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Captive markets and climate change: revisiting Edith Penrose's analysis of the international oil firms in the era of climate change

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ABSTRACT

Edith Penrose's analysis of the investments of the international oil companies (IOCs) stemmed from her interest in the economics of the large international firm and its implications for developing economies. Her approach highlights the endogenous factors shaping the growth of the large firm and cautions against viewing it as a neutral technocracy where investment automatically responds to price incentives. Drawing on Penrose's concept of a captive market in oil products, this research develops Penrose's ideas around motive, profit, self-financing and the international firm to explain why the IOC's institutional environment still favours investment in fossil fuels. The study collected country and firm level data on investment and production in downstream petrochemical refining. The data show a connection between the captive market and the strategies of the large oil firms in expanding refining capacity as a strategic hedge against regulatory policies to limit climate change. This locks society into a carbon intensive infrastructure, reduces the motivation for investment and adds to global CO_2 emissions. The findings indicate that the oil companies need to take greater risks on green investments with their retained earnings. Governments need to direct this investment towards socially useful purposes using coordinated regulatory pressure.

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'Had we invested massively in renewable energy in the past, we would not be so dramatically at the mercy of the instability of fossil fuel markets . . . . New funding for fossil fuel exploration and production infrastructure is delusional. It will only further feed the scourge of war, pollution and climate catastrophe'. António Guterres[1]

Investment and the diffusion of new green technologies is central to decarbonisation. Yet increasing evidence indicates that financial markets are not rising to the occasion, oil producers are unwilling to cut output (Jacobsson and Jacobsson 2012; Le Billon and Kristofferson, 2020; Semieniuk et al, 2022) and there has been little substantive progress on decarbonisation at the organisational level (Busch, Bauer, and Orlitzky 2016). One of the main organisation level actors are the large petroleum

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companies (IEA 2018, Christophers 2021). Why have the large petroleum firms continued to invest in downstream capacity that adds to the demand for fossil fuels? Drawing on Edith Penrose's (1968) analysis of the IOCs, this paper focuses on the IOC's strategic decision to go big on plastics and other petrochemicals and its role in increasing the emissions that drive anthropogenic climate change. Although a large body of research has focused on the transition of upstream oil producers (Heede 2014, Blondeel and Bradshaw 2022), much less is known about the strategies and emissions of refiners (Bauer and Fontenit 2021, Jing et al. 2020). Petrochemical refining is responsible for about one-third of future oil demand and along with power generation and cement production accounts for the bulk of stationary CO_2 emissions (IPCC 2018).[2] Increased investments in the petrochemical building blocks for plastics worsens carbon lock-in (Bauer and Fontenit 2021). Penrose's work indicates that the reasons for this expansion are to be found in the relationship between the oil companies long run planning of production and the uneven implementation of climate agreements.

Though often overlooked, Penrose's ideas around state-MNE relations hold enormous potential for influencing policies on sustainable economic development (Pitelis, 2009). In her analysis of the large oil firm, Penrose (1968) highlighted the role of the captive market in reinforcing the power and flexibility that vertical integration gave the IOCs. The basis of Penrose's argument was that the power of the captive market was such that it worsened the policy predicament facing developing economies, forcing them to alternate between a grateful acceptance of the IOCs proprietary technology and distrust of their pricing strategies. Conceptually, as with Penrose's (1959) *The Theory of the Growth of the Firm* (TTGF), this approach differs from viewing the oil market as characterised by Knightian-type uncertainty. Instead, the large oil firm internalises uncertainty by extending its administrative authority across countries, exploiting regulatory gaps and profiting with historical regularity. Climate change introduces a new dimension to this since its impacts on asset owners have been uneven and cooperation on reducing emissions has been limited (e.g. Colgan, Green, and Hale 2021), amplifying the conditions that Penrose (1968) viewed as leading the IOCs to discriminate across countries.

The paper focuses on the interplay between two stylised features of the petrochemical industry. The first is the projected shift in production related emissions from developed OECD economies to developing regions, especially China (IPCC 2018). In the oil sector, this shift has amplified what Penrose (1968) described as a captive market in oil products. Penrose viewed the power of the captive market as evolving from vertical integration. This allowed the IOCs to control access to advanced refining technologies and high value chemicals such as ethylene and propylene. These products have few close substitutes. Investment in refineries is also characterised by large minimum plant sizes and large sunk costs, allowing refineries to operate for extended periods at low average costs (Bauer and Fontenit 2021). Operating at low costs squeezes out the entrance of substitute products, further strengthening the captive market. Penrose (1968) viewed the flexibility and control that underpinned the captive market in oil as being so strong, it could only be broken by government pressure. Today these investments form a significant part of the fossil fuel infrastructure that creates Long Lived Capital Stock, causing societal lock-in to emissions intensive technologies and hindering a low carbon transition (Smith et al, 2019, Fisch-Romito et al. 2021, Kemfert et al. 2022).

This leads to the second feature of the contemporary captive market, namely the role of petroleum firms in ramping up downstream refinery capacity in plastics and other high value petrochemicals as part of a strategic hedge against weakening demand growth for transport fuels (IEA 2020). This increases the non-energy demand for fossil fuels and has a significant impact on emissions. A key driver of non-energy demand are petroleum-derived feedstocks. Feedstocks are key inputs in the production of a range of chemicals, plastics and synthetic rubbers and include naphtha and ethane. Data from the IEA indicate that chemicals produced by refineries account for approximately 90% of the feedstocks for plastics, fertilisers, fuels and resins, and CO_2 emissions from the chemical sector account for 18% of all industrial CO_2 emissions (IEA 2018, 50). Refineries account for around 5.97% of total worldwide CO_2 emissions with 638 plant sources with emissions greater than 0.1 Mt CO_2/year (IPCC 2018, 81). The growth in the production of plastics relative to other high emitting bulk products is driven by the low specific gravity of plastics that gives them weight, cost and fabrication advantages over metals (Freeman, Young, and Fuller 1963). The petrochemical building blocks for plastics also have few close substitutes. Alternatives such as bioplastics, which use bio-based feedstocks and pre-date petrochemicals, account for a low share of total plastics (Altman, 2022). Reducing CO_2 emissions from refining will therefore require either voluntary reductions in capacity or the large-scale investment in and rapid diffusion of low emission technologies such as carbon capture (e.g. IPCC 2018).

The next section draws on Penrose's work to set out the features of the captive market. Section 3 draws on country level data to document the structure of international production, ownership and variations in the technical complexity of refineries across countries. Section 4 analyses the trade dimension of the captive market by focusing on international trade in ethylene. Ethylene is a high value petrochemical derivative and the building block for a wide range of chemicals and plastics. Section 5 focuses on investment and production at the firm level. Given the scarcity of consistent firm level data on petrochemical refiners, a similar approach to other studies on the oil industry is followed (Green et al. 2021, Bauer and Fontenit 2021) where firm-level data on investment and ethylene output is gathered for a sample of large IOCs, NOCs (National Oil Companies) and independent refining companies. The final substantive section looks at the implications for emissions, policy, and theory.

1. Section 2: the captive market: investment, motive, profits, and uncertainty

This section outlines how Penrose's views on the relationship between the oil price, investment and the large integrated firm differed from those put forward by mainstream economics. It then draws on key theoretical contributions of her work to set out the features that sustain the captive market.

1.1. Misrepresenting oil investment: Penrose vs the mainstream

Taking its lead from the neo-classical preoccupation with equilibrium relationships between prices and investment (e.g. Robinson, 1962), economic analyses of the oil industry tends to use the hypothesised relationship between higher price

volatility and lower investment under conditions of uncertainty, reversibility and sunk costs as a starting point (e.g. Bernanke 1983; Henriques and Sadorsky 2011; van Eyden et al, 2019). This frames the oil industry in Knightian terms, facing resource heterogeneity, cognitive limitations, uncertain environments and using experience to profit from uncertainty (Knight 1921, 75). From this perspective, low investment in renewables can be explained by large upfront costs, prices and high risk.

