'The legacies of the oil price increases of the 1970s have never quite stopped unfolding, and continue four decades later to affect us in diverse ways. *Oil Shock* offers a timely and panoramic survey of the origins and consequences of 1973 at a time when oil, the politics of oil, and the Middle East are once again back in the headlines.'

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'This superb collection of essays provides a comprehensive analysis of the 1973 oil crisis. Relying on a rich archival research and examining the multiple drivers, facets and reverberations of the crisis, the volume offers important information and insightful interpretations on a pivotal moment in the history of modern international relations. This is essential reading for anyone interested in the 1970s, the Cold War, and the origins of the current global energy regime.'

– Mario Del Pero, Professor of International History, Sciences Po, Paris

'This book provides an important and valuable contribution to the understanding of the oil shock in 1973 and its long-lasting consequences.'

– Einar Lie, Professor of Economic History, University of Oslo

'Fifty years down the line, the key factors that gave rise to the first oil shock (the Middle East in flames, the dearth of "easy oil") are still with us, and yet this anniversary was passed over in near total silence in both the media and academia. This valuable book is the crystallization of the commendable effort to make sure that hard questions about the first oil shock continue to be asked.'

– Juan Carlos Buoè, Research Fellow, Oxford Institute for Energy Studies

OIL SHOCK

THE 1973 CRISIS AND ITS ECONOMIC LEGACY

EDITED BY
Elisabetta Bini, Giuliano Garavini and Federico Romero

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Shifting Sands: The 1973 Oil Shock and the Expansion of Non-OPEC Supply

Tyler Priest

The fortieth anniversary of the 'oil shock' of October 1973 passed in 2013 with hardly any public commemoration. In the US, in particular, there was little reflection about the pivotal moment when six Persian Gulf oil producers raised their benchmark oil price by 70 per cent and accelerated the renegotiation of long-time concessions to foreign oil companies, while Arab members of the Organization of the Petroleum Exporting Countries (OPEC) embargoed oil shipments to the United States and other countries that backed Israel in the Yom Kippur War. There was not a word about it in the *New York Times*. There was also nothing from the Richard M. Nixon Presidential Library, which was preoccupied with the latest release of White House tapes. This eerily mirrored how the unfolding Watergate scandal and the *first* release of White House tapes in October 1973 had distracted the Nixon officials from the oil crisis.

The sparse commentary that did come forth overlooked crucial historical details. Many stories mistakenly referred to the 'OPEC embargo', when it was Arab members of OPEC, not the organization itself, which imposed

the oil restriction.[1] They implied that the objective of the embargo was to raise oil prices, when it actually aimed to protest US support of Israel. Journalists repeated the mistake of attributing gasoline shortages to the embargo, when in fact the long lines at gas stations were mostly caused by the misguided policy of price controls and emergency supply allocations imposed by Nixon between 1971 and 1973.[2] Op-ed pieces replayed the dirge about how the US, after 40 years, is still dangerously dependent on foreign oil, with differing opinions about whether we can 'frac' our way to independence or find deliverance only through a radical shift to 'renewable' energy.[3] These stories missed the larger implications of the oil shock for both the global political economy and the oil industry itself.[4]

The embargo was a major contributor to the shock, but only one factor among others. Jay Hakes demonstrates that the US vulnerability to an interruption in foreign supplies of oil, or at least tightness in global supply, resulted from several underlying transformations, especially the loss of US domestic surge capacity in oil. Fiona Venn writes that the energy crisis of 1973 consisted of two 'distinct but interrelated crises', one 'political', which was the six-month embargo shaped by the Arab–Israeli conflict. The other was 'economic', which concerned the renegotiation of oil agreements, beginning in 1971, which increased the level of payments to host governments. By 1974, most of these nations began moving from participation to 100 per cent nationalization. This is the real significance of the oil crisis of 1973. The natural resource owners were now in the driver's seat and exercised their sovereign power to revise the rules governing oil in their nations and to assert control over oil production and prices. In none of the news stories from October 2013 was the word 'nationalization' ever mentioned, leaving the impression that the major oil companies never owned lucrative concessions in OPEC nations.[5]

The OPEC nationalizations resulted in what Steven Schneider called the 'largest non-violent transfer of wealth in human history'.[6] Nationalization changed the international petroleum industry and the world. In assessing the long-term impact of the 1973 oil shock, historians as well as journalists tend to underplay nationalization in

favour of an emphasis on the embargo and price shock, especially the varied effects of the quadrupling of oil prices on consumers, economies and governments.[7] Like much of the journalistic coverage of the fortieth anniversary, American historians often lament how little has changed in the past four decades to alleviate the nation's vulnerable dependence on oil. Paul Sabin criticizes the tepid response of US energy policy since the 1970s, which 'only modestly altered American patterns of energy use'.[8] Others are more hopeful about the lesson of the shock for solving 'America's hydrocarbon predicament'. According to Mark Fiege:

> Perhaps the most important legacy of the first great oil shock was a revived and persistent conservation ethic that reminded citizens that they could not sustain their hydrocarbon habits over the long term and that they needed to try something different.[9]

An equally important legacy of the first great oil shock, besides the 'conservation ethic', was a rejuvenated commitment to finding new oil sources. Contrary to the fears of many contemporary observers, the 1973 shock did not produce an oil or energy shortage. Rather, it provided the economic incentive and strategic imperative to expand global hydrocarbon supplies from territorial and geological frontiers beyond the control of OPEC. Consumption patterns may not have changed as much as some people would have liked, at least in the US, but the world of oil production has experienced a major transformation since 1973. This is largely a result of technological innovations in the oil and oil service industries. Rising oil revenues afforded the commercialization of sophisticated oil-field technologies that were needed to reach oil deposits in untested parts of the world and under difficult environmental conditions. The overriding lesson of the oil shock was indeed to 'try something different'. To a significant extent, that meant trying different things, in different locations, but in pursuit of the same objective – hydrocarbons.

The End of Business as Usual

As Francesco Petrini observes in this volume, the literature on the oil companies' role in the first oil crisis has alternated between interpretations that view the oil majors as all-powerful, complicit in orchestrating the price increases of the 1970s, or isolated and passive, forced to surrender to the new assertion of producer power. In fact, it was even possible for commentators at the time to hold both views simultaneously. Investigative journalist Robert Sherrill, who covered the 'oil follies' of the 1970s, alleged that the 'shortage was so blatantly contrived as to make the word conspiracy seem justified'. At the same time, he warned that 'anyone born in the 1930s who lives a normal life-span will probably see most of the wells in America come to a wheezing halt as the fields run dry'.[10] This was because the oil majors, in his opinion, had become so cozy with OPEC that they shunned exploration in the US and non-OPEC countries and were willing simply to pass on the high costs of OPEC oil to consumers through their control of downstream assets.

