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What Determines Investment in the Oil Sector?

A New Era for National and International Oil Companies

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Abstract [1]

This paper discusses recent trends in investment in the oil sector, amid new challenges for national and international oil companies in an increasingly supply-constrained environment. After more than a decade of stagnant investment rates, nominal investment has picked up sharply over the three years ending in 2007, but soaring costs (including from higher tax rates and royalties) meant that investment growth was minimal in real terms. The paper performs econometric tests using the Arellano-Bond GMM technique. It finds that 'below ground' risks are statistically very important in deterring real investment. Companies are taking on increasingly complex geological challenges, which are putting upward pressure on production costs and are leading to greater project delays compared to the past. As many of these factors are expected to persist, supply constraints are likely to remain a dominant factor behind oil price fluctuations during the next several years..

JEL Classification: E2, L7, Q4

Keywords: Investment, Oil sector, National oil Companies, International Oil Companies, finding and development costs.

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1. Introduction

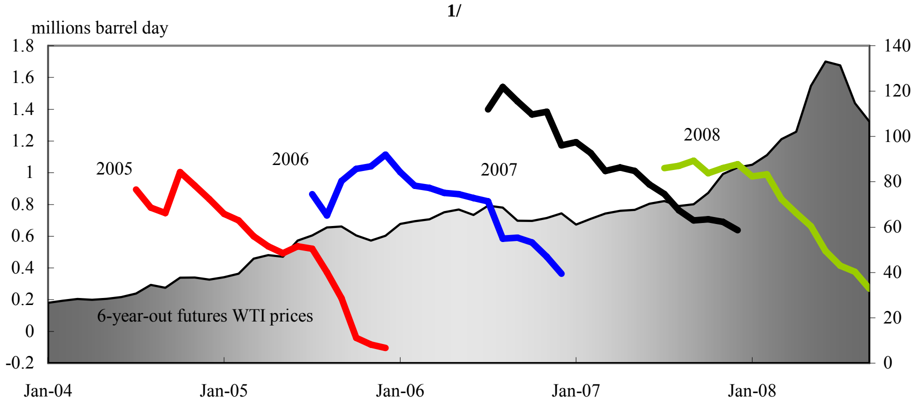
Markets and analysts alike increasingly suggest that, while we are not running out of oil, prices will need to stay above historical levels to incite the investment necessary to satisfy long-term demand. In their recent long-term reports, the International Energy Agency and the U.S. Department of Energy predicted that prices would remain between $60 and $80/barrel to 2030 under current policies as a result of sluggish supply. Medium-term forecasts by the IEA and others also suggest that current investment rates could be as much as 20 percent below what would be necessary to satisfy future global demand.

An important factor behind the firming of these expectations has been weaker-than-expected prospects for oil supply expansion. Indeed, the increase in long-dated futures prices over the 4 years ending in 2008 has coincided with steady downward revisions to projections for non-OPEC supply (Figure 1). Although initial uncertainty about how long high oil prices would last was plausibly an important reason for oil producers not to rapidly ratchet up their investment, the sluggish supply response became increasingly persistent despite high prices. While some aspects of the slow supply response are cyclical in nature, other aspects are likely to be structural: disappointing oil supply growth from Russia and the FSU, as well as higher-than-earlier-expected field decline rates in key regions (Mexico, the North Sea, Kuwait and Alaska), suggest that the market will continue to be supply-restrained in the medium term. The economic downturn in 2008 and 2009 aggravated the situation, as this quickly led to some output retrenchment and announcements by oil companies of further cancellations or postponement of investment projects.

The question of the riskiness of new technologies for extracting oil—namely, offshore drilling—have come into prominence with the recent oil spill from a British Petroleum-operated Macondo oil rig off the Gulf of Mexico. It took a few months to contain and has brought to light the complexity of such projects. Moreover, the environmental degradation caused by the spill will likely lead policy-makers to be more cautious about supporting risky technologies.

This paper examines patterns in oil investment based on company and field data over the last decade and a half, and considers prospects for capacity expansion. It characterizes investment barriers as taking one of two forms. The first, which could be termed '*below-ground*' barriers, are those related to difficult geology and technology.

Figure 1. Revision to Forecast of Non-OPEC Supply Growth and Long-Dated Futures Prices 1/



1/ The forecast refers to a simple average from OPEC, International Energy Agency and the U.S. Energy Information Agency at the time of the forecast. Futures prices are from NYMEX.

These have led to project delays amid cost overruns due to factors specific to the sector, such as scarce availability of skilled labor and shortages of sector-specific machinery and equipment. The second type of barriers, termed '*above ground*' risks, also impede investment growth: opportunities, particularly for international oil companies (henceforth IOCs), may have been constrained by limited access to reserves in some oil-rich countries. Also, changes in tax and regulatory regimes and risks of nationalization in some countries made returns on new investments more uncertain. Many oil companies, particularly domestically-oriented national oil companies (henceforth NOCs), continue to be cash-strapped or are subject to legal or discretionary limitations by their own governments.

This paper considers whether 'below-ground' risks or 'above ground' risks were more important in explaining oil investment. If the first hypothesis is true, the implication is that the cautious approach by oil companies was individually rational in the face of time-to-build lags and in the context of a tight input market. Therefore, a positive aggregate supply response should be a matter of time, assuming oil prices remain high. The uncertainty, particularly about production costs, just needs to be resolved. This argument is associated with Goldman Sachs

(2005a), among others. If this is the case, the corollary is that no policy intervention is necessary, and technology will solve the problem.

Alternatively, if 'above-ground' risks dominate, the implication is that investment cannot respond readily to prices because of market distortions (perhaps due to political instability and wrong-headed policies in oil producing countries). This argument is put forth by Pirog (2007), among others. If this hypothesis is correct, there is a clear role for policy intervention and coordination, particularly at the international level.

Using data between 1993 and 2007, the paper finds that below-ground factors have contributed importantly to delayed project execution. It also finds that companies facing higher technical risk tend to invest less on average in real terms. The paper does not find a statistically significant impact of 'above-ground factors' such as political risk, nor does it find a statistically significant difference between IOC and NOC investment levels (although IOC majors and traditional, domestically-oriented NOCs tend to be more sensitive to higher costs). The 2008 IEA World Energy Outlook analysis is consistent with this result of increasingly difficult geology and more technical difficulties. Using data for the 500 largest fields and extrapolating its findings to smaller fields, the IEA estimates an annual average decline rate of fields at 9.1 percent (the figure drops to 6.4 percent when companies invest in more wells and techniques). This means that much more investment over their 2007-2030 projection period will be needed just to offset the loss of capacity from existing fields as they mature.

Despite not finding a direct link between above-ground factors such as political stability and investment, there could be an indirect link. Our interpretation is that lack of opportunities for access to resource-rich countries has led oil companies to take on higher technological risks, which are all contributing to higher long-run capital costs of exploration and production of the marginal fields, and thus lower real overall investment. Moreover, in countries where access to foreign companies has been closed, oil output growth has tended to level out (for example, in Iraq, Iran, Venezuela, Mexico, and Russia). In the long-term, this could affect not only the recovery rates from those fields, but also, uncertainty about future access could continue to deter investment for many years to come.

One important caveat regards the data. Part of the contribution of the paper is to gather as much reliable data as is available in the public domain that is consistent, but the data is far from perfect. There are limitations, and assumptions had to be made. For example, our variable of investment refers specifically to exploration and production capital investment, but it is not possible to find a decomposition of those expenditures by company (into, for example, development, lifting and other). The investment cost data used in the regressions refer to finding and development costs, and to the extent possible, these variables are the ones that refer to the physical investment process, and exclude other costs (distribution, refining, corporate costs, etc). Also, deflating the nominal investment numbers by the U.S. PPI requires us to make the assumptions that the service sector is sufficiently international that changes in costs in the U.S. reflect service costs elsewhere. While in reality there may be a short lag in the transmission of these costs, anecdotal evidence from service companies suggest that these costs nowadays do transmit relatively quickly globally.

1.1. Recent Literature on the Topic

With the exception of major reports by the main international agencies, to date there have been few empirical papers on the topic of oil investment behavior, in part because of the difficulty of obtaining good comprehensive publicly-available data. However, many papers have addressed specific issues also covered in this paper.

On the theoretical front, Dixit and Pindyck (1994) and Caballero (1991,1992), among others, have modeled investment under uncertainty. The former explicitly looks at the oil and gas sector given its very high sunk costs. The determinant of models of investment under uncertainty have many features that are appropriate to characterize the oil industry, such as the long planning horizon, the non-reversibility of the capital stock put in place, and the variability of the output price. These features are also highlighted in Favero and Pesaran (1994) who find that it takes several lags to observe the effect of a shock to the exogenous variable (e.g. oil price) on investment. Moreover, high expected prices are crucial for undertaking an irreversible investment under low price uncertainty (Favero et al., 1994).

The relationship between prices, investment and costs have been difficult to characterize in the literature, and no clear-cut consensus has emerged. Ringlund, Rosendahl and Skjerpen.(2004) indirectly looked at the relationship between investment and oil price, and try to explain, why supply in recent times has not responded as strongly to higher prices. They find important regional differences in elasticities. One hypothesis famously studied by Dixit and Pindyck (1994) and Abel and Eberly (2004), is that when there is higher price volatility (as in these past years), then under the assumptions of uncertainty and sunk costs, investment would tend to be lower. Others such as Casassus, Collin_Dufresne and Routledge (2005) develop a model in which investment in oil fields is infrequent and 'lumpy' as a result of fixed adjustment costs. They model oil prices as a regime-switching process, which turns out to exhibit many of the salient features of oil prices (such as backwardation). They find strong evidence that supports the presence of fixed investment costs, and two investment-price regimes: an absolutely continuous component in the no-investment region, and a singular component at the investment boundary. Although their paper is mostly concerned with modeling oil price behavior, their empirical findings support the notion of 'lumpiness' and non-linearities in oil investment.

Another strand of papers has examined the optimal investment level as a function of decline rates of oil fields. Helmi-Oskoui, Narayanan, Glover and Sinha (1992) try to solve for the optimal extraction rate of petroleum resources in a model of oil fields, and show the importance of the discount rate in determining the optimal level. In studying the expenditure growth of oil-exporting countries, Mitchell and Stevens (2008) estimate a discount rate of approximately 2-3 percent for national oil companies, and about 10 percent for international oil companies. Specifically, the socially optimal discount rate of extracting oil is much higher – implying greater patience – for national oil companies of oil-rich states, because their non-renewable reserves represent the national wealth to be transferred across generations.