The drawback with this approach is that market power and an oligopolistic structure creates 'a very considerable rent in the international oil price' meaning that while supply and demand influence prices and investment, they do so within a very distorted market (Stevens, 2005, 20). Penrose (1968) argued that the relationship between these variables bore only faint resemblance to that put forward in mainstream theory. Instead, she viewed the large oil firm as characterised by the long run programming of production. This involved searching for certainty, seizing productive or greener opportunities at its boundaries, while also spending time developing existing profitable opportunities (Penrose, 1968, 21). That is not to say that Penrose dismissed the efficacy of the profit motive as a guide to resource allocation. Profit was a core part of *TTGF*. What Penrose questioned was its explanatory function when the market is not permitted and some other authority became the arbiter of the public interest (Penrose, 1968, 22).

That authority was the large integrated oil firm and its role as arbiter of the public interest held significant implications for policy. Like Penrose, Schumpeter (1928) was critical of orthodox approaches for failing to appreciate how the transition from competitive to trustified capitalism resulted in a shift in the source of innovation. Under the latter, innovation is embodied in large existing units and occurred largely independent of individuals. In the oil sector this unit was exemplified by the large oil firm, which operated as a supranational administrative unit of control. This meant that where high profits are generated from a restriction in activity in one product area or country, these can be used to create new markets in another (Penrose, 1968, 21). This occurred without any great level of predictability. In this way the integrated structure acted as an efficient form of professional management (Chandler 2002). It also meant that apart from coming from the same raw material, the prices of oil products bore little connection to that of a barrel of crude, since technological developments determine the mix of products that could be produced (Penrose, 1968, 174).

The analytical challenge this presents is that the source of unpredictability of interest to researchers is often not exogenously determined but is instead to be found in the endogenous deployment of resources within the firm. For Penrose efficiency in producing and distributing oil products, while impressive, was not sufficient to explain the IOCs dominance. In the Penrosian firm, the cohesion of closely interacting and interdependent resources could not be created under a spot market setting (Pitelis and Wahl, 1998). This is illustrated in how the sector has used financial, commercial and political power to address challenges ranging from the oil nationalisation in the Middle East to the emergence of more transparent oil markets. This meant that the control over supply, which had underpinned vertical integration, could easily be replaced by trading divisions (Stevens, 2005). Financial integration became a prerequisite for operational integration, but intermediate oil markets could also substitute for operational integration, allowing the entrance of dedicated refiners (Tordo, 2011).

1.2. The captive market: motive, profit, and international investments

Once we recognise the above, it is possible to unpack the nature of the investment problem by outlining the features of the captive market. Captive markets occur where consumer choice is limited to a small number of producers who operate under monopolistic or oligopolistic market conditions characterised by low price elasticities or captive sources of supply (Hufbauer 1965, Vernon, 1966). For Penrose (1968, 230) the captive market 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'. This inevitably meant that for many developing economies the price of market entry for the IOCs involved the construction of a refinery as a means of ameliorating the balance of payment pressures associated with importing costly petrochemicals (Hartshorn 1962). Flexibility distinguished the captive market from a cartel, while vertical integration allowed the IOCs to use diversification into petrochemicals as a strategy to upgrade the value of their crude oil (Penrose 1968, 146). These features meant that location of oil refineries and investment had often little to do with market prices. The remainder of this section draws on Penrose's broader work to outline the factors that underpinned the captive market.

The first is motive. Motive, along with other factors such as technical capabilities and market logic are often assumed to be exogenously determined or constant in studies of the oil sector (Kim 2020). In TTGF, Penrose (1959) argued that it was impossible to have a discussion of the functions of a firm without an understanding of its motivation. Since profits represented a condition for growth and that funds that could be profitably used would be invested in productive opportunities 'growth and profits became equivalent as the criteria for the selection of investment programmes' (Penrose, 1959: 26). Following this logic, whereas energy transitions present firms with productive opportunities, firms will not invest unless there is a clear rational that they meet the criteria of growth and profits.[3] The logic is remarkably like the concept of fossilised capital (Malm 2016, Christophers 2021). Like Penrose, the concept of fossilised capital suggests that there is no simplistic relationship between prices and energy transition and 'if the path to profitability is not clear and compelling, the incentive to invest in renewable energy production will not be nearly substantial enough to drive investment on the scale that is ecologically necessary' (Christophers 2021, 8–9).

A second feature is that because motivation is not a homogenous characteristic of the Penrosean firm, emergent features of capitalism could easily undermine the rational for investment. Penrose's (1952) early work made it clear that she viewed innovation as a purposeful attempt to do something, rather than a chance mutation. In this sense, Penrose's views echoed those of Schumpeter (1942) and Robinson (1962) as competition becomes both 'at once a god and a devil', desirable because it drives innovation and undesirable as it leads to concentrated structures that impede growth (Penrose, 2009: 233). For Schumpeter (1942) trustified capitalism had the potential to undermine the unique characteristics of entrepreneurial innovation. This opened complex questions around whether market power is the price society must pay for rapid technological progress (the Schumpeter Hypothesis), and the type of policy interventions appropriate for productivity growth in concentrated industries (Nelson and Winter 1982).

Concentration could lead to a decline in capital deepening or capacity utilisation caused by changes in the financial sector. Financialization undermines the process of creative destruction in energy by shifting capital from productive to speculative investment (Jacobsson and Jacobsson 2012).

Penrose's analysis captured these points by questioning the extent to which the IOCs could be depended upon to invest in socially useful purposes. For technical progress to occur, the corporate economy requires large firms to invest (Marris and Wood 1971). The challenge this creates was summed up by Kaldor (1957, 595) who wrote that 'a society where technical change and adaptation proceeds slowly, where producers are reluctant to abandon traditional methods . . . is necessarily one where the rate of capital accumulation is small'. Penrose located the reluctance to invest in the conservative investment practices of the IOCs and the preference for self-financing as opposed to any lack of financial resources. Firms 'retain as much profit as possible for reinvestment in the firm' instead of taking on external debt (Penrose, 2009: 26). The tendency of the large firm to self-finance reflects a historical feature of the large corporation where corporate retentions, measured as the difference between profits and cash distributions to shareholders, represented the financial foundations for investing in productive assets (Filippi and Zanetti 1971; Lazonick, 2015). Innovation requires firms to take risks with retained earnings (Palladino and Lazonick 2022). Penrose (1968) drew specific attention to the tendency of the IOCs to finance a large proportion of their investment from retained earnings. This provided the IOCs with a considerable financial cushion over debt financed smaller private firms. In the context of current debates around stranded assets (e.g. Semieniuk et al, 2022) and an increasing tendency of large firms to use retained earnings to fund share buybacks (Palladino and Lazonick (2022), Penrose's work implies that the IOCs might better positioned to withstand changes in financial market funding.

The same conservatism also leads oil firms to resist government requests for socially useful investments. Investment outside core business areas accounts for less than 1% of the oil firms' total capital expenditure (IEA 2020). At the same time, there has been a strategic shift towards investment in plastics and other petrochemicals as a means of exploiting the benefits of vertical integration (IEA 2020, 269). Penrose argues that the IOCs conservative financing and investment undermined any claims that unfavourable oil prices and the threat of tax increases would jeopardise future investment (Penrose, 1968, 145). This feature also meant that the IOCs have significant financial resources to invest in petrochemicals. This reflects a broader criticism of policy makers for underestimating the power of vested interests in protecting current patterns of capital accumulation (Wright and Nyberg, 2015). A key implication from Penrose's work is that states need to understand existing patterns of accumulation and direct innovation activities towards socially beneficial purposes.

A final feature underpinning the captive market and for Penrose, its chief danger as a vehicle for international investment, was the way variations in treatment across countries forced it to discriminate. In this regard, Penrose (1968, 266) was critical of how Berle and Means (1932) viewed the large firm as a 'neutral technocracy' responding to the public interest. Any tendency towards neutrality was obstructed by the international firm's ability to know where to control and where to give way based on a 'very unstable combination of individualist competitive enterprise and co-ordinated planning'

(Penrose, 1968, 150). In the oil industry this inhibited unilateral state policy actions and incentivised the free rider problem (Stevens, 2005). Penrose's analysis draws attention to the relationship between the oil firms' technological advantage and economic policy. Petroleum companies in developed economies could suppress the wider diffusion of new techniques in refining and synthetic chemicals (Mandel, 1968). In earlier work on the patent system, Penrose questioned the social loss associated with suppression of the use of the most efficient processes by all producers (Machlup and Penrose, 1950). Later she showed how this forced developing economies to implement policies incentivising the IOCs to construct refineries as a way of dealing with the balance of payments pressures caused by the large-scale importation of oil products (Penrose: 1968, 224).