This snapshot of the situation from the late 1970s sorely misread what was happening. First, the oil majors were hardly co-conspirators with OPEC, especially considering the accelerating renegotiation and nationalization of oil concessions in the early 1970s. Although not passive, the oil majors were clearly unprepared for the new reality thrust upon them. As Joseph Pratt explains in his history of Exxon, the decision-makers at the major oil companies at this time were hobbled by the fact that they 'made up one of the few generations of oil executives in history whose primary management experience came during an era of relative oil price stability and steady economic growth'.[11] Their management structures lacked the tools to cope with extreme price volatility. By the end of 1973, all their price-forecasting methods, which never accounted for the ability of suppliers to double the price of crude oil overnight, went out the window.

Not only could they not anticipate drastic price changes, they were also slow to respond to changing market conditions in the late 1960s

and early 1970s. During the stable period of low crude oil prices in the 1960s, as Sherrill correctly observed, the majors generally eased off oil exploration and shifted capital budgets downstream into refining and chemicals. Upstream planning by international oil companies often did not prioritize exploration opportunities on a global basis. By allocating capital to the top-rated projects of national affiliates, corporate strategy failed to 'take into account the rise and fall in importance of the regional companies or their potential for growth'.[12]

The major oil firms, as well as their home governments, were not merely unprepared for the oil shock. They had become so accustomed to business as usual that they disregarded warning signs that the world was about to change, or change a lot faster than they realized. Supply forecasts from some companies, as early as 1971, that spare shut-in well capacity in the US was much less than what was being reported did not find a receptive audience in industry or government until after the embargo. Domestic oil reserve estimates coming out of the US Geological Survey, meanwhile, were wildly inflated. In October 1973, right before the outbreak of the Yom Kippur War, the Aramco partners anticipated only a gradual increase in 'participation' by Saudi Arabia through the 1970s, but by the following summer they were forced to agree to 60 per cent participation retroactive to 1 January 1974. As Watergate increasingly distracted and weighed on Nixon and his chief aides, secretary of state and national security advisor Henry Kissinger, who by his own admission knew very little about the oil industry, confidently believed weapons deliveries to Israel would not provoke a boycott.[13]

The combined effects of the embargo, oil price increases and the collapse of the concession system abruptly ended the post-World War II petroleum order. Although surprised at the suddenness of this change, the major oil companies and consuming nations began developing a new structure to defend their interests. The US government and its allies implemented policy reforms that moderated demand and built up strategic stockpiles.[14] The international oil companies and their home governments began promoting bilateral investment treaties and contractual

arrangements that eroded the concept of state sovereignty at the heart of the OPEC revolution.[15] Perhaps the most significant legacy of the 1973 oil shock was the huge impetus it gave to the enlargement and diversification of non-OPEC oil supply.

Although many American commentators believed the end of oil was nigh, the tenfold increase in crude oil prices between 1973 and 1981 encouraged feverish new drilling and turned previously marginal deposits into profit machines. Another generation of oil multimillionaires sprouted up in Texas, the 'land of the big rich', according to the popular television series, *Dallas* (1978–91). 'Suddenly, everyone wanted into the oil game', writes Bryan Burrough. 'Geologists fled the majors to become wildcatters. Doctors and dentists pored [*sic*] money into discovery wells. In Houston, Dallas, and Midland new skyscrapers grew like grass'.[16] In addition to producing new fortunes in Texas, soaring crude prices boosted developments in harsh and challenging environments like the North Sea, Alaska's North Slope, and offshore Gulf of Mexico and Brazil. The industry's search for oil may have been somewhat half-hearted prior to 1973, but certainly not afterward.

Oil from the North

Efforts by oil firms and consuming nations to diversify oil supply away from OPEC and Middle East sources began, of course, before the 1973 oil shock. The 1956 Suez Crisis and the Arab–Israeli war of 1967 (Six-Day War) both cautioned nations and firms about over-reliance on Persian Gulf oil and prompted a quest for alternative supplies. Two of the boldest diversification ventures already underway before the 1973 oil shock nevertheless received a critical boost from it: the Trans-Alaska Pipeline (TAPS) and North Sea oil.

Barring the 1973 crisis, TAPS and the 20 per cent of US domestic oil production it was delivering by 1988 (1.5 million barrels per day), might have been long-delayed or, conceivably, stopped. In 1973, the promoters of the project, British Petroleum (BP) and its partners, faced a

thicket of legal hurdles and political opposition that had delayed authorization for three years. Alaskan native groups and environmental organizations objected that the pipeline, as well as the maintenance highway to be built alongside it, violated both the Mineral Leasing Act and the recently enacted National Environmental Policy Act (NEPA). Prior to 1973, opponents of the pipeline seemed to have the upper hand.[17]

Against the backdrop of the energy crisis that had already emerged in early 1973, however, environmental organizations were put on the defensive. Even then, and even as domestic supply problems and Middle East tensions rose over the summer, a US Senate amendment in August 1973 declaring that the pipeline fulfilled all NEPA requirements and modifying the Mineral Leasing Act to allow for the pipeline right-of-way only narrowly passed after a tie-breaking vote by vice president Spiro Agnew, who was not long for office as he was under investigation at the time for extortion, tax fraud, bribery and conspiracy. In Congress that autumn, pipeline supporters stepped up their rhetoric blaming environmentalists for the energy crisis. In September, President Nixon reiterated his support for the pipeline, announcing that it was his administration's priority for the rest of the congressional session. In early November, just after the embargo, Congress quickly passed, by overwhelming majority, the Trans-Alaska Pipeline Authorization Act. This legislation removed the project from further judicial review, provided new financial incentives and authorized construction of the right-of-way.[18] The ensuing oil price spike greatly enhanced the economics of building the $7.7 billion (estimated in 1976) pipeline, affording the oil consortium owner, Alyeska, a cushion to absorb the enormous costs of accommodating environmental considerations and mitigating ecological damage, thus retaining public support for the venture.[19] One Exxon engineer who worked on the project later maintained 'the only reason we have an oil pipeline today is because there was an Arab embargo'.[20]