Regarding an explanation of physical investment in the oil sector, recent literature can be divided into two strands. The first strand analyzes the investment and production behavior of national oil companies. Eller, Hartley and Medlock (2007) and Hartley and Medlock (2008) have shown that investments in NOCs is less efficient, primarily because of its dual functions of producing oil and acting as a vehicle to redistribute employment or wealth to the population. Others (Marcel, 2006, Mitchell and Stevens, 2008) have sought to explain how investment of large NOCs is intrinsically related to the long-term macroeconomic objectives of the NOCs government policies. Perhaps the most comprehensive study of modern NOCs is the PESD project (see Victor, 2008). This paper draws on many of the findings of those studies. The second, strand of literature generally relies on better OECD-level data (for example Goldman

Sachs and IEA), and analyzes investment prospects through aggregation of company data from OECD countries.

The most recent similar papers to this one, in terms of looking at determinants of investment at the company and field level are Dada (2006), and Jojarth (2008). The former paper finds plausible variables to estimate investment behavior equations for both national and international oil companies. The paper makes two interesting findings: (i) OPEC spare capacity seems to be a significant investment deterrent for IOCs, as it acts as the best indicator of a market glut; and (ii) budgetary allocations to NOCs are a significant determinant of NOCs investment the following year. While Dada's conclusions are broadly consistent with the results here, the paper does not explicitly test for the difference between IOC and NOC investment behavior. Moreover, it treats NOCs as a homogeneous group, which defies the new reality of the industry. Jojarth (2008) considers the most important factors determining average production costs using field-level data, and finds that offshore fields and those with greater depletion rates are more costly, on average, but they also tend to be located in mature regions where there is more political stability. This conclusion is consistent with our findings.

This paper is divided as follows. Section 2 describes aggregate oil investment trends over the past decade and a half and sets up the hypotheses to be tested. Section 3 describes some testable implications based on empirical observations and what some of the models above have found. Section 4 describes the data and Section 5 presents the results and discusses its possible policy implications. Section 6 concludes.

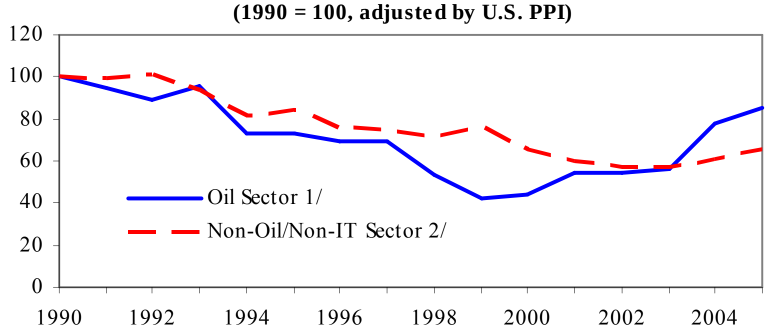
2. Investment Trends Influenced by the 1990s Environment and Tight Company Budgets.

Oil investment has begun to pick up somewhat this decade, following a period of minimal investment since the early 1990s, where a cost-cutting mentality of many international companies dominated. Before analyzing the determinants, it is useful to examine the aggregate investment trends of the oil sector during the period in question. The following sections explain the factors behind the performance of IOCs and NOCs during the 1993-2007 period, the focus of this study.

2.1 Oil Financial Investment and the Macroeconomy

An important aspect of explaining aggregate investment behavior is to infer to what extent it is driven by industry-specific variables (such as costs, technology, host government policies towards the companies), and to what extent it is being driven by macro variables. This is illustrated in Figure 2, based on balance sheet information for companies listed in G7 exchanges (which includes some NOCs). In aggregate, investment in the corporate oil and gas sector has largely followed the rest of the economy. Figure 2 shows that a significant component of the path of oil investment since 1990 followed overall economy-wide investment trends of the non-oil, non-technology (IT) sector. This implies that general macroeconomic conditions, as reflected in global GDP growth (which would determine oil demand growth), and factors affecting the overall corporate sector explained a large part of the investment cycle in the oil sector during that period, at least for G7-listed companies.[2] This is consistent with the result that oil prices are very

Figure 2. IOC's Oil And Non-Oil/Non-IT Corporate Capital Expenditures in Real Terms in the G-7 Countries (1990 = 100, adjusted by U.S. PPI)



Note: 2005 estimates were derived from company listings of a few representative companies in each sector (for oil and gas, the 9 major IOCs); therefore, they are not directly comparable with the 2004 figures.

1/ Oil cost PPI adjustment, average of oil support and oil equipment indices, 1990 = 100

2/ PPI adjusted, 1990 = 100

Sources: Worldscope, U.S. Bureau of Labor Statistics, and IMF Staff calculations

susceptible to the business cycle, as nearly a third of oil price movements can be explained by common factors (see Chapter 3, International Monetary Fund 2008a).[3] Of course, a full

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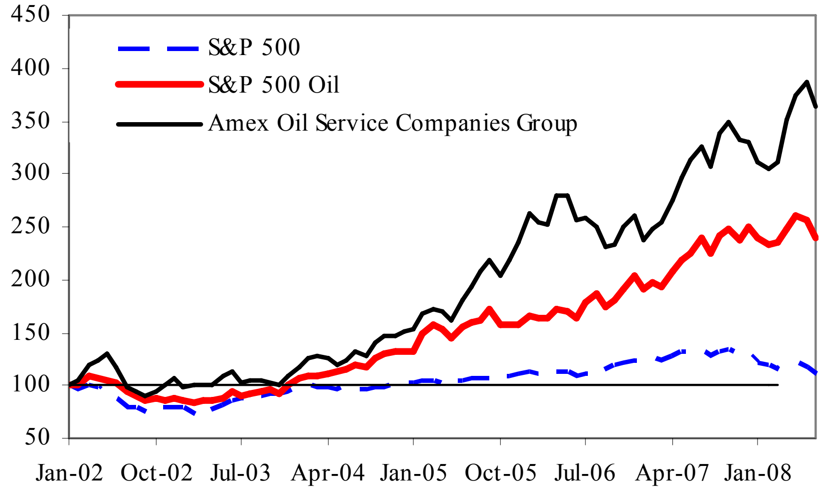
[2] This pattern of declining real investment during the 1990s, with a dip in 1997-98, is also evident in oil investment series constructed by Saavedra (2005) and IEA (2006), as discussed in Appendix 3.

[3] Another important aspect is to understand the role of OPEC in price formation, but this is a subject beyond the scope of this paper. Gately (2004) discusses the importance of OPEC in explaining output, not necessarily investment. However, as will be explained later, OPEC spare capacity turns out to be important on its own right.

understanding of investment during that period also requires explaining the behavior of both national and international oil companies (as many are not included in the above data). These are discussed below.

2.2 Investment Behavior of International Oil Companies (IOCs) in Perspective.

Figure 3. U.S. Stock Market Valuation: Total S&P Index and Oil & Gas Sector (January 2000=100)

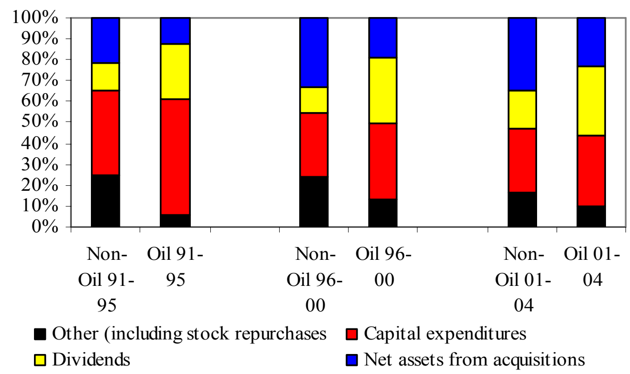


Source: Bloomberg

Oil and gas companies posted record profits in the 3 years ending October 2008 – well above the rest of the nonfinancial corporate sector – largely owing to the increase in energy prices. The S&P stock index for energy has surpassed the overall index by a substantial margin, with oil service companies performing even better (Figure 3). Nonetheless, as Figure 2 suggests, investment levels in 2004 were still below the levels in the early 1990s, even though spare oil capacity was much higher. Part of the argument of many analysts *ex-post* has been that the initial cautious approach to investment reflected a period for IOCs to resolve the uncertainty of whether the price increases were temporary or permanent. As Figure 1 suggests, there was genuine uncertainty – even from experts – that the price rise would endure. Moreover, there was more catching-up of replacement investment necessary, given the sharp decline in investment in the oil sector following the 1997-1998 Asian crisis amid limited OPEC discipline.

Moreover, low oil prices and limited geographical opportunities for international oil companies during the 1990s has gradually led to a period of consolidation of large oil companies and cost-cutting strategies, even up to this decade. This reluctance to quickly switch to a risk-taking mode has most likely also contributed to a slow initial response of oil investors to rising prices. The median share of G7-listed oil and gas companies' cash earnings spent on asset acquisitions and dividend payouts increased from 35 percent in 1990–95 to 57 percent in 2000–04, leaving a lower share to be spent on new investment (Figure 4). Moreover, fewer greenfield investments by companies meant that overall investment likely expanded less: while spending on oil acquisitions implied an increase in investment expenditures for an individual IOC, it may not

Figure 4. Oil and Non-Oil Corporate Use of Cash Earnings (as a percent of total) 1/



1/ Cash earnings after amortization

Sources: Worldscope and IMF Staff calculations

have done so for the global economy as a whole.

2.3 Investment Behavior of National Oil Companies (NOCs).

NOCs in a number of major oil producers – particularly where financial constraints are less binding or it is easy to attract private capital – ratcheted up plans for investment since 2005. Large companies – such as Saudi Arabia's Aramco, UAE's ADNOC, and Kuwait's KPC, which can self-finance projects and were able to maintain their human and productive capital base during the lean years of the 1990s – have developed ambitious capacity expansion plans at all levels of the production chain. Saudi Aramco is investing more than $50 billion between 2007 and 2012 to expand production by almost 20 percent and refining by 50 percent; Abu Dhabi

National Oil Company (ADNOC) is increasing production capacity by 30 percent and Kuwait Petroleum Company (KPC) by 60 percent by 2020 (although all these projects, particularly KPCs, have been subject to some delays).