Based on the above, what would a green transition for the IOCs look like? Several broad industry approaches to a green transition have emerged including investment in renewables; investment in carbon capture technology; investment in alternative bio-based feedstocks; and the decommissioning of infrastructure such as refineries. Penrose's work suggests that these should be judged on clear evidence that retained earnings are being invested in new technologies, which are diffused in such a way as to ensure their rapid uptake in developing economies. Existing practice points to mixed evidence of progress across these areas. Some IOCs have made voluntary commitments to accelerate investment in and scale up new technologies under the Oil and Gas Climate Initiative. This includes 12 of the largest oil and gas firms accounting for 30% of global production.[4] Green et al. (2021) note that it is telling that the focus is on reducing carbon emissions rather than switching away from fossil fuels. Other IOCs have rebranded as integrated energy companies. Total announced that it would rename itself Total Energies and increase its investments in non-fossil energy sources, but as Bonneuil, Choquet, and Franta (2021) caution, the company has a poor history in this regard. Some European IOCs, such as the Italian firm Eni, have decommissioned oil refineries with the intention of converting these facilities to produce bio-based feedstocks.[5]

2. Section 3: the evolution of the refining industry

Downstream oil refining has evolved considerably since Penrose's analysis. This section outlines the major changes in location and ownership, with a particular emphasis on how the refining sector has exploited technological developments and market opportunities.

2.1. Geographical trends in refining capacity

One of the defining features of petrochemical refining since the early 1980s has been the closure of European refineries and the shift of refining capacity to the Asia Pacific region (Figure 1). This has seen the closure of large refineries and announcements regarding the planned decommissioning of others and could see many EU countries transition from a surplus to deficit in key petrochemicals. Care must however be taken in how these closures are interpreted, since environmental regulations make it costly to fully close refineries and as result many remain designated as refineries with implications for national capacity data (Stevens, 2005).

A second development has been the re-emergence of the US as a major refiner. Like in Europe, US capacity fell during the 1980s, but began to recover in the early 1990s. By

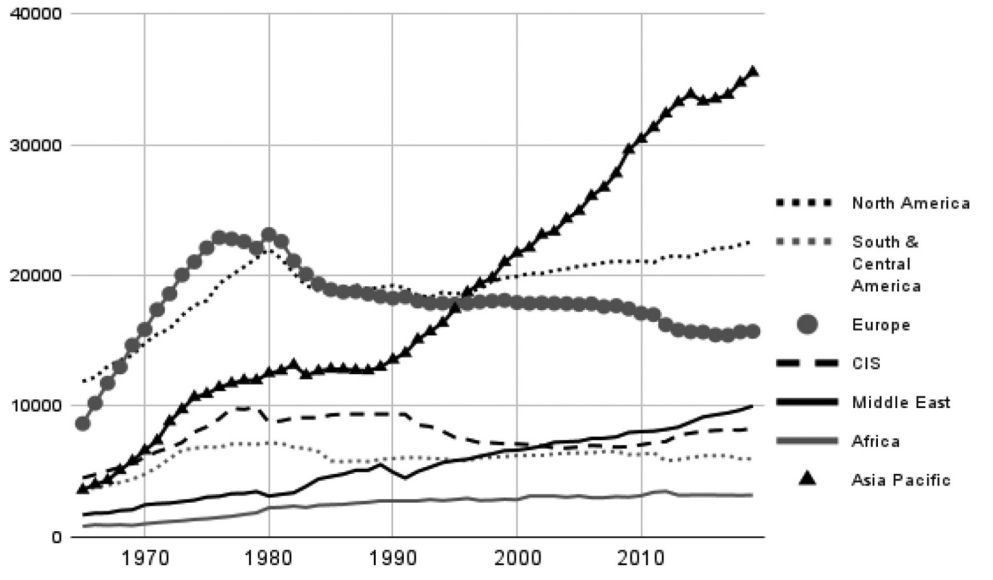

Figure 1. Refining capacities 1965–2019 (Unit: thousand barrels daily). source: adapted from BP (2020).

2019, the US accounted for 18.7% of global refining capacity, making it the county with the largest refining capacity (BP 2020). Recent capacity growth has largely been driven by shale gas discoveries. Technical breakthroughs and cost advantages have made shale oil uniquely responsive to price signals (Kim 2020). This led to an abundance of ethane, a key feedstock for ethane-based ethylene crackers. Ethane crackers yield around 80% ethylene, a key input for plastics, but unlike naphtha-based crackers, this leaves limited scope for other petrochemical products (IEA 2018). Abundant shale oil made the operational and feedstock costs of ethane crackers look extremely competitive relative to other refinery feedstocks in both the US and other regions (Table 1).

The speed at which US refineries were able to ramp up the construction of ethylene refineries in response to the productive opportunity offered by low-cost ethane is remarkable given their general reluctance to invest in lower-emission products. Three new ethylene refineries were constructed in 2017 and a further

Table 1. Feedstock cost by region 2017 (Unit: US$/per tonne of high value chemicals).

	CapEx/OpEx	Feedstock
Ethane - Middle East	176.4	85.4
Ethane - United States	176.4	211.0
Ethane – Europe	176.4	312.2
Methanol-to-Olefins – China	143.7	820.7
Naphtha - United States	244.1	825.5
Naphtha - Middle East	244.1	861.8
Naphtha – China	244.1	872.7
Naphtha – Europe	244.1	880.0

CAPEX refers to Capital Expenditure; OPEX refers to Operation Expenditure.
Source: IEA (2017): Simplified levelized Cost of Petrochemicals for selected feedstocks.

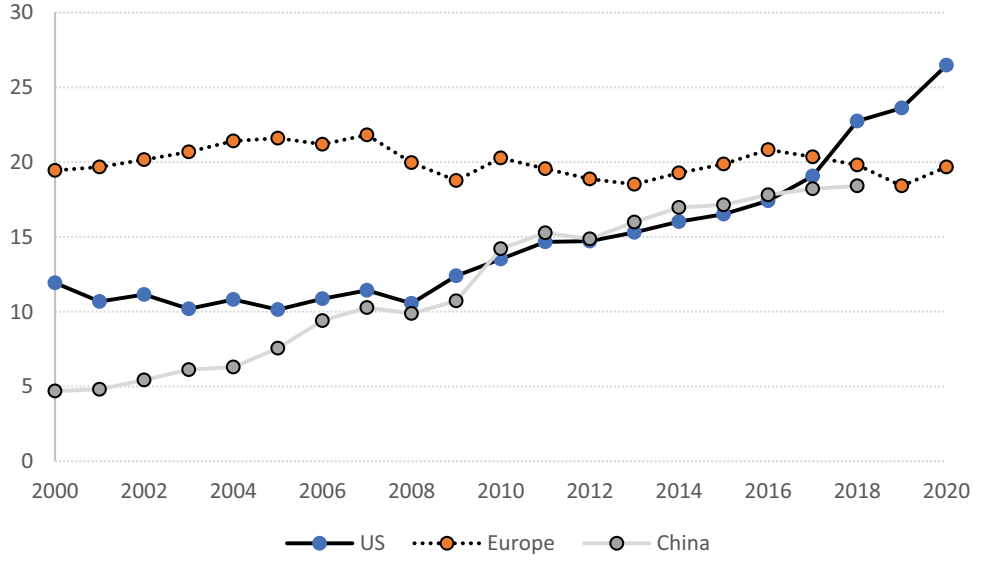

Figure 2. Ethylene output in major producers 2000–2020 (Million tons/year). Source: US data based on figures from US EIA; European data from the European Chemical Industry Council; Chinese data from State Statistical Yearbooks.

