OWNERSHIP, PRIVATIZATION AND INVESTMENT FADS: THEORY AND EVIDENCE FROM RUSSIA AND THE CASPIAN REGION

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This dissertation contains three essays that combine applied models, institutional analysis and empirical work in order to understand developments in the Russian and Caspian energy sector following the breakup of the former Soviet Union. In the first essay entitled "Partial Privatization: Evidence from the Russian Oil Sector" (joint with Daniel Berkowitz), we document that Russia's oil sector privatization has been partial because the federal government has maintained ownership rights in several vertically integrated companies and has established a near monopoly position in the allocation of scarce export transport capacity. We develop the proposition that in these circumstances the federal government would tend to give companies in which it has ownership positions preferential access to world export markets. We develop a classification system of company ownership that distinguishes between state-influence and state-independent companies. Using censored-regression techniques, we find compelling evidence that the state-influence companies had privileged access to export transport by 2003, and argue that this suggests that there are substantial efficiency losses in the Russian oil sector.

The second essay, "Caspian Oil Boom: Informational Herding among the Oil Companies", analyzes the potential causes of the Caspian oil rush of 1997-1998. It provides an institutional description of foreign investment in the Caspian region in 1997-1998, and looks at different possible explanations for the investment boom. We argue that informational herding among oil companies could have contributed to the high investment activity in the region in the late 1990s, and qualitatively check for the power of the herding against the alternative explanations.

In the third essay, "Quality of Information, Information Externalities and Sequential Decisions of Oil Companies," we develop a theoretical model that works out the logic and mechanics of the informational herding explanation for the Caspian oil boom. We show that under certain conditions a second company to enter will invest in the development of a new oil field even if it received a bad informative signal about the profitability of the project. We also show that when companies receive noisy public and private information, the second company may be more likely to invest after receiving a bad signal.

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1.0 INTRODUCTION

This dissertation contains three essays that combine applied models, institutional analysis and empirical work in order to understand developments in the Russian and Caspian energy sector following the breakup of the former Soviet Union.

After the collapse of the former Soviet Union, the Russian Federation and the newly independent states of the Caspian region (namely, Azerbaijan, Kazakhstan and Turkmenistan) found themselves in control of vast oil and gas reserves. Russia inherited not only worked out Western Siberian oil fields, but also untapped Sakhalin oil deposits as well as the ownership of the world's biggest gas reserves. The Caspian states, on the other hand, got access to poorly explored oil and gas deposits which had been considered an important strategic reserve in the former USSR. Both Russia and the Caspian states believed that their oil and gas sectors would become an important, if not the main, force behind their economic development and transition to a market economy.

The strategies of how to use the oil and gas potential to promote economic development differed in each state. Since the newly-independent states were formed in an institutional and legal vacuum in the early 1990s, the development of their oil and gas industries depended on how these states tried to fill in this vacuum. Russia privatized oil production very quickly, but kept control over the oil transportation system which allowed the Russian state to "squeeze" oil producers for the sake of the budget. The Caspian states, on the other hand, adopted more investor-friendly policies and managed to attract a great deal of international investment in a short period of time. However, despite an early vast interest in the Caspian oil deposits, investment in the Caspian oil industry turned out to be unprofitable in most of the cases.

The Russian Federation and the Caspian states gained more influential positions in the world market because of the recent fast growth of oil prices. Recent conflicts over gas exports between the Ukraine and Russia in January 2006, as well as construction of a Baku-Tbilisi-Ceyhan pipeline that will allow landlocked Caspian oil to bypass Russia, showed that Russia and the Caspian states have become major players on the world energy market. Russia's decision to stop gas shipments to the Ukraine affected not only exports to the CIS countries, but also exports to Western Europe. Opening a pipeline bypassing Russia will make Turkey a primary market for Caspian energy, as well as decreasing the economic dependency of the Caspian states on the Russian pipeline system.

However, to better understand how Russian and Caspian oil and gas will affect the world energy market, it is important to study the strengths and limitations of the oil and gas sectors of the former Soviet states. In the first essay entitled "Partial Privatization: Evidence from the Russian Oil Sector" (joint with Daniel Berkowitz), we document that Russia's oil sector privatization has been partial because the federal government has maintained substantial ownership rights in many vertically integrated companies, and the federal government has established a near monopoly position in the allocation of scarce export transport capacity. We develop the proposition that in these circumstances the federal government would tend to give companies in which it has ownership positions preferential access to world export markets, and it would use quotas to force private companies to sell on the domestic and CIS markets.

To test this proposition, we compile a large data set that includes company-level and subsidiary-level data on annual crude production, exports by route, regional cost conditions, number of wells, productivity of wells and distance from each subsidiary to the point of export, and route costs. We develop a classification of company ownership that distinguishes between state-influence and state-independent companies. Using censored-regression techniques, we find compelling evidence that the state-influence companies had privileged access to export routes by 2003, and argue that this suggests that there are substantial efficiency losses in the Russian oil sector.

The second and third essays, “Caspian Oil Boom: Informational Herding among the Oil Companies” and “Quality of Information, Information Externalities and Sequential Decisions of Oil Companies”, analyze the potential causes of the Caspian oil rush of 1997-1998. The “Caspian Oil Boom” documents that foreign investment in the Caspian region was excessive because expected returns were low relative to expected costs. The paper then provides an institutional description of foreign investment in the Caspian region in 1997-1998, and looks at different possible explanations for the investment boom. We argue that informational herding among oil companies could have contributed to the high investment activity in the region in the late 1990s, and qualitatively check for the power of the herding against the alternative explanations.

In the third essay entitled “Quality of Information, Information Externalities and Sequential Decisions of Oil Companies,” we develop a theoretical model that works out the logic and mechanics of the herding explanation for the Caspian oil boom. Herding models are driven by social learning dynamics, and they typically deliver the prediction that when the actions of decision-makers may reveal some of their private information, eventually everyone mimics the predecessor's choice. Following this framework, we show that under certain conditions a second company to enter will invest in the development of a new oil field even if it received a bad informative signal about the profitability of the project. We also show that when companies receive noisy public and private information, the second company may be more likely to invest after receiving a bad signal.

This model emphasizes that information spillovers are essential in the exploration of new and poorly explored fields. The results of the paper suggest that it is important to have a mechanism that will allow oil companies to share their private information before making investment decisions. This will reduce the noisiness of available information and improve the quality of decisions.

2.0 ESSAY ONE
PRIVATIZATION WITH GOVERNMENT CONTROL: EVIDENCE FROM THE RUSSIAN OIL SECTOR
(with Daniel Berkowitz)

2.1 INTRODUCTION

Governments around the world have been privatizing large state owned enterprises in sectors that are of national strategic importance including oil, gas and electricity. Many of these privatizations have effectively been "partial" because national governments either manage to keep a major stake in the privatized companies or often retain control of a strategic distribution method even for fully privatized companies (Megginson, 2005). For example, the state share is remarkably large in some local gas and oil giants including Petrobras in Brazil (32%), Eni in Italy (36.9%) and Sinopec in China (77.4%). In India, the generation of electricity has been privatized, but the transmission of electricity is monopolized by government electricity boards. It has been alleged that that Indian national government uses its control over transmission to force privatized generating companies to supply electricity to poor rural areas at below-market prices and at high cost because there is poor transmission equipment and theft from the transmission lines in these rural areas (Smith, 1993).

There has been a considerable body of work on how the state uses or abuses its powers in privatization programs where it manages to obtain substantial ownership positions in privatized companies (see Megginson, 2005 for a summary). However, there are no, to our knowledge, quantitative studies of how governments behave in a partial privatization in which they retain control over strategic distribution assets. This is surprising since there are many examples of this including the privatization of electricity in India and the small privatization program in Russia where local governments often retained *de facto* control rights by retaining *de jure* ownership of the land on which newly privatized shops operated (see Barberis et al, 1996).[1]

In this esay we argue that the privatization of the Russian oil sector during 1994-2003 is a useful case study of how governments use their control rights over strategic distribution assets during a privatization. Following the demise of the Soviet Union in the 1990s, the emerging Russian federal government gained jurisdiction over the major oil fields in Russia; and, it also retained control over the transport of oil exports from both Russia and many of the newly independent countries. Starting in 1994 many former state oil companies were privatized. This privatization has been partial because the federal government has obtained ownership positions in several companies and has also retained full control over the transport of oil onto lucrative world markets. In this paper, then, we seek to understand if the state effectively uses its control over the export pipeline to discriminate between fully privatized companies and those companies in which it has substantial ownership positions. And, we check whether government control over the oil export pipeline promotes or detracts from efficiency.

The theoretical analysis in Grossman and Hart (1986) and then in Boycko, Shleifer and Vishny (1996) suggests that the federal government would tend to impose tight quotas and

[1] However, for a study of how governments relinquish control over time after privatizing and its consequences for performanace, see Boubakir et al (2005).

extract rents from companies over which it has limited influence (for herein state-independent firms) versus those over which it has influence (for herein denoted state-influence firms). The idea is that the federal government can hold up any company using its control over a key distribution asset, which in the case of the Russian crude oil sector is the transport pipeline. Companies are differentiated by their ownership rights over residual cash flows. There are fully private companies (e.g., Yukos) in which outsiders have full cash flow rights. There are other companies (e.g., LUKoil or Tatneft) where the federal government or some regional government have substantial or even close to full cash flow rights. When the federal government imposes quotas on enterprises over which it has some cash flow rights, it must also bear the financial costs of this diversion of oil from lucrative world markets. This implies that the federal government is more likely to impose costly regulation on companies owned largely by outside investors and regional governments.

In this essay we check for the differential treatment of state-independent versus state-influence firms. We find that by 2003, in fact, state-influence firms have privileged access to state controlled export markets and that this privilege detracted from efficiency. In particular, state-independent companies had to be much more productive than state-influence companies to receive comparable access to world markets; state-influence companies had preferential access to routes with more capacity; and, the allocation of route capacity was sensitive to transport costs only in the state-influence sector.

The rest of this essay is organized as follows. The next Section describes the evolution of ownership and structure in the Russian oil sector; Section 2.3 describes how the federal government controls transport of oil to world markets; Section 2.4 sketches a simple theory of partial privatization that generates the hypothesis that export allocations are tighter in state-independent versus state-influence companies; Section 2.5 describes our data for testing this hypothesis; Section 2.6 presents our results about the differential treatment of state-independent versus state-influence companies; and Section 2.7 concludes.

2.2 OWNERSHIP AND STRUCTURE

This section describes ownership trends and structural dynamics in Russia's crude oil sector. We develop a typology of company ownership based on state shares and federal government representation on company boards. We argue that Russian oil companies can be classified as either private, private with regional government influence, private with federal government influence or state companies and that it is appropriate to refer to the latter two forms of companies as state-influence companies. We also show that the expansion of state-independent companies was more likely to be based on efficiency considerations than the expansion of state-influence companies.

2.2.1 Ownership

Privatization of the oil sector was regulated by Presidential Ordinance #1403 approved on November 17, 1992 (President of Russian Federation, 1992). Vertically-integrated companies (for herein, we will often use the Russian expression and call them "mothers") were created by joining some oil-producing enterprises and refineries into open-stock companies[2]. The shares of the newly-created mothers were distributed through several complex and frequently nontransparent auctions. The insiders who were allowed to participate in the bidding gained

[2] An open-stock company publicly trades its shares; a closed-stock company distributes its shares through closed subscription based on the decisions of the company's founders.

control over mothers with huge potential value in exchange for relatively small cash amounts (Megginson, 2005). Some of the smaller oil-producing enterprises were also transformed into open-stock companies and then later either became absorbed by a mother and/or had their stock allocations sold in an auction, or became joint ventures.

The privatization of the oil sector mothers during 1997-2003 was partial because the federal government managed to maintain some substantial ownership positions. As is documented in Table 1, during 1997-2003 there were three types of vertically-integrated oil companies: those fully owned by outside investors, companies where the federal government had majority or substantial minority shareholder positions (denoted **F** in Table 2.8.1) and companies where regional governments had substantial ownership (denoted as **R** in Table 2.8.1). In 1997 only four of the thirteen mothers were fully owned by outside investors, seven companies were either fully or partially owned by the federal government and two were owned by regional governments (the Repubic of Tatarstan owned 30-% of Tatneft and the Republic of Bashkotorstan owned 63-% of Bashneft).

By 1999 the federal government had managed to preserve its significant ownership positions in the crude oil production sector; and, the federal government had also placed its representatives on the Boards of Directors (herein Boards) of the companies where it had ownership. In most of the cases, the federal government representatives were from the agencies that oversaw the oil sector. For example, LUKoil's Board of 1999 included the Deputy Minister of Fuel and Energy, which at the time was responsible for allocating pipeline capacity for exports (see section 3). Another member of the Board was the top manager of the State Antimonopoly Committee, which had the responsibility of ensuring that large companies such as the oil mothers engaged in competitive business practice. Hence, federal representation on boards allowed the state not only to directly influence the mothers' decisions, but also established connections between mothers and the federal agencies with substantial influence over the crude oil sector.

The regional governments also had influence on decisions of the mothers in which they had substantial ownership positions. However, we found no evidence that the local governments had any connections to the federal agencies that supervised the oil sector. Moreover, the regional governments in Bashkortostan and Tatarstan were highly independent and often pursued policies that conflicted with federal rules (see Treisman, 1999). Thus, regional ownership and representation on the boards is not related to federal government influence.

The above analysis suggests that we can refer to state-owned mothers and mothers where federal government had significant interest as *state-influence companies*. On the other hand, regionally controlled and entirely private companies are appropriately denoted *state-independent companies*. In other words, "state" in "state-influence" and "state-independent" companies refers to the federal government.

By 2003, federal government ownership in the oil sector had decreased. The federal government owned one vertically integrated company, Rosneft (responsible for 5% of total Russian production) and had a significant share of 7.6% in the biggest Russian oil producer LUKoil. It also had seats on the boards of these companies: ten representatives out of eleven in Rosneft and one representative out of eleven total in LUKoil. Thus, by 2003 the federal government still retained substantial influence over several major oil mothers.

2.2.2 Structure

The oil sector has become more concentrated over time and there have been differences in expansion dynamics for the different mothers. By the late 1990s, the mothers started aggressively acquiring new subsidiaries, merging with other oil companies and/or buying out the stocks of other shareholders in the smaller oil producing stock companies. Some mothers expanded to new oil producing regions and some mothers exited.

As a result of these expansions, Russian crude production and exports became more concentrated over time. By 2002, three firms (LUKoil, Yukos and Surgutneftegaz) were responsible for over 50% of total production and total exports: the 3-firm concentration ratio, R_3, in production grew from 0.4 in 1997 to 0.51 in 2002; R_3 in exports increased from 0.33 to 0.51 between 1997 and 2002, respectively[3] (see Table 2.8.2).

LUKoil, a state-influence company during 1997-2003, and Yukos, a state-independent company during 1997-2003, had the most aggressive expansion programs. Between 1997 and 2003 LUKoil acquired 33 new subsidiaries and Yukos obtained five new subsidiaries, including one mother (VNK). However, as Table 3 documents, the expansion programs were very different. LUKoil mostly expanded its influence to two new regions, Urals, an old oil region with relatively low productivity fields, and the North (Komi), a relatively new and poorly developed oil region. As a result, in 2003 productivity of the newly acquired subsidiaries varied from 1.63 thousand tons per average well in the Urals to 8.5 per average well in Komi. Yukos, on the other

[3] Concentration of Russian oil production sector is very high compared to other states where oil production is privatized. For example, in the United States, the third biggest oil producer in the world after Saudi Arabia and Russia, the 2-firm concentration ratio of oil production sector is 0.25; the three biggest US oil operators control only 0.33 per cent of total oil production (EIA, 2005).

hand, improved its existing position within Western Siberia, which is the most productive Russian oil region. As a result, between 1997 and 2003 Yukos's average productivity in the region increased from 2.68 to 10.78 thousand tons per well. Table 2.8.4 documents that whether we use return on assets or return on non-current (primarily property, plant and equipment), between 1999-2003 Yukos was more profitable than LUKoil. Thus, the evidence in Tables 2.8.3 and 2.8.4 suggests that between 1997-2003 the expansion policy of the state-independent Yukos was driven more by profit criteria than the expansion policy in the state-influence company LUKoil.

The expansion policies of the state-independent Sidanko and the state-influence company Rosneft are similar (we cannot make comparisons with other companies because either they change ownership between 1997-2003, and/or they do not expand). As Table 2.8.3 documents, Sidanko improved its productivity in Western Siberia from 2 to 7.4 thousand tons per well and its output in the less productive Volga region grew from 3.4 to 4.74 thousand tons per well. Fully state-owned Rosneft, on the other hand, started developing the new North region, where it achieved productivity of 28.47 thousand tons per well, while maintaining less productive subsidiaries in the worked-out North Caucasus region that produced on average 1.31 thousand tons of oil per well.

In summary, this section has made several points about ownership and structure in the Russian oil sector. First, the privatization was partial and vertically-integrated companies in the crude oil sector can be divided into state-influence companies and state-independent companies. Second, after privatization, the oil sector was highly concentrated and its concentration increased over time. Third, companies that remained state-independent used economic criterion in their expansions in 1997-2003.

2.3 CONTROL

In this section we argue that the federal government has the power to control exports because of its almost complete monopoly position as transporter of crude oil onto domestic-CIS and world markets. Because selling crude at world market is preferred to selling it domestically (due to substantial price spreads during 1997 and 2003 and non-payment problems in domestic and CIS markets), we argue that this ability to control exports gives the federal government considerable leverage over all companies.

The profits of Russian oil mothers depend very much on their crude exports. As it is documented in Table 2.8.5, in 1997-2003 mothers exported on average about 20-35% of the total crude they produced; the state-owned Rosneft consistently exported the largest share of its production compared to other mothers. One reason for the reliance on exports was the significant spread between the domestic and world prices for crude oil. According to ***The Wall Street Journal*** in February of 2003, local oil selling prices were as low as $5 per barrel, compared to $31 per barrel on the world market (Anna Raff for ***The Wall Street Journal***, 2003.) Another reason for the reliance was that international buyers were more likely than customers in Russia and the CIS to pay in a timely fashion.

Over 95% of total crude exports from Russia are transported through a system of trunk pipelines. The system is state-owned and operated by a 100% federally-owned company, Transneft[4]. Hence, the federal government has almost complete monopoly control over Russian oil exports. This extent of federal power is unusual. In most countries where oil production is private, oil transportation is also privately provided. For example, in the United States the system

[4] As of April, 2005, 100% of common stocks of the company belong to the Federal Agency of Federal Property Management (Transneft, 2005).

of trunk pipelines is owned and operated by over 3, 000 companies, some of which are oil producers, others have no relation to oil production (Office of Pipeline Safety Communications, 2005). This is also true for Norway where all the segments of its complex oil transportation system are operated by oil producers working in the country (Norwegian Petroleum Directorate, 2005).

According to independent experts, the Transneft pipeline system had in 2001 the capacity to ship roughly 153-154 million tons per year (Oil and Capital, 2001). Since 2002, Transneft trunk pipelines have been operating at full capacity (Oil and Capital, 2004). As a result of system overload, available throughput capacity has to be rationed between the companies. The federal government thus has tremendous control over the crude oil sector because of its ability to allocate highly valuable capacity to export.

The export quotas allocation rules were introduced in 1994 and stayed practically unchanged through 2003 (Government of Russian Federation, 1994). According to the official laws on the books, export pipeline capacity is allocated between the oil companies according to a grandfathering rule: each company's quota is determined by its production in the past quarter. In particular, the allocation quotas depend on three factors: the capacity of the Transneft system, the production of an exporter in the previous quarter and, since 1997, her tax arrears (Government of Russian Federation, 1997). This formal allocation rule does not depend on the willingness of oil producers to pay for capacity and so does not promote efficiency. The rules also appear to be quite vague as to the exact relationships between past production, route capacity and current export access.

Contrary to the unchanged allocation rules, the agencies enforcing them changed over time. Before 2000, the Ministry of Fuel and Energy and the Interdepartmental Commission (controlled by the Ministry of Fuel and Energy) were responsible for export transport allocations (Government of Russian Federation, 1995). The oil export allocation schedule was prepared quarterly by the Ministry of Fuel and Energy. It received information on the capacity of the transportation system and quotas requests of mothers from Transneft, and then sent the preliminary schedule to the Interdepartmental Commission for confirmation. The final schedule was then sent to Transneft and the mothers.

The Ministry of Fuel and Energy was controlled mostly by former Soviet officials. Berkowitz (2000) documents that in 1995-1996 access to the oil pipeline was highly political. In particular, he noted that bribes and political favors played an important role in determining the size of the final quota. Furthermore, he also found that it is difficult to separate the impact of rules from the impact of the political influence that a company enjoys from being large on export allocations.

In the spring of 2000, the Ministry of Fuel and Energy was restructured and became the Ministry of Energy, and the Interdepartmental Commission was dismissed (Government of Russian Federation, 2000). As a result of this restructuring, the Ministry of Energy lost a lot of its responsibilities to other state institutions. In particular, the main responsibility of quotas allocation was shifted to the specially created Commission of Russian Government (Government of Russian Federation, 2000) which now was controlled by one of the major players on Putin's team, the Vice Prime Minister.

Allocating export quotas between the companies is not the only way the state can control the oil producers. It is important to mention that Russian crude can be exported through several routes that are differentiated by cost. Thus, not only volume of the quota matters to a producer, but also WHERE this volume is allocated to be shipped. Specifically, Russian crude is exported through ports and the pipeline sub-system called Druzhba that delivers oil directly to European refineries (see Figure 2.8.1). Over half of the total Russian crude exports go through sea ports since exports through the Druzhba subsystem are constrained by the capacity of the European refineries to which it is connected. In 1997 four ports were exporting Russian crude: Russian Novorossyisk and Tuapse, Ukrainian Odessa and Latvian Ventspils. By 2003 three more export ports appeared: Lithuanian Baltic export terminal Butinge[5] in 1999, Russian Baltic port Primorsk in 2001 and Ukrainian oil terminal "Yuzhnyi" in 2003.