Some NOCs in more fiscally strapped countries have sought new ways of accessing private sector financing and know-how, while at the same time abiding by the constitutionally mandated prohibition of foreign ownership, with mixed success. NOCs such as Mexico's Pemex, Algeria's Sonatrach, and the Islamic Republic of Iran's INOC set up "build-operate-transfer" projects with IOCs, and have seen investment in these projects take off very rapidly, although overall investment has lagged. At the same time, outward-oriented NOCs such as Petrobras, Statoil, PetroChina and Petronas have recently experienced high investment levels.

With the exception of recent surges in investments by some of the main Gulf states, as well as Petrobras, PetroChina and Sonatrach, real investment of small, more traditional NOCs does not appear to have fully recovered from the decline in the 1990s despite a slight pickup since 2000[4]. Investment has been constrained by numerous explicit and implicit restrictions imposed by their own governments. During the 1990s, in particular, NOCs in many low-income, but oil-rich, countries were often short of financial resources. Cash flow was typically siphoned off to the budget – for example, through high implicit fuel subsidies (when the domestic fuel price for consumers is kept artificially low) and in some cases, as a result of corruption. Even where the intentions of the government were benign, competing objectives led to politically difficult trade-offs. For example, if the government needed to undertake fiscal adjustment, it did so at the cost of reducing resources available to the NOC. Consequently, the lack of investment in oil production infrastructure over a number of years has led to a situation in which a number of NOCs were not in a position to take full advantage of potential gains from current price levels. The text box discusses how the changing ownership structure of the global oil sector is itself posing new challenges for investment.

[4] Data deficiencies, in particular for the case of NOCs, do not permit a conclusive statement on investment behavior. The above inference is based on information on capital and exploratory expenditures from the Oil and Gas Journal for 19 NOCs to 2007. The NOCs that publish investment data produced about 53 percent of total NOC oil output. There is no investment information on four major Middle Eastern NOCs – Aramco, ADNOC, INOC and NIOC (Iraq) – and limited data on other NOCs, so some of the trends are inferred from country production data collected from IMF staff economists.

While the different structures and objectives of national and international oil companies may imply different investment trends, differences among companies within these groups are even starker, with a much greater diversity of operation modes among national oil companies. One of the hypotheses to test is whether there are differences in investment behavior between IOCs and NOCs, to be discussed further in the next section.

Box. International and National Oil Companies in a Changing Oil Sector Environment

The increasing importance of national oil companies (NOCs) has brought new challenges and potential opportunities for international oil companies (IOCs). This box discusses the changing relationship between IOCs and NOCs, and suggests that improved partnership between the two – taking better advantage of each other's strengths and needs – would strengthen prospects for increasing investment in the oil sector as a whole.

The global oil industry continues to have an oligopolistic structure, but the importance of NOCs in the control of production has risen dramatically. Twenty national and international oil companies own almost 80 percent of the world's proven reserves. Significantly, the top four – which own 60 percent of the world's reserves – are NOCs from Saudi Arabia, the Islamic Republic of Iran, Iraq, and Kuwait with full ownership and control of their oil wells. Moreover, some NOCs are quickly expanding outside their borders. Companies like PetroChina, Petronas, and Petrobras, formerly exclusively involved in domestic production, have won lucrative international contracts. NOCs from oil-importing countries such as China, Japan, and India have been very active in forging foreign upstream ventures and acquiring foreign assets, a behavior akin to traditional major IOCs. The difference is that these strategies are often driven by their countries' energy security policies. The distinction between types of companies is also becoming blurred. It is not uncommon to have a project run as a joint venture where the partners are a subsidiary of the host NOC, an IOC, and a foreign NOC.

Partnerships among different types of companies should, in theory, allow each side to contribute its strengths, but in practice differences between major IOCs and large NOCs make such unions rare. Part of the explanation may have to do with fundamentally different and clashing objectives between the two, as suggested in Marcel (2006). IOCs want access to equity, acceptable rates of return, and incentives for enhanced recovery. NOCs, for their part, want access to the managerial, technical, and financial expertise of IOCs without having to give up ownership and control of their national reserves. NOC managers sometimes express concern that IOCs have a tendency to over produce fields in a quest to satisfy the short-term expectations of their shareholders, and that in the past they have not received the full benefits of production-sharing agreements. A number of governments have recently altered contracting laws and production-sharing rules with foreign investors so as to increase control over their resources to varying degrees (as in Bolivia, Ecuador, Venezuela, and Russia). For their part, IOCs have expressed frustration about changing "rules of the game." Indeed, this may partly explain why profitability of international oil service companies has been even higher than oil and gas exploration and production companies since 2002; their services are in high demand by NOCs because they provide the know-how without generating competition for the NOC assets. delays, and dealing with the bureaucratic structures of NOCs. They believe the host governments do not always adequately factor in the risks associated with unpredictable political and tax environments.

Well-designed partnerships could lead to increasing investment levels in the oil industry as a whole, especially if the risks and returns from the production venture are appropriately distributed. Given that NOCs today own the majority of the world's reserves, IOCs are coming to terms with the reality that their future activity may have to increasingly take place in partnerships in which profits and control must be shared. In turn, governments of NOCs will have to work to provide a more stable and transparent investment environment and stronger governance of NOCs. Once these frictions are worked out, global investment in the sector would be better placed to respond to price incentives.

3. Testable Implications for Oil Investment

3.1 Implications from the Literature

The main testable implications derive from some of the recent models mentioned earlier, in particularly Casassus et al.(2005), and Hartley and Medlock (2008). These models characterize the optimal problem of a representative oil company: an IOCs which maximize profits (or net revenues in the case of an NOC), subject to costs. In many of these models, the cost of finding and developing a barrel of oil is assumed to be a decreasing function of proven reserves of the country where the company is drilling. These costs will clearly depend on the geology. For example, deepwater offshore drilling is costlier than traditional wells, and most companies engage in various projects of different types. Nonetheless, by definition countries closed off to IOC investment generally have cheaper-to-produce oil wells (abstracting from indirect costs arising from security concerns). In many of these models (for example, Caballero (1991), capital investment is irreversible once installed, and cannot be costlessly abandoned, a typical and suitable assumption for industries with increasing returns and long planning horizons such as the oil industry.

The difference between and IOC and NOC (as modeled in Hartley and Medlock, 2008) reflect the fact that NOCs in some countries may face additional costs, such as 'in kind' transfer to the government or the NOC is required to hire otherwise unnecessary labor to satisfy local content requirements. In other cases, the NOC may have additional costs because it is forced to sell in the domestic market at subsidized prices. An NOC exploiting fields in its country is likely to have a lower discount rate (be more patient) than an IOC (Mitchell and Stevens, 2008). However, operation and investment costs for both companies can be modeled similarly given the global mobility of skilled labor and the relatively fast technology transfer afforded through the use of joint ventures and service companies in today's oil industry. Consequently, some aspects of the cost structures may be similar, if they are working on the same field.

The specific implications from these models are the following:

- The higher expected profitability in the future, the higher is investment.

- Since profits and output prices are correlated, then investment will also increase with a higher expected price of oil.
- The lower the level of company oil reserves, the more it costs (in real terms) to extract the last barrel of oil.
- The more patient the investor is, the lower the level of investment. Likewise for the cost of capital: the greater the interest rate, the lower investment, all else equal.
- A higher government tax take (whether in the form of taxes/royalties, or transfers to the government) should lead to lower investment levels through its effect on lower expected profits/net income.

Oil companies to ratchet up investment this decade, which may even go back to the experience in the 1970s, where the very strong response created a supply glut and the ensuing price collapse. Many NOCs came into prominence in large part because the government needed to compensate for some of the informational asymmetries between the oil-producing countries and the IOC producers (Stevens, 2004 and Mitchell and Stevens, 2008). Since the IOC profits are maximized by producing at faster rates than what is optimal for the country where the reserves are located, the corollary is that if a company, particularly an NOC, is headquartered or owned by a country where reserves are declining or not plentiful, their investment tends to be much higher, all else being equal. This may explain why higher costs imply higher investment levels, because the harder it is technologically to extract oil at the enhanced recovery stage domestically, the more attractive it becomes to expand abroad. Implicit in this hypothesis is the fact that the company is unable to tap into cheaper sources. Two major implications ensue that we will test:

(i) With traditional NOCs constrained by governments, and major IOCs constrained by difficult geology given limited opportunities, the implication from the dynamics is that new NOCs that have more government support are the most able to expand abroad, but also the most likely to heavily invest. Conversely, inwardly-oriented NOCs are the ones less likely to be investing, especially when budgets are tight or government interference intense.

(ii) At an aggregate level, this would imply that greater political stability in the host country would, all else equal, lead to higher investment. This is because the associated costs (in terms of ad-hoc charges and changes in the rules of the game) are lower in politically stable countries.

3.2 Hypotheses to be Tested

We test econometrically for the following relationships, based on the above-mentioned literature. Real investment by a company should depend positively on expected real profits (net income) for IOCs (NOCs); expected future prices (proxied by spare capacity or long-dated futures prices); and per-unit exploration and production costs, which should be negatively related to the ease of extracting reserves, and thus require greater investment. These variables can be considered the control variables of a standard oil investment model. Other additional control variables included are: past investment, reserves, company size, whether and when a company has merged[5], and interest rates.

Moreover, to test whether 'above ground' factors or 'below ground' factors matter more for investment, we include variables characterizing the host-country investment environment. These are: (i) political stability (derived from the World Bank governance indicators); (ii) the share of oil and gas revenues to total general government revenues; and (iii) the fiscal deficit to GDP of the host country (the latter two intended to capture the possible increasing need of a host country to raise large amounts of revenues through the oil sector). It is expected that a company operating in an environment where the tax take is high and rising tends to invest less. 'Below ground factors' will be captured mostly by a technical risk variable (which should deter investment, all else being equal), and finding and development costs (which are the highest in the pre-production stages of oil exploration).

Finally, the company ownership structure and strategies are considered. We test whether the NOCs' investment behavior is significantly different from IOCs, or whether a certain subset of these groups (for example, inwardly-oriented NOCs, or IOC majors) tend to invest significantly more or less.

[5] While the model is not designed to analyze the question of mergers and acquisitions (M&A), experience from the period suggests that these companies that have newly merged may be more sensitive to costs, but may invest more (perhaps after merging). Regardless, a merger dummy is included at least to control for the company/year when two companies merged.

4. Data and Methodology

4.1 Data Description

Data on investment in the oil sector outside of a few large international oil companies is very scarce. The analysis in this paper pieced together three main sources of data:

(i) *Oil and Gas Journal* data on capital expenditures on exploration and production by company spanning the 1993–2007 period.