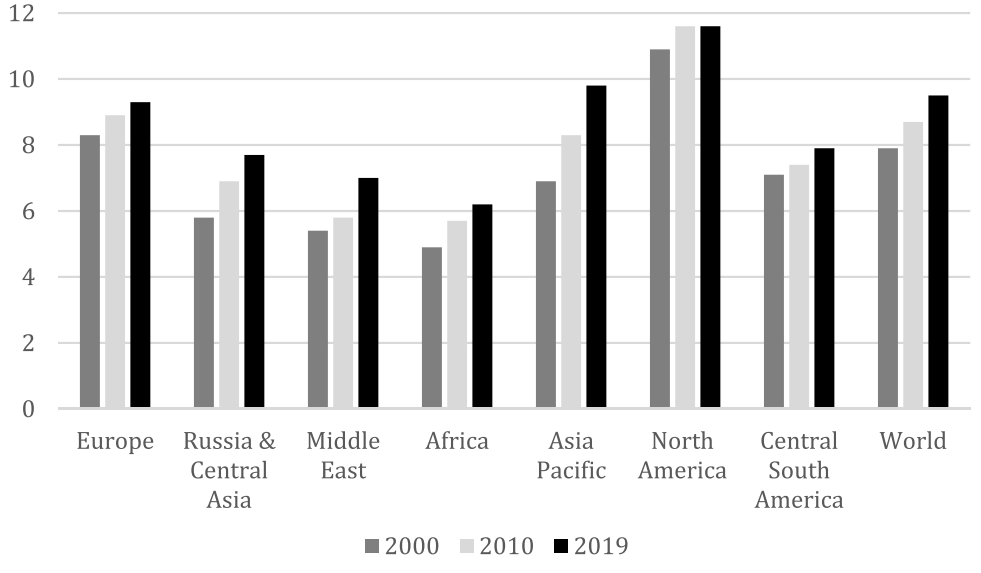

Figure 3. Nelson complexity index by region (2000–2019). Source: ENI (2015; 2020).

six ethylene refineries were penned for completion by the end of 2020.[6] The response saw US ethylene production overtake Chinese production in 2017 and European production after 2018 (Figure 2). This represented an increase in ethylene output from 392,368 thousand barrels daily in 2015 to 628,961 thousand barrels daily by 2020.

A third development has been the growth in refining capacity in Asia and the Middle East. Figure 1 shows that between 2000 and 2019 refining capacity in the Asia Pacific grew by 69% while capacity in the Middle East increased by 50%. Much of the growth in the former has been driven by China, which by 2019 accounted for 16.0% of global capacity, while the latter has been driven by Saudi Arabia, which grew refining capacity from 700,000 barrels per day in 1980 to 2,835,000 barrels per day by 2019 (BP 2020). This has been primarily driven by NOCs seeking to exploit uncertainties in oil markets by replicating the integration advantages of the IOCs by investing in downstream capabilities in large oil consuming countries (Marcel 2006). Countries like Saudi Arabia and Kuwait, which were viewed by Penrose (1968) more as suppliers than competitors to the IOCs, were well suited to this. Saudi Arabia has followed an economic diversification strategy based on capturing more value across the hydrocarbon value chain though vertical integration, exploiting shale oil and leveraging on the region's cost competitiveness (Fattouh 2021). Increasing refining capacity and the complexity of products produced has been a key aspect of this. Middle Eastern ethane enjoys significant cost advantages over the US and European feedstocks as well as over naphtha as feedstock in such regions as China (Table 1). Kuwait has also pursued vertical integration by acquiring overseas refining assets to compensate for any lack of open market refinery demand for its sour crude (Marcel 2006, Tordo, 2011).

The differences between growth in aggregate refining capacity and that in high value-added chemicals such as ethylene illustrate a fourth feature of the market. As such, capacity increases by themselves provide a limited insight into who captures value. Petrochemicals have become more complex reflecting the more sophisticated products demanded by industry. More complex refineries also have higher emissions (Jing et al. 2020). But refinery complexity is unevenly distributed across regions. One measure, the Nelson complexity index, shows that the US (followed closely by Europe) has consistently benefited from more complex refineries (Figure 3). Increasing investment in the Asia Pacific region has seen its complexity increase rapidly over the last decade. The Middle East, which benefits from large oil reserves, has traditionally had lower levels of refining complexity.

2.2. Ownership and the geographies of production

The most significant change to the IOCs since Penrose's account has been the change in control over oil reserves. In the 1970s the IOCs had access to 85% of the world's oil reserves; by 1980 this situation had completely reversed, and the IOCs had full access to 12% and the NOCs had access to some 59% (Diwan, 2007). Further distinctions can be made between the NOCs themselves. Saudi Aramco benefits from a high level of integration between upstream and downstream (Fattouh 2021).[7] While Norwegian, Venezuelan and Mexican NOCs were established to manage large existing reserves, Petrobras was established with the objective of turning Brazil into an oil producer (Priest, 2016). China's NOCs have sought to further national self-sufficiency in production and refining, and have minority listings on international stock markets (Tobin, 2019, Verbeek and Mah, 2020).

There have also been changes in the ownership of refining infrastructure. The share of global capacity accounted for by the IOCs fell, declining from 26% in 2000 to 14% in

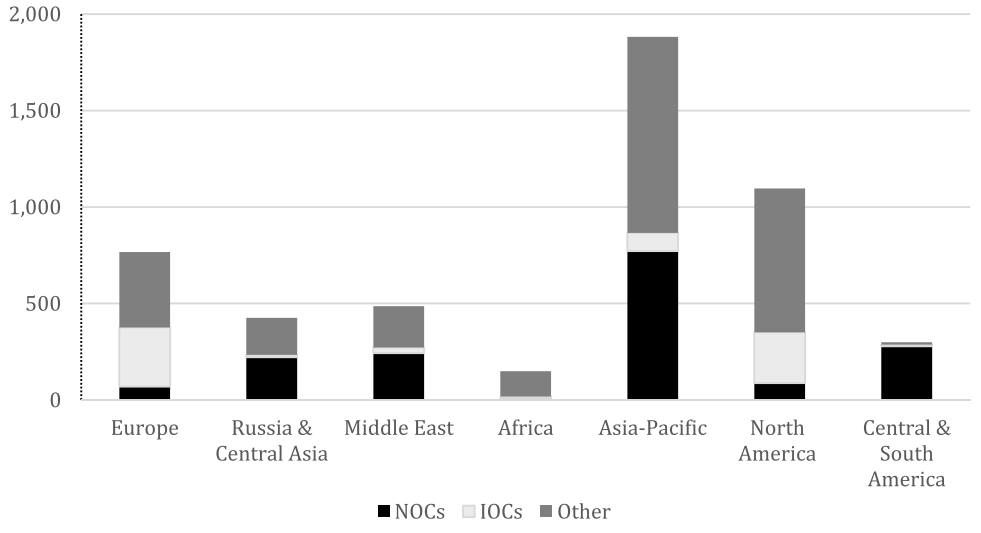

Figure 4. Primary refining capacity by region and type (2019, Unit: million tons). Source: Adapted from ENI (2020)

2019, while the NOCs share increased from 23% to 33% over the same period, with the share of other independent refineries remaining largely stable at around 50% (ENI 2020). These figures vary by region. The IOC's account for a small proportion of refining capacity in the Middle East. Here Saudi Aramco's refining subsidiary Saudi Basic Industries Corporation (SABIC), established in 1976 to develop Saudi Arabia's refining infrastructure, benefits from a lean western-style management structure and has emerged as a globally competitive player (Hertog 2008). In Central and South America, NOCs are responsible for most refining output (Figure 4). The African continent accounts for a small amount of global capacity and lacks established NOCs, with most capacity accounted for by independent refiners. North America accounts for the second largest region in terms of capacity. Here private refiners account for the largest proportion of capacity. Although the IOCs account for a smaller proportion of US capacity, this capacity dwarfs that of other smaller regions. The Asia-Pacific accounts for the largest share of global capacity. Here, the IOCs account for a small proportion of capacity compared to the NOCs and independents.

The above highlights two important factors for further analysis of the captive market. First, in many cases, oil reserves and refining infrastructure are owned by non-publicly traded companies and decisions on their future rest in political hands. In these cases, the risk of stranded assets lies in the hands of governments not market shareholders (Semieniuk et al, 2022). Secondly, the significant role of independent refineries and their control over advanced refining techniques highlights the need to include them in any analysis of the captive market.

3. Section 4: the captive market, trade and technology

The strength of the Penrose's captive market depends on the ability of refiners to use technical and trade advantages to transform crude oil into a variety of high value-added

petrochemicals. It is based on the fact that there is no general relationship between a country's oil reserves, and whether it runs a surplus or deficit in refined oil products. As Penrose (1968) argued, the mix of products that can be refined from a barrel of cure oil continues to depend on a mix of geological characteristics and technical capabilities. This section illustrates this by examining the trade balance in oil products generally and the case of ethylene specifically.