The export costs of different routes can be roughly estimated by using the costs of delivering oil to a refinery or a port and the costs of oil transshipment in the port. The costs of shipping oil are determined by the operators of the pipelines. Oil transshipment costs are separately determined in each port. They include costs of transferring oil from a pipeline to a terminal and then to a tanker. The export and transshipment costs at different export routers are presented in Table 2.8.6. The table shows that Transneft (the operator of the Russian pipeline system) offers the best transit tariffs and that working with non-Russian countries adds substantial costs. Hence, the Druzhba route to Europe is the cheapest since the producers only have to pay transit costs and avoid transshipment costs. However, because of the capacity constraints of the European refineries, this route may not be the most profitable since it allows exporting limited volumes of crude. Among the sea exporting terminals, Russian ports charge relatively small transshipment costs. This makes Russian ports the most desirable among sea export routes.

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[5] Yukos bought control of Butinge in mid-2002 from the American company Williams (Oil and Capital News, 2002a; Oil and Capital News, 2002b).

In summary, the Russian oil transport system can be characterized by the following features. First, exporting onto world markets is more lucrative than shipping onto the domestic or CIS market. Second, the Russian federal government has substantial leverage in the oil industry because it has a nearly monopoly position in allocating scarce transport capacity for world market exports. Third, the Russian federal government's procedure for allocating export capacity is unrelated to efficiency criterion and is rather non-transparent. Fourth, the allocation rules did not change much in 1997-2003. Finally, besides controlling export quotas, the federal government also controls the allocation of company world market exports through particular export routes that are differentiated by their costs. Druzhba and Russian ports are the cheapest export routes for Russian crude, and shipping through non-Russian countries to obtain access to world markets adds substantial costs.

2.4 THEORY

This section develops a simple theory of just how differences in ownership can influence the state allocation of export quotas to companies. In our model, there is a state regulatory body that allocates export capacity, Q, in the form of access to a pipeline route to a company. In turn, the company chooses the share of its oil output that it exports on world markets and the share that goes to the domestic/CIS market. The world price exceeds the domestic/CIS price: $P_w > P_d$. This captures two features of the Russian oil market that we have already noted: first, world prices are usually higher and, second, many domestic and CIS refineries delay or simply withhold payments while this is not an issue on world markets. Formally, a company solves the following program:

$$Choose\ L \geq 0,\ and\ \alpha \in [0,1]: Max\ \beta\{(\alpha P_w + (1-\alpha)P_d)f(L) - L\} \qquad (1)$$

$$s.t.\ \alpha f(L) \leq Q\ ,\ where$$

L denotes a variable input such as labor, *f(L)* is a non-decreasing, continuous and concave production function that converts *L* into oil output, *α* is the share of output that is exported on world markets, (*1-α*) is the share shipped to the domestic-CIS market and *Q* denotes the export quota. The parameter *β* captures ownership; when *β* is close to unity the company has close to full rights to it residual profits after choosing *L*, and is categorized as state-independent. As *β* falls and approaches zero the company has most of its cash flows appropriated by the federal government and is classified as a state-influence company.

In this setup, when the export quota is non-binding, the company chooses $\alpha = 1$ and exports all of its output to world markets. It also chooses *L* so that its marginal value product *on world markets* equals its marginal cost:

$$P_w f'(L^*) = 1\ and\ \alpha^* = 1,\ when\ f(L^*) < Q \qquad (2)$$

If the quota is binding, then $Q = \alpha^* f(L)$ and the company sells ($f(L) - Q$) on domestic/CIS market. In this case, the shadow price of the quota is $\beta(P_w - P_d)$, which is the company's revenue simply lost by shifting a unit of output sales from the world to domestic-CIS market. The company now chooses *L* so that its marginal value product *on domestic markets* equals its marginal cost:

$$P_d\, f'(L^*) = 1,\ where\ \alpha^* < 1,\ and\ f(L^*) = (Q/\alpha^*) \qquad (3)$$

Equation (3) generates several predictions about the behavior of a quota constrained company. First, since cash flow rights apply to revenues net of variable costs, an increase in ownership rights has no impact on output or allocations of output to the world and domestic/CIS markets:

$$\partial \alpha^* / \partial \beta = \partial L^* / \partial \beta = 0$$

Furthermore, a relaxation of the quota induces a company to shift its sales from the domestic-CIS market to world markets without changing overall output:

$$\partial \alpha^* / \partial Q > 0, \ \partial L^* / \partial Q = 0$$

We use this setup to make predictions about how the federal government regulatory agency chooses its optimal quota. Our basic premise is that the federal agency is driven by political criteria, and wins loyalty, favors and transfers in-kind when it has companies deliver cheap oil to its clients on the domestic-CIS market. To capture this idea, we denote the political benefits of quotas as $Z(f(L) - Q)$, where $Z' > 0$, $Z'' < 0$. The cost borne by the federal government is the loss in revenues by diverting from the world market: $(1 - \beta)(P_w - P_d)(f(L) - Q)$. Thus, the private ownership parameter, β, influences the federal government's costs of using a quota to force a company to ship on the domestic-CIS market. The federal government can pass a higher share of its costs of foregoing world market prices to a state-independent company that has a β close to unity. However, in a state-influence company where β is much lower, the federal government picks up more of the cost.

When the quota is binding, the state chooses an optimal quota so that its marginal benefit equals its marginal cost:

$$-Z' + (1 - \beta)(P_w - P_d) = 0 \qquad (4)$$

Implicitly differentiating (4), then

$$\partial Q / \partial \beta = (P_w - P_d) / Z'' < 0 \qquad (5)$$

Thus, a binding quota becomes tighter as private ownership increases. The logic of this result is that an increase in β depresses the marginal cost of diverting oil from the export to the domestic/CIS market. This result implies that the federal regulatory agencies would use their control over the oil export pipeline to discriminate against state-independent companies. We will take this prediction to the data in what follows.

2.5 DATA

The data were acquired from ***Oil Trade***, a statistical annex to ***Oil and Capital***, a leading magazine for the Russian oil industry. Our dataset includes subsidiary level export volumes through different routes, measures of company size, regional production costs, transportation costs and the capacity of each pipeline route. In the dataset we report the exports of 32 subsidiaries in 1997 and 54 oil subsidiaries in 2003 through each possible route (there are eight export routes, but because some routes are very close to each other, we categorize shipments into seven possible routes).

2.5.1 Export Volumes

Export volumes are reported in thousands of tons, and there is a negligible difference in the quality of oil exported by the subsidiaries. This is because after a company pumps oil into the transport pipeline, that oil is blended with all of the oil currently in the pipeline, so that at the final export destination oil generally priced on world markets as the Urals blend.[6] In the dataset we included exports of only those subsidiaries of mothers that reported production in 1997 and

[6] The exceptions to this are exports from the Rosneft subsidiary in the Sakhalin area, which typically prices closer to Asian blends, and exports from companies using the Caspian Pipeline Consortium. However, these companies are excluded from our sample. We thank Michael Cohen from the Office of Energy Markets and End Use, the Department of Energy, for help with this issue.

2003, and reported production was higher than reported exports. The reason to exclude exporting subsidiaries with no reported production or reported exports higher than production is the possibility that they exported re-distributed oil. Russian mother companies can re-distribute their output intended for export between the subsidiaries, i.e., a certain subsidiary may receive additional oil, produced by another subsidiary, for export. This re-distribution does not change the receiving subsidiary's production costs, but affects its transportation costs. Since it is impossible to tell how much extra oil the subsidiary received, the actual costs of the exporting subsidiary are impossible to calculate. There was one exporting subsidiary that did not report production in 1997 and four in 2003. One in 1997 reported significantly higher exports than production; and, in 2003 all of the subsidiaries' exports were lower than reported production.

2.5.2 Company Size

We use subsidiaries' number of total wells and number of operating wells as measures of its size. We find that both measures are highly correlated with total production: 0.79 for the number of total wells and 0.75 for the number of operating wells. Company size can pick up the importance of size for export access, which would include ability to produce and political influence.

2.5.3 Company Productivity

We measure productivity as output per well and output per productive well. We would expect this variable to be positively associated with export access when access to world markets is based upon efficiency.

2.5.4 Regional Production Costs

We use regional producers' price (rubles per ton) as a measure of regional production costs. The oil-producing subsidiaries included in the dataset are located in six different oil regions of Russia. Regional prices capture the region-specific production costs that vary between different regions due to different climate zones (e.g., Western Siberia vs. Volga) and had different levels of oil production development (e.g., old and high cost wells in the North Caucasus region vs. new, poorly developed production infrastructure in the North in the Komi Republic). We understand that this measure does not capture all company-specific production costs, but it is the best measure available since the mothers do not report their production costs. If access to world markets is based upon economic criteria, then we would expect that this variable would be negatively associated with exports on world markets.

2.5.5 Exports Routes

In 1997, Russian crude exports went through five routes (Druzhba pipeline sub-system; ports of Novorossiysk, Tuapse, Ventspils and Odessa); in 2003, the number of export routes for Russain oil was seven (Druzhba and ports of Tuapse, Novorossiysk, Primorsk, Odessa, Yuzhnyi and Butinge) (see Figure 2.8.1). We do not include the Yuzhnyi export route for 2003 since its exports account for less than 0.1% of total exports. Also, since Tuapse and Novorossyisk are located very close to each other, we unite these routes and report them as joint Tuapse-Novorossyik export route. For this route, we use total exports that went through both ports and total joint capacity of the two ports. The distance of this route is calculated as average of the distances from a subsidiary to each port.

Thus, in the dataset we look at the total of four export routes in 1997 (Druzhba, Tuapse-Novorossyisk, Ventspils and Odessa) and five export routes in 2003 (Druzhba, Primorsk, Tuapse-Novorossyisk, Odessa and Butinge). Below we describe how we use data on distance to world market on each route and tariffs to compute transportation costs. However, we also control for routes to pick up additional factors that would determine the impact of routes on export access.

2.5.6 Transportation Costs

We have transportation costs for 2003 only. We measure transportation costs as dollars per ton per kilometer, i.e., tariff times the distance from the subsidiary's location to the point of exit onto world markets. The tariffs per ton/km of different routes as of 2003 are given in Table 2.8.6. We use distance in km from a subsidiary to ports or points of exit as a measure of distance from a subsidiary to a particular export point. Distance in km was defined by the shortest route from a subsidiary allocation to a port or Russian border (in case of Druzhba) along Transneft trunk pipelines. The location of a subsidiary was approximated either by location of its most productive fields or by location of its office. The information on the most productive fields was taken from mother companies' websites; the office addresses were obtained from the website of the Russian System of Full Information Disclosure and News "Skrin" (http://www.skrin.ru).

The data on the pipeline routes location was taken from Transneft's website (www.transneft.ru). To calculate distance between cities where the pipeline nodes are located, we used the AutoTransInfo website (http://www.ati.su/) that provides information on distances between Russian cities and towns along highways. We assume that the oil from a subsidiary enters the pipeline at the node-city that is closest to the location of the subsidiary. If the allocation of export capacity is related to efficiency considerations, then we would expect to observe a negative association for subsidiaries between export volumes on a particular route and transportation costs.

As a robustness check, we also use an alternative distance measure. Following Berkowitz (2000), alternative distance is measured in total numbers of Transneft regional sub-systems the subsidiary has to pump its oil through to get to the port or Russia border. The two measures are highly correlated (0.84).

2.5.7 Route Capacity

Route capacity is reported for 2003 only. Capacity of each export route is reported in million tons per year in Table 2.8.6. For the Tuapse-Novorossyisk route we use the sum of the capacities of the two ports. Since the export system is capacity constrained, we would expect to observe a positive association between route capacity and export volumes.

2.5.8 Additional controls

As additional control variables, we use route and mothers dummy variables. As previously noted, route dummy variables pick additional factors related to access besides transport costs and capacity, which could include long term relationships between a subsidiary and a particular regional Transneft company. Mother dummies pick mother-specific factors such as political connections that could be important for access.

2.6 EMPIRICAL RESULTS

We have compiled detailed data on export volumes by route, regional costs, company productivity and size in 1997 and 2003. Additionally, in 2003 we have detailed data summarizing transportation costs and route capacity. Hence, we first test the prediction that the federal regulatory agencies provide preferential access to state-influence companies in 2003 only. Then, we will perform a less detailed analysis of 2003 and 1997 data and compare the results. We will show that in 2003 the state-influence companies indeed received preferential treatment, while in 1997 there was no difference in access provided to state-influence and state-independent companies.

2.6.1 Analysis of 2003

We set the indicator variable S = 0 for the state-independent companies and S = 1 for the state-influence companies and estimate the following model in 2003:

$$\begin{aligned} y_{pm_i} = {} & \alpha + (\alpha_1 + \alpha_2 S) * reg\_costs_{m_i} \\ & + (\alpha_3 + \alpha_4 S) * trans\_costs_{pm_i} + (\alpha_5 + \alpha_6 S) * route\_cap_p \\ & + (\alpha_7 + \alpha_8 S) * prod_{m_i} + (\alpha_9 + \alpha_{10} S) * oil\_wells_{m_i} \\ & + \gamma_{1j} route_p + \gamma_{2j} S * route_p + \gamma_{3j} mother_m + \varepsilon_{pm_i} \end{aligned} \quad (6)$$

Here y_{pm_i} denotes thousands of tons of oil exported to world markets on the p^{th} pipeline route for the i^{th} subsidiary in the m^{th} mother company, $reg\_costs_{m_i}$ denotes regional production costs for the i^{th} subsidiary of the m^{th} mother, $trans\_costs_{pm_i}$ denotes transportation costs (dollars per km per ton) for the i^{th} subsidiary of the m^{th} mother on the p^{th} route, $route\_cap_p$ denotes the oil volume capacity for the p^{th} route, $prod_{m_i}$ denotes productivity (measured as output per well) of the i[th] subsidiary of the m[th] mother, $oil\_wells_{m_i}$ is the number of oil wells (either total or operating) in the i[th] subsidiary of the m[th] mother and is our proxy for company size, $route_p$ is a dummy variable for the p[th] route and $mother_m$ is a dummy variable for the m[th] mother. The odd-numbered regressors, α_1, α_3, α_5, α_7, α_9, γ_{1j} measure the estimated impact of $reg\_costs_{m_i}$, $trans\_costs_{pm_i}$, $route\_cap_p$, $prod_{m_i}$, $oil\_wells_{m_i}$, $route_p$ and $mother_m$ on y_{pm_i}. The even numbered coefficients, α_2, α_4, α_6, α_8, α_{10}, γ_{2j}, measure the estimated differential impact of these variables on *the state-influence net of state-independent sectors* and enable to test the following hypotheses:

Hypothesis 1: The state influence companies are not privileged because they cannot export more than the state-independents if their production costs are higher (the null is $\alpha_2 = 0$).

Hypothesis 2: The state-influence companies do not have privileged access to export routes because of their geographic location (the null is $\alpha_4 = 0$);

Hypothesis 3: The state-influence companies do not receive better access to routes with greater capacity (the null is $\alpha_6 = 0$);

Hypothesis 4: The state-influence companies do not receive privileged treatment because they cannot ship more than the state-independents if they are less productive (the null is $\alpha_8 = 0$).

Our sample includes 270 observations of exports by 54 subsidiaries through the five possible routes. However, there are 145 observations in which a particular subsidiary that is an exporter does not use at least one of the five available routes. Thus, we use the Tobit procedure and censor all the export observations that are zero.

We test our hypothesis using the km distance measure (results with the alternative measure are similar and are available upon request). In Table 2.8.7 the columns entitled State-

Influence Net of State-Independent present the results relevant to our hypothesis tests (i.e., $\alpha_2 = 0$, $\alpha_4 = 0$, $\alpha_6 = 0$ and $\alpha_8 = 0$). In addition, the columns entitled State-Independent and State-Influence presents estimates of the associations between our independent variables and oil exports for the subsidiaries. In each cell we first report point estimates, standard errors (in parentheses) and then quantitative significance: this is the point estimate for a regressor times its sample standard deviation; it measures the impact of a one-standard deviation increase in the independent variable on thousands of tons oil exports.

Checking column (1) in specifications 1 and 2, we fail to reject the hypothesis ($\alpha_2 = 0$) that the state influence companies are not privileged because of regional production costs. However, it is clear from columns (2) and (3) in each specification that only the state-influence subsidiaries pay attention to regional production costs. A possible explanation of this finding is state-independents face tighter capacity constraints and will export as much as the federal government allows, while the state-influence companies can be more sensitive to costs.

We reject the hypothesis ($\alpha_4 = 0$) that the state influence companies do not have preferential access due to their location at 1 % level in both specifications. Once again, the estimates in columns (2) and (3) suggest there is a major difference in treatment of state-independent versus state-influence subsidiaries. For example, the results in specification 2 imply that a one standard deviation increase in transport costs is associated with a 1.6 million ton cut in exports in the state-influence group and a 1.2 million ton increase in the state-independent group. This suggests that the shadow price of the quota is so high for the state-independent companies that when state-influence companies reduce their exports following an increase in transportation costs, the state-independents pick up this slack capacity.

We also reject the hypothesis ($\alpha_6 = 0$) regarding access to the routes with better capacity at 1 % level in both specifications. The point estimates and the quantitative significance parameters are striking in this case. For example, in specification 2, a one-standard deviation increase in route capacity (roughly 20.8 million tons in exports per year) is associated with roughly 1.9 million tons in additional exports in the average state-independent subsidiary; the average state-influence subsidiary will export 8.3 million tons more.

Finally, we reject the hypothesis ($\alpha_8 = 0$) that there is no discrimination by subsidiary-productivity per well at the 1 % level. What is striking is that state-independents export more on world markets only if they are more productive while productivity does not matter for state-influence subsidiaries.

Thus, there is strong evidence that in 2003 state-influence companies and state-independent companies are not treated in the same way in the export allocation system. The state-independent companies are more efficient, but have relatively limited access to export routes. Moreover, since the shadow price of the export quota is high, the state-independent companies are forced to behave inefficiently and export more when the transportation costs increase and extra export capacity frees up. These results also provide evidence that federal government control over the export pipeline is detrimental for efficiency. State-influence subsidiaries, on average, are less productive and yet get more access to pipeline capacity.

2.6.2 Comparison of 1997 and 2003

It is interesting to check if the federal government has changed in how it has exercised control over the pipeline. We have data that enables us to make some rough comparisons between 1997 and 2003. This is interesting since the reformist Yeltsin government was in power in 1997 while the Putin administration was firmly in control in 2003. As previously noted, we do not have the transportation costs and route capacity data for 1997 that we have for 2003. Thus, to compare 1997 and 2003, we re-estimate equation (6) for 2003 without transportation costs and route capacity variables and let route dummy variables pick up all the fixed effects of the routes. Since these independent variables are only slightly correlated with the production costs and uncorrelated with other independent variables (see Table 2.8.8), the point estimates for the impact of productivity in 2003 should not be strongly affected; however, we do expect that the estimates for regional costs will change.

Table 2.8.9 reports estimation results for 1997 and 2003 with number of total wells as a proxy of the companies' size (the results with operating wells are similar and available upon request). As expected, the point estimates for productivity per well in 2003 have not changed significantly compared to Table 2.8.7; regional production costs are changed but are not statistically significant. Consistent with our estimates from Table 2.8.7, state-influence companies have privileged access because state-independent subsidiaries must be more productive to get the same access to world markets. However, in 1997 there is no such discrimination between state-influence and state-independent subsidiaries.

This result suggests some changes in the Russian political situation between 1997 and 2003. In 1997, Boris Yeltsin was in his second Presidential term and the privatization of the crude sector was only three years old. There were rumors that on the eve of the highly contested Presidential election between Yeltsin and the communist party, several oligarchs offered Yeltsin their financial support. Several of these oligarchs (for example, Yukos's Khodorkhovsky and LUKoil's Vagit Alekperov) owned substantial interests in state-influence and state independent companies. After Yeltsin's win in the summer of 1996, there were rumors that the oligarchs who supported Yeltsin received preferential treatment including access to under-priced blocks of state property.

By 2003 the position of oligarchs in Russia had changed dramatically. The new President Putin was following up on his election promise to eliminate corruption. Many of the oligarchs who were influential in 1997 were in exile or arrested (for example, Khodorkhovsky). Putin had also replaced most of Yeltsin's officials. In particular, in 2000 the authority to allocate export quotas was moved from the Ministry of Fuel and Energy to a new Committee headed by Victor Khristenko, Vice Prime Minister at the time. Our results are consistent with the interpretation that by 2003 the Putin administration toughened its treatment of oligarchs that operated state-independent companies while providing concessions to oligarchs associated with state-influence companies.

2.7 CONCLUSION

Subsequent to the financial crisis of 1998, GDP in Russia has grown at an impressive average annual rate of more than 6% (CIA World Fact Book, 2005). One of the major concerns with this growth record, however, is that it is driven primarily by high oil prices rather than deep structural reform (see Berglöf et al, 2003). In this essay we have documented that the Russian oil sector, which is one of Russia's most profitable sectors, is in need of substantial restructuring. Our results show that the partial privatization imposes major inefficiencies for several reasons. First, state-influence companies appear to adopt acquisitions policies that are driven by non-economic criterion. Second, the allocation of pipeline capacity is sensitive to transportation costs for state-influence enterprises, but it ignores these costs for state-independents. Third, state-influence companies benefit more from increased capacity of the export routes. Finally, productivity is not important for access to the export pipeline for the state-influence companies.

