Table 2). This coincided with Japan's transition from labour and chemical intensive industries to higher-end manufacturing and services. Japanese conglomerates had gained much of their technological capabilities from strategic interactions with US and European multinationals during the 1920s and 1930s and benefited from the Japanese government policy support and commitment to FDI.[90] What is significant is that even after selling technology to China, conglomerates such as Mitsui and Toray continued to retain leading and innovative positions in industry.

A second lesson from the region comes from Singapore. In 1975 Singapore's President Lee Kwan Yew requested Japanese financial assistance in the construction of a refinery on the island of Ayer Merbau. The complex was based on cooperation between the Singaporean government and the town of Jurong involving the establishment of a private petrochemical corporation. The construction of a parallel world class refining complex on Jurong Island with a capacity of 3.5 million tons per year by Exon Mobil led to the world's largest ethylene complex in 2014. This has allowed Singapore to liberalise parts of its retail fuel market and is consistent with its ambitions to become an LNG price setter for the Asian region more generally.[91] The lesson from both countries is that an orchestrated state policy can support and nurture the domestic chemical and refining industry by pursuing policies that seek to maximise the net contribution of FDI.

Conclusion

Few developing economies have successfully developed large NOCs that can be counted among the largest international refiners; even fewer have developed globally significant refining capacities from such backward industrial starting points as faced by China. From this perspective China's historic preference for self-sufficiency, its promotion of NOCs and it use of foreign technology to develop primary and intermediate capacity has been successful in avoiding the worst effects of the captive market. Yet, China's experience since the 1960s also confirms a historical regularity in the market imperfections that underpin the power of the IOCs. Neither does the modernization of the sector dispute the benefits of an international division of labour. Periods of self-sufficiency, especially during the 1960s, slowed the rate of technical innovation. Technical progress required a continual re-evaluation of the concept of self-sufficiency, and as argued by Penrose, a revaluation the suitability and regulation of the vehicle through which this division takes place. Penrose's approach helps explain China's historical reluctance to liberalise prices and its preference for state ownership. China never did achieve the technical self-sufficiency it sought in the 1960s, nor did it outpace the IOCs, facts that reinforce Penrose's view that innovation was not a chance occurrence. Periods of accelerated progress went hand-in-hand with the IOCs participation in refinery construction. Industrial history has also shown that scale drives innovation. China is no exception to this. Although refineries were able to pioneer innovations and add extra capacity without recourse to large scale FDI during the 1970s and 1980s, this did not create the plant size necessary for more complex breakthroughs in intermediate refining. The impacts of this were prolonged by investment austerity and an inability to implement the refinery consolidation that has occurred in developed markets such as the US. Consequently, China's NOCs converged with international investment trends before they had developed similar levels of technical capacities and plant consolidation. The lessons of Japanese firms and the emergence of Singapore as a refining centre indicate that upgrading ultimately depends on well-orchestrated state-led cooperation with the IOCs.

Notes

[1] Nolan, Global Business Revolution; Odell, Petroleum Exploration Strategies.

[2] Penrose, Large International Firm

[3] Kim, Refining the Prize,

[4] Downs, Chinese Energy Security; China's National Development and Reform Commission (NDRC) was quoted as saying that when market prices go too low, it increases China's international dependence, China Daily, 13 January 2016; State Council, Deepening Reform

[5] BP, Statistical Review

[6] Penrose, Large International Firm.

[7] Langlois, Vanishing Hand

[8] Chandler, Visible Hand

[9] IEA, Asia Energy Outlook

[10] Shao, China Britain Businessmen, 74-76

[11] Correspondence relating to the withdrawal of the IOCs from China and the displeasure of the Chinese authorities towards their trading activities are described in FO 371/175950 (1964) Activities of Shell and BP.

[12] Chiang, Taching Oilfield; In a speech to the UN in 1974 Deng Xiaoping cited Peking's support for the Arab oil producers as evidence that China had joined other developing economies in their claims for control over their own economic resources. See: Foreign and Common Wealth Office (FCO) Diplomatic Report No. 48/75 (21/1376) "China: Annual Review For 1974"

[13] Nolan, Global Business Revolution, 452.

[14] Wu, Capacity Complexity Expansions.

[15] Kim, Refining the Prize, 362.