The oil production and product data in Table 2 illustrates this point. The US ran one of the largest deficits in crude oil and oil products in the early 2000s. Technical advancements in shale oil production and more complex refineries allowed the US to turn a large product deficit into a surplus by 2019. Only Russia and the Middle East ran larger oil product surpluses. On the other hand, Central and Southern American countries have run crude oil surpluses but need to import oil products. Similarly, the African continent runs a crude oil surplus and an increasing deficit in oil products. There are also large variations between countries in North and Western Africa, which have larger crude reserves and smaller product deficits and Eastern and Southern Africa, which tend to run crude and product deficits.

Table 2. Oil balance and oil product balances, selected countries and regions.

	2005		2010		2015		2019	
	Product Balance	Crude Balance	Product Balance	Crude Balance	Product Balance	Crude Balance	Product Balance	Crude Balance
United States	−8,964	−10,017	−404	−9,131	2,095	−6,860	2,952	−4,030
South & Central America	671	1,544	−254	2,216	−1,303	3,058	−1,817	2,509
Europe	−9,153	−9,772	−1,252	−8,954	−1,146	−9,597	−1,751	−9,957
Russia & CIS	1,702	5,374	2,057	6,385	3,078	6,219	3,553	7,212
Middle East	2,287	17,124	2,029	16,416	2,178	17,507	3,421	17,730
African Continent	7	6,117	232	6,679	−639	5,427	−1,638	5,853
China	−2,260	−2,418	−638	−4,670	−686	−6,686	−241	−10,177

Source: BP Statistical Review, various years.

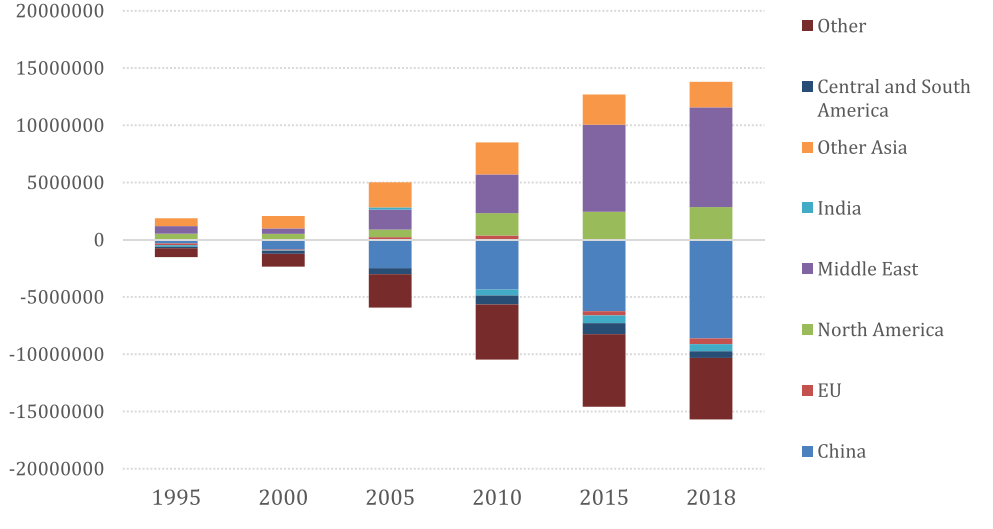

Figure 5. Ethylene polymers trade balance 1995–2018 (Unit: US$ 1,000).
Notes: Trade balances calculated using value of ethylene polymers in primary forms with a specific gravity of more than 0.94 (Product code: 390120) Source: WITS Database

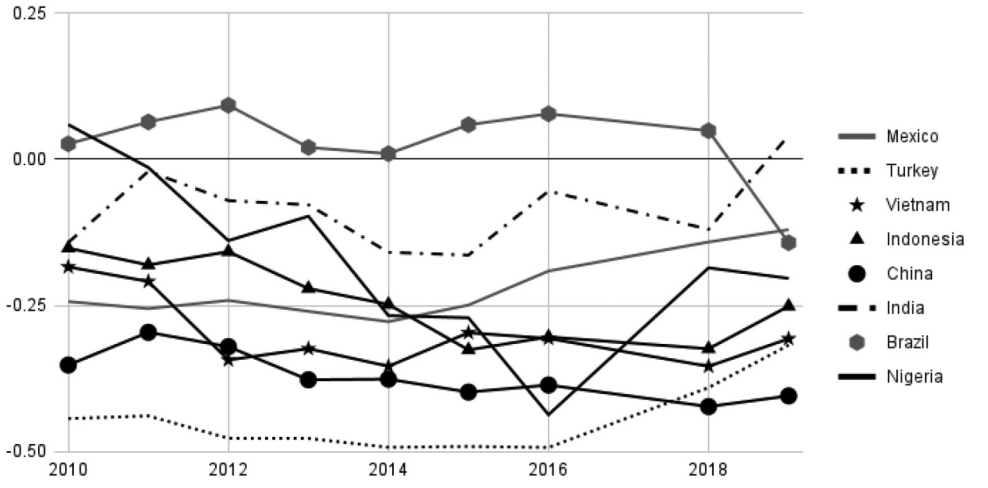

Figure 6. Net imports of ethylene polymers for selected deficit countries (% GDP). Sources: Word Development Indicators; WITS Database

Looking specifically at trade data for ethylene polymers, Figure 5 shows both the growth in the trade of ethylene since the 1990s and how the gap between surplus and deficit countries has seen a consistent widening between exporters and importers. Although China has expanded its ethylene production (Figure 2), this has not been of a sufficient scale to satisfy domestic demand and its trade deficit in ethylene polymers has increased over the period 1995 to 2019. On the other hand, the increased ethylene capacity of US refineries and their ability to export surplus petrochemical products has seen the US emerge as a major exporter of ethylene.

A central concern of Penrose's analysis of the captive market was the impact of these balances on the balance of payment of importing countries. Figure 6 shows ethylene polymer imports as a percentage of GDP. This shows that Nigeria, although benefiting from domestic oil reserves but lacking an advanced refining infrastructure and a state oil company, has seen an increase in its ethylene deficit as a percentage of GDP. In response, Nigeria has sought to expand their existing capacity to mitigate the effect of petrochemical deficits (Ogbuigwe 2018). China, which has the largest ethylene deficit in Figure 5, has sought to grow its capacity rapidly using a combination of NOCs and technology transfer (Tobin, 2019), but has seen its ethylene deficit increase. Turkey and Indonesia continue to run large deficits. Mexico has reduced the size of its deficit since 2014, while Brazil started to run a deficit after 2018. Both countries have used NOCs to develop their domestic oil reserves and refining infrastructures.

The data in Figures 5 and 6 illustrate the increasing import dependence and balance of payments pressures on developing economies. Low-cost ethane benefited countries with technological capabilities in complex refining such as the US but had had a negative impact on the petrochemical deficit countries south of its border. South American countries typically have surplus upstream production (Table 2), but low-cost ethane has locked in the region's dependence on imports from the US and other surplus countries. More generally the data point to a substantial growth in the global trade of emissions intensive petrochemical products.

4. Section 5: the captive market at the firm level

The value of Penrose's approach is that it reminds us that the data in Figures 5 and 6 reflect endogenous firm-level responses to the institutional environment faced by the large oil firms. This section examines this in greater detail using two metrics: production capacity and the ratio of capital expenditure to retained earnings. This helps assess the validity of Penrose's contention regarding the production and investment strategies of the IOCs and the extent to which these trends are also present in independent refiners and the NOCs.

4.1. The international oil companies

Figure 7(a) provides data for ethylene capacity growth at four of the largest IOCs for which data on ethylene capacity is publicly available. This shows that the IOCs have been quick to ramp up ethylene capacity. Significantly, Figure 7(b) indicates that the ratio of capital expenditure to retained earnings has shown a tendency to decline. Much of the growth in capacity is centred on the IOCs US operations and is geographically clustered around the Texas area. In 2018, Exxon's Corporation Baytown Ethylene Plant (along with Formosa Plastics Corporation Point Comfort Plant) had the largest ethylene capacity in the US with a capacity of 2.3 mtpy (million tonnes per year) followed by Shell's Beaver County Ethylene Plant and Chevron Phillips Chemical's (CPChem) Baytown Ethylene Plant with capacities of 1.5 mtpy. Shell is building an ethylene cracker in Pennsylvania (US) that will process ethane from shale gas to produce 1.6 mtpy of polyethylene. The motivation for the plant is its proximity to the source of low-cost ethane and its customer base for plastics.[8] Other IOCs such as Exxon are taking advantage of the opportunities offered by the growing Asian market. In 2020 it announced the construction of a 1.6 mtpy wholly-owned ethylene facility in Huizhou, China[9].