(ii) Publicly-available field-level data allows the construction of more detailed independent variables and the mapping of data from investment by company to investment by host country. Using the oil and gas surveys for various years of Goldman Sachs, technical and financial data by field and company was matched with host-country variables.

(iii) This data was complemented with some OPEC data on investment plans by field. Comprehensive data for Saudi Arabia is not available. However, as a swing producer, it is unlikely that its decisions on production and investment are independent of oil prices, Consequently, we were able to conveniently exclude Saudi Aramco's data from the sample.

Appendix 1 summarizes the rest of the data sources and explains their derivation. The sample has 73 IOCs and 29 NOCs. These companies are classified into four subgroups: (i) domestically-oriented, traditional NOCs; (ii) outwardly-oriented NOCs (with heavy foreign investments); (iii) IOC majors; and (iv) IOC independents. See Appendix 2 for details.

Simple statistics illustrates that there are notable differences between national and international oil companies in our sample, as illustrated in Table 1. National oil companies on average appear to have higher average investments, production, total assets and net income. International oil companies, on the other hand, have slightly higher mean revenue.

Table 1. Sample Averages and Standard Deviations, in Millions of US$
102 Companies (73 IOCs and 29 NOCs), 1993 – 2007

	NOC		IOC		All	
Variable	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Real Investment/Real Revenues	0.22	0.24	0.51	0.57	0.46	0.54
Net Income (Profits)/Assets	0.13	0.24	0.07	0.10	0.08	0.14
Production	415.7	1,052.7	128.4	366.0	194.7	610.576
Total Assets	24,460	32,577	18,827	37,947	20,056	36,901
Net Income(profits)	1,931	3,533	1,594	4,130	1,665	4,013

Simple correlations find an important relationship between investment and production (with a lag, as will be discussed further ahead), as well as a strong negative relationship between proxies of the future expected oil price and investment. Correlations between selected variables are presented in Table 2. There is strong positive correlation, 0.92, between investment and its first lag. Similarly, there is a strong relationship between investment and production of 55 percent.

Table 2: Correlations, 102 Companies (73 IOCs and 29 NOCs), 1993 – 2007

	Investment	Lagged Investment	Production	Spot	Futures
Lagged Investment	0.92***				
Production	0.55***	0.47***			
Spot	0.26***	0.20***	0.17***		
Futures	0.27***	0.21***	0.17***	0.98***	
OPEC10 Spare Capacity	-0.14***	-0.13***	-0.06**	-0.58***	-0.58***

Note: *** and ** denote significance at 1% and 5 %, respectively.

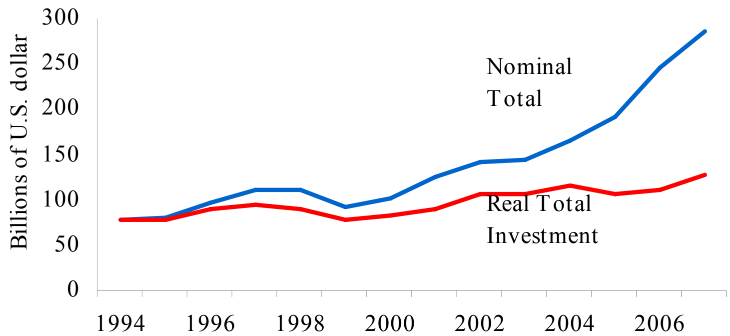
In order to avoid endogeneity, the paper first tests for the relationship between spot prices, future prices, spare capacity and investment. This exercise determines not only that the first three variables are highly correlated (Table 2), but that spare capacity Granger causes spot prices, which in turn (not surprisingly) Granger causes long-dated futures prices (of a 6-year-out horizon). This is also found in other studies (see Appendix 1.1, International Monetary Fund, 2005). We take advantage of this relationship to use the negative of spare capacity as a proxy for expected future prices in the regressions. Certainly, the two cannot be used.

Related to this is the role of OPEC spare capacity in oil price formation. OPEC's spare capacity can be used as a single statistic to describe the market balance, as high OPEC spare capacity is typically considered a deterrent to investment, and it comes hand in hand with higher prices[6].

4.2 Relationship between Investment, Costs and Technical Risk

In addition to the above variables, the relationship between aggregate investment and two key production variables bring to light some of the characteristics of investment in the recent past.

Figure 5a. Total Investment of 53 National and International Oil Companies, 1993-2007 1/

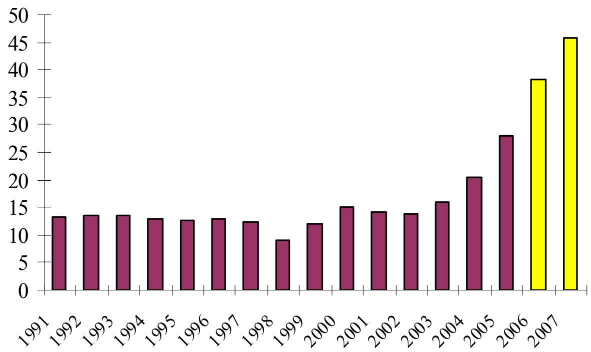


1/ Nominal capital investment in exploration deflated by the U.S. oil cost producer price index (weighted average of oil and gas wells drilling services, operational support services, and oil and gas field' machinery and equipment indices).
Source: Oil and Gas Journal Bureau of Labor Statistics and authors.

First, aggregate real investment seems to have risen in line with costs over the analyzed period. Figures 5 and 6 show that over the last three years costs have reflected supply bottlenecks

[6] There are two channels through which high OPEC spare capacity could lead to lower investment. The first is a direct effect: low spare capacity implies a shortage of current or future supplies relative to demand, which could create an incentive to invest. The second, indirect effect is that spare capacity can be interpreted as a 'fixed cost' that OPEC pays in order to create a 'barrier to entry' for non-OPEC-member companies. Both interpretations imply a negative relationship between prices and spare capacity, but most of the evidence in this paper suggests that the direct effect is the most important.

Figure 5b. Average Capital Cost of Producing a Barrel of Oil



Source: Bloomberg and Goldman Sachs, Inc. Capital costs consists of finding and development costs, lifting costs and income taxes of major international oil companies. 2006 and 2007 are estimates based on HIS-CERA upstream capital cost index

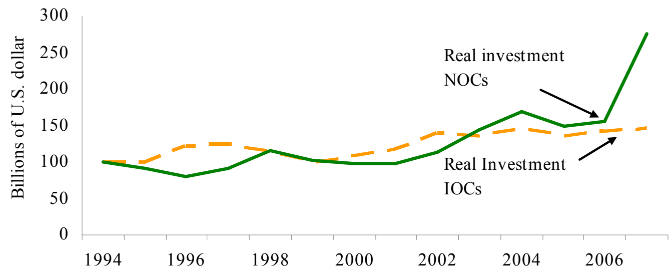
(although demand factors and economy-wide factors have mostly determined the cyclicality over a longer period, as discussed earlier). Higher oil prices have led to soaring nominal investment levels: during 2004–07, nominal oil investment for a sample of 54 companies grew by about 156 percent (Figure 5a).[7] However, soaring prices of investment goods and services meant that this did not translate into large real investment increases, which grew less than 10 percent over the same period. The higher investment costs were due to a global scarcity both of equipment (such as rigs) and of services such as skilled engineers and project managers and to higher average finding and development costs. According to Goldman Sachs (2007), marginal field finding and development costs have soared from $5 per barrel in 2000 to about $10 per barrel in 2007 (the data underlying these costs by company, available only for recent years, are those used in the regressions below). According to IHS/Cambridge Energy Research Associates' *Upstream Capital Cost Index*, over the two years ending in Q3 2007, upstream costs doubled. In 2007, costs began to increase slower than nominal investment, so that a welcome uptick is visible (see Figure 5b)[8].

[7] To illustrate the total investments over time, we focus on companies that do not have missing investment observations. The resulting balanced subsample consists of 54 companies between 1994 and 2007 inclusive.

[8] These costs, in particular the index, control for size and structure of the companies.

Many of the factors contributing to higher costs are cyclical in nature and should moderate as input supplies adjust to the increased demand. However, based on evidence

Figure 6. Total Real Investment Index of Companyes by Ownership Structure, 1994-2007 1/



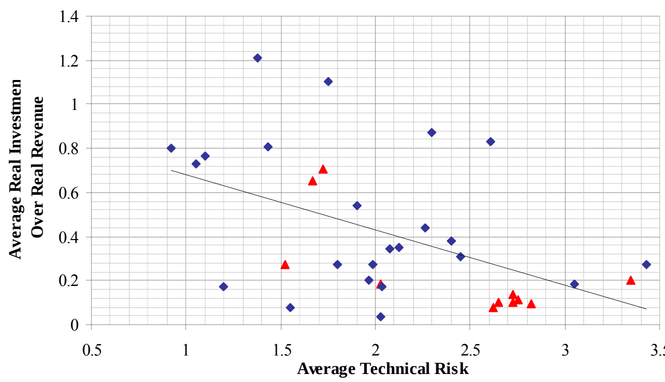
1/ Nominal capital investment in exploration deflated by the U.S. oil cost producer price index (weighted average of oil and gas wells drilling services, operational support services, and oil and gas field' machinery and equipment indices). The data comprises 47 IOCs and 5 NOCs.
Source: Oil and Gas Journal, Bureau of Labor Statistics and authors.

presented below, a significant component of these costs is the result of geological constraints – a more permanent rigidity. The sluggish growth of real investment, at least for our sample, was present for both national and international oil companies (Figure 6), however, within those groups, there were important differences.

Second, the data shows that technical risk in oil exploration is high and is expected to become even more so in the future. The technical risk variable used in this study, constructed by Goldman Sachs (and only available for the more recent years), is intended to capture the technology dependence, geology constraints and geographical environment of an oil field (a weighted average index is computed for every oil company, see Appendix 1 for a detailed definition). A clear trend is emerging over time of increased average technical risk, and this trend is expected to continue based on the location and nature of sanctioned projects (at least for the 190 projects surveyed): "In an effort to replace reserves, IOCs are increasingly looking to develop more complicated projects…as a number of LNG schemes, deepwater projects (often subsalt) and complex gas projects are due to be sanctioned" (Goldman Sachs (2008) page 34).