The 1973 oil crisis also cast a lifeline to the world's other hugely ambitious frontier oil development at this time, in the North Sea. In 1969, Phillips Petroleum discovered the Ekofisk field in the Norwegian sector,

and the following year, BP discovered the Forties field in the UK sector. These were massive fields, but they were farther north, in deeper water, and with more extreme weather conditions than in the southern North Sea, where natural gas fields had been successfully developed in the late 1960s. The technical challenges and costs were so high that success in extracting oil from these new fields was far from guaranteed. Too often, historical accounts of North Sea oil skim past this period of high uncertainty, moving rather quickly from discovery to flowing oil.[21] The fact was, explained Dick Wilson, the Brown & Root manager who oversaw the construction of the early production facility at Ekofisk and platforms for Forties, 'deepwater North Sea oil from fields like the BP Forties was not commercial at $3 a barrel', the prevailing price of crude at the time. As Phillips and BP moved cautiously ahead with the projects, they ran into delays caused by design changes, materials shortages, labour problems, and inclement weather, all of which ballooned costs and postponed revenues. Wilson recalled one dispiriting meeting with BP representatives, who informed him that 'this project can't continue on this basis because [...] the costs were just getting too high'. Then, like a divine wind, 'the October War happened and the price of oil by the end of the year had moved up to where we did not discuss the overall project cost implications again with BP'.[22]

Oil from the great discoveries at Prudhoe Bay and in the North Sea probably would have been developed eventually, oil shock or not. The fields were simply too large to leave in the ground, and UK and American governments were firmly committed to assisting the diversification of oil supply away from the Middle East even before the price increases. Still, there were many political, economic and technical constraints to overcome. It is safe to say that the 1973 crisis immediately removed those constraints and hastened the process of bringing these valuable non-OPEC sources to market. The impact of this new production was huge. By 1980, Prudhoe Bay output was nearly 1.5 million barrels per day and the North Sea was producing more than 2 million barrels per day, rising to 3.5 million barrels per day five years later.[23]

North Sea and North Slope Alaskan oil helped restore supply flexibility for North America and Western Europe, ease pressures on global prices, and calm runaway inflation. In doing so, they also helped to underwrite the political success of right-wing heads of state Margaret Thatcher and Ronald Reagan, and their neoliberal, market-friendly agendas. Finally, oil from the north, especially the North Slope of Alaska, stimulated the oil industry's curiosity about regions further to the north, in the Arctic, which has become a major focus of oil exploration in recent years.

The Gulf of Mexico

The 1973 oil shock also stimulated oil activity in a different region of the world with a long history of oil production – the Gulf of Mexico basin. In the southern sector of the Gulf, the shock set in motion a chain of events that produced one of the world's largest oil discoveries of the late twentieth century and reshaped the way oil was priced and traded. Along the northern Gulf Coast, the shock helped propel companies and technology into 'deepwater' for the first time.

Mexico, the world's largest oil producer in the 1920s and the first nation to nationalize its oil resources (in 1938), had seen its reserves decline sharply by the late 1960s. In 1971, the nation became a net importer of crude oil. The price spike of 1973–4 plunged the nation into economic crisis. The government responded by ramping up oil exploration both onshore and offshore. The big payoff was the 1975 discovery of the first giant field, Chac, in what would become the enormous 'Cantarell Complex' of fields, located in the relatively shallow waters (150–200 feet) of the Bay of Campeche.[24] When the new government of José Lopez Portillo took office in December 1976, it unveiled a six-year programme to invest $15.5 billion in new oil exploration and development, a large percentage of which was directed offshore. Three other major nearby discoveries in 1977–8 led to a crash programme of offshore drilling and platform construction that lifted Mexico's oil output from 700,000 barrels per day in 1975 to nearly 2.6 million barrels per day by the end of 1980, half

of which came from Cantarell. The second oil price shock following the Iranian Revolution meant that all this new oil was earning tremendous revenues for Mexico.[25]

These revenues, however, were not enough to stem the fiscal bleeding from Mexico's heavy foreign borrowing. By the late 1970s, a large portion of these funds went to finance Cantarell and other oil developments. Rising interest rates and a steep US recession in 1981 cut demand for Mexican oil, lowered revenues and dramatically increased the country's foreign debt. The nation's finance minister suspended debt service in August 1982, setting off the Latin American debt crisis. Although Mexico negotiated new loans and rescheduled payments, the nation's fiscal position remained precarious, as oil exports drifted downward, reaching a crisis in mid-1985 when Saudi Arabia ramped up production and introduced 'netback' pricing to regain global market share.[26] PEMEX, the Mexican national oil company, responded by adopting an innovative marketing strategy called 'formula pricing', which linked the price for Mexican crude to estimates for different crudes sold on both long-term and spot contracts. Winning back market share, PEMEX's new pricing policy brought transparency and simplicity to international oil transactions. It also contributed to the introduction of market forces and the demise of the age-old system of 'administered' prices first by the major oil companies and then by OPEC.[27]

Across the Gulf of Mexico to the north, prior to the shock, offshore operators had been exploring in progressively deeper water, reaching out to 300- to 600-foot depths. They had been searching for new reserves to meet growing demand and offset declining onshore production. Intense competition for acreage, however, had inflated the costs of leasing and production to a point that made offshore oil in the Gulf, as a whole, uneconomical. Since 1954, the industry had invested an estimated $16 billion in the Gulf, but the total value of oil and gas produced by 1972 was only $12 billion.[28] The average price for a 5,000-acre lease had skyrocketed from $2.66 million in 1960 to $15.35 million in 1972. According to one study, operators had to

produce nearly three times the amount of oil that they had ten years before to pay for platforms.[29]

Although operators made a number of promising discoveries on leases obtained in 1970 and 1972, something still had to give. Accelerated offshore leasing was a key component of President Nixon's new energy strategy. In April 1973, the administration announced plans to triple lease offerings by 1979 and auction Gulf of Mexico tracts in 600- to 2,000-foot depths, beyond the edge of the continental shelf. Aside from the technical challenges of operating in those depths, which were too much for many companies to stomach, the staggering costs still made deepwater exploration a highly speculative and risky endeavour.