[16] Zhang, China's Petroleum Industry

[17] Wu, Capacity Complexity Expansions; BP, Statistical Review.

[18] Pitelis, Edith Penrose

[19] Lazonick, Chandlarian Corporation

[20] Pitelis, Edith Penrose; Chandler, Visible Hand.

[21] Penrose, Large International Firm, 150

[22] Chandler, Visible Hand

[23] Penrose, Large International Firm

[24] Hartshorn, Oil Companies

[25] Hartshorn, Oil Companies, 68

[26] Hartshorn, Oil Companies

[27] Penrose, Large International Firm, 224-229

[28] Penrose, Large International Firm, 230.

[29] Odell, Petroleum Exploration Strategies

[30] Heal and Chichilnsiky, Oil and International Economy

[31] Odell, Petroleum Exploration Strategies

[32] Fattouh and El-Katiri, Energy Subsidies.

[33] World Bank, Modernizing China's Oil

[34] World Bank, China Engaged

[35] State Council, Deepening Reform [in Chinese]

[36] Meidan, China's Oil Industry, 5

[37] Chen, China Petroleum,

[38] Chang, Chinese Petroleum Bibliography, 24

[39] Chen, China Petroleum, 16

[40] Chang, Petroleum Resources Production, 24

[41] Chang, Petroleum Resources Production, 10

[42] China's Refining Industry [in Chinese], 73

[43] Ho, Peking's Petroleum Industry

[44] Uchida, Technology in China

[45] Sato, Technological Trends

[46] Kambara and Howe, China Energy Crisis, 14

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47 China Refining Industry [in Chinese], 88, 94

48 Hao, Chinese Petroleum Industry, 22-23

49 Williams, Chinese Petroleum Industry, 245

50 Bartke, Oil Peoples Republic, 30

51 Ho, Peking's Petroleum Industry, 31

52 Sato, Technological Trends

53 Lim, Oil in China, 11

54 Chang, Chinese Petroleum Bibliography, 49

55 Heymann, Technology in China

56 Lim, Oil in China, 132

57 Lim, Oil in China, 110

58 Smil, China Energy Prospects, 232-233.

59 Uchida, Technology in China

60 Williams, Chinese Petroleum Industry

61 Oil and Gas Journal, June 1997; Chinese Petrochemical Quarterly, Third Quarter, 2001.

62 Zhao, Prisoner of State, 107

63 Chandler, Visible Hand

64 Zhang, China's Petroleum Industry

65 China's Refining Industry, 214-215

66 Zhang, China's Petroleum Industry

67 Shanghai Petrochemical Company (SPC), IPO Prospectus 1993, 36

68 China Energy Statistical Yearbook, Tables 1.8; and 4.8 - 4.11

69 Zhang, China's Petroleum Industry

70 These issues were pointed out to the author during a discussion with Sinopec management in August 2004

71 'Update on China's Petroleum and Petrochemical Industry' December 2001 Hong Kong Trade Development Council

[72] Jiang, CNPC

[73] Penrose, Large International Firm, 145

[74] Chandler, Visible Hand

[75] Bartke, Oil Peolpes Republic, 31

[76] EIA, Refinery Capacity Report

[77] "93 Grade Gasoline back to 6 Yuan Era [93 Hao qiyou chong hui 6 shidai]" NDRC July 11, 2012

[78] ABB Lummus Global – China

[79] SPC, Annual Report 2010

[80] SPC, Annual Report 1994, 29

[81] USTR, China's WTO Compliance, 117

[82] The two rules were the "Administrative Rules for Crude Oil Market" and the "Administrative Rules for Refined Petroleum Products Market" (See Sinopec From 20-F, 2012)

[83] Sinopec Shanghai Petrochemical Company, Annual Report, 1996, page 21.

[84] Between January 2009 and January 2015 the tax on a litre of gasoline was raised from RMB1.0 to RMB 1.52. See Notice on Continuing to Raise the Refined Oil Consumption Tax, *Cai Shui* 2015 No.11

[85] Kambara and Howe, China Energy Crisis

[86] Zhang, China's Petroleum Industry

[87] Penrose, Foreign Investment, 234

[88] Pitelis in Growth of the Firm, xiv

[89] Nolan, Zhang and Liu, Global Business Revolution

[90] Fitzgerald and Rowley, Japanese Multinationals

[91] IEA, Asia Energy Outlook

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