Figure 7 plots average technical risk against real investment to real revenues by company. While there are important differences among companies in their technical risk index, the

Figure 7. Real Investmnet Over Real Revenue Against Technical Risk, Average Over 2004-2007 1/



1/ Major IOC companies are in red triangulars, the rest are in blue diamonds.

association of the index with investment is negative, as companies are increasingly drilling on frontier fields and confronting more uncertainty on the technological side. It also shows that IOCs (denoted in red triangles) are generally taking on more technical risks than other types of companies.

4.3 Econometric Methodology

To capture the dynamics of investment adjustment of the oil companies, we model investment in a dynamic panel framework. The general model is specified as follows:

$$y_{it} = \beta_0 + \beta_1 y_{i,t-1} + \beta_2 x_{it} + \eta_i + v_{it}, \; i = 1, 2, ..., N, \; t = 2, 3, ..., T$$

where β_0 is an intercept that accounts for a common trend component in the investments, $y_{it} = \frac{I_{it}}{K_{it}}$ is the ratio of investment *(I)* to capital (*K*), of company *i* at time *t*, x_{it} is a vector of additional explanatory variables, η_i captures time invariant unobserved firm-specific heterogeneity and v_{it} is the error term that varies with individual companies and time. We assume that both η_i and v_{it} are *i.i.d.* variables with zero mean and constant variance, independent of each other and among themselves.

Since η_i is a part of the process that generates $y_{i,t-1}$, it follows that $E(y_{i,t-1}, \eta_i) > 0$. It implies that the introduction of the lags into the regression model causes bias and inconsistency of the Ordinary Least Squares estimators. Even though the fixed effects (within) estimator removes the time invariant company specific effect, the regressor and the error term are still correlated by construction, thus rendering the within estimators biased (Nickel, 1981). Moreover, the bias of these estimators does not disappear asymptotically.

Anderson and Hsiao (1981) suggest to apply first differencing to remove the company specific effect η_i and then to instrument the differenced regressor $\Delta y_{i,t-2} = y_{i,t-2} - y_{i,t-3}$ with $y_{i,t-2}$ or its first difference. In this approach, the instrument is correlated with $\Delta y_{i,t-2}$ and it is uncorrelated with $\Delta v_{i,t} = v_{i,t} - v_{i,t-1}$ assuming v_{it} is uncorrelated. Although instrumental variable approach gives consistent estimators, they can be shown to be inefficient.

Arellano and Bond (1991) propose a method to overcome this problem in autoregressive linear regression models with unobserved individual specific time-invariant effects. They argue that a more efficient estimator can be found through the use of qualified instrumental variables. Assume that the genuine error term v_{it} is serially uncorrelated:

$$E(v_{it}, v_{is}) = 0 \text{ for } i = 1, 2, ..., N \text{ and } t \neq s,$$

and orthogonal to the dependent variable y_{it}:

$$E(y_{it}, v_{it}) = 0 \text{ for } i = 1, 2, ..., N \text{ and } t = 2, 3, ..., T$$

It implies there are $m = 0.5(T-1)(T-2)$ moment restrictions:

$$E(y_{it-s}, \Delta v_{it}) = 0 \text{ for } t = 3, ..., T \text{ and } s \geq 2.$$

These moment restrictions imply the use of the lagged levels starting from *t-2* and earlier as instruments because the proposed instruments are correlated with the differenced regressor and are orthogonal to the error term Δv_{it}.

The advantages of using the generalized method of moments (GMM) framework are that the estimators are not biased because of the omitted fixed effects variables (company-specific variables that are constant over time), the coefficients are estimated consistently in the models that contain endogenous variables (e.g. investment rates in the growth models) or even in the presence of measurement error (Blundell and Bond, 1998). In addition, this technique is well suited for the unbalanced panel data and performs well when number of companies N is large but number of time intervals T is small. The last two features are especially important as the company-level data on oil investment normally contain a lot of missing observations and is usually available for a relatively short time interval.

5. Econometric Results and Implications

5.1 Estimation Results

Tables 3 and 4 present the results of the Arellano-Bond GMM regressions. The dependent variable, real investment over real revenue by company, represents the capital investment-to-output ratio, the variable of interest. Column 1 shows the most robust relationship: investment is significantly and positively related to past investment levels (due to time-to-build-related dependency), expected output prices, and unit finding and development costs[9] . The coefficients on these variables are very robust and significant. The net income (profits) variable is also positive and significant, as expected, although less robust than the expected price variable; specification 3 shows that part of the reason is that the expected price effect is also captured by the profits variable: excluding the expected price variable, the profits variable is very positive and statistically significant. Finally, regarding the price proxy, consistent with the earlier discussion, the negative of spare capacity is utilized. Nonetheless, long-dated futures prices are an equally significant proxy, although there is some multicollinearity between average unit finding and development costs and long-dated futures prices (Table 3, specification 4). Therefore, the specification including the price proxy (negative of spare capacity) is preferred.

In addition to the above variables, which could be considered the control variables, various others were considered. Neither reserves (which proxies for own-resource availability) nor assets of the company (which proxies for company size) are significant in explaining the level of

[9] Note that due to data limitations F&D cost and technical risk series are varying starting from 2003 and are constant before 2003. However, this does not pose a problem for the Arellano-Bond GMM estimation, since matrix containing the first differences is still invertible.

investment in any of the specifications. Moreover, the variable denoting the reserves of the country where the company is headquartered is only robust and significant when the specified dependent variable was the change in nominal investment-to-revenue (not reported here), possibly suggesting that it is important in determining nominal investment growth (negative relationship), but not actual real investment. Finally, while the merger dummy was included in most of the specifications to control for possible outliers, it is rarely significant. Inclusion of an OPEC dummy was insignificant. Finally, the cost-of-funds variable, LIBOR, is never significant[10].

Table 3. Results of the Arellano-Bond Generalized Method of Moments Panel Estimations. Dependent Variable: Company Real Capital Investment in Exploration and Production Over Real Revenues, Annual, 1993-2007

	Full sample (102 companies)				Smaller sample (54 companies)	
	1	2	3	4	5	6
Constant	**0.28** ***	**0.34** ***	**0.18** **	**0.27** ***	**0.29** ***	**0.21** **
	0.09	*0.08*	*0.08*	*0.08*	*0.09*	*0.08*
Real investment/Real Revenue Lagged (t-1)	**0.10** *	**0.12** *	**0.13** **	**0.10**	**0.12** *	**0.15** **
	0.06	*0.06*	*0.06*	*0.06*	*0.07*	*0.06*
Profits (Net Income) to Assets	**0.25**	**0.21**	**0.51** **	**0.30**	**0.31**	**0.50** **
	0.26	*0.26*	*0.24*	*0.25*	*0.28*	*0.26*
Expected Price Proxy 1/	**0.02** ***	**0.02** ***			**0.02** **	
	0.01	*0.01*			*0.01*	
Long-Dated Futures Prices				**0.003** ***		
				0.001		
Technical Risk	**-0.04**	**-0.06**	**-0.05**	**-0.06** *	**-0.09** *	**-0.09** **
	0.04	*0.04*	*0.04*	*0.04*	*0.05*	*0.05*
Average Finding and Development Costs	**0.06** ***	**0.03** **	**0.06** ***	**0.02**	**0.09** ***	**0.09** ***
	0.02	*0.01*	*0.02*	*0.02*	*0.02*	*0.02*
Merger Dummy	**0.05**	**0.05**	**0.05**	**0.01**	**0.03**	0.03
	0.04	*0.04*	*0.04*	*0.04*	*0.04*	*0.04*
F&D Costs*IOC Major dummy	**-0.06** *		**-0.06** **	**-0.04**	**-0.08** ***	**-0.21** ***
	0.03		*0.03*	*0.03*	*0.03*	*0.03*
F&D Costs*NOC_Domestic_Dummy		**-0.42** *				
		0.24				
No. of observations	340	340	340	340	304	304
Wald (Chi) statistic	37.51	35.65	30.69	40.65	45.29	41.15

Note: ***, ** and * denote significance at 1%, 5 % and 10% significance level, respectively. Standard errors are in italics. Appendix 4 describes the variables
1/ The negative of OPEC spare capacity

The main results that come out from the various specifications are that the variable denoting 'below ground' risks are the most robust and significant, suggesting that our results give more weight to the hypothesis of 'below-ground' constraints (the interaction with the company ownership variables are discussed below).

[10] For oil companies with large fixed costs and long investment horizons, LIBOR is much less likely to matter directly, as short-term working capital is a small part of the costs. Therefore, this result is not surprising. It is more likely that profits and/or the expected oil prices matter more for the cost of funds or opportunity cost of capital.

- Comparing investment across companies, higher technical risk is a significant impediment to investment, even after controlling for higher finding and development costs. Technical risk on its own, however, is less significant and robust in the regressions which include the full sample, but very negatively significant and robust for the sample of companies that tend to operate more technically sophisticated projects (oil sands, deepwater drilling, etc). Table 3, columns 5 and 6 present the results for a subsample of 54 companies most represented in the data, which also tend to be involved in the most efficient projects.[11]
- In contrast, political and fiscal variables in the host country were not significant in explaining investment. Political stability was rarely statistically significant. (see for example Table 4, columns 1). However, it is possible that fears of "resource nationalism" have increased uncertainty about investment in a less tangible way that is not yet being captured by the data.[12] There could also be some self-selection present: the *positive* and statistically significant correlation between finding and development costs and political stability may suggest that oil companies would prefer to gamble on high-cost, technically risky fields, rather than to take the necessary steps to hedge against political uncertainties[13]. Indeed, only when technical risk and F&D costs are excluded from the regressions does the political stability variable comes out positive and significant[14].
- Table 4 also suggests that companies operating in countries where the share of government revenues from oil and gas as a share of the total (a proxy for the tax take) is high do not necessarily invest less. The coefficient on the variable is not always

[11] Much of the data, including the "below ground" variables, are taken from the Goldman Sachs surveys, which by definition pick the most efficient and successful projects from a larger sample.

[12] Here it is worth noting how limited the availability of data is. For example, data for Iraq is not available and is limited for Iran. Moreover, the data do not fully reflect the possible negative effects of recent nationalizations on investment (for the case of Venezuela, investment data for PDVSA, the national oil company, is unavailable after 2003). The variable would also fail to capture localized problems within countries. For example, Nigeria's onshore production has been hampered by frequent violent attacks, but investment in offshore production, which is less vulnerable to attacks, has grown steadily. Jojarth (2008) shows that fields affected by hostilities do experience statistically significant higher costs.

[13] Goldman Sachs (2007 and 2008) show that these capital costs are particularly high for deepwater offshore drilling projects and oil sands projects, even though F&D costs may not be that high. Our results are consistent with this.