Again, the oil shock in the autumn of 1973 changed the equation. Following the embargo, the Nixon administration redoubled its focus on offshore leasing as part of its 'Project Independence' strategy and announced its intention to auction off 10 million acres by 1975. This was a highly unrealistic goal, but it signalled the government's intention to ramp up the pace of leasing. In the March 1974 sale, companies spent $2.2 billion in bonus bids for dozens of tracts. Deeper water offshore offered the best prospects for new oil discoveries, and exploration for new oil was given a major push under Phase IV price controls, implemented in August 1973, which exempted 'new' oil production from controls.[30] The groundbreaking project that came out of the landmark March sale was Shell Oil's Cognac platform, installed in 1,000 feet of water at the edge of the shelf. With first production in 1979, Cognac was a hugely sophisticated and costly project, with mammoth cost overruns pushing the total to $800 million from start to finish. But, thanks to high oil prices, it still turned a profit.[31] Cognac established the viability of deepwater, which has since become a major focus area for nearly all the major oil companies. It commercialized numerous technologies that would be applied to the expansion of deepwater development, and, thanks to soaring oil prices in the wake of the 1973 oil shock, demonstrated that companies could still make money to bring in valuable domestic oil from this new frontier.[32]

During the 1970s, the Nixon, Ford and Carter administrations experimented with a series of policies to reduce US dependence on foreign oil, including conservation measures, backing oil (and natural gas, for that matter) out of power generation in favour of coal, and the promotion of synthetic fuels, ethanol, nuclear power and other renewables.[33] Possibly the most successful policy in this regard, however, was the expansion in federal offshore leasing, which helped increase offshore crude oil output from about 10 per cent of total US production in 1975 (820,000 barrels per day (b/d) out of 8.2 million b/d) to 24 per cent of the total (1.36 million b/d out of 5.8 million b/d) by the year 2000.[34]

Offshore Brazil

In addition to the North Sea and the Gulf of Mexico, the first oil shock also spurred oil and technological development offshore Brazil. Prior to the 1970s, the Brazilian state oil company, Petrobras (established in 1954) had found very little oil domestically, despite intensive onshore exploration. Rapid national economic growth in the late 1960s had raised Brazil's oil import bill, which, after the OPEC price increases, spiked from $469 million in 1972 to $2.89 billion in 1974. The Brazilian government of General Ernest Geisel (1974–9), a former chairman of the board of Petrobras, borrowed heavily to finance the country's economic development programme. All of this put immense pressure on Petrobras to reduce dependence on imported oil.[35]

The company committed more resources to offshore exploration and drilling. In November 1974, it drilled a discovery well on a carbonate prospect called Garoupa in the Campos Basin, off the coast of Rio de Janeiro. This well, in 413 feet (126 metres) of water and 62 miles (100 km) from shore, was a major turning point for Petrobras and Brazil. Not only was this a significant discovery, but it also opened up an entirely new geological play in Cretaceous limestone. As *World Oil* magazine wrote with some reserved scepticism in 1980, 'the naturally optimistic Brazilians thought they had at last found the giant that existed in their country'.[36]

Garoupa and other early discoveries such as one called Namorada, in less than 650 feet (200 metres), were relatively medium-sized fields by world standards. Driven by the desperate need to replace oil imports and take advantage of high global oil prices, the company searched for ways to shorten the time to production. Installing traditional fixed platforms, like most operators were doing in the Gulf of Mexico, would have required four to eight years of development and a substantial amount of fixed capital investment for fields of that size.[37] This Petrobras and Brazil could not afford. 'Bringing the newly discovered prolific oil province on to production, and at the lowest cost possible, became a key issue for Petrobras', company officials later reflected. 'The increased throughput would help reducing [*sic*] the burden of Brazil to manage its increasing external debts'.[38]

Fortunately, there were floating production solutions available that could speed development. In 1975, a small US independent, Hamilton Brothers Oil, converted the *Transworld 58* semi-submersible drilling vessel into a novel, 'floating production facility' for a subsea-completion in the North Sea's Argyll field, and thus rapidly brought in the first oil production from the UK sector. Two years later, Petrobras applied a similar 'early production system' using the converted *Sedco-135D* semi-submersible and North Sea 'wet tree' subsea technology to produce 10,000 b/d from a single well in the Enchova field in 110 metres of water, only seven months after the discovery.[39]

For more extensive field development, at Garoupa and others, Petrobras found a different solution. In 1977, in an evolutionary step from the use of tankers as single-buoy offshore terminal facilities, Shell España successfully adapted this concept into a Floating Production, Storage, and Offloading (FPSO) facility for the Castellon field in the eastern Mediterranean. Two years after the Castellon, Petrobras began operating the world's second FPSO, the *P.P. Moraes*, in the Garoupa field. The Garoupa production system was designed with 'dry tree' Lockheed subsea wellheads developed for the Gulf of Mexico.[40] Garoupa was a much more trying project than Enchova, suffering one technical setback after another with Lockheed wellhead chambers, the production tower

and downhole safety valves. This resulted in long delays and contributed to the escalation in Campos Basin development costs, estimated in 1980 at $3 billion for eight fields with approximately 600 million barrels of recoverable oil. To some extent, the delays undermined the goal of shortening time to production. Still, this experimentation would have long-range benefits. As one Petrobras manager (Carlos Cunha) put it, 'The *P.P. Moraes* was a floating lab for testing the FPSO concept'.[41]

These early production technologies, products of Brazil's oil self-sufficiency drive in the aftermath of the 1973 oil shock, created a learning curve for developments that would open up significant new sources of oil in deeper waters. By the 1980s, Petrobras had become the world leader in floating and subsea production technology, turning the Campos Basin into a major deepwater province.[42] At the end of 1989, thanks largely to the Campos fields, Brazil's oil production had reached 790,000 barrels per day, 60 per cent of the country's consumption of 1.3 million barrels per day, which was major progress on the road to self-sufficiency (Brazil became fully self-sufficient in oil in 2007).[43]

Moreover, the confirmation of the theory of plate tectonics, endorsed by the worldwide core drilling programme of the Joint Oceanographic Institutions Deep Earth Sampling (JOIDES) project launched in 1968, indicated that Brazil's Atlantic margin was once geologically sown into the hinge of West Africa, meaning that the petroleum geology of the Campos Basin was directly analogous to that of the Gulf of Guinea and the Congo Basin across the Atlantic Ocean.[44] Brazil's deepwater success prompted exploration off West Africa, leading to giant deepwater discoveries off Nigeria and Angola in 1996, opening the world's third great deepwater oil province.[45] A large number of the production developments off West Africa have employed the FPSO concept that evolved under Petrobras's leadership in Brazil.[46]