The long lead times involved supports the view that these investments represent a deliberate and long-term strategic hedge against reduced demand for fuels, rather than resistance to climate action. Exxon Mobil's Baytown ethylene facility was first announced in 2012 and did not come into operation until 2018.[10] The investment was planned with full knowledge of its negative climate impact. Internal planning documents for the project showed that by 2025, the Baytown plant will emit 1.6 million metric tonnes CO_2 equivalent.[11] The same documents revealed that its Huizhou refinery in China is predicted to add some 3.7 million metric tonnes CO_2 equivalent by 2025.

4.2. The independent refiners

Although independent refineries control some of the largest ethylene refining facilities in regions such as North America and Europe, there is less publicly available granular data on their operations. Large chemical refiners such as Dow, Formosa and Nova Chemicals have also made large investments in expanding ethylene capacity in North America. Available data on the ratio of capital expenditure to retained earnings indicate that they also follow a conservative investment approach (Figure 8). Increased production of

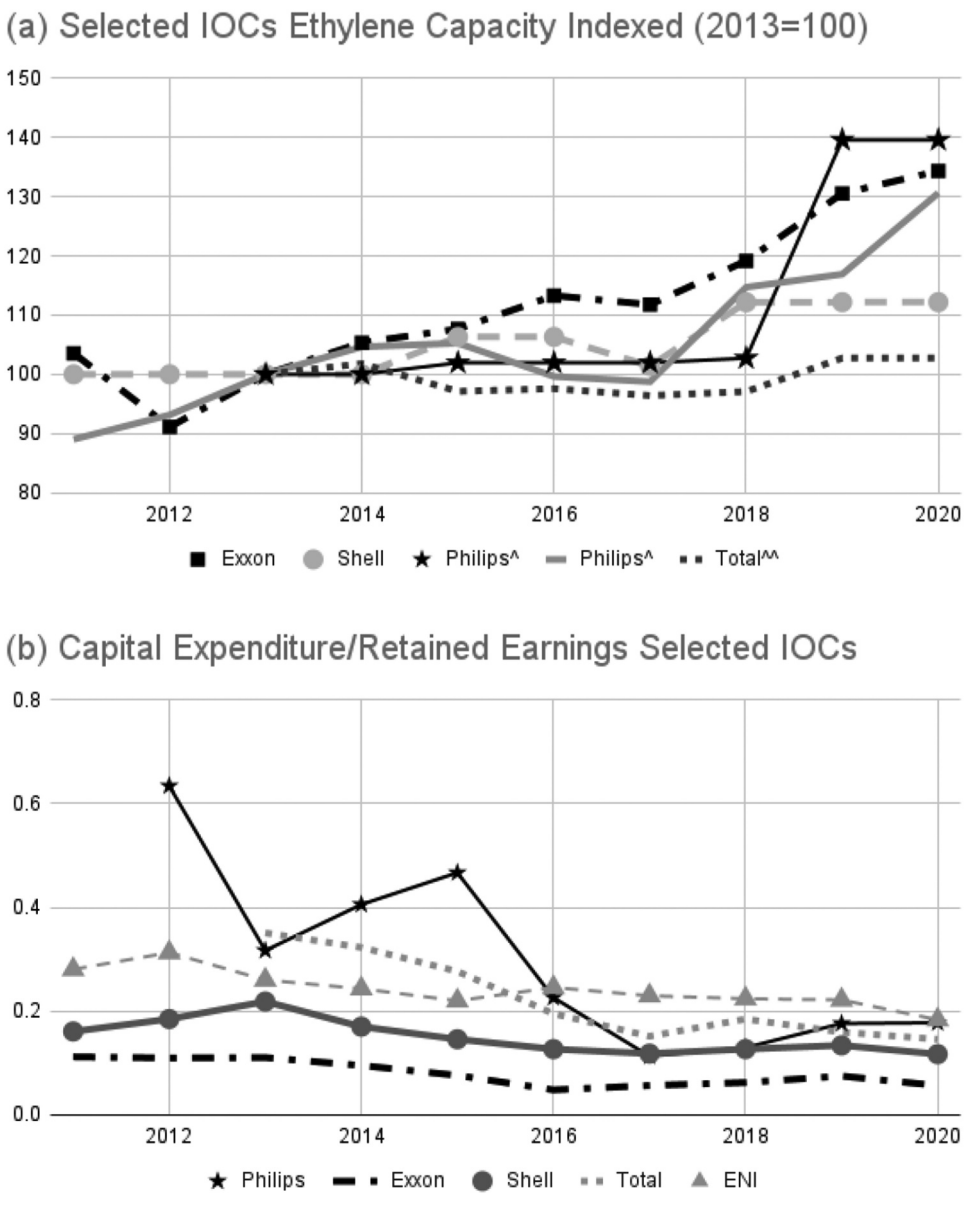

Figure 7. IOCs Ethylene Production Capacity and Capital Investment.
Notes: ^ Data for Philips 66 data based on ethylene capacity at CPChem in which it has a 50% equity share ^^ Total Energy capacity based on Olefins (Ethylene, Propylene and Butadiene) Source: Company Annual Reports and SEC Filings

intermediate chemicals allows the independents reduce their dependence on sourcing these in the market, creating a high value-added integration advantage.

As one of the world's largest producers of ethylene for the plastics industry, Dow provides a useful benchmark for how the independents have responded to the shale oil boom. Dow's announcement in 2015 of a major ethylene investment in its Freeport

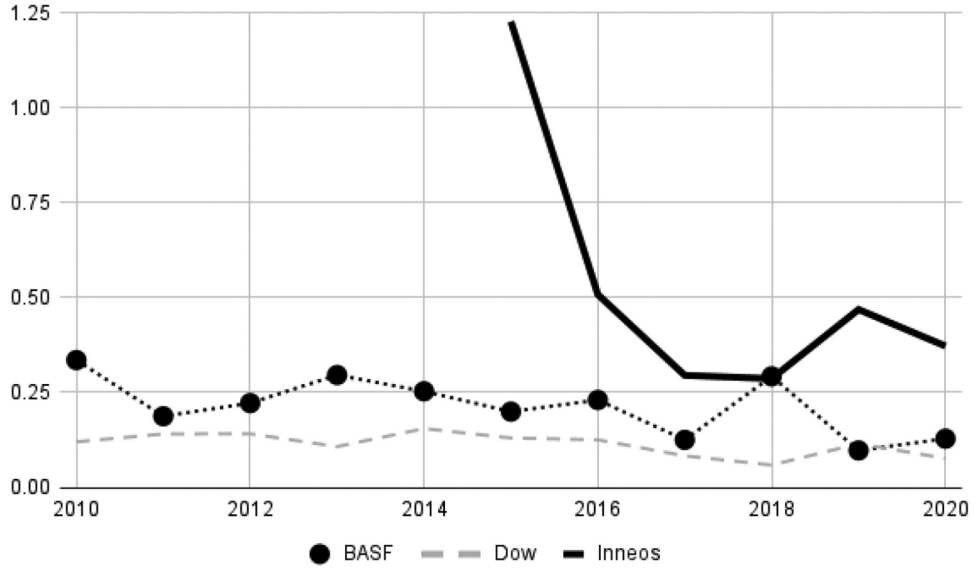

Figure 8. Ratio of CapEx/retained earnings selected independent refiners. Source: Annual Company Reports and SEC filings

refinery in Texas sought to exploit the cost advantages of shale oil. The facility came onstream in 2017 and a further investment saw the creation of the world's largest ethylene cracker, which commenced operation in 2020, bringing the facility's total ethylene capacity to 2 mtpy. The refinery reduced Dow's reliance on purchasing ethylene in the marketplace (Dow, Form 10K, 2015: 14). Illustrating the profitability of these investments, Dow claimed the investment delivered returns on invested capital greater than 15%.[12] In 2021 Dow announced the construction of an additional 1.8-million-ton of ethylene capacity at its refinery in Fort Saskatchewan, Alberta, due to come onstream in 2027. It will use carbon capture technology which could decarbonise 20% of Dow's global ethylene capacity by 2030 (see footnote 12).