[14] Although the regression is not reported, we replaced the technical risk and F&D cost variables in Table 3, equation 1, with the political stability variable. Political stability comes out positive and significant, but the regression loses significance (and some coefficients change sign). This is the only case in which the coefficient on "political stability" came out positive and significant. Political stability is also significant in regressions where nominal investment to revenue is the dependent variable (possibly suggesting that, with less payments to the government or associated costs, there is more cash to invest).

significant. Of course, to the extent that increased tax takes is reflected in lower profit rates, this will lower the level of investment. Indeed, increased tax assessments by governments have escalated the costs of international joint venture projects in the past two years. In 2007 alone, payments to governments (including royalties) represented more than half the cost of a barrel of oil[15]. However, the results suggest that there does not seem to be any *additional* contemporary effect of a higher tax take beyond its effect through after-tax profits, given the lack of statistical significance of the tax take proxy (columns 2 and 3 of Table 4).

Turning to the question of company ownership structure, the results do not show any statistically significant difference in the behavior of IOC and NOC investment. The time-invariant dummy variables were interacted with various other variables[16]. For example, Table 4 columns 4 and 5 show the interaction of the NOC dummy with the F&D costs variable and the size proxy, respectively (to test whether higher costs and/or a smaller size would lead NOCs to invest less than IOCs). The coefficient on the interaction variables rarely turns out to be significant. Using the smaller sample (which has a group of relatively more efficient companies), this interaction variable is sometimes negative and significant, so there may be a small effect for some of the projects.

[15] The share of oil and gas revenue to total of the host country was not significant by itself. However, on its own the variable is not too relevant: there is no reason to believe *ex-ante* that a large oil exporting country that has fiscal accounts heavily dependent on oil should levy high taxes and/or have an unstable tax regime.

[16] The Arellano-Bond method does not consider time-invariant dummies in the solution procedure, which is why the dummies were interacted with time-varying variables. Therefore, it is not possible to directly test whether a certain type of company tends to invest less than another depending on ownership. The regression results using the Generalized Least Square panel estimation method – despite its problems – confirm that the NOC dummy is not statistically significant.

Table 4. Results of the Arellano-Bond Generalized Method of Moments Panel Estimations. Dependent Variable: Company Real Capital Investment in Exploration and Production Over Real Revenues, Annual, 1993-2007, 102 Oil Companies

	1	2	3	4	5
Constant	**0.56**	**0.23** ***	**0.24** ***	**0.09**	**0.33** ***
	0.39	*0.08*	*0.07*	*0.26*	*0.09*
Real investment/Real Revenue Lagged (t-1)	**0.09**	**0.11** *	**0.11** *	**0.14** **	**0.14** **
	0.06	*0.06*	*0.06*	*0.06*	*0.06*
Profits (Net Income) to Assets	**0.31**	**0.23**	**0.39**	**0.14**	**0.08**
	0.27	*0.21*	*0.27*	*0.26*	*0.27*
Expected Price Proxy 1/	**0.02** ***	**0.01** *	**0.01** **	**0.02** ***	**0.02** ***
	0.01	*0.01*	*0.01*	*0.01*	*0.01*
Technical Risk	**-0.04**	**-0.03**	**-0.02**	**-0.05**	**-0.05**
	0.04	*0.03*	*0.03*	*0.04*	*0.04*
Average Finding and Development Costs	**0.06** ***	**0.04** ***	**0.04** **	**0.03** ***	**0.04** **
	0.02	*0.02*	*0.03*	*0.02*	*0.02*
Merger Dummy	**0.02**	**0.04**	**0.04**		**0.05**
	0.04	*0.03*	*0.03*		*0.04*
F&D Costs*IOC Major dummy	**-0.06** **	**-0.06** ***	**-0.06** ***		
	0.03	*0.02*	*0.02*		
Political Stability	**0.56**				
	0.39				
Tax take proxy		**0.06**			
		0.15			
Tax take Proxy * Profits to Assets			**-0.70**		
			0.89		
Size Proxy (Real Assets)				**0.01**	
				0.02	
Size * NOC				**0.13**	
				0.14	
F&D Costs*NOC_Dummy					**-0.04**
					0.04
No. of observations	304	295	295	358	358
Wald (Chi) statistic	36.74	31.33	31.66	35.19	36.04

Note: ***, ** and * denote significance at 1%, 5 % and 10% significance level, respectively. Standard errors are in italics.

1/ The negative of OPEC spare capacity

Nonetheless, at a further disaggregation, the results clearly show that the subgroups of IOC majors and traditional, domestically-oriented NOCs are much more sensitive to F&D costs, so their investment behavior is different in this regard. The negative and statistically significant coefficient on the F&D costs and IOC major dummy interaction variable suggests that IOC majors will tend to invest less than other types of companies when costs escalate. The same is true for domestically-oriented NOCs (Table 3, column 2). In contrast, outwardly oriented national oil companies are investing very rapidly, in some cases with strong political and financial support from their governments, and are thus less sensitive to higher costs, on average.

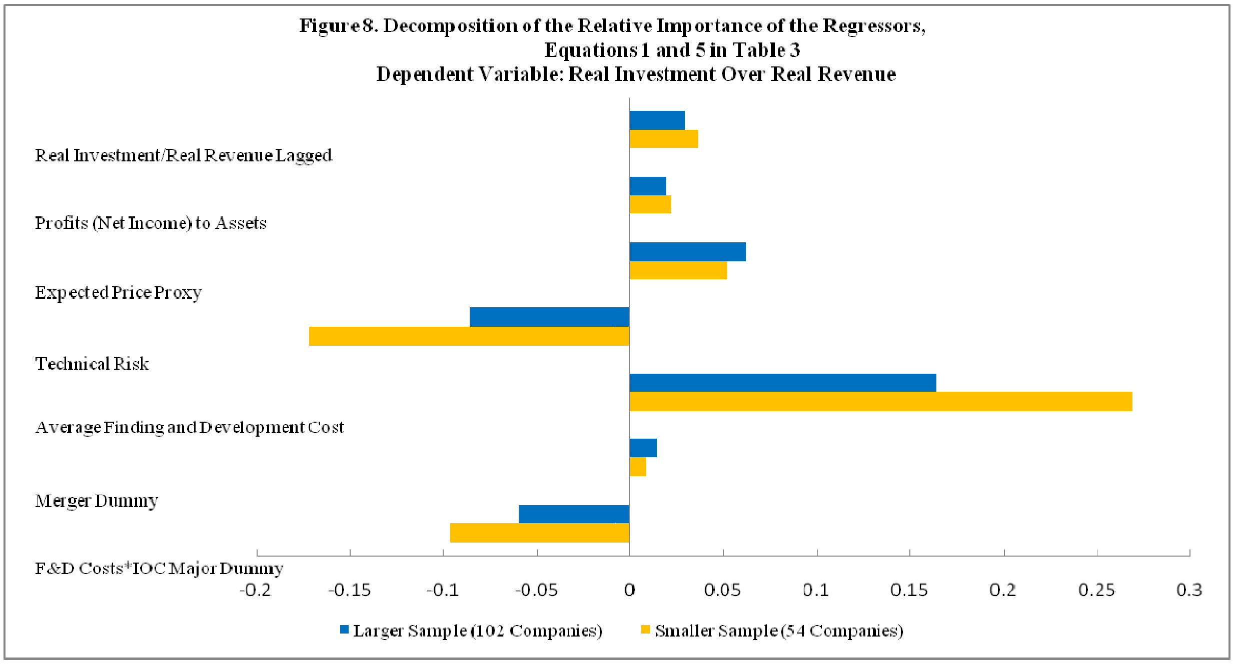


Figure 8. Decomposition of the Relative Importance of the Regressors, Equations 1 and 5 in Table 3
Dependent Variable: Real Investment Over Real Revenue

Figure 8 presents a decomposition of the different factors that determine the average real investment to revenues, using the equations that represent the best fit (both for the small and large sample). Not surprisingly, the technical risk variable has an important negative impact on investment, and is very strongly negative for the smaller sample (implying that it is a more important determinant for those companies, on average). This negative effect is mostly offset by the positive relationship between finding and development costs and the investment ratio. Indeed, on average more than three quarters of the increase in the dependent variable can be explained by the main control variables: the lagged investment ratio, profits, and the expected price proxy.

6. Supply and Policy Implications

This section considers the implication of our results in the more general context of global oil supply going forward.

6.1 Geological Factors Make Supply Rigidities More Persistent

The results suggest that the slow investment response is being strongly affected by technological and geological factors. As a result, capacity growth will be more constrained by geology than in the past. In other words, although peak production rates in major fields are attained earlier – because extraction methods have become more efficient – "decline rates" are also higher in major fields.[17] The International Energy Agency suggests that almost two-thirds of the additional gross capacity needed over the next eight years will be required just to replace declines in output from existing fields. Second, oil will increasingly come from unconventional sources, because output has declined from peak levels at conventional fields in many countries, and the size of oil fields is getting smaller on average.[18] This does not mean that the world is about to run out of oil, but it suggests that higher oil prices are needed to induce the additional investment required to balance the market over the medium term.

Table 5. Optimal Lags of Production - Investment

Results by Type of Exploration (in Years)	
Traditional	1
Enhanced Recovery	1.5
Heavy Oil	2
Deepwater Drilling	2
Siberian Prospects	3
Results From Dividing the Full Sample	
1994-1999	1.45
2000-2006	2 to 3 1/

Note: For the type, field level data Goldman Sachs (2007) was used. For the latter, estimations are by company.

1/ It was not always significant for three lags. An NOC dummy was included, but it was insignificant.

The issue of longer investment lags was also investigated with our available data. The results are as follows:

[17]Decline rates refer to the natural rate of depletion once an oil field reaches its peak.

[18]See the International Energy Agency (2007), National Petroleum Council (2007), and Van der Veer (2008).

- Oil companies' investment—in particular that of major international firms—was slower to respond to the price signals in the current boom than in earlier periods. Using company data for investment between 1993 and 2007, the lag between spare capacity (a proxy for the price signal) and investment has grown to about 2-3 years (Table 5). Of course, the oil sector is an industry with long planning horizons and high sunk costs, and so long lags are not unusual. However, this lag has increased in recent years.
- The amount of time it takes, on average, for investment to translate into output has also increased, as more complex projects have become the norm. Based on field-level investment data of about 150 projects during 2003–07, Table 5 shows that the projects attracting most of the marginal investment – such as deep-water offshore drilling in Brazil, the Gulf of Mexico, and West Africa, Canadian oil sands projects; and Siberian projects – take longer to explore and develop than more traditional projects. These projects showed roughly twice the lag before the start of production as conventional projects.