Innovation in Oil

The common theme linking all the developments described above was the application or commercialization of new production and transportation

technologies to expand oil supply from environmentally challenging locations. The first oil shock placed tremendous time-cost pressures on nations and companies to replace expensive oil that they did not own and bring expensive but potentially lucrative discoveries on line as quickly as possible. For nations like Mexico and Brazil, these pressures resulted from the oil import-debt spiral. For major oil companies like Shell, BP and others, discounted cash-flow considerations shaped decision making for capital-intensive, long-term projects. In an inflationary climate, especially, such appraisals placed a high premium on money earned as early as possible. Furthermore, many people in industry appreciated the cyclical nature of the business and realized that the window of opportunity provided by the huge crude oil price increases might be short.[47]

One clear way to minimize the time-to-market for oil was to strive for more precision, efficiency and automation in oil operations. By the early 1970s, oil-drilling technology had changed very little since the introduction of rotary drill-bits by Howard Hughes in the 1910s, blowout preventers by James Abercrombie and Henry Cameron in the 1920s and electric well logging by the Schlumberger brothers around the same time. Manual processes still controlled most drilling procedures. Increased time-cost pressures following the 1973 oil shock, however, compelled oil operators, drillers and service companies to automate the rig floor for greater speed and efficiency, as well as safety.

Although some advances – such as hydraulic hoists, mechanical handlers and power swivels – had been added to mobile drilling vessels during the 1950s and 1960s, the efflorescence of drilling innovations truly burst forth in the 1970s. During 1972–5, labour-saving devices like power slips and spinning wrenches replaced hand tools in roughnecking (the work done connecting the drill pipe into the well bore). Meanwhile, the first multiplexed controls for subsea blowout preventers made their appearance, as did Varco's (now National Oilwell Varco) patented 'Iron Roughneck', which could mechanically torque drill pipe and drill collars with power and accuracy. Other incremental innovations followed, culminating in Varco's revolutionary 'Top Drive' Drilling System

(TDS), which removed much of the manual labour previously required to drill wells. Successfully demonstrated in 1982, the TDS consisted of a power-swivel motor suspended from the derrick that provided a tremendous increase in power and torque over the traditional Kelly Joint and rotary table, enough to drill longer, heavier sections of drill pipe with greater speed and reduced frequency of stuck pipe.[48]

The new ability to acquire real-time information from inside the well bore also enabled faster and more accurate drilling. In the late 1970s, the development of Measurement-While-Drilling (MWD) and Logging-While-Drilling (LWD) techniques, which used a mud-pulse system to measure and transmit formation data to the surface while continuing to rotate pipe and circulate drilling mud, allowed for steerable drilling and immediate formation evaluation. The US Department of Energy's post-oil shock Drilling, Completion, and Stimulation Program (established in 1975) assisted with the research & development (R&D) for mud-pulse telemetry that went into MWD tools. Together, TDS and MWD/LWD laid the foundation for so-called directional and extended-reach drilling.[49]

Directional drilling, combined with other watershed innovations pioneered or commercialized in the 1970s, permitted oil firms to explore, drill and produce oil from deepwater. High oil prices provided the economic incentive to improve the technical reliability of expensive and finicky subsea wellheads and flow lines. Directional drilling and subsea completions allowed companies to optimize oil development around a single production facility, rather than have to install more than one for a given prospect or set of prospects. After the first oil shock, conceptual designs for compliant and floating production facilities for deepwater (beyond 1,500-foot depths), such as tension-leg platforms (TLPs), compliant towers and spars, started coming off engineers' drawing boards.[50] In 1974, R&D commenced on remotely operated underwater vehicles (ROVs) to perform tasks in water depths beyond the reach of human divers. Subsea engineers designed first-generation ROVs to inspect pipelines and assist divers, which proved their worth on Shell's Cognac

project among others. By the early 1980s, ROV capabilities had evolved to support drilling and subsea installations as well.[51]

In the same time frame, thanks to major advances in digital computing, the Dallas-based seismic contractor, Geophysical Services Incorporated (GSI) worked out the massive computational challenges of producing three-dimensional images from seismic acoustic signals. By the late 1970s, GSI established the commercial utility of 3-D seismic for developing producing fields and defining reservoirs. As costs of 3-D came down and as wells became more expensive in ever-deeper waters, companies began to gather all their seismic information from 3-D surveys before leasing and exploratory drilling. The result, by the 1990s, was a dramatic increase in drilling success and a growing ability to visualize sub-salt oil deposits, extending offshore exploration into yet deeper waters. Moreover, the impact of digital technology was not limited to exploration and drilling. After the introduction of desktop workstations in the early 1980s, digital technology further advanced the precision, automation and remote monitoring capabilities of offshore oil operations across the board.[52]

Technological innovation in oil continued and even accelerated through the extended period of low oil prices that began with the bust of the mid-1980s. The bust drove the major exploration and production companies to reduce internal R&D and begin divesting from the great exploration & production (E&P) technology labs they had run for decades. Service companies such as Schlumberger, Halliburton, Baker Hughes, Oceaneering and Varco, however, picked up the slack, increasing their R&D spending almost in direct proportion to the decline by the large E&P firms. New programmes at US research universities, such as the Offshore Technology Research Center at Texas A&M University, created in 1990 with National Science Foundation funding, also became important centres of industry technology development. While high oil prices in the 1970s had stimulated the commercialization of advance oil hunting and drilling technologies, the increasing competitiveness in the oil and oil service businesses and

shift in the source of innovation to contractors during the ensuing low oil price regime drove E&P companies to continue applying new technologies, which they could now buy rather than have to build them themselves.[53]

Many of the technologies first put to use in the high-cost environment offshore also had applications on land, especially for the hydrofracturing of shale gas and shale oil, which, since 2005, has revolutionized the oil and gas industry. George Mitchell's dogged determination to unlock the natural gas potential of the Barnett Shale in North Texas instigated the fracking boom, but innovation also came from other post-oil shock initiatives.[54] Notably, National Oilwell Varco designed a portable Top Drive compact enough to be installed in land-drilling derrick masts. Along with MWD and LWD, Top Drive systems made possible the directional and horizontal drilling required for shale plays. Furthermore, US government research efforts catalysed by the 1973 oil shock again played a role in advancing these technologies. The Department of Energy's Eastern Gas Shales Program (EGSP), established in 1976, assisted the development of directional drilling techniques in early shale tests. And the Sandia National Laboratory built on 3-D seismic technology to develop 3-D microseismic imaging critical for understanding hydraulic fracturing.[55]