Furthermore, the Russian federal government continues to influence the oil sector in ways that are of concern. In October 2003, the Russian federal government arrested Mikhail Khodorkovsky, the chairman of the management committee of Yukos; this was the beginning of a process by which this state-independent mother company was radically downsized. Most notably, in 2005 Yukos's biggest productive subsidiary was sold at roughly 60-percent of its market value to the state-owned mother company Rosneft. In October 2005 the state-owned natural gas monopoly Gazprom bought the state-independent mother Sibneft. Our analysis of oil transport during 1997-2003 provides evidence that partial privatization in fact has allowed the federal state to impose major distortions on the operation of a lucrative sector. We plan to analyze developments between 2003 and 2005 in future research.

2.8 TABLES AND FIGURES

Table 2.8.1 Evolution of Corporate Governance: 1997, 1999 and 2003

Mothers	1997	1999		2003	
	Share of the State	Share of the State	Representatives of Russian Government on BOD	Share of the State	Representatives of Russian Government on BOD
LUKoil	26.6[0] (F)	26.2[1] (F)	3 out of 11 (F)	7.60[2] (F)	1 out of 11 (F)
Yukos	0[3]	0[3]	0	0[4]	0
Sibneft	0[5]	0[5]	0	0[6]	0
Surgutneftergaz	0[7]	0[7]	0	0[8]	0
Sidanko	0[9]	0[9]	n/a	0[10]	0
Tatneft	30.34[11] (R)	30.9[11a] (R)	5 out of 15 (R)	0[12]	5 out of 15 (R)
Onako	85 [13] (F)	85 [13] (F)	n/a	Does not exist	Does not exist
VNK	36[14] (F)	Does not exist	Does not exist	Does not exist	Does not exist
TNK	49.87[15] (F)	49.87[15a] (F)	n/a	0[16]	0
Bashneft	63[17] (R)	63[17] (R)	4 out of 14 (R)	1.34[18] (R)	3 out of 9 (R)
Rosneft	96.25[19] (F)	96.25[19] (F)	n/a	96.25[20] (F)	10 out of 11 (F)
Slavneft	77.1[21] (F)	77.1[21a] (F)	7 out of 12 (F)	0[22]	0
KomiTEK	21.7[23] (F)	1.07[23a] (F)	n/a	Does not exist	Does not exist
Russneft	Does not exist	Does not exist	Does not exist	0[24]	0

Notes: **R** denotes a regionally owned company and **F** denotes a federally owned company, and no notation means outside ownership

[0] Vedi (Analytical Laboratory). http://www.vedi.ru/s_pe/pe5101_r.htm
[1] Lukoil. 1999. Annual Report. http://www.lukoil.ru/materials/doc/reports/annual/AR1999-rus.PDF
[2] Lukoil. 2003. Annual Report. http://www.lukoil.ru/materials/doc/2003/AR%202003%20ENG.pdf
[3] Oil Review "Well" ("Нефтяное Обозрение «Скважина»). http://nefte.ru/company/rus/yukos.htm; Yukos. "It Is Much Easier to Kill a Good Deed than Redo It (Доброе дело легче погубить, чем возродить)". http://www.yukos.ru/12218.shtml
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[13] Oil Review "Well" ("Нефтяное Обозрение «Скважина»). http://nefte.ru/company/rus/onako.htm
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[15] Oil Review "Well" ("Нефтяное Обозрение «Скважина»). http://nefte.ru/company/rus/tnk.htm
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[17] Oil Review "Well" ("Нефтяное Обозрение «Скважина»). http://nefte.ru/company/rus/bashneft.htm
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[23a] Oil Review "Well" ("Нефтяное Обозрение «Скважина»). http://nefte.ru/company/rus/komitek.htm
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Table 2.8.2 Concentration of Russian Oil Production and Exports, 1997-2003

		1997	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Production	**Share of Mothers**	0.89	0.87	0.83	0.87	0.87	0.90	0.88
	R_2	0.29	0.29	0.30	0.35	0.35	0.38	0.36
	R_3	0.40	0.41	0.41	0.47	0.47	0.51	0.49
Exports	**Share of Mothers**	0.69	0.46	0.78	0.80	0.85	0.90	0.88
	R_2	0.24	0.18	0.29	0.31	0.35	0.38	0.35
	R_3	0.33	0.22	0.41	0.42	0.47	0.51	0.47

R_n -- n-firm concentration ratio

Table 2.8.3 Subsidiaries and Average Well Productivity

Region	Mothers	1997			2003		
		# of Producing Subsidiaries	Reported # of Wells	Average Production per Well (thousand tons)	# of Producing Subsidiaries	Reported # of Wells	Average Production per Well (thousand tons)
Western Siberia	LUKoil	1 (+4 subdivisions)	15227	2.87	7 (+4 subdivisions)	16352	6.11
	Yukos	1	10006	2.68	5	12101	10.78
	VNK	2	3879	2.84	-	-	-
	Sibneft	1	6869	2.64	1	7997	3.93
	Surgutneftegas	1	14133	2.40	1	16964	3.18
	Sidanko	5	6837	2.00	3	3737	7.40
	TNK	3	9614	2.33	4	13277	2.55
	Rosneft	1	2195	2.04	2	2525	3.90
	Slavneft	2	3599	3.41	6	3944	6.78
	Russneft	-	-	-	2	1168	2.80
North	KomiTEK	1	1609	2.23	-	-	-
	LUKoil	-	-	-	11	3264	8.50
	Rosneft	-	-	-	2	139	28.47
Volga	LUKoil	2	1067	3.08	2	1071	20.43
	Yukos	1	5462	1.56	1	5609	2.20
	Sidanko	1	339	3.70	1	380	4.74
	Tatneft	1 (14 subdivisions)	20711	1.18	1 (14 subdivisions)	21477	1.15
	Rosneft	1	166	1.50	-	-	-
	Russneft	-	-	-	2	184	2.47
North Caucasus	Rosneft	4	4529	1.37	5	3753	1.31
Urals	LUKoil	1	4670	1.21	5	6257	1.63
	Sidanko	1	4448	1.27	2	4004	1.84
	Onako	2	2773	2.70	-	-	-
	Bashneft	1 (10 subdivisions)	16958	0.91	1 (10 subdivisions)	18505	0.65
	TNK	-	-	-	2	2885	102.50
Far East	Rosneft	1	2263	0.66	1	2320	0.71

Table 2.8.4 Profitability of LUKoil versus Yukos

Year	Return on Assets		Return on Non-Current Assets	
	LUKoil	**Yukos**	**LUKoil**	**Yukos**
1999	9.6%	20.4%	12.4%	31.4%
2000	22.4%	41.0%	32.4%	77.5%
2001	11.4%	33.2%	16.7%	80.0%
2002	8.8%	24.6%	12.4%	52.0%
2003	10.6%	21.6%*	15.0%	37.8%*

*The figures for Yukos in 2003 are calculated through September 2003 and are based on an un-audited interim report.

Notes: Return on assets (non-current assets) in year is net income at the end of the year t divided by the average value of assets (non-current assets) on December 31 of year t and year t-1. Non-current assets equity include (most importantly) the net value of property, plant and equipment; it also includes equity investees and long-term investments at cost, deferred income tax assets and other long term assets.
Sources: For Yukos, see http://www.yukos.com/New_IR/Financial_reports.asp
and http://www.yukos.com/New_IR/Financial_reports_archive.asp and download the YUKOS Oil Company U.S. GAAP Consolidated Financial Statements, from December 31, 2002, December 31, 2001, and December 31, 2000 . We also used (for 2003) the YUKOS Oil Company U.S. GAAP Interim Condensed Consolidated Financial Statement Setpember 30, 2003, which is an un-audited report that covers the first nine months of 2003. For LUKoil see http://www.lukoil.com/static_6_5id_210_.html and download the OAO LUKOIL Consolidated Financial Statements (prepared in accordance with US GAAP) As of December 31, 2002 and 2001; As of December 31, 2000 and 1999 and for each of the years in the three year period ended December 31, 2000; and As of and for the years ended December 31, 1999 and 1998.

Table 2.8.5 Exports of Crude Oil as Share of Production

Mothers	1997	1998	1999	2000	2001	2002	2003
Rosneft	0.47	0.36	0.40	0.23	0.19	0.19	0.44
LUKoil	0.26	0.23	0.30	0.16	0.17	0.17	0.36
Surgutneftegas	0.34	0.13	0.33	0.17	0.18	0.18	0.34
Yukos	0.26	0.25	0.44	0.19	0.20	0.18	0.34
Sidanko	0.26	0.19	0.25	0.12	0.14	0.16	0.31
Slavneft	0.24	0.12	0.33	0.17	0.18	0.19	0.32
VNK	0.25	0.19	**n.a.**	**n.a.**	**n.a.**	**n.a.**	**n.a.**
Onako	0.24	0.19	0.26	0.07	**n.a.**	**n.a.**	**n.a.**
TNK	0.16	0.21	0.31	0.23	0.18	0.17	0.38
Sibneft	0.26	0.26	0.31	0.16	0.18	0.20	0.36
Tatneft	0.24	0.12	0.31	0.20	0.19	0.18	0.38
Bashneft	0.22	0.14	0.32	0.16	0.17	0.17	0.31
KomiTEK	0.24	0.36	0.41	**n.a.**	**n.a.**	**n.a.**	**n.a.**
Russneft	-	-	-	-	-	-	0.41
AVERAGE PER MOTHER	0.27	0.21	0.33	0.17	0.18	0.18	0.36
TOTAL MOTHERS	**0.27**	**0.20**	**0.33**	**0.18**	**0.18**	**0.18**	**0.35**

Notes: **n.a.** means that these companies do not exist in a particular year.

Table 2.8.6 Costs of Export Routes for Russian Oil Producers, 2003

Port/Route	Pipeline Route to Port/Refinery	Average Transit Tariff ($ per ton/km)	Port Transshipment Tariff ($ per ton)	Capacity of the Route/Port (mln tons per year)
Druzhba (till Russian border)	Russia	.33[1]	-	62[6]
Novorossyisk	Russia	.33[1]	2[2]	45.3[7]
Primorsk	Russia	.33[1]	n/a	30[8]
Tuapse	Russia	.33[1]	2.4[2]	20[9]
Odessa	Russia-Ukraine	Through Russia: .33[1] Through Ukraine: .44[1] **Average Tariff : .39**	n/a	24[10]
Yuzhnyi	Russia-Ukraine	Through Russia: .33[1] Through Ukraine: .44[1] **Average Tariff : .39**	3.5[5]	n/a
Ventspils	Russia-Byelorussia-Lithuania-Latvia	Through Russia: .33[1] Through Byelorussia: .64[3] Through Lithuania: .9[3] Through Latvia: .6[3] **Average Tariff : .62**	4.7[4]	50[11]
Butinge	Russia-Byelorussia-Latvia-Lithuania	Through Russia: .33[1] Through Byelorussia: .64[1] Through Latvia: .71[1] Through Lithuania: .99[1] **Average Tariff : .67**	n/a	14[12]

Source: [1] Transneft, 2002.
[2] Marine Tariff Center. http://www.russianports.ru/novo/Tarif/35_p.htm; http://www.russianports.ru/tuap/Tarif/52_p.htm
[3] Oil and Capital, 2000.
[4] Ventspils Nafta, 2000.
[5] Caspian Energy, 2003.
[6] Energy Information Administration, 2005.
[7] Oil and Capital, 2003a.
[8] Transneft, 2003.
[9] Oil and Capital, 2003b.
[10] Odessa Matine Port. http://www.port.odessa.ua/od199.php
[11] Oil and Capital, 2002.
[12] Mazeikiu Nafta. http://www.nafta.lt/en/content.php?pid=18

Table 2.8.7 Oil Exports in State-Independent and State-Influence Subsidiaries

Dependent Variable Is Tons (000s) of Oil Exported by Route and Subsidiary in 2003

Independent Variables	**Specification 1**			**Specification 2**		
	1	**2**	**3**	**1**	**2**	**3**
	State-Influence Net of State-Independent	**State-Independent**	**State-Influence**	**State-Influence Net of State-Independent**	**State-Independent**	**State-Influence**
Regional Costs	-2.37 (1.581) *-773.40*	0.42 (1.558) *138.26*	-1.95** (0.537) *-631.57*	-2.40 (1.623) *-780.52*	0.37 (1.599) *121.07*	-2.02** (0.544) *-655*
Transport Costs for Pipeline Route	-3.39** (0.976) *-2540.51*	1.34 (0.846) *1004.02*	-2.05** (0.539) *-1525.56*	-3.71** (1.017) *-2783.79*	1.61* (0.867) *1204.60*	-2.10** (0.544) *-1565*
Pipeline Route Capacity	263.89** (77.598) *5485.40*	80.32** (27.159) *1669.22*	344.20** (94.67) *7152.29*	309.87** (86.552) *6439.97*	90.21** (28.684) *1874.86*	400.08** (104.918) *8314*
Productivity	-22.26** (6.068) *-2012..08*	22.28** (5.894) *2013.36*	0.01* (1.25) *1.29*	-19.13** (5.486) *-1743.33*	19.20** (5.299) *1740.98*	0.07 (1.254) *6.4*
Additional Controls	Total wells, five pipeline routes and the eleven mothers			Operating wells, five pipeline routes and the eleven mothers		
Log Pseudolikeli-hood	-1153.54			-1153.91		

Notes: Results are base on a maximum likelihood estimation of a Tobit model where the dependent variable is censored at zero. All standard errors are adjusted for heteroskedasticity. There are 270 observations and ** denotes significance at the 5-% level and * denotes significance at the 10-% level. Productivity is output per well in Specification 1 and output per operating well in Specification 2.

Table 2.8.8 Correlation Coefficients

	Regional Production Costs	Number of Wells	Number of Producing Wells	Production per Well	Production per Producing Well
Transportation costs	-0.30	-0.01	-0.02	-0.08	-0.08
Route Capacity	0.00	0.00	0.00	-0.00	-0.00

Table 2.8.9 Oil Exports in State-Independent and State-Influence Subsidiaries, 1997 and 2003

Dependent Variable Is Tons (000s) of Oil Exported by Route and Subsidiary

Independent Variables	**2003**		**1997**	
	State-Independent	**State-Influence Net of State-Independent**	**State-Independent**	**State-Influence Net of State-Independent**
Total Wells (100s)	67.35** (17.7)	-37.29** (17.6)	47.62* (28.3)	-38.26 (28.3)
Operating Wells	X	X	X	X
Regional Costs	-1.34 (1.037)	0.36 (1.114)	48.04 (74.98)	-44.88 (75.01)
Productivity	18.95** (5.482)	-18.63** (5.750)	-60.97 (249.47)	74.82 (293.15)
Additional Controls	Five pipeline route used by mothers including Druzhba, Tuapse&Novorossiysk, Odessa, Butinge and Primorsk, differentiated by state-independent and state-influence companies; eleven mothers		Five pipeline route used by mothers including Druzhba, Tuapse&Novorossiysk, Odessa, Butinge and Primorsk, differentiated by state-independent and state-influence companies; eleven mothers	
Log Psuedolikelihood	-1160.74		-533.30	

Notes: Results are based on a maximum likelihood estimation of a Tobit model where the non-negative dependent variable is censored at zero. All standard errors are adjusted for heteroskedasticity. There are 270 observations for 2003 and 108 observations for 1997. ** denotes significance at the 5-% level and * denotes significance at the 10-% level. Productivity is output per well.

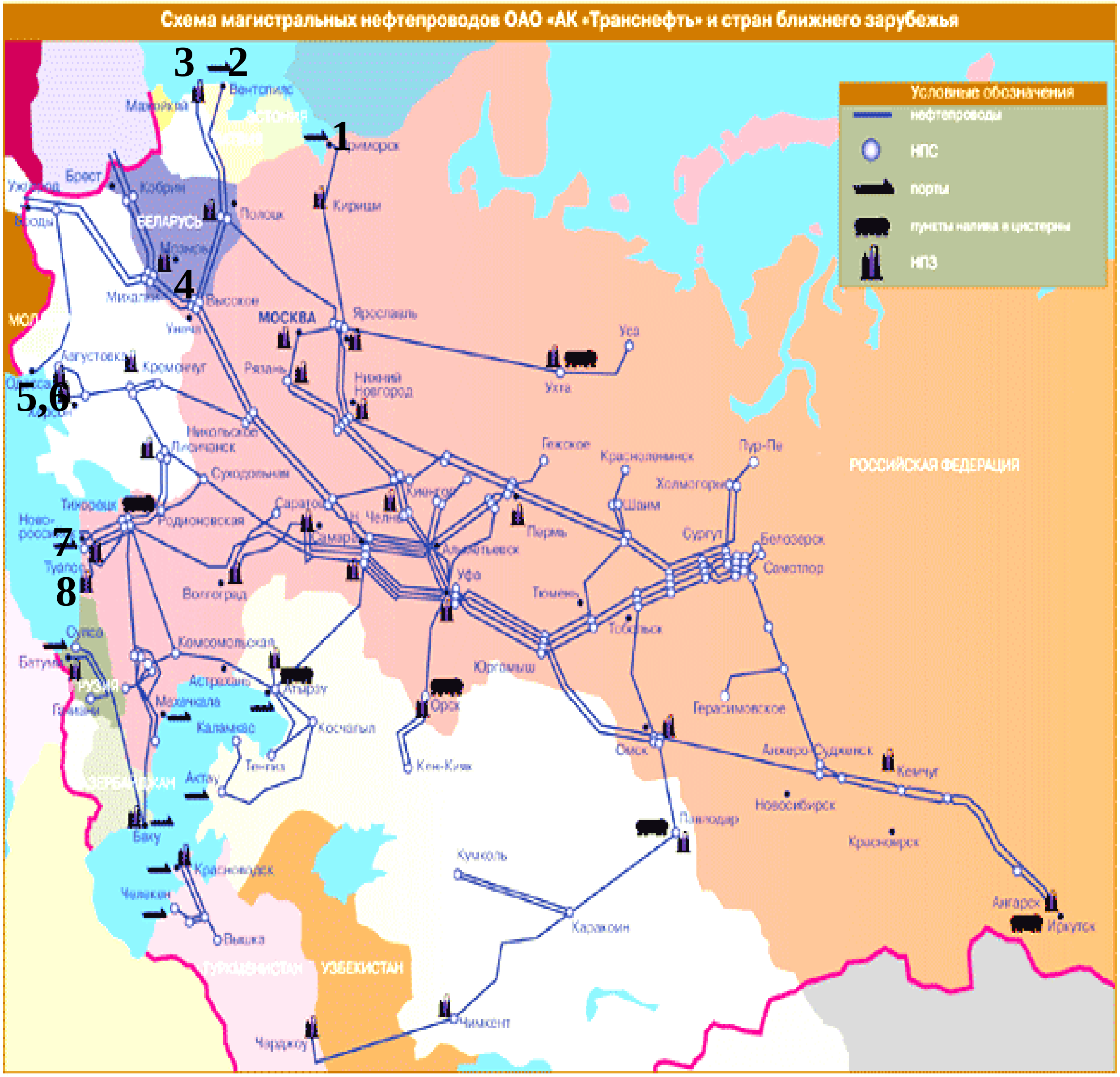

Figure 2.8.1 Export Routes for Russian Crude Oil

CODE

1:	Primorsk	5, 6:	Odessa, Yuzhnyi
2:	Ventspils	7:	Novorossyisk
3:	Butinge	8:	Tuapse
4:	Druzhba		

3.0 ESSAY TWO
CASPIAN OIL BOOM:
INFORMATIONAL HERDING AMONG THE OIL COMPANIES

3.1 INTRODUCTION

In the mid-1990s, the Caspian region[7], especially the states of Azerbaijan and Kazakhstan, managed to generate a great deal of excitement around wildcat exploration of its poorly researched oil and gas fields. In a short period of time, 1997-1998, an extraordinary volume of international investment poured into the region. However, this hype was soon over. In early 1999, several oil development projects were closed, some companies exited contract negotiations without picking up a project and no new oil companies signed contracts despite the availability of potential oil-bearing structures. This massive entry and exit of investment in the region is hard to explain: it could not have been caused by the size of the available reserves, which was quite uncertain and insignificant in comparison to other oil regions in the world; it was countercyclical to the movement of oil prices and, as we will document, is not likely to have been caused by the developments in the legal environment in the region. In this essay we argue that the Caspian oil boom story may be consistent with informational herding: despite weak and

[7] The Caspian region (namely, the former Soviet republics of Azerbaijan, Kazakhstan and Turkmenistan) is defined by geology, i.e. location of conformed oil and gas reserves in particular, rather than demography.

noisy private information on the available Caspian reserves, the international investment started coming to the region after strong public signals on the Caspian potential were released. Similarly, the investment stopped after negative public information about the size of the Caspian reserves became available.

It is straightforward to document the Caspian oil boom. The massive investment inflow in the Caspian oil in mid-1990s was often called “the global rush to explore” (Coll for ***The Washington Post***, 1993), "the last great oil rush of the 20th century" (Ottaway and Morgan for ***The Washington Post***, 1997), “a nasty case of resource fever” (***The Economist***, 1998) and "the Great Game" (Raff for ***The Wall Street Journal***, 2004). As Figure 3.5.1 shows, by 1999 over 20 oil exploration contracts were signed in Azerbaijan alone. Most of the projects were created in 1997-1998: 5 and 7 new contracts signed in 1997 and 1998, respectively. By 1998, these contracts represented over $30 billion in long-term capital investment with some $2.5 billion in sunk and committed investment (International Energy Agency, 1998; International Energy Agency, 2000). On the other hand, direct foreign investment in Kazakhstan’s oil and gas sectors were about $2 bln for 1991-1996 with $410 mnl invested in 1996 alone (International Energy Agency, 1998).