Other independents like BASF have sought to exploit the productive opportunity arising from the relaxation of restrictions on full foreign ownership of refineries in China. In 2019 it began construction of a wholly owned refinery in Zhejiang.[13] Part of the justification for the plant's ownership structure was that it would protect what its chief executive described as its 'crown jewels', namely its intellectual property in high value-added chemical refining. There is also evidence of the emergence of new independent refineries in China. One of China's largest ethylene additions to come on stream in the next decade will be the Shandong Yulong Petrochemical Complex, which will have two 1.5 mtpy ethylene crackers.[14] The refinery has a mixed ownership structure involving private owners and a provincial government entity, with the ethylene technology supplied by the US firm Lummus, a global ethylene specialist.

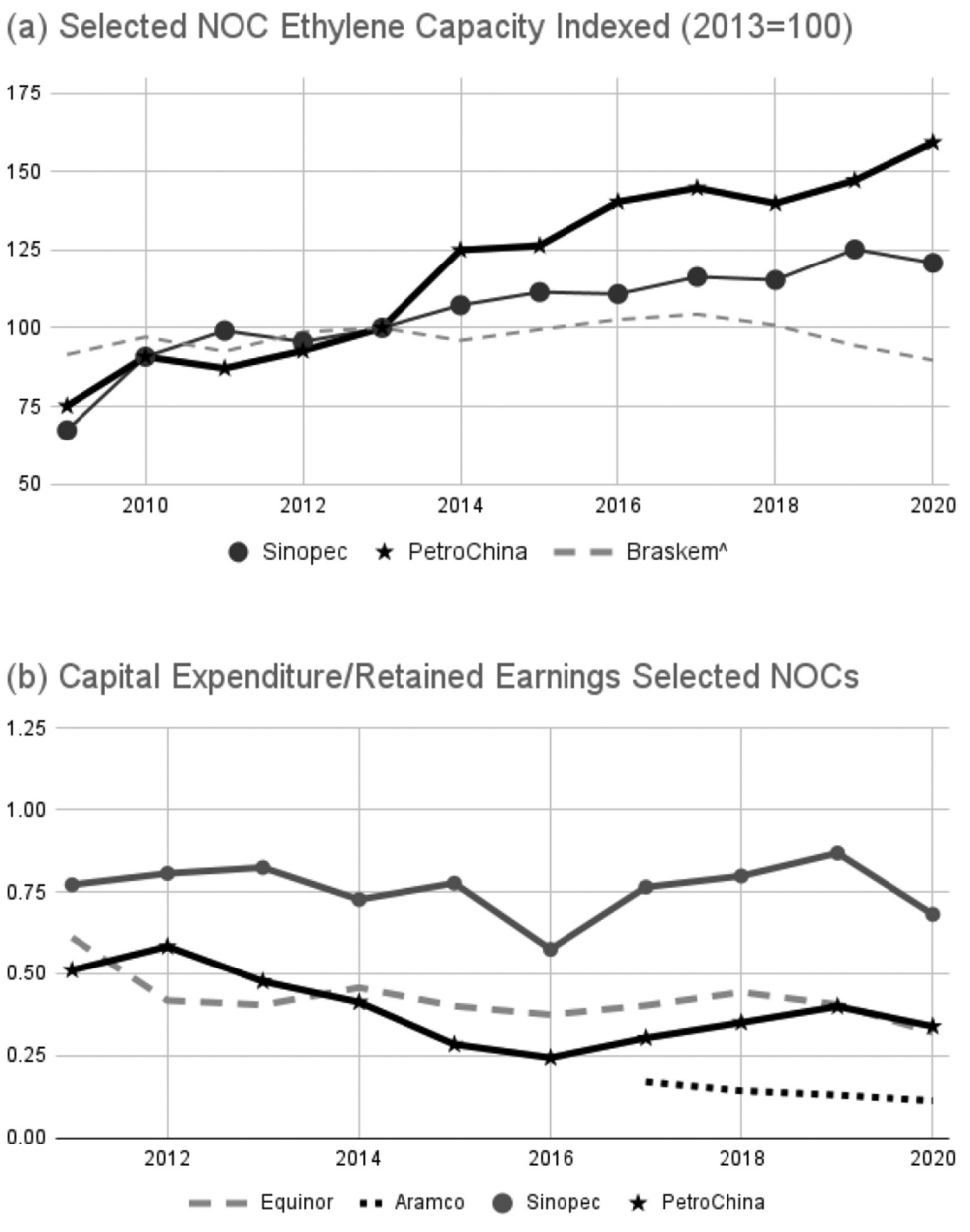

Figure 9. NOCs ethylene production capacity and capital investment.

4.3. The national oil companies

For the NOC's there is a clear geographical division between Chinese and Middle Eastern NOCs, who have grown their ethylene capacities, and their South American counterparts. China's NOC's have become significant contributors to the growth in global ethylene capacity (Figure 9). While these growth rates are impressive, they have not

reversed China's import demand, suggesting that the IOCs and independents have exercised tight control their intellectual property through ownership of technology or joint ventures (Tobin, 2019).

Saudi Aramco's refining subsidiary SAIBC has significantly expanded its capacity from 12.5 mtpy of basic chemicals including ethylene in 2000 to 35.7 mtpy in 2021 (SABIC, 2000; 2021). This reflects Aramco's strategy of using joint ventures with other NOCs and IOCs to secure a market for its low-cost heavy crude oil. In 2020 it announced a joint venture with Petronas, the Malaysian NOC (SABIC Annual Report, 2020: 63), and in 2021 SABIC announced the commissioning of the world's second largest ethane cracker in Texas as part of a joint venture with Exxon Mobil.[15] These investments appear to be part of a deliberate strategy to position Aramco close to the cost advantages of US ethane and the Asian growth market.

What is remarkable about the investment position of the NOCs is the extent to which it mirrors the that of the IOCs. Only Sinopec, China's largest state-owned refiner runs a ratio of capital expenditure to retained earnings that is noticeably higher than the IOCs. Data from the IEA (2014, 55) for 2002–2012 show that the NOCs financed close to 80% of their investments from retained earnings (IEA 2014, 55). Petrobras, the Brazilian NOC provides a notable exception to this relying on debt financing to fund capital spending in the development of the Lula oilfield (IEA 2014). The use of debt finance represents a big departure from the past where the infusion of social capital was substantial and included tax receipts, the reinvestment of dividends and the favourable pricing of the outputs of Petrobras's refining output (Penrose, 1968, 241).

The data in Figure 9(a) also show that it is difficult to generalise the NOCs. This point is illustrated in the case of Braskem. It has the largest polyethylene refining capacity in Latin America but has struggled to grow capacity Figure 9(a). South American NOCs were severely impacted by the decline in oil prices in the 2010s, with many divesting their downstream refining assets, preferring instead to import cheaper petrochemicals from the US, Middle East and Asia.[16] To diversify its supply of feedstock and take advantage of cheaper US ethane, Braskem has invested in a refining facility in Northern Brazil that will refine ethylene from ethane supplied from the US (Braskem, 2017, Form 20-F: 28). These investments ultimately serve to lock Latin American deficit countries into a captive market, increasing their dependence on cheap US ethane.

Braskem also shows the challenges for NOCs transitioning away from fossil fuel-based refining, even where there are natural resource advantages. Brazil's ample sugarcane supply provides it with a resource advantage in plant-based feedstocks. About 50% of the world's bio-ethylene capacity is in Brazil (IEA 2018, 44). In 2020, Braskem announced a project to expand production capacity for green ethylene, a feedstock made from sugarcane ethanol, which would add 60,000 tonnes/annum capacity by 2022 (Braskem, 2020 20-F: 50). Braskem has a target of increasing its production of green polyethylene to 1 million tonnes/annum by 2030.[17] However, like fossil fuel-based refining, this requires operational integration and scalable technologies. Braskem is dependent on technology provided by US firm Lummus.

Table 3. Forecast refinery expansion by regions (unit: thousand barrels/day).