Conclusion

It may be possible to overstate the significance of the 1973 oil crisis to the technological trends in the industry in the 40 years since, but there is no gainsaying the immediate and huge impact that the shock of 1973 had on propelling oil companies into new territorial and technological frontiers. The new supplies discovered as a result gave oil firms and oil-consuming nations a measure of independence from OPEC. Today's expanding supply of oil and gas from offshore and deepwater provinces, such as the deepwater 'Golden Triangle' of Gulf of Mexico–Brazil–West Africa, the growing interest in the hydrocarbon potential of the Arctic,

and the dramatic shale plays that are emerging around the world can all trace their legacy back to the industry's technological response to the shock of 1973.

The industry's development of non-OPEC oil sources, combined with the other pillars of the new global structure oil created in the wake of the OPEC revolution, has made our dependence on oil, in security terms, less problematic than much of the commentary on the fortieth anniversary of the shock would have us believe. OPEC nations now provide only 20 per cent of US oil imports, which make up only 40 per cent of US consumption. Globally, the influence of OPEC decisions on oil trading, in both the physical and futures markets, has been steadily declining.[56] The world is less vulnerable – although not invulnerable – to supply disruptions than it was in 1973. Even more important, the world is less threatened by the concentrated control over oil, such as by the International Petroleum Cartel prior to 1973, or by the relatively small number of oil exporters in OPEC immediately after 1973.

The sudden rebalancing of this control through a wholesale transformation in the ownership of oil in 1973 was what created the shock. The global oil system today is not liable to undergo a similar transformation. Compared to 1973, it is more integrated, with a much wider array of producers, consumers and types of hydrocarbons. For now, the question may be less about whether supply can keep up with demand, and more about whether we have too much supply, too large a carbon budget, to keep from altering the global climate in destructive ways.

Notes

1 Marck Fischetti, '40 years after OPEC oil embargo, U.S. may finally get off imported crude', *Scientific American*, 16 October 2013, available at http://blogs.scientificamerican.com/observations/2013/10/16/40-years-after-opec-oil-embargo-u-s-may-finally-get-off-imported-crude/; Robbie Diamond, 'OPEC embargo – 40 years later', *The Hill*, 15 October 2013; Ken Blackwell, 'Forty years of OPEC manipulation', *Townhall.com*, 16 October 2013, available at http://townhall.com/columnists/kenblackwell/2013/10/16/forty-years-of-opec-manipulation-n1724630/page/full. It is inaccurate to speak of an 'OPEC

embargo'. The embargo was an agreed policy of another organization, the Organization of Arab Oil Exporting Countries (OAPEC), whose headquarters is in Kuwait and whose members were and are Saudi Arabia, Kuwait, the Arab Emirates, Algeria, Bahrain, Egypt, Iraq, Libya, Qatar and Syria. One key member of OAPEC, Iraq, declined to take part.

2 See the analysis in Richard H.K. Vietor, *Energy Policy in America Since 1945: A Study of Business–Government Relations* (Cambridge: Cambridge University Press, 1984), pp. 236–71; and Peter Z. Grossman, *U.S. Energy Policy and the Pursuit of Failure* (Cambridge: Cambridge University Press, 2013), pp. 5–30.

3 Diamond, 'OPEC embargo – 40 years later'; Fischetti, '40 years after OPEC oil embargo'.

4 The profound macro impact of the oil shock is well established. The year 1973 was an epic turning point in the political economy of the late twentieth century. Coming on top of the US retreat from Vietnam and the collapse of the Bretton Woods system, it caused a crisis of US world leadership. The hikes in oil prices, moreover, created simultaneous recession and inflation ('stagflation'), thus abruptly ending 25 years of sustained global economic growth. Keynesianism yielded to free market orthodoxy. The 'long boom' of post-war capitalism gave way to a 'long slump', followed by repeated cycles of bubbles and busts that endure to this day. Thomas J. McCormick, *America's Half-Century: United States Foreign Policy in the Cold War and After*, 2nd ed. (Baltimore: The Johns Hopkins University Press, 1995), pp. 161–5 and 238–41.

The crisis of 1973 also had unforeseen effects that ultimately bolstered US economic and global power. The recycling of 'petrodollars' by newly enriched oil states lubricated the global circulation of capital and guaranteed the continued pre-eminence of the US dollar as the world's reserve currency. Oil states also lavishly spent their petrodollars on arms from US defence contractors, but at the cost of further destabilizing the Persian Gulf region. One could even argue that the oil crisis marked the beginning of the end for the Soviet Union, as high oil prices made the Russian economy increasingly dependent on oil exports, and when prices collapsed in the mid-1980s it knocked the legs out from under the Soviet economy. Tyler Priest, 'The dilemmas of oil empire', *The Journal of American History* 99, no. 1 (2012): 243–4.

5 Darren Goode, '1973 Arab oil embargo shaped energy policy', *Politico.com*, 14 October 2013, available at http://www.politico.com/story/2013/10/arab-oil-embargo-shaped-energy-policy-98300.html; Daniel Yergin, 'Why OPEC no longer calls the shots', *Wall Street Journal*, 14 October 2013, available at http://online.wsj.com/news/articles/SB10001424052702303382004579131460420974406; Jill Tennant, '40 years later: legacies of the 1973 oil crisis persist', *World Oil* 234, no.10 (2013), available at http://www.worldoil.com/October_2013_40_years_later_Legacies_of_the_1973_oil_crisis_persist.html; Jeff Colgan, '40 years after the oil crisis: could it happen again?', *The Washington Post*, 16 October 2013, available at www.washingtonpost.com/blogs/monkey-cage/wp/2013/10/16/40-years-after-the-oil-crisis-could-it-happen-again//?print=1.

6 Steven Schneider, *The Oil Price Revolution* (Baltimore: The Johns Hopkins University Press, 1983), p. 1.

7 See, for example, Charles S. Maier, '"Malaise": The crisis of capitalism in the 1970s', pp. 25–48, and Daniel J. Sargent, 'The United States and globalization in the 1970s', pp. 49–64, both in Niall Ferguson, Charles S. Maier, Erez Manela and Daniel J. Sargent (eds), *The Shock of the Global: The 1970s in Perspective* (Cambridge, MA: Harvard University Press, 2011). Most essays in this volume somehow manage to avoid the subject of oil entirely.