What is also surprising is that at the end of the 1990s this interest in Caspian oil died, and “the last great oil rush” turned into “oil-rush euphoria evaporated” (***The Economist***, 1999). Again, according to Figure 3.5.1, after 1999 almost no new projects were picked up despite the fact that there were over 200 identified potential oil structures – only 2 new contracts were signed in 1999 and 1 in 2000. Moreover, two oil companies, Arco and Conoco, decided to exit the country after long negotiations without picking up a contract

Further evidence of the oil boom is the extent to which the foreign companies became involved in the Caspian oil sector. The spike of investment activity among the oil companies was especially vivid in Azerbaijan. As shown on Figures 3.5.2 and 3.5.3, direct investment of oil companies grew from $0 to $845 million between 1994 and 1997, bringing total direct and portfolio investment in the country to $1.1 billion in 1997 alone (IMF, 2000) . Gross private capital flows as percent of Azeri GDP increased from 14.6% in 1995 to 28.8% in 1997 (The World Bank, 2004). However, after reaching its peak in 1997, the foreign direct investment fell to only $119 million as well as private capital flows decreased drastically to 3% of GDP in 2000.

International creditors also rapidly entered the Caspian states during 1997-1998. Figure 3.5.4 documents that the total commitments of official and private creditors grew from $40.5 million in 1996 to $374.1 million in 1998 in Azerbaijan, and from $414 million in 1994 to over $1 billion in 1997 in Kazakhstan. Increasing investment appears to have contributed to the faster capital formation and development of the communication infrastructure, as seen from Figures 3.5.5 and 3.5.6. In 1995-1998, the gross capital formation in Azerbaijan grew from $726 million to $1.2 billion. The number of Azeri phone mainlines and cell phone users per 1000 people stayed almost constant in 1994-1995 (85 mainlines per 1000 people and 0 cell phone users per 1000 people), but started growing rapidly in 1996-1999. By 1999 the number of mainlines increased by 10 and became 95 per 1000 people; the number of cell phone users became almost 50 per 1000 people.

However, again, the creditors' hype about the region subsided quite drastically after 1999, when their commitments fell to $215 million in Azerbaijan and $665.9 million in Kazakhstan by the year 2000. Also, the gross capital formation in Azerbaijan decreased from well over $1 billion in 1998 to about $900 million in 2000. The growth of infrastructure slowed down: by 2000 the number of mainlines increased only by 7 per 1000 people and the number of cell phone users stayed almost unchanged.

More evidence of the Caspian boom can be found in the international media. As Figure 3.5.7 shows, media reports on the region increased drastically in 1997-1998. In 1994, all major international news sources (e.g., The Economist, The New York Times, The Wall Street Journal and The Washington Post) reported only one story on the region: the signing of the first mega-deal, “the contract of the century”, in Azerbaijan. However, in 1997 The Washington Post published 12 stories on Caspian international projects development, pipeline issues and Russian involvement in the region; The New York Times and The Washington Post published 8 stories each on the Caspian issues in 1998. Yet again, the media interest in the region died soon after. In 2000 there were only 4 Caspian stories published in The Wall Street Journal, 2 in the Washington Post, 1 in The Economist and The New York Times did not write about Caspian oil at all.

Thus, there is a great deal of evidence of the Caspian oil boom: it appears that there was a rapid entry of international investors in the region during 1997 and 1998, but by 1999 the interest in the Caspian oil was lost. However, what is not that straightforward is how to explain this dynamics of Caspian frenzy among the investors and media. First, the size of the Caspian proven reserves was not significant enough to attract such a massive investment flow in such a short period of time. According to Figure 3.5.8, Azerbaijan and Kazakhstan’s proven oil reserves were 3.6 and 10 billion barrels respectively, which is much smaller than, let’s say, Russia’s 56 billion barrels or Venezuela’s 74.9 billion barrels or Saudi Arabia’s 261.5 billion barrels (US Department of State, 1997; BP, 2005).

Second, the size of the potential Caspian reserves was quite uncertain for prospective investors. The estimates of the upper bound of the possible Caspian reserves varied from 13.2 billion barrels of undiscovered reserves in Azerbaijan by the US Department of the Interior (US Department of Interior, 1982) to 27 billion barrels of possible reserves in Azerbaijan only and a probable 178 billion barrels in the whole region by the US State Department (US Department of State, 1997). Most of the researchers, however, were comfortable with more conservative estimates projecting that the Caspian would never become "the second Middle East" and was more likely to be comparable in its importance with the North Sea (Bahgat, 2003; Gregory, 2000; Skagen, 2000).

Third, usually the spike of oil exploration investment happens when the oil prices are relatively high and rising. However, as it is seen from Figure 3.5.9, the world oil prices were actually falling when the majority of oil companies entered the Caspian wildcat exploration projects in 1997-1998. By the time the oil prices recovered in 2000, the Caspian frenzy died.

Fourth, in order to draw international oil companies to the region, the Caspian states offered the contracts with very attractive terms and made sure that the legal environment became more stable for the investors. According to Business Environment and Enterprise Performance Survey developed by the World Bank and European Bank for Reconstruction and Development, by 1999 most of the survey respondents reported that the local legal systems would uphold contract and property rights. However, starting in April 1999, no new companies were willing to sign contracts in the region.

The above analysis suggests that the Caspian oil boom may not be consistent with the obvious explanations: the size of the region's recoverable reserves was not enough to cause a huge influx of investors' interest; the oil companies were not reacting to the dynamics of the oil prices; and the legal environment in the region could not be the cause of the investors' lost interest in the Caspian oil.

However, there is another possible explanation is consistent with the spike of investment activity in the Caspian. The dynamics of the Caspian frenzy may be explained by informational herding. A lot of investors could have come to the Caspian region as a part of the herd that was created by informational externalities and available public information. Informational externalities were provided to the potential investors by observable decisions of the companies that first had come to the region: every investment decision revealed a little bit of the company's private information. Hence, every potential investor could have used this additional piece of information in making a decision. Also, all potential Caspian investors had access to credible public information on Caspian reserves

There are two important factors that make informational herding relevant to the Caspian oil boom. First, public information releases and informational externalities are important in oil exploration. Very often the tracts within an oil region may be located over a common oil pool or have similar geological characteristics. In both cases, the values of nearby tracts are correlated. Hence, the discovery of oil in a region is seen as a signal that there is more oil in nearby tracts. Similarly, a decision of an oil company to invest in the exploration of a tract (i.e., drill) also gives some insight into how promising was the company's private information on the oil area. Thus, successful drillings as well as exploration works per se are informative signals that companies can benefit from when making their own investment decisions.

Second, the investment and information environment in the Caspian in the mid-1990 was consistent with the setting where informational herds can occur. The companies invested in the Caspian fields sequentially; and some aspects of the investment environment were common knowledge while others were known only to the specific companies. The common-knowledge factors included the number of contracts signed, location of the contracted tracts, the name of the companies involved in each project and the progress of work on each project. These factors provided information externalities to each company that was in the process of contract negotiations. The seismic information on specific tracts, on the other hand, was not available publicly. Each company considered seismic information on the tract of interest privately before making its decision.

In this essay, we will present available evidence to argue that the Caspian oil boom is consistent with informational herding. Our strategy will be to eliminate obvious explanations for the investment spike, and provide direct and indirect evidence that supports the informational herding hypothesis. First, we will show that the Caspian oil boom is not consistent with the following explanations: it could not have been caused by the movement of oil prices, the sudden availability of new, abundant oil reserves, or by changes in the legal environment in the region. Then we will argue that under the available informational environment in the Caspian region it was quite possible for informational herding to occur and that informational herding caused a huge investment influx. We will also argue that the herding was very fragile and was broken after negative public information about the region became available.

One interpretation of the paper's argument is that in order to minimize investment risk, the oil companies consider all of the available information, not just privately obtained but also publicly available information, including the investment decisions of other oil companies. However, this strategy of using maximum available information may not necessarily improve the companies' decision. As it will be shown, in the case of the Caspian oil available public information was quite noisy and including it in the process of investment decision making could not have been necessarily beneficial to the oil companies. Ex post, a company may have been better off by just considering its own private signal and not following the herd.

This essay contributes to the literature that empirically investigates the presence of informational herds. Despite the fact that informational learning models are motivated by real-life examples[8], there are not that many papers that actually document the presence of informational herding in real life. One of the most recent empirical studies was done by Kennedy (2002), where the author showed the strong herding tendencies among the networks when they introduce prime-time television programs.

The essay is structured as follows: section 3.2 argues that under the available investment environment the Caspian oil boom cannot be explained by oil prices, availability of new investment opportunities or changes in the legal system; section 3.3 develops a herding hypothesis; and section 3.4 concludes.

3.2 CASPIAN OIL BOOM: POSSIBLE EXPLANATIONS

In this section, I will limit my discussion to investment in the Azerbaijani oil sector. As it has been mentioned in the Introduction, Azerbaijan is probably the best example of how the Caspian states were affected by the oil boom. There, the massive inflow and consequent outflow of oil investment was most vividly observed. Hence, evidence from the Azeri oil sector will be most helpful in describing Caspian oil boom.

[8] E.g., Bikhchadani, Hirshlefier and Welch (1992) motivate their model by observing fads and different fashion trends; Avery and Zemsky (1998) develop an informational herding model to explain conforming behavior in financial markets.

It is important to emphasize that the Azeri government adopted a very cautious mechanism of contracting off oil fields: tracts were offered either individually or in small groups at different time periods to a particular oil company; each contract individually negotiated. To guarantee the legal stability of investment with each contract was ratified by the Parliament thereby gaining legal status. There were no entry barriers for the oil companies: they just had to be offered an oil field by the Azerbaijani government for a potential development project. Since Azerbaijan saw its oil reserves as the main force behind its fast economic development, the government did not have any incentive to limit oil companies' participation in the Azeri oil sector.

Under such an investment environment, there may be several possible explanations that can justify the Caspian oil boom. The oil companies could have started coming and investing in the region because oil prices were on the rise; because they recognized that the newly-opened Caspian reserves were the best investment opportunities at the time; and because the legal system created enough incentives for investors to come in. In this subsection, we will discuss whether the Caspian oil boom can be explained by changes in oil market prices, by the availability of new oil resources for international development and by changes in the legal environment.

3.2.1 Change in Oil Market Prices

Higher oil market prices make expensive investment in wildcat exploration more attractive. Hence, as long as oil prices are growing, companies will invest more in poorly explored oil regions. As soon as oil prices fall, however, companies will decrease their investment in the exploration of new oil regions and concentrate on oil production at old working fields.

Figure 3.5.9 shows the changes in price for the Russian Urals blend[9] in 1994-2000. As it is seen from the graph, the Urals blend price was growing until early 1997; in 1997 and 1998 it was falling steadily; then in mid-1999 the price began recovering and grew till late 2000.

The dynamics of the oil price changes is quite the opposite of the investment pattern in the Caspian. As it has been discussed in the introduction, most of the oil companies came to the region in 1997-1998, when the prices were falling, and stopped investing in the new oil fields in the region after 1999, when the oil prices were on the rise.

There are two possible arguments that can explain investment into the exploration of the Caspian region when oil prices were falling. First, contract negotiations are long and costly. So, the decision of an oil company to enter into a contract may lag behind an oil price change. Second, the exploration investment becomes commercially unviable after the oil price hits a certain lower bound. So, as long as the price is above that level, a company will still choose to invest.

Both of the arguments above also suggest that as soon as the price starts recovering, oil companies will increase their investment in the oil fields. However, even when in November, 2000, the Urals blend price reached its highest point for 1994-2000 ($33.93 per barrel), no new contracts were signed in Azerbaijan. Hence, the Caspian oil boom cannot be entirely explained by the dynamics of world oil prices.

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[9] Most of the Caspian oil in 1994-2000 was shipped to the world markets through the Russian pipeline system, where it was blended with all of the oil currently in the pipeline. Hence, at the final export destination the Caspian oil was priced as the Russian Urals blend. The exceptions to this are exports from companies using the Caspian Pipeline Consortium and Baku-Supsa pipeline through Georgia. This oil is typically priced closer to the Asian blends, which are a little more expensive than the Russian Urals blend. However, the change dynamics of the Russian Urals and Asian blends are usually similar.

3.2.2 Availability of New Oil Resources for International Development

Oil is not a renewable resource; hence, oil companies are constantly looking for replacement of their work-out reserves. As soon as a new oil rich region opens up for international investment, oil companies will start acquiring tracts in that region.

In mid-1990, oil production from the Alaskan North Slope and the North Sea was declining. However, most of the richest oil regions (e.g., Middle East countries) were either completely closed or offered limited opportunities to international investment, as can be seen from Figure 3.5.10. Thus, the opening up of the Caspian region for international development after the collapse of the Soviet Union provided oil companies with the best investment opportunities despite the fact that the Caspian was not as rich in oil as some other regions. According to one oil executive, there were “not a lot of Caspians out there” in 1998 (***The Washington Post***, 1998).

By the same argument, the oil companies should have stopped acquiring oil tracts in the Caspian region after another, more promising region had opened up. However, in 1999-2000 it was not the case. There were no new oil discoveries or sudden new investment opportunities for oil companies to pursue. When Arco decided to close its office in Azerbaijan, its representative stated that the company planned to concentrate its activities in the regions that it was already involved – Alaska, China, Nigeria and the North Sea (Alexander’s Oil & Gas Connections, 1999). Thus, the fall of investment in the Caspian region did not coincide with the sudden availability of new resources; and the Caspian oil boom cannot be entirely explained by the sudden availability of new oil resources to develop.

3.2.3 Change in Legal Environment

A stable legal framework is important for oil companies when they make their investment decisions. Moreover, if the states in the region are able to offer contracts with more attractive terms than similar contracts in other oil regions, then the oil companies will have more incentives to come in. Similarly, if the states in the region change the terms of the contract to the investors' disadvantage, then the oil companies will stop signing contracts in the region and move to the states that offer better contracts.

After the collapse of the former Soviet Union, the Caspian states occurred in a legal vacuum. In order to signal guaranteed legal protection and profitability of investments, Azerbaijan did two things. First, as it has been described in section 3.1, it adopted an ad hoc legal strategy. Each contract was considered individually and ratified by the Parliament, thereby solidifying its legal status. Second, to make Azeri oil tracts more attractive, the terms of the contracts offered were much more attractive than the terms of similar contracts in other oil regions. Table 3.5.1 compares Azeri contracts to similar agreements in other regions. As it is seen from the table, Azeri contracts did not require royalty payments and the tax rate on profit oil was much lower than similar taxes in other regions.

It would be expected that the oil companies would stop coming to a region if the legal environment became unstable and/or the government started offering less attractive contracts. This was not the case in Azerbaijan. In 1994-2000, Azerbaijan had the same President; the State Oil Company of Azerbaijan was led by the same person as well, and there were no changes in the legal procedures of the adoption of contracts. The terms of the contracts offered also did not change much. Moreover, according to The Business Environment and Enterprise Performance Survey developed by the World Bank and European Bank of Reconstruction and Development, in 1999, 69.2% of respondents agreed that the Azeri legal system would uphold contract and property rights; while only 44.9% of respondents agreed that the contracts and property rights had been honored three years before, in 1996, and 30.1% of respondents noted that the notion of protected property rights did not exist in 1996 (The World Bank, 1999). This implies that the legal protection of investors in Azerbaijan was better in 1999 than in 1996. The above analysis suggests that the decrease in oil investment in the Caspian region was not caused by the change in the region's legal environment; and the Caspian oil boom is not fully consistent with the change in legal environment explanation.

3.3 CASPIAN OIL BOOM: INFORMATIONAL HERDING

The previous section argues that the Caspian oil boom cannot be explained by the most obvious hypotheses: it was countercyclical to oil prices dynamics, was not consistent with the availability of reserves and could not be predicted by the developments of the legal system in the Caspian states.

There is another possible explanation that may help us tell the story of the Caspian oil boom. In 1997-1998, the investors could have been following the informational herd, i.e. investing in the region despite weak positive or simply poor available information. The investment stopped coming to the region when the herd was broken by a strong release of information that contradicted the investment decision of the herd.

The phenomenon of informational herding was first discussed independently by Banerjee (1992) and Bikhandani, Hirshleifer and Welch (1992), and further developed by Smith and Sorensen (2000). The authors describe an economy with exogenously ordered Bayesian agents who sequentially make once-in-a-life-time investment decision under incomplete and asymmetric information. Each individual receives a private signal conditioned on the state of the world and can observe the actions of the agents before her. Since every agent uses her private information to choose a profit-maximizing action, each individual's decision reveals some information about her private signal. Therefore, if return for each decision is uncertain and an agent's choice reveals some of her private information, then the next agents can free-ride on this additional piece of information to improve their decisions. Put differently, an observable decision provides so called "information externality" for the next individuals in line.

The main conclusion of the model is that because of the information externality eventually the informational herd starts: after a finite number of agents, we observe that every individual makes the same decision as her predecessor, even if her private signal only weakly supports the decision of the herd or even contradicts it.

This conformity in actions is caused by the convergence of agents' beliefs. So, any information that can affect the beliefs of the agents can either reinforce or break the herd. We will observe the conformity in agents' decisions faster if there is a release of public information that supports the investment decisions of the earlier individuals. Similarly, the informational herd will be broken if the public information release refutes the decision of the herd.

As it has been discussed in section 3.1, the investment and information environment in Azerbaijan is consistent with the setting where informational herds can occur. First, informational externalities are important in oil exploration since the oil fields can be located on top of a common deposit or have similar geological characteristics as a field where the oil is discovered. In both cases, the value of neighboring tracts is correlated. Second, the oil companies invested in the Azeri fields sequentially. Companies were randomly invited by the Azeri governments to negotiate an oil development contract. Each contract signed included a so-called "minimum exploration program" clause. This clause obliged the company to conduct a detailed seismic analysis of the area, and drill several exploratory wells within a certain period or pay a fine if the minimum exploration was not finished on time. Thus, when entering a contract, the company was actually committing to exploration investment on the tract.

Third, the informational environment had common-knowledge, public information as well as private signals. The common-knowledge factors included the number of contracts signed location of the contracted tracts, the name of the companies involved in each projects and progress of work there. This information was almost instantly distributed through media or company press releases. These factors provided information externality to each company that was in the process of contract negotiations.

In contrast, the seismic information on specific tracts was not available publicly. Before signing a contract, the oil company would receive some seismic information about the tract it had been offered. Most often, it was a high-quality two-dimensional seismic survey of the area done by the local research institutes. Once in possession of the data, the company could not resell it to any other party[10].

Using the conclusions of the informational herding models, we can formulate the following hypothesis:

The massive investment started coming to the Caspian region after enough public information indicated that the investment decisions made by the first companies would pay off. The

[10] We thank Dr Parviz Mamedov, Chair of the Department of Geophysics at Azerbaijan Oil Academy, for help with this issue.

investment stopped coming to the region after public information revealed that investment in the Caspian region was not profitable.

In other words, we would observe a massive influx of investment after strong, credible public information about the first contract areas and the region's reserves in general became available. We should also observe that some of the oil companies decided to enter projects even with a rather weak positive private signal about their contract areas. We should also expect few contracts signed after credible negative information about the Caspian reserves was released.

To see whether the Caspian oil boom is consistent with the above hypothesis, we constructed Tables 3.5.2 and 3.5.3. Table 3.5.2 documents major news releases in 1994-2000 as published in companies' press releases as well as in selected expert reports and from international media outlets. We used reports prepared by the Information Energy Agency and the U.S. Department of State. We looked through ***The Economist***, ***The New York Times***, ***The Wall Street Journal***, ***The Washington Post*** as well as ***Caspian Business Report***[11] and ***Alexander's Gas & Oil Connections***[12] when surveying the international media outlets. Table 3.5.3 provides information on each contract signed in Azerbaijan in 1994-2000: the name of the tract, when it was contracted off, which oil company signed the contract as well as the size of the signature bonus, the amount of total projected investment and the estimated reserve size.

As table 3.5.2 shows, in 1994-1996 there was only one big news release on Caspian oil: the international media reported that the first production-sharing agreement on the Azeri-Chirag-Deepwater Guneshli mega-structure was signed by international majors. In this period very few

[11] Biweekly market intelligence report on the Caspian Region prepared by U.S.-Azerbaijan Council, a U.S.-based non-partisan, non-profit organization.

[12] A website that surveys major news sources for information on the global gas, oil, power and affiliated industries.

new contracts appeared in Azerbaijan. Only production-sharing agreement was signed in 1995 and two more appeared in 1996.

The influx of positive news about the Caspian oil reserves is observed in 1997-1998. In April 1997, the U.S. Department of State released information about huge estimates (up to 178 billion barrels) of possible oil reserves in the region. Later this year, in November 1997, BP reported the beginning of oil production and export from an Azeri field. In early 1998, reports appeared on more negotiations in progress between the international oil companies and the Azeri government. In the period of 1997-1998, we observe a dramatic increase in contracts signed: 5 new production-sharing agreements were created in 1997 and 7 more were signed in 1998.

The first negative news about the Caspian reserves came in late 1998. In October 1998, the reports on dry wells drilled appeared in the media. These stories were confirmed in early 1999, when in February and April 1999, respectively, two Azeri contracts were closed. This news was followed by reports of the international companies exiting renegotiations in Azerbaijan without signing a contract. In July and November, 1999, Arco and Conoco respectively released their decision to leave Azerbaijan. After 1999, no major news on the Caspian oil reserve was published. In the period of 1999-2000, we observe the drastic decrease in the contracts signed for Azeri fields; there were only 3 production-sharing agreements created in 1999 and only 1 appeared in 2000.

The above analysis shows that the dynamics of investment in the Azerbaijani oil fields follows the release of information: most of the companies came to the region after an influx of positive news about the first projects signed and the region's oil reserves in general. The investment stopped coming to the region after bad public news arrived. Such a pattern of investor behavior is consistent with the informational herding hypothesis.

The further consistency of the Caspian oil boom with informational herding can be seen from Table 3.5.3. This table provides some insights into the private information available to oil companies before they signed contracts. The signature bonuses reported in the table give us some idea about the companies' beliefs about the success of the project. The bonus is negotiated before the contract is signed, and is typically paid to the government of Azerbaijan within 30 days of the contract going into effect. The size of the bonus positively depends on the expected reserves and the probability of getting them. Projected investment per barrel of estimated reserves (calculated as amount of total projected investment over the estimated reserves) can give us an idea on how expensive the project was expected to be for the company.