Table 6. Then and Now: Average Values of Oil Market Variables During Two Major Oil Booms

(in percent unless otherwise stated)

	1977-1980	2004-2006
Supply-Related Factors		
Oil capacity growth rate	2.5	1.6
Share of production by seven major international oil companies 1/	21	15
Share of production in conventional oil fields to total 2/	93	52
Share of OECD production in total	61	38
Memorandum Item:		
OECD Oil Intensity (million barrels per day consumed to GDP)	1.07	0.57

1/ Data for 1977-1980 estimated based on major operations of large seven countries

2/ Non-conventional defined as offshore, Siberian, and oil sands.

Source: IMF (2008b).

The results regarding field-level data are also consistent with the econometric results of Table 3 and 4. The production lags in deep offshore drilling and oil sands, for example, likely reflect the complexities of working with emerging technology and are intrinsically related to soaring finding and development costs. In some cases, projects have been delayed because governments have refused to renew some contracts in their current form in the face of higher-than-expected cost overruns, particularly in 2007[19]. While renegotiation requests will likely subside with lower global demand, the same forces that have created the drag on output will endure.

The rigidities that are currently preventing an adjustment toward greater supply growth are somewhat different from the investment rigidities encountered during the major oil boom of the late 1970s. Table 6 shows many of the underlying oil market factors associated with both episodes: in the late 1970s oil companies had ample opportunity to expand geographically, more oil fields were conventional so the oil was relatively cheaper to extract, and production was located close to the main consuming centers. More importantly, price increases were in large part the result of supply shocks spurred by geopolitical events, unlike the 2004-2008 price increase, which was spurred by rising demand growth and increasingly constrained supply.

6.2 Policy Implications

High and sustained future prices, however, will eventually incite greater investment, despite that fact that it may at first come hand-in-hand with higher capital costs, as the results show. Therefore, the policy implication for the long-term is that by not interfering in the signaling element of oil prices, investment can respond. However, this does not mean that stable policies are not playing some role.

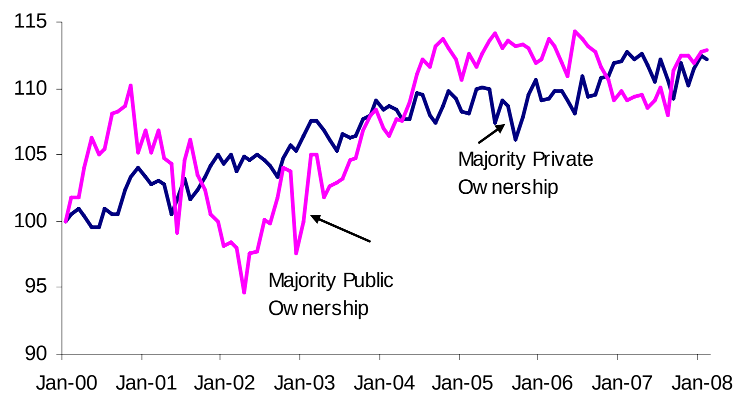
- While there is no direct effect of political stability on investment, anecdotal information suggests that there does seem to be an effect on output. Countries such as Nigeria, Russia, Venezuela and Iraq that have experienced political instability during this decade are beginning to see lower output growth. This is irrespective of the main form of ownership of the companies operating in the country. Figure 10 shows that output of different countries does not depend on the form of ownership.
- In addition to the direct effect of higher taxation on prices, there is another potentially more damaging effect which the data in this paper may not yet be able to capture: the

[19] A few recent examples include: (i) the efforts of Kazakhstan to increase the state oil company's equity in Kashagan, requiring contract renegotiation; (ii) the hefty increase in royalties for oil companies in Alberta, Canada; and (iii) and the forcing of Shell and BP from the Russian joint venture projects in Sakhalin and Kovytka, respectively.

increased uncertainty created by changing regimes for oil investors. In the long term, investment theory tells us that this may have the most damaging effect. Indeed, OPEC investors often complain about uncertain tax policies of consumer countries which may favor high-carbon coal or biofuels over imported energy. Oil companies such as Exxon-Mobil preferred to abandon contracts in various countries in 2007 because the risks of future policies seem unacceptably high. While ad-valorem income tax rates and royalties will tend to rise with prices, surveys suggest that it is unexpected changes in the terms of contracts and taxes that deter investors. Establishing credible and stable long-term agreements with governments (through joint ventures, fiscal stability clauses, or if an established reputation already exists), will help attract prospective future investments.

- These uncertainties and constraints are sometimes even greater for domestically-oriented national oil companies. Generally the constraints are budgetary, but there are also issues of incentive compatibility. Consequently, transparency rules in the budget, namely, the extent of control of the NOC by the government, and the formula for the net transfer of funds to the budget need to improve. This is sorely lacking in many countries, in particularly oil-rich countries. Testing for this effect is more difficult and beyond the scope of this paper.

Figure 10. Oil Production by Country Groups with Different Ownerships (January 2000=100)



Sources: IEA and IMF staff.

7. Conclusion and Policy Recommendations

This paper has illustrated how oil investment in the current environment faces considerable new challenges. In the 1990s, low oil prices and reduced government budgets led companies to neglect investment, and thus may have contributed to obsolete capital, which delayed the response to higher prices which began later, around 2004. While nominal investment over the past 2-3 years has picked up remarkably, soaring costs and overdue maintenance costs have meant that little has translated into real investment. It became an industry in which the amount of available cash was running ahead of the ability of the service and technology industries to satisfy demand rapidly (Horsnell, 2007). Moreover, limited geographical opportunities in some major producing countries led many outward-oriented companies – both national and international – to take greater technological risks, contributing to already high finding and development costs. Efforts by many governments to increase tax takes may have also been a significant contributor to lower investment through the effect on profits. Consequently, the evidence suggests that although investment eventually does respond to prices, it does so with a greater lag and more slowly than in the past.

Traditional classifications across ownership structure do not seem to explain supply trends much, particularly in a global era where service companies provide so much of the expertise and skilled labor of the industry is mobile geographically. The distinction between companies from OPEC versus non-OPEC countries is not informative because countries within OPEC have very different investment and ownership regimes and very different levels of political stability, and because only a small percentage of OPEC members have effective spare capacity to utilize in quota policies. Moreover, national and international companies work jointly in many areas of the world, in some cases with the national oil company acting mostly as a coordinating agency.

Ultimately, technology will determine the ensuing size of the supply response to prices in the years ahead. It will also be important to remove investment obstacles and foster efficient and stable tax policies for companies, but the potential impact of these policies in the short term should not be overestimated, given that the slow capacity expansion is highly influenced by geology.

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Appendix 1: Definitions of the Variables and Sources

Real Investment/Real Revenue –	The ratio of real capital and exploratory expenditure for company ***i*** in time period ***t*** (real terms are obtained by adjusting for the oil PPI with 1994 as the base year) to real revenue (adjusted using spot prices). Investment and revenue data available from the Oil and Gas Journal, OGJ100 and OGJ 200 company datasets between 1993 and 2007. The oil PPI is the U.S. oil sector producer price index, constructed as an equal-weights average of oil and gas wells drilling services, operational support services, and oil and gas field' machinery and equipment indices. The source is the Bureau of Labor Statistics.
Profits (Net Income) to Assets	The ratio of net income of the company to its total assets. Both the net income and assets are reported by company in the Oil and Gas Journal as explained above.
Technical Risk	The technical risk variable is an index constructed by Goldman Sachs Global Investment Research that takes into account various factors, each weighted based on its importance. The data is collected at the field level but constructed by company. The index is a weighted sum of the following factors (with the direction of risk and the weights in the index, respectively, denoted in parenthesis). (i) Water depth (higher risk, 15 percent); (ii) hostile operating conditions in terms of environment, geography and/or climate such as Artic operations (more difficulty is higher risk, 14 percent); (iii) technology dependence (greater than average dependence on new or complex production technologies, e.g., subsea systems, early generation deepwater development, heavy oil development, 33 percent); (iv) geological issues (risks are higher if there are complex reservoirs, sour gas or sour liquids, etc, 11 percent); (v) OPEC quota compliance (meaning that certain risks are greater if the company has to cut output to comply with OPEC quotas, 6 percent); and infrastructure dependence (higher risk the greater the technology or political complexity required of the infrastructure to safeguard the development and exporting of the hydrocarbon, 21%. Source: Goldman Sachs (2007, 2006, 2005 and 2004).
F&D Costs	Average finding and development costs by company. Source: Goldman Sachs reports (2007, 2006, 2005 and 2004).
Political Stability	World Bank indicators of the political stability in the country. It consists of an unweighted average four dimensions of governance: (i) Political Stability and Absence of Violence (ii) Regulatory Quality; (iii) Rule of Law; and (iv) Control of Corruption. The data is available between 1996 and 2007 at: http://web.worldbank.org/WBSITE/EXTERNAL/WBI/EXTWBIGOVANTCOR/0,,contentMDK:20771165~menuPK:1866365~pagePK:64168445~piPK:64168309~theSitePK:1740530,00.html. The variable is transformed from the country-specific to the company-

	specific variable via the weighted approach explained below.
Production	Company's oil production in millions of barrels (in logs). Source: Oil and Gas Journal, OGJ 100 and OGJ 200 databases.
Reserves (in Logs)	Company's total reserves in logarithms, 1994-2007. Source: Oil and Gas Journal, OGJ 100 and OGJ 200 datasets.
Size Proxy (Real Assets)	Company's total assets adjusted for the oil PPI with 1994 as the base year. Source: Oil and Gas Journal, OGJ 100 and OGJ 200 datasets.
Tax Take Proxy	Ratio of revenue from hydrocarbons (taxes, royalties, dividends and corporate income taxes, if available) to total general government revenues. This variable will tend to be large for a large oil-producing country even if tax rates are not too large, and this is a flaw in the construction of the variable. However, in the absence of a marginal effective tax rate for oil production, this is the best. The source of the data is the IMF country economists. The data for some large producers is available in the Middle East Economic Outlook and African Economic Outlook (October 2008) published by the International Monetary Fund. Data for advanced economies generally was derived from country statistics. The variable is transformed from the country-specific to the company-specific variable via the weighted approach explained below, and is available (for many companies) between 1993 and 2006.
Merger Dummy	A variable that takes the value 1 in the year when a company experienced a merger and in subsequent years after the merger, and 0 otherwise (constructed by authors using various sources).
HQ Country-Reserves	Oil reserves (in logs) of the country where the company's headquarter is located. Source: BP Statistical Review of World Energy 2008. The variable is transformed from the country-specific to the company-specific variable via the weighted approach explained below, and is available (for many companies) between 1993 and 2006[20].
The following variables do not vary over time. See Appendix 2.	
NOC Dummy	A binary variable that takes the value 1 if the company is a National Oil Company (NOC), 0 if it is an International Oil Company (IOC).
IOC Major	A binary variable that takes the value 1 if the company is a major International Oil Company (IOC), 0 otherwise.
NOC Domestic Dummy	A binary variable that takes the value 1 if the company is a domestically oriented National Oil Company (NOC), 0 otherwise.