8 Paul Sabin, 'Crisis and continuity in U.S. oil politics, 1965–1980', *Journal of American History* 99, no. 1 (2012): 185.

9 Mark Fiege, *The Republic of Nature: An Environmental History of the United States* (Seattle: University of Washington Press, 2012), p. 400. Unfortunately, Fiege's chapter, 'It's a gas: The United States and the oil shock of 1973–1974', pp. 358–402, repeats many of the common myths and misunderstandings about the oil shock and the history of oil in its aftermath. Fiege attributes gas lines directly to the impact of the embargo, without any discussion of price controls. He also treats the oil crisis as the beginning of an era of oil shortages, uncritically accepting the disproven claim that world oil production peaked in 2005 (p. 398). In fact, it rose from 73.6 million barrels/day in 2005, to 74 million barrels/day in 2010, to 75.8 million barrels/day by mid-2013. US Energy Information Administration (EIA), *Monthly Energy Review*, July 2013, available at http://www.eia.gov/totalenergy/data/monthly/pdf/sec11_5.pdf. For historical treatment of the peak oil debate, see Tyler Priest, 'Hubbert's peak: The great debate over the end of oil', *Historical Studies in the Natural Sciences* 44, no. 1 (2014): 37–79.

10 Robert Sherrill, *The Oil Follies of 1970–1980: How the Petroleum Industry Stole the Show (and Much More Besides)* (New York: Anchor Press, 1983), pp. 145 and 506.

11 Joseph A. Pratt with William E. Hale, *Exxon: Transforming Energy, 1973–2005* (Austin, TX: Dolph Briscoe Center for American History, 2013), p. 17.

12 *Ibid.*, p. 18.

13 S.G. Stiles, 'Presentation', Shell Oil Public Relations Meeting, 21 March 1973, copy provided to author by Mr. Stiles; Priest 'Hubbert's peak', pp. 63–5; Pratt, *Exxon*, p. 43; Jay Hakes, 'The road to America's first energy crisis: new insights on the growing weakness of the United States as a global energy power, 1967–1973', *H-Energy*, 23 June 2013, available at https://networks.h-net.org/system/files/contributed-files/henergy-j-hakes-road-americas-first-energy-crisis.pdf.

14 Reforms in consuming nations involved government policies and investments in energy efficiency (such as fuel efficiency standards for automobiles) and conservation that moderated demand. The phased lifting of price controls in the US, starting in 1979 and completely removed in 1981, after the Iranian Revolution caused another price shock, making it easier to align supply and demand. At the international level, the creation of the International Energy

Agency (IEA) in 1974 provided a formal mechanism for the sharing of oil in any future crisis through the establishment of strategic stocks such as the US Strategic Petroleum Reserve (700 million barrels stored in a series of salt caverns in south Louisiana). On the IEA and the new role of consuming countries, see Bernard Mommer, *Global Oil and the Nation State* (Oxford: Oxford University Press, 2002), pp. 138–42. On the US Strategic Petroleum Reserve, see Bruce Beaubouef, *The Strategic Petroleum Reserve: U.S. Energy Security and Oil Politics, 1975–2005* (College Station: Texas A&M Press, 2007).

15 Mommer, *Global Oil and the Nation State*, pp. 142–51; Daniel Johnston, *International Petroleum Fiscal Systems and Production Sharing* (Tulsa, OK: Pennwell, 1994).

16 Bryan Burrough, *The Big Rich: The Rise and Fall of the Greatest Texas Oil Fortunes* (New York: Penguin Press, 2009), p. 357.

17 Peter A. Coates, *The Trans-Alaska Pipeline Controversy: Technology, Conservation, and the Frontier* (Fairbanks, AK: University of Alaska Press, 1993), pp. 235–45.

18 *Ibid.*, pp. 245–50.

19 *Ibid.*, pp. 251–65.

20 Morris Foster quoted in Pratt with Hale, *Exxon*, p. 92.

21 See, for example, Daniel Yergin, *The Prize: The Epic Quest for Oil, Money, and Power* (New York: Simon & Schuster, 1991), pp. 668–9.

22 Wilson quoted in Joseph Pratt, Tyler Priest and Christopher Castaneda, *Offshore Pioneers: Brown & Root and the History of Offshore Oil and Gas* (Houston, TX: Gulf Publishing, 1997), pp. 223 and 252. See also Charles Woolfson, John Foster and Matthias Beck, *Paying for the Piper: Capital and Labour in Britain's Offshore Oil Industry* (London: Mansell, 1996), pp. 16–17.

23 For the 'official' histories of North Sea Oil, see Alex Kemp, *The Official History of North Sea Oil and Gas, Vol 1: The Growing Dominance of the State* (London: Routledge, 2011) and Alex Kemp, *The Official History of North Sea Oil and Gas, Vol. 11: Moderating the State's Role* (London: Routledge, 2013).

24 In addition to Chac, the other fields are Akal (the largest), Nohoch and Kutz.

25 Pratt, Priest and Castaneda, *Offshore Pioneers*, pp. 180–8.

26 Netback pricing linked the price of crude oil to refined products, guaranteeing specific profit margins to refiners, and thus attracting buyers. See Robert Mabro, *Netback pricing and the oil price collapse of 1986* (Oxford: Oxford Institute for Energy Studies, WPM 10, 1987).

27 Francisco Flores-Macías, 'How can a state-owned enterprise become a profit maximizer? A political and economic history of Pemex's PMI', draft paper, March 2011.

28 'Will a $16 billion investment pay off?', *Offshore*, September 1973, pp. 33–5.

29 Nixon Quintrelle, 'Lease, production costs require big production in the Gulf of Mexico', *Offshore*, February 1973, pp. 43–5.

30 On Phase IV price controls, see Vietor, *Energy Policy in America Since 1945*, pp. 242–4.

31 Tyler Priest, *The Offshore Imperative: Shell Oil's Search for Petroleum in Postwar America* (College Station, TX: Texas A&M Univeristy Press, 2007), pp. 191–201.