It is seen from Table 3.5.3 that the signature bonuses for the tracts contracted off in 1997-1998 are smaller, on average, than the signature bonuses paid by the first companies: $150 million paid by BP and Amoco in 1994 as opposed to $10 million per project paid by most of the companies in 1997-1998. This suggests that the private information of the companies that signed contracts in 1997-1998 was weaker than the private information received by the first companies. The poorer private information received by the later companies is explained by the fact that most of the later contracts involved wildcat exploration of the tracts. On the other hand, the area of the first contract (Azeri, Chirag and Deepwater Gunieshli) was thoroughly drilled and explored. The mega-structure was discovered by Soviet geologists in the 1980s and was extensively studied; however, full production of the fields was not possible thensince the Soviet Union did not have the necessary drilling technology.

The contracts signed in 1997-1998 also appear to be more expensive than the first ones: $0.91-$5.33 per expected barrel in 1997-1998 compared to $1.20-$2.41 in 1994-1996. This suggests that the companies that came to Azerbaijan in 1997-1998 were eager to undertake more expensive projects despite poorer private signals.

The analysis of Table 3.5.3 also suggests that the oil companies' decisions to invest in Azeri fields are consistent with informational herd behavior. Most of the companies that signed contracts in 1997-1998 did so despite weak private information.

Recall that informational herding is caused by the conformity in the agents' beliefs. Indirect evidence of the convergence of oil companies' expectations, despite available weak private information, can be found in the reports of the journalists who were stationed in Azerbaijan at the time. Before 1997, there were not so many oil companies' officials who would go on the record to discuss Caspian oil reserve potential. This, however, changed in 1997 and 1998. According to Morgan and Ottaway (***The Washington Post***, 1997), a consultant for Pennenergy claimed that the Caspian was "a huge pool of oil"; Hamilton (***The Washington Post***, 1998) quoted the president for international exploration of Mobil Corp. who compared Caspian potential to "the Middle East back in the 1930s and 1940s". Copper and Pope (***The Wall Street Journal***, 1998) talked to the world-wide exploration chief of the Phillips Petroleum Co. and spokesman of Oryx Energy Co., who claimed that the Caspian was "a premier area in discovering new reserves".

We can also indirectly document the change in the companies' expectations of the Caspian reserves after the bad news started arriving in early 1999. ***The Economist*** in March, 1999, reported that a lot of businessmen were leaving the country because they were "just tired of pouring money into a black hole"; Kinzer (***The New York Times***, 1999) noted that the Caspian enthusiasm was tempered by "a few dry holes and pullouts by several companies."

3.4 CONCLUSION

This paper suggests that the investment boom in the Caspian region may be consistent with informational herding. The Caspian oil boom was preceded by releases of positive information about the Caspian reserves as well as good news about the development of some tracts. The boom died after the news of the dry holes had been released as well as after several companies decided to leave the region without signing a contract. Given the sequential nature of contract negotiations as well as the presence of information externalities in the region, this behavior of investors fits the predictions of informational herding models. Companies tend to make the same investment decision despite their weak private signals as long as this decision is supported by both the choices of their predecessors and publicly available information. However, as soon as some company deviates and/or strong public information contradicting the herding decision arrives, conformity is broken.

Our findings imply that in order to minimize investment risk, the oil companies considered all of the available information: both privately obtained and publicly available, including the investment decisions of other oil companies. However, does this strategy of using all available information improve a company's decision? The latest development of the contracts signed in 1997-1998 suggests that it does not. Out of twelve contracts signed in Azerbaijan in 1997-1998, three are closed and drillings in another four revealed no oil.

This suggests that there should be a better mechanism of information disclosure between the companies in oil exploration.

3.5 TABLES AND FIGURES

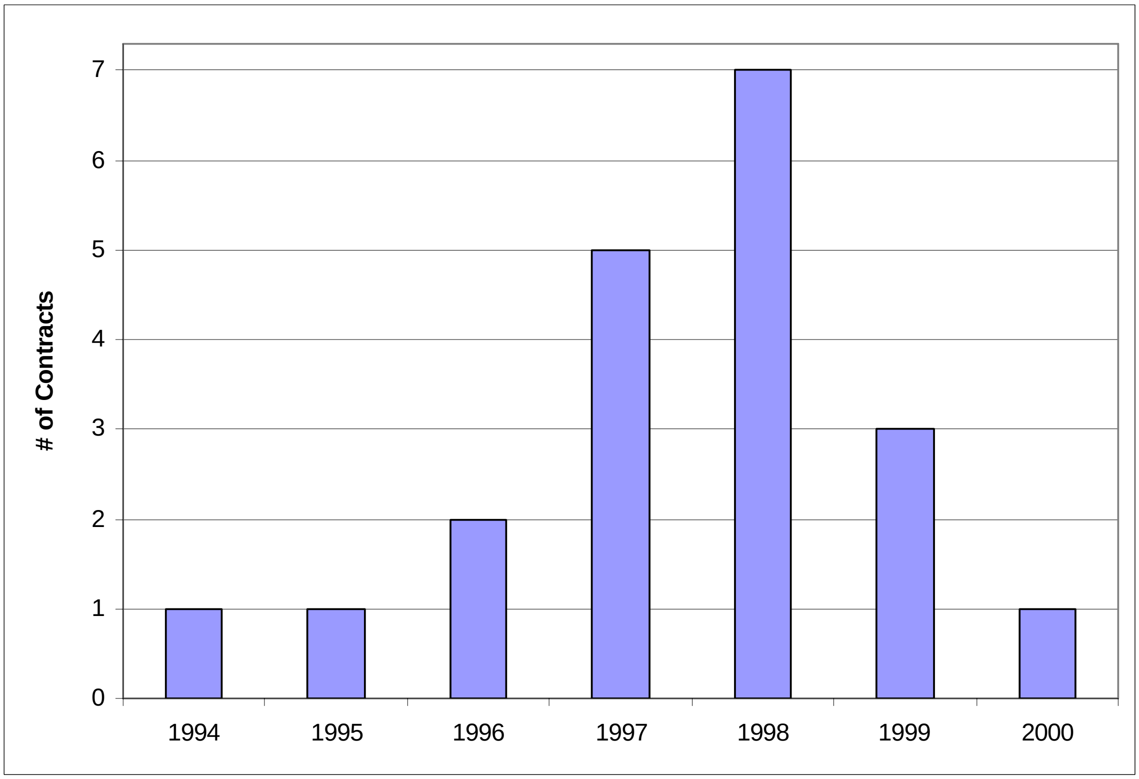


Figure 3.5.1 Number of Contracts Signed in Azerbaijan in a Given Year, 1994-2000

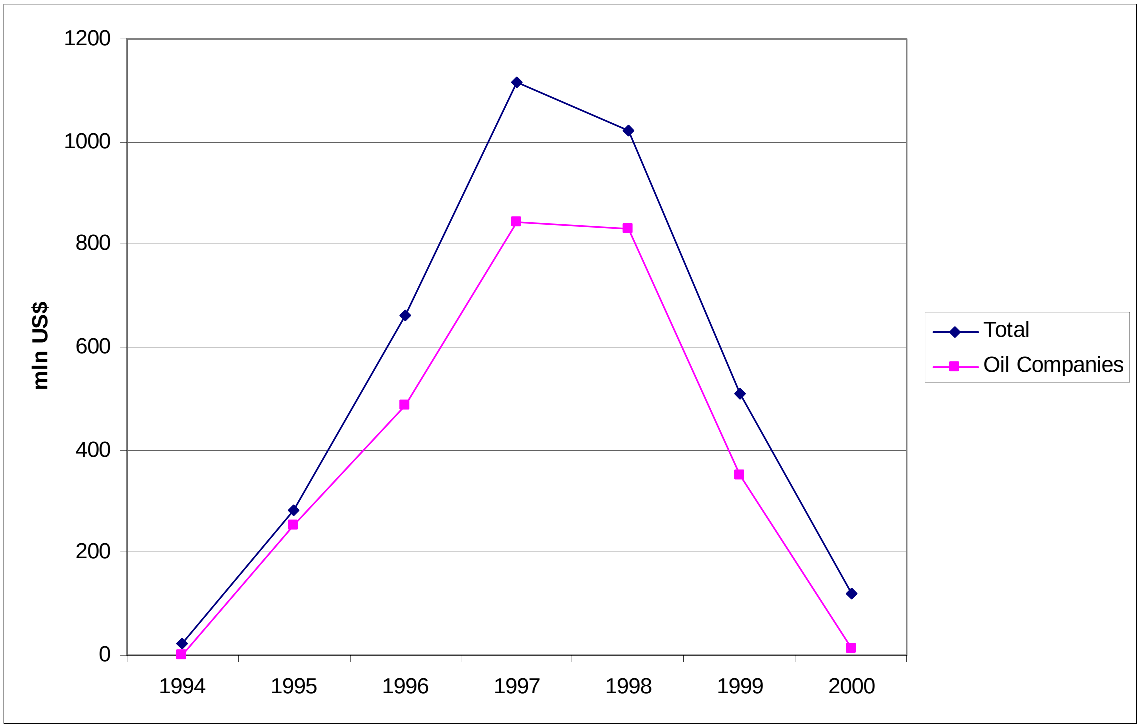


Figure 3.5.2 Direct and Portfolio Investment in Azerbaijan, 1994-2000, Million $
Source: IMF

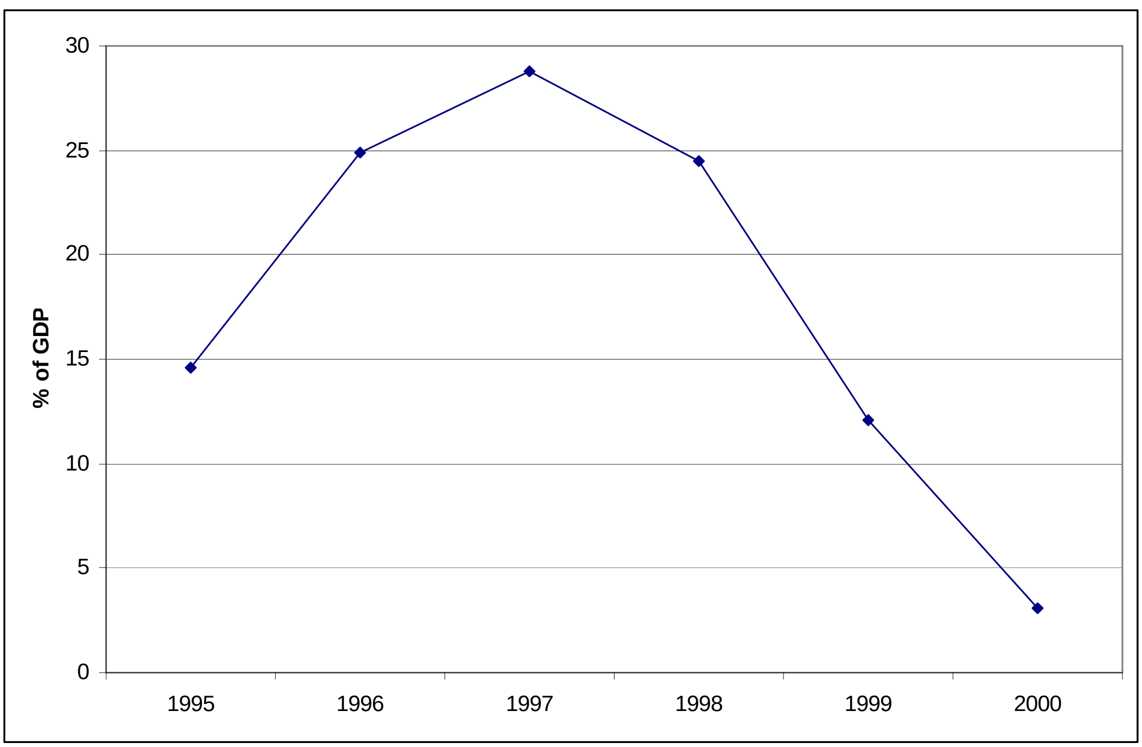


Figure 3.5.3 Gross Private Capital Flows in Azerbaijan as % of GDP, 1995-2000

Source: WB

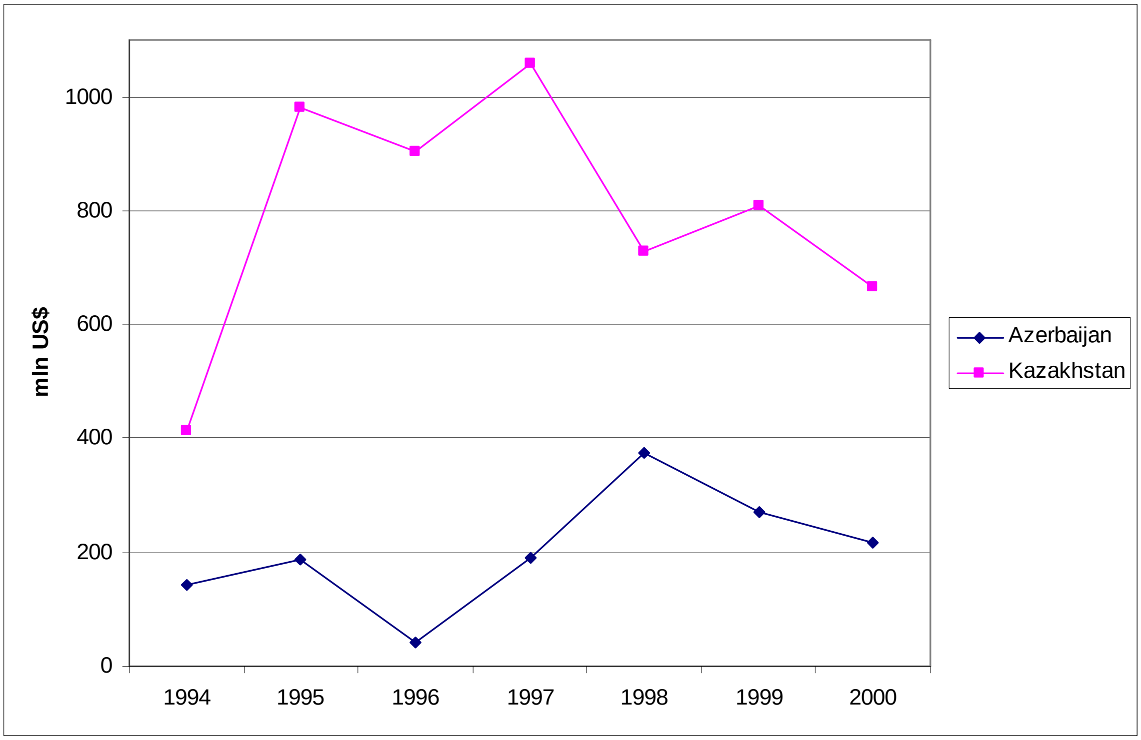


Figure 3.5.4 Commitments of Creditors in Azerbaijan and Kazakhstan, 1994-2000, Million $
Source: WB

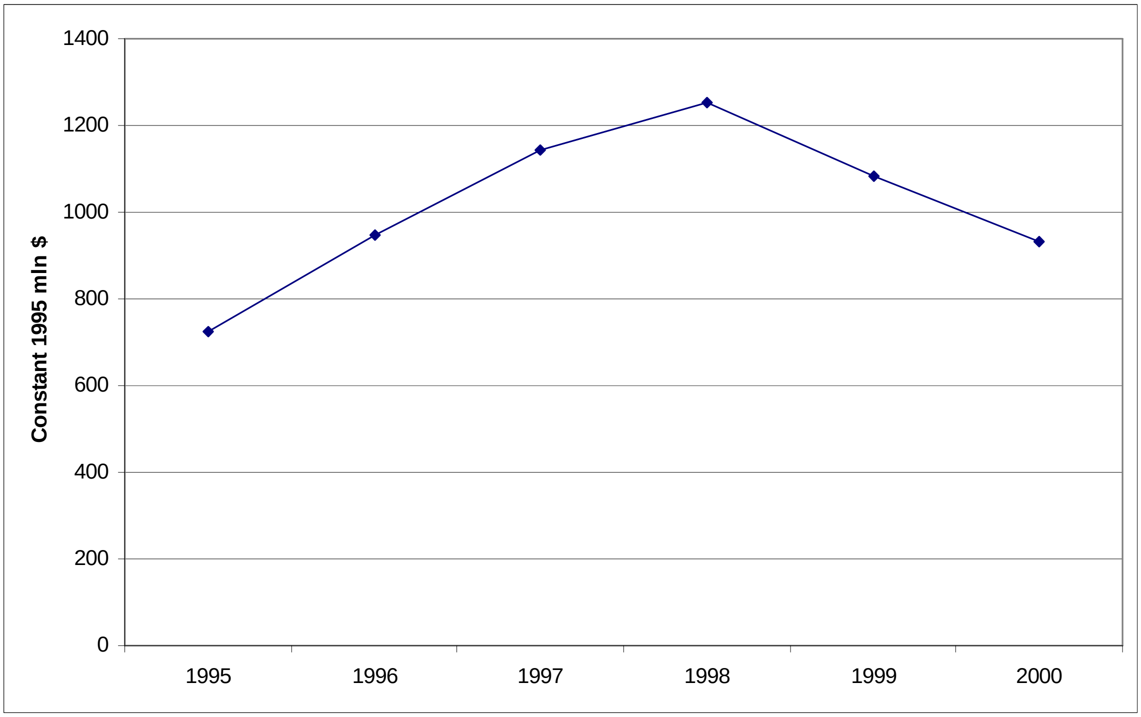


Figure 3.5.5 Gross Capital Formation in Azerbaijan, 1995-2000, Constant 1995 Million $
Source: WB

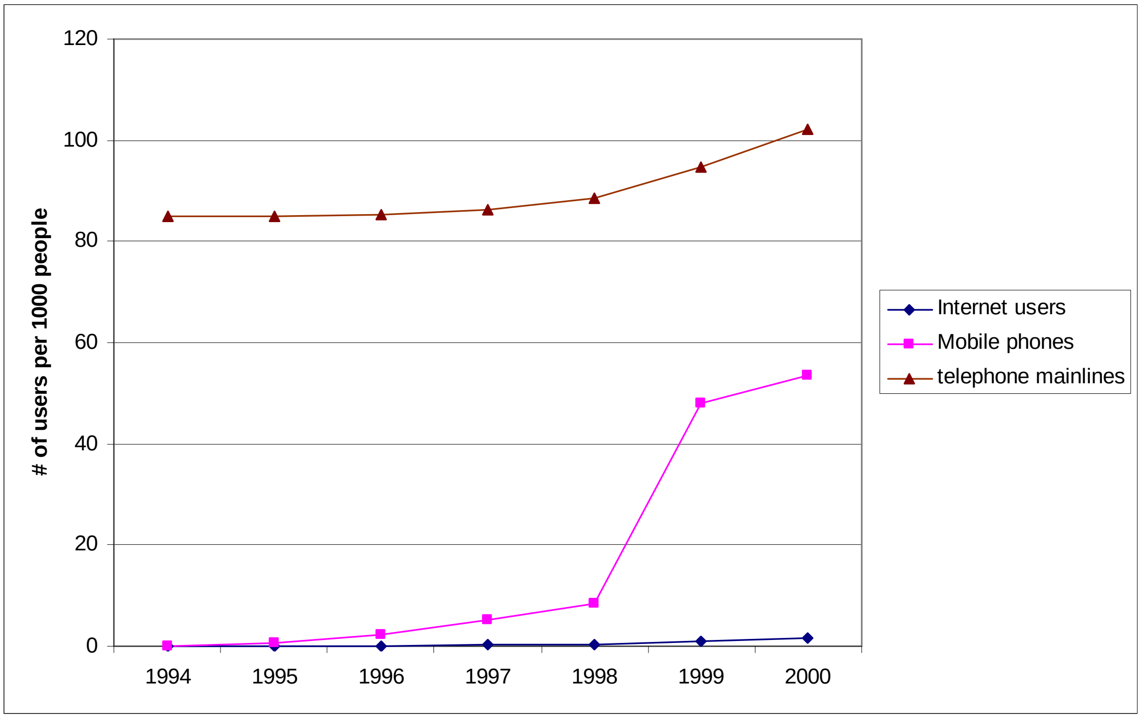


Figure 3.5.6 Development of Communication Infrastructure in Azerbaijan, 1994-2000
Source: WB