	2020	2021	2022	2023	2024	2025	2026	Total
OECD Americas	−338	−203	50	250	340			99
OECD Asia Oceania		−466	−120	−109				−694
Europe	−278	−242	−120	0	0	0	0	−640
China	204	266	190	500		400		1,560
Other Asia	14	225	−60	446	100	630	290	1,644
Latin America			33	15			−36	12
Middle East	520	230	610	340	140	−20	60	1,880
Africa		10	650	30	150		100	940
Former Soviet Union		50	30		30			110
Total	121	−129	1,263	1,472	7,60	1,010	414	4,911

Source: Adapted from IEA (2021) Oil 2021 Analysis and forecast to 2026 Table 4. World refinery capacity additions.

5. Section 6: policy implications: captive markets, technology and climate

Petrochemical refining represents a growing part of the fossil infrastructure that locks in society to carbon intensive technologies. Each additional unit of refining capacity adds to the demand for fossil fuel inputs. While the analysis here only covers a sample of leading IOCs, NOCs, and independent refiners, its findings are consistent with other research that shows an acceleration of downstream projects, especially in ethylene-based plastics (IEA 2020, Bauer and Fontenit 2021). Forecasts indicate a continued growth in refining capacity, much of which will be in developing economies (Table 3). This section considers the impacts of this for developing economies, climate policy and theory. Its central argument is that reducing the emissions from downstream refining will require recognition of one of Penrose's (1968, 264) key conclusions namely that while 'the administrative controls of international firms are supranational', their strategies impact on individual nations differently, creating a serious distortion of the benefits and costs of their international investments.

Nowhere is this point more apparent than in the relationship between the investment strategies of the large petroleum refiners and their impacts on developing economies. Many developing economies are increasingly dependent on petrochemical imports and the investments of the large firms. In addition, much of new refining capacity to come on stream will come from non-OECD Asia, China and Africa (Table 3). The analysis in this paper indicates that the benefits and costs of this expansion are distorted by the role of the large petroleum firms. The economic benefits of this expansion will largely accrue to a small number of large refining and independent chemical companies, who have the integration advantages and proprietary technology.

While Penrose focused on the balance of payment costs of such investments, climate change has drawn increased attention to their environmental costs. The pollution costs of plastics have been well documented (Altman 2022), but the emissions implications are less well understood. There is a large degree of uncertainty regarding future CO_2 emissions from heavy emitters due to differences in the drivers of their growth and technological progress (IPCC 2018). One study put the carbon impact of refining at 13.9–62.1 kg of CO_2-equivalent per barrel (Jing et al. 2020). The variation in estimates have their origins in Penrose's (1968) point on way technical progress determines the product mix of a barrel of crude. Ethylene units contribute about 258 million tons of CO2 emissions per year globally or 1.08 million tonnes per ethylene cracking unit (IPCC

2018, 81). The EIA (2021) estimates that between 2013 and 2020, the US increased it ethylene capacity from 27 million mtpa to 40 million mtpa. By hedging against a reduction in fuel consumption and focusing on plastics, US refineries have added approximately 14.0 million tonnes of CO2 equivalent.

How do we interpret Penrose's work today and does it help with the policy dilemmas outlined above? One of the implications of Penrose's work is that in the absence of coordinated regulation, the oil companies cannot be depended upon to undertake socially useful investments in green technologies. At the same time, the retreat of states from efforts to shape oil markets, let alone the market for petrochemicals, has allowed the IOCs significant space to shape these markets in their own interests (Hughes 2014). Climate agreements such as the Paris Nationally Determined Contributions and the proposed European Green Deal retain national level flexibility in how targets are met. Klenert et al (2020) argue that in terms of levels of national cooperation, many developed countries have become stage three actors, committing to meet ambitious nationally determined targets, but falling short of meeting what they see as stage four cooperation, which would involve full international cooperation backed by financial resources for lower and middle-income countries.

One of the less explored, but potentially fruitful implications of Penrose's work going forward concerns the regulatory aspects of state-MNE relationships and antitrust policy (e.g. Pitelis, 2009). It is likely that Penrose would have favoured the Harvard approach to antitrust regulation over its Chicago counterpart (Thomson and Wright, 2005). There is empirical evidence to support the positive role for more stringent regulation in the oil industry (Green et al, 2021). Other research has highlighted the dangers and potential contests inherent in an uneven adoption of climate targets and its impacts on large firms holding different forms of climate forcing assets that accelerate damage to the climate such as oil fields and refineries (e.g. Colgan, Green, and Hale 2021). It is increasingly recognised that to be effective, technical solutions such as carbon capture, which tend not to capture all emissions from refineries, will still require a shift towards non-fossil fuel inputs and a regulatory framework that is favourable to a net zero transition (Sunny et al, 2022). Penrose (1968) recognised the tension between firms' supranational coordination and national level policies required coordinated state response that had sufficient power to break the captive market.

6. Conclusion

In drawing attention to question of motive, flexibility and the investments of the large firm, Penrose's (1959, 1968) work highlights the importance of understanding the endogenous and institutional-level incentives underpinning current patterns of accumulation. It cautions against market-based interpretations of the large firm. As supranational administrative units of control, large firms internalise risk and therefore, the relationship between the oil price and investment is distorted by the large firm. Her approach suggests that we need to look closer at the inner workings of oil firms and their external environments to understand why the large oil and chemical firms continue to invest in downstream capacity that adds to the demand for fossil fuels.

The analysis in this paper indicates that the broad institutional environment facing the large oil firm still favours fossil fuel investment. The captive market has enabled the oil

firms to hedge against action on climate change by increasing capacity in high value-added chemicals such as ethylene. This adds to global emissions and represents a clear obstacle to a green transition. There is little evidence of decarbonising or a departure from historical trends in accumulation. Instead, the paper shows that the conservative patterns of investment and the tendency to resist government requests for socially useful investments that Penrose identified in her analysis more than fifty years ago still characterise the sector today. These are consistent with the risks that both Schumpeter (1942) and Penrose (1956) associated with a trustified form of capitalism, where monopoly conditions are viewed necessary for continued innovation and progress Penrose (1956, 233–234) was clear that in some cases this condition was plainly not true. In short, the oil firms do not invest or take risks at the scale required for the corporate economy to make a sufficient positive contribution to a green transition. The role of the captive market in slowing a green transition, the potential for global regulatory coordination and business state relations are areas of Penrose's work that deserve further research in this regard.

The international nature of the captive market implies that petrochemical deficit low- and middle-income economies in South America, Asia and Africa continue to face the policy dilemma between becoming locked-in to imports or accepting technological dependence. Climate change adds an additional dimension to this. This highlights a more general point that regardless of whether we talk about alternative or petroleum derived ethylene or the potential of carbon capture technologies, the barrier for many developing economies remains one of access to technology. In this regard further research is needed on the mechanisms that can facilitate faster rates of technical diffusion. In short, addressing the impacts of climate change calls for a better authority as an arbiter of the public interest (Penrose, 1968, 22).

Notes

1. UN Secretary-General's video message to the Sixth Austrian World Summit 14th June, 2022
2. The IEA (2018) predicted oil demand growth of 9.6mb/day from 2017–2030 with petrochemicals accounting for 3.2mb/day.
3. Penrose (2009: 26–27) was clear that in making this assumption 'there is no need to deny that other objectives are often important – power, prestige, public approval, or the mere love of the game – it need only be recognised that the attainment if these ends more often than not is associated directly with the ability to make profits'
4. These include Aramco, BP, Chevron, CNPC, Eni, Equinor, ExxonMobil, Occidental, Petrobras, Repsol, Shell and TotalEnergies. See ocgi.com.
5. In 2021 Eni announced the closure of its Porto Maghera refinery. See 'Italy's petrochems units face uncertain future as Porto Marghera set to close' https://www.icis.com/explore/resources/news/2021/03/24/10621155/italy-s-petchems-units-face-uncertain-future-as-porto-marghera-set-to-close
6. U.S. Energy Information Administration, Short-Term Energy Outlook February 2018.
7. In 2021 Saudi Aramco claimed that 43% of its oil production was consumer by its downstream activities (Annual Report, 2021: 61).
8. See https://www.shell.com/about-us/major-projects/pennsylvania-petrochemicals-complex.html
9. 'Exxon Mobil starts building $10 billion China petrochemical complex: Xinhua' Reuters, 22nd April 2020. https://www.reuters.com/article/us-exxonmobil-china-petrochemical-idUSKCN2241DJ

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