32 *Ibid.*

33 On these developments, see Jay Hakes, *A Declaration of Energy Independence: How Freedom from Foreign Oil Can Improve National Security, Our Economy, and the Environment* (New York: Wiley, 2008), pp. 41–70.

34 Data from the EIA available at http://www.eia.gov/petroleum/. Increases in deeper water production also offset the decline in shallow water production from leases developed in the 1950s and 1960s.

35 Brazil's foreign oil dependence was extreme. The country depended on oil for 45 per cent of its entire energy consumption, and 80 per cent of its oil demand was met by imports, 65 per cent of which came from the Middle East. Stephen J. Randall, 'The 1970s Arab–OPEC oil embargo and Latin America', *H-Energy*, 26 June 2013, available at https://networks.h-net.org/system/files/contributed-files/henergy-s-randall-latin-america-and-1973-oil-crisis.pdf.

36 T.J. Stewart Gordon, 'Brazil: The target is oil at any cost', *World Oil*, March 1980, p. 74.

37 Wagner Freire, 'An overview on Campos Basin', paper presented at the Annual Offshore Technology Conference, Houston, TX, 2–5 May 1988, OTC 5807.

38 M.I. Assayag, G. Castro, K. Minami and S. Assayag, 'Campos Basin: A real scale lab for deepwater technology development', paper presented at the Annual Offshore Technology Conference, Houston, TX, 5–8 May 1997, OTC 8492, p. 509.

39 Salim Armando, 'Petrobras experience on early production systems', paper presented at the Offshore Technology Conference, Houston, TX, 2–5 May 1983, OTC 4546. A 'wet tree' is a wellhead located on the sea floor.

40 The Lockheed 'dry tree' was a wellhead encased in a one-atmosphere chamber on the seafloor.

41 'The history of the FPSO unit', *Petrobras Magazine*, 2007, p. 9.

42 Joseph P. Riva, Jr., 'Technology boosting success in Campos Basin', *Oil & Gas Journal*, 27 November 1989, pp. 85–8.

43 EIA, Country Analysis, Brazil, available at http://www.eia.gov/countries/country-data.cfm?fips=BR#pet.

44 On JOIDES, see David K. van Keuren, 'Breaking new ground: The origins of scientific ocean drilling', in Helen M. Rozwadowski and David K. van Keuren (eds), *The Machine in Neptune's Garden: Historical Perspectives on Technology and the Marine Environment* (Sagamore Beach, MA: Science History Publications, 2004), pp. 183–210.

45 N.R. Cameron and Ken White, 'Exploration opportunities in offshore deepwater Africa', paper presented at the IBC Oil and Gas Developments in West Africa Conference, London, 25–6 October 1999.

46 See the list of projects in the FPSO database, available at http://fpso.com/.

47 Shri B. Mathur and Omer Carey, 'Economic decision-making practices in the U.S. petroleum industry', paper presented to the Society of Petroleum

Engineers of AIMA, Houston, TX, October 1974, SPE 5011; Gene B. Wiggins III, 'Oil and gas property evaluation', in Richard Steinmetz (ed.), *The Business of Petroleum Exploration* (Tulsa, OK: American Association of Petroleum Geologists, 1992), pp. 148–9.

48 Michael W. Sutherlin, 'The path from technology to performance', *World Energy* 3, no. 2 (2000); Walt Aldred, Jim Belaskie, Rustam Isangulov, Barry Crockett, Bobby Edmondson, Fred Florence and Sundaram Srinivasan, 'Changing the way we drill', *Oilfield Review*, Spring 2005, pp. 42–9.

49 David Reid, Larry Wells and Jeremy Ogg, 'Top drives have transformed drilling: now, new design targets ultra-deep ERD', *Drilling Contractor*, September/October 2008, available at http://www.drillingcontractor.org/top-drives-have-transformed-drilling-now-new-design-targets-ultra-deep-erd-1735; Offshore Energy Center, Hall of Fame: Technology Pioneers, available at http://www.oceanstaroec.com/fame_technology.html; Committee on Benefits of DOE R&D on Energy Efficiency and Fossil Energy, Board on Energy and Environmental Systems, Division on Engineering and Physical Sciences, National Research Council, *Energy Research at DOE: Was It Worth It? Energy Efficiency and Fossil Energy Research 1978 to 2000* (Washington, DC: National Academies Press, 2001), pp. 193–7.

50 Conoco's Hutton TLP, designed for a North Sea field in 485 feet of water discovered in 1973, became the prototype for the first series of TLPs installed in 2,000- to 4,000-foot depths of the Gulf of Mexico in the 1990s. See Pratt, Priest and Castaneda, *Offshore Pioneers*, pp. 273–6.

51 F.R. Frisbie, R.L. Wernli and D.W. Given, 'The role of the ROV in 1985: A capability in transition', paper presented at the Offshore Technology Conference, Houston, TX, 5–8 May 1986, OTC 5169.

52 'Digital revolutionaries: Technical advances reverberated through the industry', *AAPG Explorer Special Issue – A Century* (Tulsa, OK: AAPG, 2000), pp. 51–2; G.G. Walton, 'Three-dimensional seismic method', *Geophysics* 37, no. 3 (1972): 417–20; C.G. Dahm and R.J. Graebner, 'Field development with three-dimensional seismic methods in the Gulf of Thailand – a case history', *Geophysics* 47, no. 2 (1982): 149–76.

53 On the 'buy vs. build' strategy, see 'Oil and gas technology development', Topic Paper #26, National Petroleum Council Global Oil & Gas Study, 22 November 2006, p. 16. This topic paper was one of 38 working documents used to produce the 2007 NPC study, *Facing the Hard Truths About Energy*, available at http://www.npchardtruthsreport.org/.

54 See Diana Davids Hinton, 'The seventeen-year overnight wonder: George Mitchell and unlocking the Barnett Shale', *Journal of American History* 99, no. 1 (2012): 229–35.

55 National Research Council, *Energy Research at DOE*, pp. 200–2; N.R. Warpinski, P.T. Branagan, R.E. Peterson, J.E. Fix, J.S. Uhl and R. Wilmer, 'Microseismic and deformation imaging of hydraulic fracture growth and geometry in the C sand interval, GRI/DOE M-site project', paper presented at the Society of Petroleum Engineers Annual Technical Conference and Exhibition, 5–8 October 1997, San Antonio, TX, SPE 38573-MS.

56 'Oil traders give OPEC short shrift', *Wall Street Journal*, 29 November 2013.