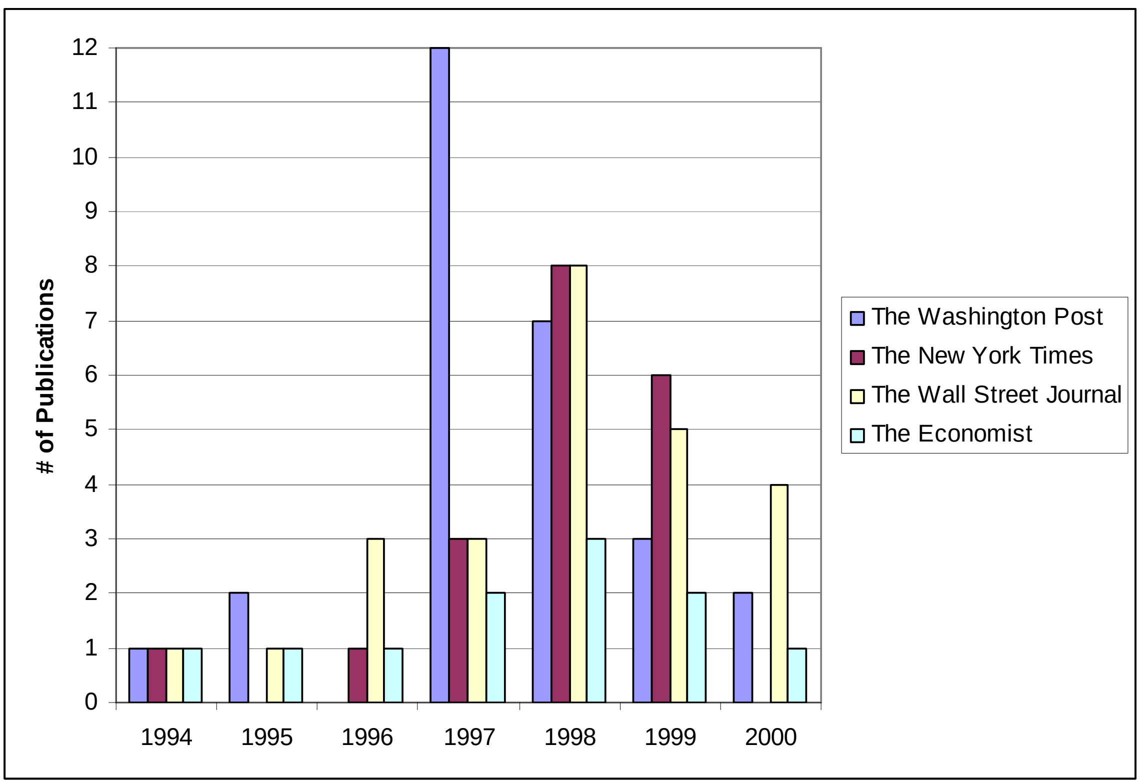


Figure 3.5.7 Number of Major Publications on Caspian Issues
in Selected International Media Sources in a Given Year, 1994-2000

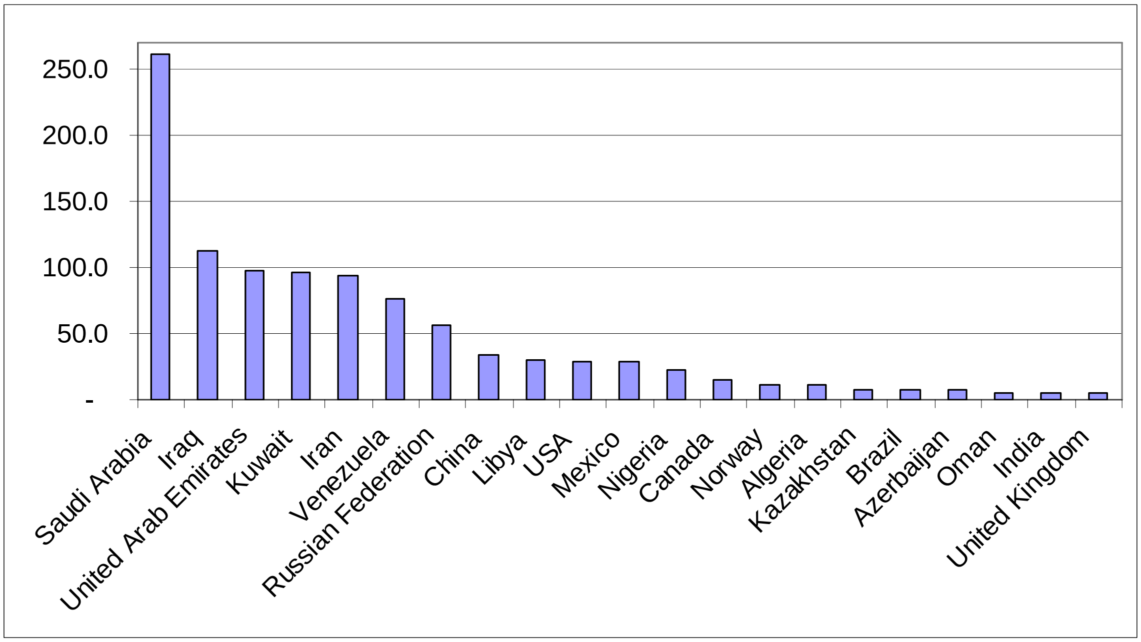


Figure 3.5.8 Oil: Proven Reserves, 1998, Thousand Million Barrels

Source: BP

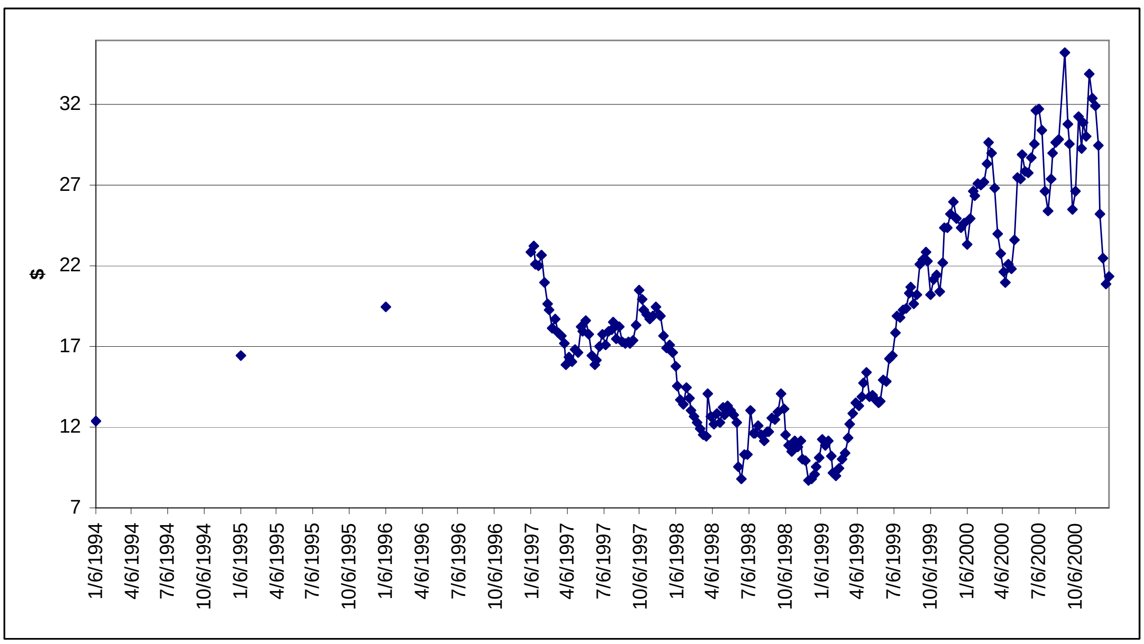
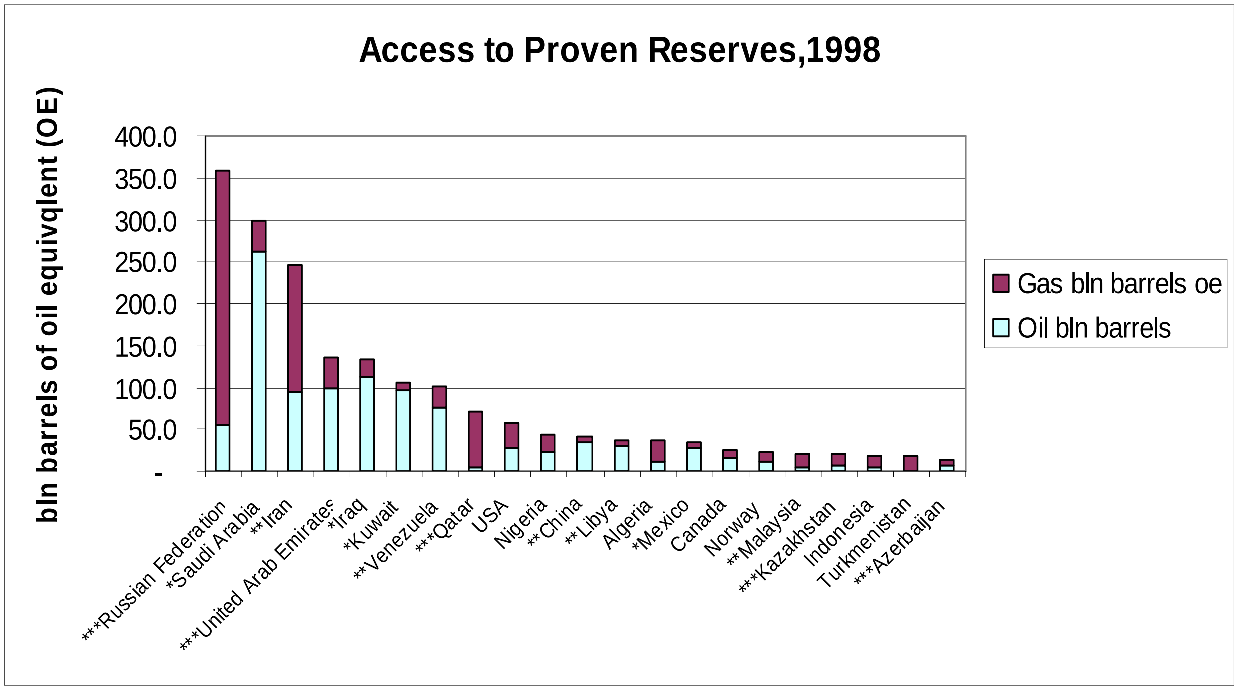


Figure 3.5.9 Mediterranean Russian Urals Spot Price FOB[13], 1994-2000,

$ per Barrel; 1994-1996 Annually; 1997-2000 Weekly

Source: U.S. Energy Information Administration, 2006

[13] Free on Board is defined as: A sales transaction in which the seller makes the product available for pick up at a specified port or terminal at a specified price and the buyer pays for the subsequent transportation and insurance. We are grateful to Larry Alverson of Weekly Petroleum Status Report, Energy Information Administration, for help with this issue



* Foreign firms have no access to reserves and production
** Foreign firms have limited access
*** Foreign firms can book oil and condensate as liquids reserves

Figure 3.5.10 Access to Proven Petroleum Reserves, 1998, Billion Barrels of Oil Equivalent
Source: BP, 2004; Nanay, 2000

Table 3.5.1 Comparison of Contract Terms in Different Oil Producing Regions

Country	Signature Bonus	Royalty Rate	Profit Oil Tax Rate
Azerbaijan	Yes	0	25%-32%
Angola	Yes	0	50%
Average African PSA	Yes	yes; may reach 20%	50%
India	No	0	50%
Average Asian PSA	Yes	5.5%	41%

Source: Bindemann, 1999; texts of the contracts

Table 3.5.2 Major News Releases on Developments in Azeri Oil Sector and Contracts Signed, 1994-2000

Year	News Release	News Source	# of Contracts Signed in a Given Year
1994	Sept, 1994: BP and Amoco signed the first production sharing agreement in Azerbaijan, Azeri, Chirag and Deepwater Guneshli	The New York Times The Wall Street Journal The Economist	1
1995	--	--	1
1996	--	--	2
1997	April, 1997: U.S. Department of State releases high estimates of the Caspian reserves (up to 178 billion barrels)	U.S. Department of Sate The Wall Street Journal	5
	Nov, 1997: BP starts production and export of oil from Chirag field	BP **check the source**	
1998	Spring 1998: Reports on concessions in working, including negotiations with Arco and Conoco	International Energy Agency Caspian Business Report	7
	April, 1998; Oct, 1998: Reports that the Caspian reserves may have been exaggerated	The Washington Post	
	Oct, 1998: Reports on dry wells drilled in Azeri fields	The Wall Street Journal	
1999	Feb, 1999: Karabakh project officially became non-operational	SOCAR	3
	April, 1999: Dan Ulduzu-Ashrafi project was officially closed	SOCAR	
	July, 1999: Arco leaves Azerbaijan	Alexander's Gas & Oil Connections	
	November, 1999: Conoco leaves Azerbaijan	Alexander's Gas & Oil Connections	
2000	--	--	1

Table 3.5.3 Production Sharing Agreements in Azerbaijan, 1994-2000

#	Tracts	Year	Company	Signature Bonus (million $)	Estimated Reserves (billion barrels)	Projected Investment (billion $)	Projected Investment per Barrel ($)
1	Azeri, Chirag, and Deepwater Gunashli	Sept 1994	BP Amoco	150[3]	5.4[1]	13[1]	2.41
2	Karabakh	Nov 1995	Pennenergy	8[3]	.88[2]	1.5[2]	1.70
3	Shakh-Deniz	June 1996	BP	37[3]	2.5[1]	3[1]	1.20
4	Dan Ulduzu-Ashrafi	Dec 1996	Amoco	8[3]	1[2]	2[2]	2.00
5	Lankaran-Talysh Deniz	Jan 1997	Elf	10	.70[1]	2[1]	2.86
6	Yalama	July 1997	Lukoil	n/a	.75[1]	2.5-5.5[1]	3.33
7	Absheron	Aug 1997	Chevron	10	.86[1]	3.5[1]	4.07
8	Oguz	Aug 1997	Mobil	10	.73	2	2.74
9	Nakhichevan	Aug 1997	Exxon	10	.75[1]	2[1]	2.67
10	Kurdashi-Araz-Kirgan	June 1998	Eni	32	.73[1]	2.5[1]	3.42
11	Genubi-Garbi Gobustan	June 1998	Commonwealth of Oil and Gas	n/a	.15[2]	.8[2]	5.33
12	Inam	July 1998	Amoco	32	2.2[1]	2[1]	0.91
13	Ahikh (Araz-Alov-Sharg)	July 1998	Amoco	10	4[1]	10[1]	2.50
14	Muradkhanli-Jafarli-Zardab	July 1998	Ramco	n/a	.73[1]	1[1]	1.37
15	Kursangi-Garabagly	Dec 1998	Frontera	n/a	.73[1]	1[1]	1.37
16	Atashgan	Dec 1998	Japan-Azerbaijan Oil Company	10	.6[1]	2.3[1]	3.83
17	Padar-Kharami	Apr 1999	Moncrief	n/a	.58-.75[1]	.14[1]	0.24
18	Lerik-Lenab-Savalan-Dalga	Apr 1999	Mobil	n/a	1[1]	3[1]	3.00
19	Zafar-Mashal	Apr 1999	Exxon	75[3]	1-2[1]	3[1]	3.00
20	Zukh-Govsany	June 2000	Lukoil	n/a	.06-.15[1]	.25[1]	4.17

[1] U.S. Energy Information Administration, 2004
[2] Bisnis, 1999
[3] As stated in the contract

4.0 ESSAY THREE

QUALITY OF INFORMATION, INFORMATION EXTERNALITIES AND SEQUENTIAL DECISIONS OF OIL COMPANIES

4.1 INTRODUCTION

In the mid-1990, the Caspian region managed to attract a great deal of investment in wildcat exploration of its oil and gas fields. This interest in the Caspian oil was often called "the great oil rush of the 20th century" (Ottaway and Morgan for ***The Washington Post***, 1997) and "the Great Game" (Raff for ***The Wall Street Journal***, 2004). However, some experts questioned the size of investment. Despite the fact that there was no agreement on the upper bound of the possible reserves, most of the researches were comfortable with more conservative estimates (U.S. Department of Interior, 1982; U.S. Department of State, 1997; Bahgat, 2003; Gregory, 2000; Skagen, 2000). Moreover, ex post some of the observers started calling investment in the Caspian "pouring money into a black hole" (***The Economist***, 1999).

So, what determines oil companies' decision to invest in a poorly explored oil region? In this essay, we argue that the oil companies tend to invest more in unexplored fields when information externalities are important, the decision-making is sequential and available public and private information is noisy.

We attempt to explain investment decisions of oil companies using social learning framework. In particular, we model investment of oil companies as sequential decisions to invest in projects of unknown value, when the values of the projects can be different but are correlated and the second company to invest can observe and get additional information from the investment decision of the first one. We show that under certain conditions the second company will invest in the development of a new oil field even if it received a bad informative signal about the profitability of the project. We also show that when companies receive noisy public and private information, the second company may be more likely to invest after receiving a bad signal.

There are reasons why information externalities and information spillovers might be important in oil exploration. The fields within a region may be located over a common oil pool or have similar geological characteristics. In both cases, the values of nearby tracts are correlated. A discovery of oil in a region is usually seen as a signal that there is more oil in nearby fields. Thus, there are information externalities provided by exploratory drillings.

The role of information externalities in oil exploration was studied by Hendricks and Kovenock (1989) and Hendricks and Porter (1996). Both papers were motivated by leasing practices of the US federal government, when the tracts are auctioned at the same time. Then the firms that won choose simultaneously whether and when to invest in exploratory drillings in the fields they acquired taking into account their private information and possible information externalities.

A few economists considered similar problem in more general framework. These papers include Bolton and Harris (1999), Frisell (2003) and Decamps and Mariotti (2004). All these models look at simultaneous irreversible investment decisions of the agents in the presence of asymmetric information and information externalities. Bolton and Harris (1999) study a strategic setting where each period players decide how much time they would invest into risky action given that they can learn from the experience of others. Frisell (2003) looks at a situation when two firms simultaneously decide when to enter the market and where to position themselves in product space. The firms do not know the exact market demand, but possess some asymmetric private information as well as can benefit from information spillover provided by the decision of the firm that invests first. Decamps and Mariotti (2004) study a duopoly model where players investment decision improves the quality of the signal received by its rival about the return of a common value project. Each firm has an incentive to delay its investment decision to convince the rival company that its costs are lower and it should invest first.

However, it is not always the case that the companies simultaneously decide whether to invest or not. As it was the case in the Caspian, tracts can be offered randomly at different times, so that by the time an oil company decides whether to invest in a field, it may observe the result of exploratory efforts in neighboring tracts. In this case, the firms that acquire oil fields later do not care about how much information their exploration decision may provide to the firms that will invest after them (since they do not know when and whether more tracts are going to be offered), but may free-ride on the additional public information provided by firms that have already invested in the neighboring fields. The information revealed by other firms may be so strong that the companies that make investment decision later may choose to invest in exploration despite their bad private signal.

The situation described above fits the social learning framework introduced by Sharfstein and Stein (1990), and Banerjee (1992) and Bikhandani, Hirshleifer and Welch (1992), which was further developed by Smith and Sorensen (2000) and Kariv (2004). The social learning models analyze an economy where exogenously ordered Bayesian agents try to pick the profitable project among given possibilities. Each decision-maker receives a private signal conditioned on the state of the world and can observe the picks of the agents before her. Since every agent uses her private information to choose the best project, each individual's decision reveals some information about her private signal hence producing an information externality. Therefore, the agents that decide later can free-ride on this additional information to improve their decisions.

The main conclusion of the models above is that eventually effect of the information externality becomes so overwhelming that every individual mimics the choice of her predecessor, even though she would have picked differently if she had decided on her own information alone. However, this behavior is fragile in a sense that a strong signal may cause it to change dramatically.

The above models also cannot be applied directly to explain the Caspian investment case since in oil exploration, the companies do not choose between the same projects. To the contrary, the companies are considering different investment opportunities which outcomes are correlated. In other words, after the state of the world is realized, it may be good for some companies and bad for the others. Hence, the information delivered through information externality is weaker than in traditional social learning models. It depends on the correlation between the projects' payoffs. This makes the decision of oil companies more complicated and their mimicing behavior more fragile than under a traditional social learning set-up.

We expand the existing social learning and oil exploration literature by examining decisions of the companies when they sequentially choose to invest in the projects of probably different but correlated values. Following Sharfstein and Stein (1990), we model the situation when two oil firms sequentially decide whether to invest in exploratory drillings in neighboring fields after each company received a private signal about the deposits in its field. The main features of our model are motivated by the oil development practices in the Caspian region which are discussed in Section 2. The reserves of the fields are unknown, but correlated in a sense that if one field contains oil, the other tract is more likely to contain oil as well. The actual size of the reserves can only be learned after drilling. Since the firms decide sequentially, the first firm will use its private information only in making investment decision. Its action will reveal some additional information to the firm that decides second because of the correlation of the deposits. The amount and quality of the revealed information will influence the decision of the second company.

We analyze the conditions that make companies explore in their fields. In particular, we are interested in the decision of the second firm since it is the one that can exploit information externalities. We pay additional attention to the situations when the second firm decides to drill in the field despite its bad private signal.

We will consider two possible situations: 1) both companies receive informative signals and 2) both companies receive noisy signals. We will show that under certain circumstances, the second company will be more eager to contradict its bad signal and follow the decision of the first company to drill when the available information is noisy. We argue that this is consistent with what we observed during the Caspian oil boom. Despite the noisy available public and private information, the companies with bad signals were more prone to follow the decision of the first companies to invest in Caspian oil. That's why we observed a somewhat unexpected high investment in the region where the possible reserves were very poorly explored.

We will also contrast the situation when the second company observes not just the decision of the first one, but also the size of the deposit it found if it decided to drill, with the situation when the second company observes just the investment decision of the first company. The information externality in the second case is noisier than in the first one since it reveals not as much information about the reserves in the first field, but information about the signal of the first company which is not a perfect predictor of its reserves.

We will show that the second company will be more likely to contradict its signal after observing the reserves in the other field, i.e. when information externality is less noisy. In other words, the second company will be less likely to mimic the decision of the first one and explore in its field after the first company found low reserves. We argue that this result is consistent with the decrease of investment flow to the Caspian oil fields after 1999: a strong negative public information made the companies more cautious.

The rest of the essay is organized as follows: Section 4.2 discusses oil exploration boom in the Caspian region; Section 4.3 presents the model; Section 4.4 defines decisions of the firms under information externalities of different quality, Section 4.5 compares these decisions and Section 4.6 concludes.

4.2 OIL EXPLORATION IN THE CASPIAN REGION

The Caspian region[14] opened for international investment in early 1990. In a short period of time, the region managed to attract a huge volume of investment into its oil and gas fields. For example, in Azerbaijan alone the contracts signed with the foreign oil companies by 1998 represented over $30 billion in long-term capital investment with some $2.5 billion in sunk and committed investment (International Energy Agency, 1998; International Energy Agency, 2000).

[14] The Caspian region (namely, former Soviet republics of Azerbaijan, Kazakhstan and Turkmenistan) is defined by geology, i.e. location of conformed oil and gas reserves in particular, rather than demography.