[20] Other proxies considered were: fiscal deficit o GDP and hydrocarbon government revenue to GDP, to capture the need of the country to raise more revenues from oil companies. These were also converted from country variables to company variables. None of them were significant.

The following variables do not vary across companies.

Long-Dated Futures Prices	The logarithm of the 12 month ahead NYMEX futures prices on the last trading day of the previous year. Source: Bloomberg.
Expected Price Proxy	The inverse of the logarithm of the average annual OPEC spare capacity in the previous t-1 period. Source: Energy Information Agency.
LIBOR	Annual London Inter-bank offer interest rate. Source: International Financial Statistics.

Method for transforming variables available at the country level into company-level indicators

In order to capture the environment of the host country in which a country is operating, it is necessary to construct a variable that denotes the weighted average of all the projects that the company is involved in globally. For this, data on investment share of each company by oil project was taken from Goldman Sachs (2006) dataset, and the exposure of a given company to a country was weighted by the share of capital invested in that particular country relative to the company's total capital expenditures in that year. The average over the 2003-2007 period was taken to construct the weight.

The formula is as follows: Suppose there is a country i and a company j, and there is a variable, x_i , that is only at the country level (such as GDP). Define g_{ij} as the average share of company j's total investment committed to country i during 2003-2007. Then x_j is defined as

$$x_j = \sum_i g_{ij} x_i \quad .$$

If project data was not available in the Goldman Sachs reports 2004 to 2007, then the data was taken from OPEC's database, based on shares of planned investments in 2006. For some independent companies, the data was available at their web page. For large OPEC producers and many domestically-oriented NOCs without much data, the assumption was made that 100 percent of their investment occurs in their country of origin, and they are exposed to that environment.

Appendix 2: Company Classification Criteria

The paper defines the following four analytical groupings. The Appendix Table shows the classification.

Traditional, Domestically-Oriented NOCs: contain vast reserves, full government ownership and control. It may engage in other non-core activities such as providing social services. Some of these NOCs may have a a short-term horizon, either because decision-making at the top is very politicized, or because the weak government finances lead them to use the NOC as the cash-cow.

Outwardly-Oriented NOCs: these companies may be required to implement some non-core activities at home (such as implement social development programs, domestic retail and distribution activities requiring a subsidy for consumers, etc.). However, their main activity (exploration and production) is developed with considerable technical expertise, to the extent that they are able to compete for projects abroad, indeed, with the full support and political backing of their governments.

Integrated International Oil Majors: these companies are vertically integrated, generally have the objective of acquiring different types of reserves all over the world, and are mostly able and willing to engage in cutting-edge, risky technology, thereby diversifying their risk. Strategies and risk preference of majors can vary, in many cases based on their asset composition and the geographical distribution of those assets.

Independent IOCs: are generally involved only in upstream (exploration and production) work. By definition they own less assets (reserves) and are not necessarily diversified geographically. They also typically focus on one type of technology (traditional on-shore, tar sands, offshore deepwater, etc). They are actively involved in partnerships and joint ventures around the world.

- **Service Companies** are not really classified in either group. They provide specific services (such as exploration) or equipment services (such as building and operating rigs). They do not own oil reserves, but rather, their value added is based on skilled workers and advances in specific technologies. They are generally involved globally--with all IOCs and NOCs-- and given the nature of their work, tend to be more susceptible to the industry price cycles. These were not included in the estimations. Oil production growth in 2000–07 by country does not seem to depend too much on whether there is majority-public ownership or minority-private ownership. (Figure 7).

Appendix table 1. Classification of Oil Companies by type

Outwardly-oriented National Oil Companies
Japan National Oil Corporation
Liwa Energy-owned by ADNOC
Lukoil
ONGC
Petrobras
Petrochina
Petrogal
Petronas
Petropars
Statoil

Domestic, Tranditional National Oil Companies
Abu Dhabi National Oil Company
CNOOC
INOC
Kazmunaigas
Korean National Oil Corporation
Kuwait Petroleum Corporation
Lybia National Oil Company
NIOC
NIOC
NNPC
Oman Oil Company
Petroleos de Venezuela
Pemex
Pertamina
PetroEcuador
PetroVietnam
Qatar Petroleum
Saudi Aramco
Sinopec
Société Nationale des Pétroles du Congo
SOCAR
Sonangol
Sonatrach
Turkish Petroleum Corporation

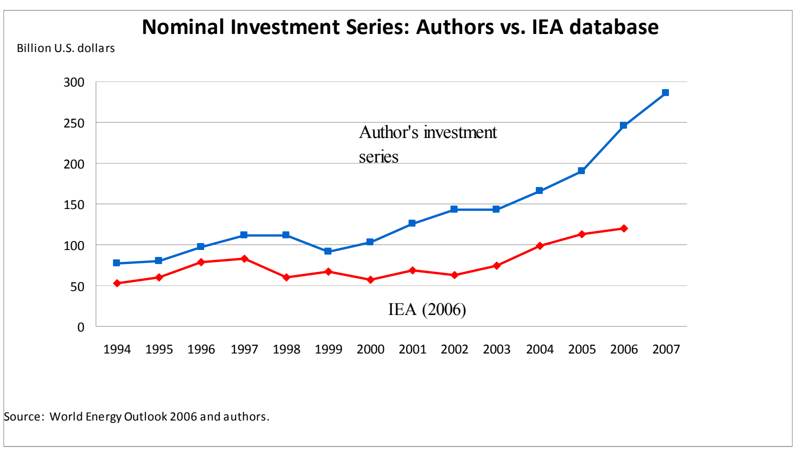
Integrated International Oil Companies
Anadarko
BP
Chevron
ConocoPhillips
ENI
ExxonMobil
Hess
Occidental
Royal Dutch Shell
TOTAL

Oil Service Companies
Enermark
Hyundai
Inelectra
Itochu
Mitsubishi
Mitsui
OIEC
OPIC -part of Chevron
Otepi

Other Independent Oil Companies
BG
BHP Billiton
Burren Energy
Cairn India
Canadian Natural Resources
Canadian Oil Sands Trust
Centrica
CEPSA
Dansk Olie og Naturgas AS
Devon Energy
Dyas
Gas Natural
Gaz de France
Gazprom
Geopetrol
Hunt Oil
Husky Energy
INPEX
Kogas
LNG Japan Corporation
Maersk
Marathon
Mocal Energy
Murphy
Nexen
Niko Resources
Nippon
Norsk Hydro
OMV
Opti Canada
Oranje-Nassau
Osaka Gas
Petoro
Petro-Canada
PGNIG
Pluspetrol
Reliance
Repsol
Ruhrgas
RWE
Santos
Sapetro
SASOL
SK Corp
Suncor
Synenco
Talisman
Teck Cominco
Tecpetrol
TEPCO/TG
Tullow
Uranium Oil and Gas
UTS Corp
Western Oil Sands
Woodside
YGC Resources

Appendix 3. Deciphering the Relationship Between Production and Investment

An important handicap of this paper, and any on oil investment, is the lack of broad data on oil investment. To check the robustness of the investment series, we looked at the relationship between oil production during this period and oil investment for the companies for which data is available[21]. Table 2 shows the results. There is a positive and significant pair-wise correlation between investment, lagged investment and production series. We use this information to 'bootstrap' and construct a predicted investment series based on past production. This is important to validate what may have been happening for some of the (mostly OPEC) companies for which we do not have data.[22] Appendix Figure 1 shows the results. The profile shows a minimal increase in nominal investment until the 1997-98 Asia crisis, which had a sharp dip, and then a strong recovery thereafter. This is also consistent with a sample of the International Energy Agency (2007) report, also shown. Moreover, the general trend of the investment series is consistent with Saavedra (2005), who was able to obtain data directly from OPEC to construct a broader series, in addition to the Lehman Brothers' company survey.



[21] Using the FE regressions of production on investment by company over 14 year period we show a statistically significant relationship between the two variables. For example, one million increase in the investment leads to 15-20 thousand bbl increase in oil production, on average. Lagged investment also has statistically significant effect on production.

[22] An issue that plagues our study, like others, is the lack of good data on investment and company structure of many important OPEC-member companies.

Appendix Table 2. Pair-wise Correlation Coefficients Between Investment, Investment Lagged and Production Series, 102 Oil Companies, 1993 - 2007

	Investment	Investment Lagged	Production
Investment	**1.000**		
	1126		
Investment Lagged	**0.917**	**1.000**	
	(0.0000)		
	900	*1064*	
Production	**0.545**	**0.468**	**1.000**
	(0.0000)	(0.0000)	
	1106	*999*	*1174*

Note: Correlation coefficients are in bold, significance level is in parentheses, number of observations is in italics.

A similar methodology was applied to consider the lag between investment and production has increased over the years (where the period was divided into two sub-periods: (1993-2000, and 2001-2007), and the optimal lag of production on investment by company was considered using fixed effects. Appendix Table 3 shows the results for the full sample.

The results for the sub-periods are reported in Table 5. For the type of project, the same exercise was conducted using 2003-2007 average investment and production using the Goldman Sachs (2006) survey data, where a dummy for the type of project was included (whether deepwater, oil sands, Siberian prospects or conventional). This was complemented with some investment information from OPEC (www.OPEC.org).

Appendix Table 2. Regressions of Production (in Million of Barrels) on Investment (Million Dollars), 102 Oil Companies, 1993-2007, Fixed Effects.

	One Regressor		Two Regressors
Investment	0.020***	-	0.015***
	0.003		*0.006*
Investment lagged	-	*0.038****	*0.013**
		0.007	*0.008*

Notes: ***, **, * denote significance at 1, 5 and 10-percent level, respectively. Standard errors are in italics.