To some of the experts, the volume and dynamics of the foreign investment flow was surprising. First, the size of the Caspian proven reserves was not significant in comparison to some other areas in the world. Despite the fact that the region had been poorly explored and its real oil potential was unknown[15], most of the experts agreed that the Caspian would never become "the second Middle East" and was more likely to be comparable in its importance with the North Sea. Second, the majority of the oil companies entered the region in 1997-1998, six years after they had gained access to the Caspian reserves. Soon after, however, the investment excitement started calming down with no new companies coming to the region and no new exploration projects emerging.

Some of the possible explanations of the shape and amount of investment in the Caspian are the nature of the oil industry and the legal environment in the region. Since oil is not a renewable resource and the companies are constantly looking for replacement of their old, worked-out reserves, the opening up of the Caspian oil provided the companies with the access to new oil areas which were the best investment prospects given the other oil regions open for international development[16]. The decent legal environment strong enough to support investment of oil companies emerged by 1996-1997, thus the most of the contracts were signed in 1997-1998.

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[15] According to the US State Department report to the Congress, Azerbaijan and Kazakhstan's proven oil reserves were 3.6 and 10 billion barrels respectfully, which is much smaller than, let's say, Russia's 56 billion barrels or Venezuelan 74.9 billion barrels or Saudi Arabian 261.5 (US Department of State, 1997; BP, 2004). Despite the fact that there were no agreement on the upper bound of the possible reserves, it varied from 13.2 billion barrels of undiscovered reserves in Azerbaijan by the US Department of the Interior to 27 billion barrels of possible reserves in Azerbaijan only and probable 178 billion barrels in the whole region by the US State Department (US Department of Interior, 1982; US Department of State, 1997).

[16] In mid-1990, the production from the oil provinces of the Alaskan North Slope and the North Sea was declining. However, most of the richest oil regions (e.g., Middle East countries) were either completely closed or offer limited opportunities to the international investment.

However, the above explanations still do not provide a decent reason why so much investment came to the poorly explored region in such a short period of time and why it fell drastically after 1999. After 1999, no new region opened up as a major new play; the legal environment in the Caspian stayed unchanged.

To our mind, the problem with the above explanations is that they do not take into account informational environment in which the companies had to make their investment decisions. As it has been mentioned above, the actual reserves in the region were unknown. Hence, the possible information externalities from any new exploration efforts had to play a very important role in oil exploration in the Caspian.

Let's look at the Caspian investment boom closer. To make discussion less complicated, we will examine investment in Azerbaijan only since it attracted most investment in unexplored fields. Table 4.2.1 presents the dynamics of investment in Azerbaijan in 1994-2000:

Table 4.2.1 Dynamics of Oil Investment in Azerbaijan

Year	**Number of Contracts Signed**	**Company**		**Average Bonus Per Contract**	**Main Events**
		Major	Non-Major		
1994	1	1	0	150	
1995	1	0	1	8	
1996	2	2	0	22.5	
1997	5	5	0	10	The first contract started production
1998	7	3	4	14	2 contract areas revealed no oil
1999	3	2	1	75	
2000	1	0	1	n.a.	

The companies entered Azerbaijan sequentially, with a few projects emerging in 1994-1996 and much more in 1997 and 1998. Starting 1999, almost no one was willing to invest in the country's oil fields.

The reason for sequential decision-making by the companies was a cautious procedure of contracting off the tracts introduced by the local government. The fields were offered either by one or in small groups in different periods of time to the particular oil company/consortium; each contract was negotiated individually. All contracts in Azerbaijan had the following feature: if a company had entered a contract, it committed itself to a minimum exploration program on the area of the contract. The company was to conduct seismic analysis of the area and drill three to five exploratory wells with targeted depth within a certain period of time or pay a fine equal to the costs associated with the commitment. Thus, if a company decided to enter the contract, it committed itself to the irreversible investment decision; it could not simply sit and wait till some one else drilled first.

Information on the signed contracts and their development updates was available through companies' press releases and different media outlets. Hence, by the time the later companies were considering signing a contract, they were able to observe whether other companies had entered contracts in neighboring fields and even the results of their exploratory drillings if the timing of investment decision was long after the first contracts were signed.

The traditional models of investment in the presence of information externalities cannot be applied to the investment process described above. These models look at the cases, when the firms decide simultaneously whether to invest or not; in their decision they have to take into account the trade-off between additional information revealed through information externalities and lost profit due to delaying investment decision.

Investment in Azeri oil fields is closer to the decision-making mechanism analyzed in social learning literature. There, the agents make sequential investment decisions and every next decision maker is able to observe the history of actions taken before her. The history of decisions provides information externality, the effect of which can be so strong that the later companies may choose to invest in a certain project despite their private information. This may be consistent with the investment spike in the Caspian in mid-1990s: some of the companies that were offered the tracts later might have been following the decision of the first companies to invest.

However, the results of social learning models also cannot be directly used to explain Caspian oil boom. In the social learning set-up, the agents are choosing to invest in the same projects. In the Caspian, the companies were offered investment opportunities in different tracts, deposits size of which could have been correlated. Hence, the information externalities provided to the later companies were not as strong. The amount of information revealed by the decisions of the first-comers depended on the beliefs about correlation between the fields reserves.

Besides, different companies observed information externalities of different quality. Some of the companies were offered a tract after the first company just had made its investment decision; others were considering drilling in a tract after the drilling results of the first company had become known.

Decisions of oil companies also depend on private signals and their quality. When the companies were offered a tract, they would receive some seismic information on the area. Ex post, we can infer how promising this information was. After texts of the contracts were released, we got information on the size of signature bonuses of each contract (average bonus per year is presented in Table 4.3.1). A signature bonus is a company's cost of signing a contract. Its' size is negotiated before the contract is signed and it is typically paid to the government of Azerbaijan within 30 days of the contract going into effect. The size of a signature bonus depends on the size of the expected reserves and probability of getting them: the bigger the field and the more certain its reserves are, the bigger is the signature bonus.

Note that the signature bonus information was not disclosed to other companies at the time the contract was signed. However, ex post we can conclude that the first company to enter Azerbaijan had the most promising private information (see Table 4.3.1): it agreed to pay a huge bonus of $150 million dollars.

As experts noted, the seismic information provided by local governments was of good quality but difficult to interpret: Caspian off-shore reserves are located in a young basin that has not reached its equilibrium yet because the productive part of the Caspian Sea is still moving (Appendix a: interviewees #6, #9, #11). Hence, some companies would have more difficulties in interpreting data that the others.

Note from Table 4.3.1 that Azeri fields attracted oil companies of different types. In particular, the companies that entered Azeri contracts can be divided into two categories: (1) internationally integrated oil companies ("majors"), and (2) domestically integrated and independent exploration and production oil companies ("non-majors"). Majors are involved in every aspect of oil business (exploration and production, transportation of crude oil and refined products, and refining and marketing) both in the domestic and overseas markets. Non-majors have their main operations in the domestic markets and only limited exploration and production operations in the foreign markets. Since the majors have more involvement in oil production, it is believed they have more expertise in exploring new fields and thus are better in interpreting the data they receive on potential projects. Note from Table 4.3.1 that the first companies to enter the region were mostly majors. Non-majors come to the region after good exploration results of the first project were disclosed.

To summarize, the decision making of oil companies concerning Caspian oil projects had the following features. First, the companies decided whether to invest in exploration of the fields (i.e., whether to enter a contract or not) sequentially; the timing and order of decision-making was rather random and determined exogenously (by the government). Second, before making an investment decision, companies received private information about the contract area. This information could have been not just promising or not, but also quite noisy due to interpretation difficulties.

Third, because of media disclosures, the companies to decide later were able to observe whether other companies entered contracts in neighboring fields and even the results of their exploratory efforts. This publicly available information provided some information externalities which were weaker in the case when the later companies observed the decision of the first company compared to the case when they observed the actual reserves found by the first company.

These features of the sequential exploration in presence of information externalities of different quality can be captured in a model with two firms and two fields presented in the next section. We show that the second company is more likely to contradict its private information and follow the decision of the first one when both companies receive noisy signals. We also show that the second company is more likely to contradict its private information when the quality of its signal is equal or less than the quality of the signal of the first company.

The result above explains why majors with relatively poor private information (i.e., information worth a rather small signature bonus) entered the region in 1995-1996. Under noisy private information and weak information externality (they just observed the decision of the fist major to enter), they were more prone to mimic the decision of the first major to enter.

We also show that when information externality is stronger, i.e. the second firm is able to observe the results of the first firm's exploration efforts; it is more likely to contradict its signal. This explains a spike in investment in the Caspian region in 1997-1998: after good drilling results of the first project were released, non only majors but also non-majors were attracted to the region. Also, this result provides explanation why investment stopped coming to the region after 1999. In 1998 bad exploration information became available. As a result, almost no new projects emerged; the projects that were signed, had rather high signature bonuses suggesting that the seismic information was so promising that it overwhelmed negative public information.

The next two sections will develop the described above results formally.

4.3 A MODEL OF SEQUENTIAL EXPLORATION

Assume there are two oil fields located next to each other, 1 and 2. The reserves in the fields are disjoint. The size of the reserves r in each field is unknown; it could be either high (r_i=1) or low (r_i=0) with equal probability, i.e.,

$$\Pr(r_i=1) = \Pr(r_i=0) = 0.5; \; i = 1,2 \quad (1)$$

The actual reserves of a field can be observed only after drilling. There are four states of the world, R, that are possible: $\{1_1,1_2\}$, $\{1_1,0_2\}$, $\{0_1,1_2\}$ and $\{0_1,0_2\}$.

The reserves sizes in the fields are believed to be correlated. If high oil reserves are found in one of the fields, the other field is believed to contain high reserves with probability q>0.5; similarly, if there are low oil reserves found in one field, then the other is expected to have low reserves with probability q as well. I.e.,

$$Pr(r_i=1|r_j=1) = Pr(r_i=0|r_j=0) = q>0.5; \quad (2)$$

$$Pr(r_i=1|r_j=0) = Pr(r_i=0|r_j=1) = (1-q);\ i,j = 1,2;\ i\neq j$$

(1) and (2) define the following joint distribution of the reserves:

Table 4.3.1 Joint Distribution of Reserves, $Pr(r_i,r_j) = Pr(r_i|r_j)\ Pr(r_j)$

	$\mathbf{1_j}$	$\mathbf{0_j}$
$\mathbf{1_i}$	$0.5q$	$0.5(1-q)$
$\mathbf{0_i}$	$0.5(1-q)$	$0.5q$

(3)

Note that since q>0.5, then matching states of the world (i.e., the states where both fields have the reserves of the same size) are more likely.

There are two firms, F_1 and F_2, considering drilling in each field: F_1 in field 1 and F_2 in field 2. If a firm drills and finds high reserves, it starts developing the field and gets a positive payoff of x_H; if it drills and finds low reserves, the firm has a loss of $-x_L$; $|x_H| > |x_L| > 1$.

Each firm receives a informative private signal, s_i^I, about oil reserves in the field it is considering: $s_i^I = 1$ for high reserves and $s_i^I = 0$ for low reserves (the assumption of informative signals will be relaxed later in the paper). The signals have the following structure:

$$s_i^{\,I} = \begin{cases} 1_{\{f(r_i)+\varepsilon_i>0\}} \\ 0_{\{f(r_i)+\varepsilon_i<0\}} \end{cases},$$

$$s_j^{\,I} = \begin{cases} 1_{\{f(r_j)+\varepsilon_j>0\}} \\ 0_{\{f(r_j)+\varepsilon_j<0\}} \end{cases};$$

$$\begin{pmatrix} \varepsilon_i \\ \varepsilon_j \end{pmatrix} \sim N\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}; \begin{pmatrix} 1\,0 \\ 01 \end{pmatrix}\right)$$

where $f(r_i)$ is some function of the reserves in field i. Note that given the reserve size in each field, the signals are independent. However, when deposits sizes are unknown, the signals are correlated since random variables r_i and r_j are correlated.

We assume that

$$f(1_i) > 0; \qquad (4)$$
$$f(0_i) < 0$$

(4) insures that firm i is more likely to receive a high signal about its field reserve size if the field actually contains high reserves.

The structure of the signals imposes the following conditional distribution of the signals:

$$\Pr(s_i^I = 1|r_i) = \Pr(f(r_i) + \varepsilon_i > 0) = \Pr(-\varepsilon_i < f(r_i)) = \Phi(f(r_i));$$
$$\Pr(s_i^I = 0|r_i) = 1 - \Phi(f(r_i)) \qquad (5)$$

(4) implies that for firm i,

$$\Phi(f(1_i)) > 0.5 > \Phi(f(0_i)) \qquad (6)$$

Distribution (5) defines the following conditional distributions of the signals:

$$\Pr(s_i^I = 1|r_i,r_j) = \Pr(s_i^I = 1|r_i) = \Phi(f(r_i))$$

$$\Pr(s_i^I = 0|r_i,r_j) = \Pr(s_i^I=0|r_i) = 1 - \Phi(f(r_i)) \quad (7)$$

$$\Pr(s_i^I = 1,s_j^I=1|r_i,r_j) = \Pr(-\varepsilon_i < f(r_i), -\varepsilon_j < f(r_j)) = \Phi(f(r_i))\,\Phi(f(r_j)) \quad (8)$$

$$\Pr(s_i^I = 1,s_j^I=0|r_i,r_j) = \Phi(f(r_i))(1 - \Phi(f(r_j)))$$

Note that signals are good instruments since (6) implies the following about distributions (7) and (8):

1) $\Pr(s_i^I = r_i|r_i) > \Pr(s_i^I \neq r_i|r_i)$

2) $\Pr(\{s_i^I,s_j^I\}= \{1,1\}|1_i,1_j) > \Pr(\{s_i^I,s_j^I\}\neq \{1,1\}|1_i,1_j)$

$\Pr(\{s_i^I,s_j^I\} = \{1,0\}|1_i,0_j) > \Pr(\{s_i^I,s_j^I\} \neq \{1_i,0_j\}|1_i,0_j)$

$\Pr(\{s_i^I,s_j^I\}=\{0,0\}|0_i,0_j) > \Pr(\{s_i^I,s_j^I\}\neq\{0_i,0_j\}|0_i,0_j)$

(all of the proofs are presented in Appendix B).

Hence, an informative signal i does a good job in predicting the reserves of field i as well as the combination of the signals does a good job in predicting the state of the world.

For simplicity, let

$$f(0_i) = - f(1_i)$$ [17]

[17] It is possible to construct such a function. For example, for firm i

$f(r_i) = 2r_i - 1 \rightarrow$

$f(1_i) = 1;\ f(0_i) = -1$

and $\Phi(f(1_i) = a > 0.5$

Then conditional distributions of firm i's signals defined in (7) and (8) look as follows:

Table 4.3.2 Distribution of Firm i's Signal Conditional on r_i, $Pr(s_i^I|r_i)$

	$Pr(s_i^I\|1_i)$	$Pr(s_i^I\|0_i)$
$s_i^I=1$	a	$1-a$
$s_i^I=0$	$1-a$	a

(9)

Table 4.3.3. Distribution of Firm i's Signal Conditional on $\{r_i,r_j\}$, $Pr(s_i^I|r_i,r_j)$

	$Pr(s_i^I\|1_i,1_j)$	$Pr(s_i^I\|0_i,1_j)$	$Pr(s_i^I\|1_i,0_j)$	$Pr(s_i^I\|0_i,0_j)$
$s_i^I=1$	a	a	$1-a$	$1-a$
$s_i^I=0$	$1-a$	$1-a$	a	a

(10)

Table 4.3.4 Distribution of Combinations of Signals Conditional on $\{r_i,r_j\}$, $Pr(s_i^I,s_j|r_i,r_j)$

	$Pr(s_i^I,s_j^I\|1_i,1_j)$	$Pr(s_i^I,s_j^I\|1_i,0_j)$	$Pr(s_i^I,s_j^I\|0_i,1_j)$	$Pr(s_i^I,s_j^I\|0_i,0_j)$
$s_i^I = 1, s_j^I = 1$	a^2	$a(1-a)$	$a(1-a)$	$(1-a)^2$
$s_i^I = 1, s_j^I = 0$	$a(1-a)$	a^2	$(1-a)^2$	$a(1-a)$
$s_i^I = 0, s_j^I = 1$	$a(1-a)$	$(1-a)^2$	a^2	$a(1-a)$
$s_i^I = 0, s_j^I = 0$	$(1-a)^2$	$a(1-a)$	$a(1-a)$	a^2

(11)

Note that a priori, each signal is equally likely to be received by firm i:

$$\Pr(s_i^I=1) = \Pr(s_i^I=0) = 0.5 \tag{12}$$

From Tables 4.3.1 and 4.3.4 we can get unconditional distribution of all possible signals combinations:

$$\Pr(s_i^I=1,s_j=1) = \Pr(s_i^I=0,s_j=0) = 0.5a^2q + 0.5(1-a)^2q+a(1-a)(1-q) \tag{13}$$

$$\Pr(s_i^I = 1,s_j=0)=\Pr(s_i^I=0,sj=1) = 0.5a^2(1-q) + 0.5(1-a)^2(1-q)+a(1-a)q \tag{14}$$

Note that a priory, it is more likely to receive a matching combination of the signals than a non-matching combination since

$$\Pr(s_i^I = 1,s_j=1)=\Pr(s_i^I=0,sj=0) > \Pr(s_i^I=1,s_j=0)=\Pr(s_i^I=0,s_j=1)$$

This makes sense since a priory matching states of the world are more likely than non-matching states.

Firms decide whether to drill in its field sequentially: F_1 decides first and F_2 decides second. F_2 can observe the action of F_1. Each firm will decide to drill if its expected profit from drilling is positive. The decision process goes as follows: first, the nature determines the state of the world; then, the firms get signals; next, F_1 decides whether to drill or not; finally, F_2 observes the action of F_1 and then makes its decision to drill.

4.4 DECISION OF THE COMPANIES UNDER PRIVATE AND PUBLIC INFORMATION OF DIFFERENT QUALITY

4.4.1 Case 1: Firm 2 Received an Informative Signal and Observes Reserves in the Neighboring Field

Here, before making its decision, F_2 considers the best information possible under the above set-up. F_2 has received an informative signal, s_2^I, and observes not only the decision of F_1 to drill or not, but also the reserves in field 1, r_1, if F_1 decides to drill. In other words, information externality generated by F_1's exploration efforts is rather strong. This corresponds to a case, when F_2 has to decide whether to drill or not in its field long after F_1 decided to drill. In Case 1 we address the situation when F_1 decides to drill in its field and finds the size of its deposit (the situation when F_1 decides not to drill in its field is analyzed in Case 2).

In this case, F_1's decision to drill per se is not important to F_2 since the size of the deposit in field 1 provides stronger information externality. F_2 incorporates this additional information and uses (3), (10) and (12) to calculate its expected profit:

$$E\Pi_2 \mid \{s_2{}^I, r_1\} = \Pr(1_2 \mid s_2{}^I, r_1\} x_H - \Pr(0_2 \mid s_2{}^I, r^1\ ) x_L = \frac{\Pr(s_2{}^I \mid 1_2, r_1)\Pr(1_2, r_1)}{\Pr(s_2{}^I)\Pr(r_1)} x_H - \frac{\Pr(s_2{}^I \mid 0_2, r_1)\Pr(0_2, r_1)}{\Pr(s_2{}^I)\Pr(r_1)} x_L$$

F_2 will decide to drill in its field if $E\Pi_2|\{s_2^I, r_2\}>0$. I can write the decision rule of F_2 as follows:

drill iff $0 < E\Pi_2|\{s_2^I, r_1\} \leftrightarrow$

$x_L < T^{\{s_2^I, r_1\}}(x_H)$

$:= T^{\{s_2^I, r_1\}}$

As it is seen, we define F_2's decision as a cut-off strategy: it decides to drill if the losses are below some function of the possible gain. There are four cutoffs since F_2 has two possible signals and observes two possible reserve sizes in the other field. The cutoffs are presented in the table below:

Table 4.4.1.1 Case 1: Cutoffs of F_2, $T^{\{s_2^I, r_1\}}$

Signal of F_2	**Reserves of F_1**	
	1_1	**0_1**
s_2=1	$\frac{a}{1-a}\frac{q}{1-q}x_H$	$\frac{a}{1-a}\frac{1-q}{q}x_H$
s_2=0	$\frac{1-a}{a}\frac{q}{1-q}x_H$	$\frac{1-a}{a}\frac{1-q}{q}x_H$

The thresholds, defining F_2's decision in each case, show the trade-off between information delivered by the signal (the first part of each cutoff) and information delivered through the information externality (the second part of each cutoff). If the signal is very precise, i.e., $a \rightarrow 1$, then F_2 will be less likely to drill after receiving a low signal and more likely to drill after receiving a high signal despite the reserve size in the other field. On the other hand, if the correlation between the fields is very high, i.e., $q \rightarrow 1$, then F_2 will be more likely to drill after observing high reserves and will never drill after observing low reserves independent of its private signal.

Note that $x_L < T^{\{s_2^{I,r}{}_1\}}$ for all *a, q* >0.5; $x_H > x_L$. Thus, F_2 will always drill after receiving a high signal and observing high reserves in the neighboring field. F_2's decision rule in Case 1 is summarized in Table 4.4.1.2:

Table 4.4.1.2 Case 1: Decision Rule of F_2

Signal of F_2	**Reserves of F_1**	
	1_1	**0_1**
$s_2^I = 1$	Always drill	Drill if $x_L < T^{\{s_2^{I=1,0}{}_1\}}$
$s_2^I = 0$	Drill if $x_L < T^{\{s_2^{I=0,1}{}_1\}}$	Drill if $x_L < T^{\{s_2^{I=0,0}{}_1\}}$

The above thresholds are ordered as follows:

$$T^{\{s_2^{I=1,0}{}_1\}} > T^{\{s_2^{I=0,0}{}_1\}} \tag{15}$$

$$T^{\{s_2^{I=0,1}{}_1\}} > T^{\{s_2^{I=0,0}{}_1\}} \tag{16}$$

$$T^{\{s_2^{I=1,0}{}_1\}} \gtrless T^{\{s_2^{I=0,1}{}_1\}} \text{ iff } \frac{a}{1-a} > or < \frac{q}{1-q} \tag{17}$$

Note that the last ordering depends on information provided by F_2's signal vs. information provided through information externality. If a→1, then $T^{\{s_2^{I=1,0}{}_1\}} > T^{\{s_2^{I=0,1}{}_1\}}$ and F_2 will be more likely to trust its signal than look at the reserves in the other field. On the other hand, if *q*→1, then $T^{\{s_2^{I=1,0}{}_1\}} < T^{\{s_2^{I=0,1}{}_1\}}$ and F_2 will be more likely to look at the reserves in field 1 than at its signal.

(15), (16) and (17) together with Table 4.4.1.2 imply Proposition 1:

Proposition 1

1) Given low reserves were found in the other field, F_2 is more likely to drill in its field after receiving a high informative signal than after receiving a low informative signal.

2) Given it received a low informative signal, F_2 is more likely to drill in its field after high reserves were found in the other field than after low reserves were.

3) F_2 is more likely to follow its informative signal when its informativeness, a, is very high. If the correlation between the reserves, q, is very high then F_2 is more likely to contradict its informative signal.

4.4.2 Case 2: Firm 2 Received an Informative Signal and Observes Decision of Firm 1

In Case 2, F_2 will just observe the decision of F_1 to drill or not when both firms receive informative signals, i.e., information externality provided by F_1's decision is weaker. This corresponds to the situation, when F_2 has to make its decision after F_1 decided whether to drill or not, but before the drilling results became available if F_1 decided to drill. In this case decision of F_1 may reveal its signal about the reserves in field 1. This information is still valuable to F_2 since the fields reserves are correlated. But F_2 also has to consider that there is a positive probability that F_1's signal is wrong.

In order to see how much information can be revealed by F_1, let's analyze its decision rule. Since there is no strategic element in its decision, F_1 will choose to drill using its signal only. In particular, after receiving a signal, F_1 uses (3), (9), (12) and Bayes rule to find its expected profit:

$$E\Pi_1 \mid \{s_1{}^I\} = \Pr(1_1 \mid s_1{}^I\} x_H - \Pr(0_1 \mid s_1{}^I) x_L = \frac{\Pr(s_1{}^I \mid 1_1)\Pr(1_1)}{\Pr(s_1{}^I)} x_H - \frac{\Pr(s_1{}^I \mid 0_1)\Pr(0_1)}{\Pr(s_1{}^I)} x_L$$

and decides to drill if the expected profit is positive. As in deriving the decision rule of F_2, we can identify the cutoffs, $T^{\{s_1{}^{I=1}\}}$, of F_1:

Table 4.4.2.1 Case 2: Cutoffs of F_1

Signal of F_1	**Cutoffs of F_1, $T^{\{s_1{}^{I=1}\}}$**
$s_1{}^I = 1$	$\frac{a}{1-a} x_H$
$s_1{}^I = 0$	$\frac{1-a}{a} x_H$

F_1 will drill in its field if the loss is below the corresponding cut-off. Note that $x_L < T^{\{s_1{}^{I=1}\}}$ for all $a>0.5$, meaning that F_1 will always drill after receiving a high signal. Consequently, if $x_L < T^{\{s_1{}^{I=0}\}}$, then F_1 drills independent of its signal and no private information is revealed. However, if $x_L > T^{\{s_1{}^{I=0}\}}$, then F_1 drills only after receiving a high signal revealing its private information.

Let

$$x_L > T^{\{s_1{}^{I=0}\}} \qquad (18)$$

so that F_2 can benefit from observing the decision of F_1. It then updates its expectation of reserves in its field accordingly and uses (3), (11), (13) and Bayes rule to get expected profit:

$$E\Pi_2 \mid \{s_2{}^I, s_1{}^I\} = \Pr(1_2 \mid s_2{}^I, s_1{}^I\} x_H - \Pr(0_2 \mid s_2{}^I, s_1{}^I) x_L = \frac{\Pr(s_2{}^I, s_1{}^I \mid 1_2)\Pr(1_2)}{\Pr(s_2{}^I, s_1{}^I)} x_H - \frac{\Pr(s_2{}^I, s_1{}^I \mid 0_2)\Pr(0_2)}{\Pr(s_2{}^I, s_1{}^I)} x_L$$

The decision cutoffs for F_2 are:

Table 4.4.2.2 Case 2: Cutoffs of F_2, $T^{\{s_2^I, s_1^I\}}$

Signal of F_2	Signal of F_1	
	$s_1^I = 1$	$s_1^I = 0$
$s_2^I = 1$	$\frac{a}{1-a}\frac{A}{B}x_H$	$\frac{a}{1-a}\frac{B}{A}x_H$
$s_2^I = 0$	$\frac{1-a}{a}\frac{A}{B}x_H$	$\frac{1-a}{a}\frac{B}{A}x_H$

where $A = (1-a)(1-q)+aq$; $B = a(1-q)+(1-a)q$

As in Case 1, the first part of the above thresholds evaluates the information delivered to F_2 by its private signal. The second part evaluates information externality, i.e., the information delivered by the decision of the other firm. This information depends now not only on the correlation between the fields, but also on the informativeness of F_1's signal.

Note that $x_L < T^{\{s_2^{I=1}, s_1^{I=1}\}}$, $T^{\{s_2^{I=1}, s_1^{I=0}\}}$, for all $a, q > 0.5$; $x_H > x_L$. Thus, after receiving a high informative signal, F_2 always drills. This result is quite intuitive: F_2's signal provides noisy information externality since it is not a perfect predictor of the reserves in field 1. Given that F_2 has no reason to trust the signal of another firm more than its own, it will always drill after receiving a good signal.

Also, $T^{\{s_2^{I=0}, s_1^{I=0}\}} < T^{\{s_1^{I=0}\}}$. Thus, under restriction (18), F_2 will never drill if it received a low informative signal and observes that F_1 decided not to drill in its field. Since $T^{\{s_2^{I=0}, s_1^{I=1}\}}$ $> T^{\{s_1^{I>0}\}}$, then F_2 will contradict its low informative signal and decide to drill after observing F_1's decision to drill iff

$$T^{\{s_1^{I=0}\}} < x_L < T^{\{s_2^{I=0}, s_1^{I=1}\}}$$

Decision rule of F_2 in Case 2 is summarized in Table 4.4.2.3:

Table 4.4.2.3 Case 2: Decision Rule of F_2

Signal of F_2	**Signal of F_1, $x_L > T_1^{\{s_1^I=0\}}$**	
	$s_1^I = 1$	**$s_1^I = 0$**
$s_2^I = 1$	Always drill	Always drill
$s_2^I = 0$	Drill iff $T_1^{\{s_1^I=0\}} < x_L < T_2^{\{s_2^I=0,\, s_1^I=1\}}$	Never drill

Table 4.4.2.3 gives Proposition 2:

Proposition 2

Let $x_L > T_1^{\{s_1^I=0\}}$.

Then after receiving a low informative signal, F_2 is more likely to drill in its field after it observes F_1's decision to drill in field 1 than after observing F_1's decision not to drill.

In the next two cases, we complicate the information structure. We assume that firms' private signals are not completely informative anymore, but noisy. Let's call these signal s_i^N. F_i expects to receive an informative signal, s_i^I, with probability $\Pr(s_i^N=s_i^I) = \theta_i > 0.5$; in this case the signal provides some information about deposit of field i and its conditional distribution is the one defined in (9). However, with probability (1- θ_i), F_i expects to receive an uninformative signal, s_i^U. The probability of receiving high or low uninformative signal is simply 0.5 independent of the deposit size, i.e.

$$Pr(s_i^U = 1|r_i) = Pr(s_i^U=0|r_i) = 0.5$$

$$Pr(s_i^U = 1|r_i,r_j) = Pr(s_i^U=1|r_i,r_j) = Pr(s_i^U=1|r_i,r_j) = Pr(s_i^U=0|r_i,r_j)=0.5 \quad (19)$$

The next two cases discuss situations examined in Cases 1 and 2 in the presence of noisy signals.

4.4.3 Case 3: Firm 2 Received a Noisy Signal and Observes Reserves in the Neighboring Field

Similar to Case 1, here F_2 is able to observe the reserves in field 1. Given that the signal is noisy, the expected profit of F_2 is a linear combination of its expected profits when the signals are informative and uninformative, weighted by the probabilities of getting an informative and uninformative signal:

$$E\Pi_2 \mid \{s_2^N, r_1\} = \sum_{\{x\};x=I,U} \Pr(s_2^N = s_2^x) E\Pi_2 \mid \{s_2^N = s_2^x, r_1\},$$

where $E\Pi_2 \mid \{s_2^N = s_2^x, r_1\} = \dfrac{\Pr(s_2^N = s_2^x \mid 1_2, r_1)\Pr(1_2, r_1)}{\Pr(s_2^N = s_2^x)\Pr(r_1)} x_H - \dfrac{\Pr(s_{2N} = s_2^x \mid 0_2, r_1)\Pr(0_2, r_1)}{\Pr(s_2^N = s_2^x)\Pr(r_1)} x_L$

As in previous cases, there are four cutoffs to be considered by F_2 depending on its signal and observed reserves. F_2 will decide to drill if the loss is below the corresponding threshold. The cut-off for Case 2, $T^{\{s_2^N, r_1\}}$, are presented in Table 4.4.3.1:

Table 4.4.3.1 Case 3: Cutoffs of F_2, $T^{\{s_2^N, r_1\}}$

Signal of F_2	Reserves of F_1	
	1_1	0_1
$s_2^N = 1$	$\frac{2\theta_2 a + (1-\theta_2)}{2\theta_2(1-a) + (1-\theta_2)} \frac{q}{1-q} x_H$	$\frac{2\theta_2 a + (1-\theta_2)}{2\theta_2(1-a) + (1-\theta_2)} \frac{1-q}{q} x_H$
$s_2^N = 0$	$\frac{2\theta_2(1-a) + (1-\theta_2)}{2\theta_2 a + (1-\theta_2)} \frac{q}{1-q} x_H$	$\frac{2\theta_2(1-a) + (1-\theta_2)}{2\theta_2 a + (1-\theta_2)} \frac{1-q}{q} x_H$

Here again we see that the first part of the cutoffs evaluates the information delivered by the signal; the second part evaluates the information delivered through the information externality.

Note that $x_L < T^{\{s_2^{N=1}, 1_1\}}$ for all θ_2, a, $q > 0.5$; $x_H > x_L$. Hence, F_2 will always drill after receiving a high noisy signal and observing high reserves in the neighboring field. The decision rule of F_2 in Case 3 is provided in Table 4.4.3.2:

Table 4.4.3.2 Case 3: Decision Rule of F_2

Signal of F_2	Reserves of F_1	
	1_1	0_1
$s_2^N = 1$	Always drill	Drill if $x_L < T^{\{s_2^{N=1}, 0_1\}}$
$s_2^N = 0$	Drill if $x_L < T^{\{s_2^{N=0}, 1_1\}}$	Drill if $x_L < T^{\{s_2^{N=0}, 0_1\}}$

The cutoffs in Table 4.4.3.2 can be ranked as follows:

$$T^{\{s_2^{N=1}, 0_1\}} > T^{\{s_2^{N=0}, 0_1\}} \quad (20)$$

$$T^{\{s_2^{N=0}, 1_1\}} > T^{\{s_2^{N=0}, 0_1\}} \quad (21)$$

$$T^{\{s_2^{N=1,0}{}_1\}} \gtrless T^{\{s_2^{N=0,1}{}_1\}} \text{ iff } \frac{2\theta_2 a + (1-\theta_2)}{2\theta_2(1-a)+(1-\theta_2)} > or < \frac{q}{1-q} \quad (22)$$

As in Case 1, the last ordering depends on the trade-off between information provided by the signal and information revealed through information externality. However, in this case information revealed by F_2's signal depends not only its informativeness, *a*, but also on its quality. Thus, if θ_2, $a \to 1$, then $T^{\{s_2^{N=1,0}{}_1\}} > T^{\{s_2^{N=0,1}{}_1\}}$ and F_2 will more likely to trust its signal rather than look at the drilling results in the other field. Similarly, if $q \to 1$, then $T^{\{s_2^{N=1,0}{}_1\}} > T^{\{s_2^{N=0,1}{}_1\}}$ and F_2 is more likely to trust the information provided by the reserves in the other field than trust its signal.

(20), (21) and (22) prove Proposition 3:

Proposition 3

1) Given low reserves were found in the other field, F_2 is more likely to drill in its field after receiving a high noisy signal than after receiving a low noisy signal.

2) Given it received a low noisy signal, F_2 is more likely to drill in its field after high reserves were found in the other field than after low reserves were found.

3) F_2 is more likely to follow its noisy signal when its signal's informativeness, a, and quality , θ, are very high. If the correlation between the reserves, q, is very high, then F_2 is more likely to contradict its noisy signal.

4.4.4 Case 4: Firms 1 and 2 Received Noisy Signals; Firm 2 Observes Decision of Firm 1

In this Case, F_2 decides whether to drill in its field or not under the noisiest information out of all the four cases: it received a not perfect signal and the information externality provided by observing the decision of F_2 is of poor quality since F_2's signal may be uninformative.

Let's see how much information can be revealed by the decision of F_1 under this information structure. Note that now F_1's decision is more complicated: after receiving its signal, F_1 has to take into account the possibility that it may be uninformative. F_1's expected profit, given the probabilities of receiving informative and uninformative signals, is

$$E\Pi_1 \mid \{s_1^N\} = \sum_{\{x\};x=I,U} \Pr(s_1^N = s_1^x) E\Pi_2 \mid \{s_1^N = s_1^x\},$$

where $E\Pi_1 \mid \{s_1^N = s_1^x\} = \Pr(1_1 \mid s_1^N = s_2^x)x_H - \Pr(0_1 \mid s_1^N = s_1^x)x_L$

F_1's decision cutoffs are:

Table 4.4.4.1 Case 4: Cutoffs of F_1

Signal of F_1	**Cutoffs of F_1, $T^{\{s_1^N=1\}}$**
$s_1^N = 1$	$\frac{2\theta_1 a + (1-\theta_1)}{2\theta_1 (1-a) + (1-\theta_1)} x_H$
$s_1^N = 0$	$\frac{2\theta_1 (1-a) + (1-\theta_1)}{2\theta_1 a + (1-\theta_1)} x_H$

Since $x_L < T^{\{s_1^N=1\}}$ for all θ, $a>0.5$, F_1 always drills after receiving a high signal. When $x_L > T^{\{s_1^N=1\}}$, F_1 will drill in its field only if it received a high noisy signal and will not drill otherwise. Hence, when $x_L > T^{\{s_1^N=1\}}$, then decision of F_1 will indicate its signal.

Let

$$x_L > T^{\{s_1^N=1\}} \qquad (23)$$

so that F_2 is able to guess the private signal of F_1 after observing its decision. Now F_2's task to incorporate information externality provided by F_1 is quite difficult. It knows that there are four possible cases: 1) both firms received informative signals; 2) F_2 received an informative signal and F_1 received noise; 3) F_1 received an informative signal and F_2 received noise; 4) both firms received uninformative signals. Thus, there are four possible conditional distributions each combination of signals can be drawn from.

These distributions can be derived as suggested in (7) and (8) using (9), (10) and (19). Conditional distribution of combinations of informative signals is giver by (11). The other conditional distributions are given below:

Table 4.4.4.2 Distribution of Combinations of Informative and Uninformative Signals $\{s_i^I,s_j^U\}$ Conditional on $\{r_i,r_j\}$, $Pr(s_i^I,s_j^U|r_i,r_j)$

	$Pr(s_i^I,s_j^U\|1_i,1_j)$	**$Pr(s_i^I,s_j^U\|1_i,0_j)$**	**$Pr(s_i^I,s_j^U\|0_i,1_j)$**	**$Pr(s_i^I,s_j^U\|0_i,0_j)$**
$s_i^I = 1,s_j^U = 1$	$0.5a$	$0.5a$	$0.5(1-a)$	$0.5(1-a)$
$s_i^I = 1,s_j^U = 0$	$0.5a$	$0.5a$	$0.5(1-a)$	$0.5(1-a)$
$s_i^I = 0,s_j^U = 1$	$0.5(1-a)$	$0.5(1-a)$	$0.5a$	$0.5a$
$s_i^I = 0,s_j^U = 0$	$0.5(1-a)$	$0.5(1-a)$	$0.5a$	$0.5a$

(24)

Table 4.4.4.3 Distribution of Combinations of Uninformative Signals $\{s_i^U,s_j^U\}$ Conditional on $\{r_i,r_j\}$, $Pr(s_i^I,s_j^U|r_i,r_j)$

	$Pr(s_i^U,s_j^U\|1_i,1_j)$	**$Pr(s_i^U,s_j^U\|1_i,0_j)$**	**$Pr(s_i^U,s_j^U\|0_i,1_j)$**	**$Pr(s_i^U,s_j^U\|0_i,0_j)$**
$s_i^U = 1,s_j^U = 1$	0.25	0.25	0.25	0.25
$s_i^U = 1,s_j^U = 0$	0.25	0.25	0.25	0.25
$s_i^U = 0,s_j^U = 1$	0.25	0.25	0.25	0.25
$s_i^U = 0,s_j^U = 0$	0.25	0.25	0.25	0.25

(25)

From joint distribution of reserves (3) and (24), (25) it follows that

$Pr(s_i^I = 1,s_j^U=1) = Pr(s_i^I=1,s_j^U0) = Pr(s_i^I=0,s_j^U=1) = Pr(s_i^I=0,s_j^U=0) = 0.25$

$$\Pr(s_i^U = 1, s_j^U=1) = \Pr(s_i^U=1, s_j^U 0) = \Pr(s_i^U=0, s_j^U=1) = \Pr(s_i^U=0, s_j^U=0) = 0.25 \qquad (26)$$

Using (11) and (24)-(26), F_2 can figure out its expected profit in each of the four possible cases; then total expected profit is a linear combination of them weighted by their probabilities of occurrence:

$$E\Pi_2 \mid \{s_2^N, s_1^N\} = \sum_{\{x,y\};x,y=I,U} \Pr(s_2^N = s_2^x, s_1^N = s_1^x) E\Pi_2 \mid \{s_2^N = s_2^x, s_1^N = s_1^x\},$$

where

$$\Pr(s_2^N = s_2^x, s_1^N = s_1^y) = \Pr(s_2^N = s_2^x)\Pr(s_1^N = s_1^y)$$
$$E\Pi_2 \mid \{s_2^N = s_2^x, r_1\} = \Pr(1_2 \mid s_2^N = s_2^x, s_1^N = s_1^y) x_H - \Pr(0_2 \mid s_2^N = s_2^x, s_1^N = s_1^y) x_L$$

F_2's cutoffs in Case 4 are:

Table 4.4.4.4 Case 4: Cutoffs of F_2, $T^{\{s_2^N, s_1^N\}}$

Signal of F_2	**Signal of F_1, $x_L > T^{\{s_1^{N=0}\}}$**	
	$s_1^N = 1$	**$s_1^N = 0$**
$s_2^N = 1$	$\dfrac{C+\Theta_2 A+\Theta_1(a+0.5\Theta_2)}{D+\Theta_2 B+\Theta_1((1-a)+0.5\Theta_2)} x_H$	$\dfrac{F+\Theta_2 B+\Theta_1(a+0.5\Theta_2)}{E+\Theta_2 A+\Theta_1((1-a)+0.5\Theta_2)} x_H$
$s_2^N = 0$	$\dfrac{E+\Theta_2 A+\Theta_1((1-a)+0.5\Theta_2)}{F+\Theta_2 B+\Theta_1(a+0.5\Theta_2)} x_H$	$\dfrac{D+\Theta_2 B+\Theta_1((1-a)+0.5\Theta_2)}{C+\Theta_2 A+\Theta_1(a+0.5\Theta_2)} x_H$

where $A = (1-a)(1-q)+aq$

$B = a(1-q)+(1-a)q$

$$C = \frac{aA}{aA + (1-a)B},$$

$$D = \frac{(1-a)B}{aA + (1-a)B},$$

$$E = \frac{(1-a)A}{(1-a)A + aB},$$

$$F = \frac{aB}{(1-a)A + aB},$$

$$\Theta_i = \frac{1-\theta_i}{\theta_i}$$

The above thresholds capture a very complicated trade-off between the information provided to F_2 by its signal and through information externality. Now, F_2 has to consider not only the informativeness of the signals, but also their relative quality captured by Θ_1 and Θ_2.

Note that $x_L < T^{\{s_2^{N=1}, s_1^{N=1}\}}$ for all *a, q* > 0.5; $x_H > x_L$. Then F_2 will always drill after receiving a high noisy signal and observing that F_1 decided to drill.

Recall that in order for F_1 to reveal its signal, we assumed that $x_L > T^{\{s_1^{N=0}\}}$. So for F_2 to drill in its field after receiving a low noisy signal and guessing F_1's signal, loss from drilling should be such that

$$T^{\{s_1^{N=0}\}} < x_L < T^{\{s_2^{N}, s_1^{N}\}}$$

The decision rule of F_2 in Case 4 is presented in Table 4.4.4.5:

Table 4.4.4.5 Case 4: Decision Rule of F_2

Signal of F_2	Signal of F_1, $x_L > T^{\{s_1^N=0\}}$	
	$s_1^N = 1$	$s_1^N = 0$
$s_2^N = 1$	Always drill	Drill iff $T^{\{s_1^N=0\}} < x_L < T^{\{s_2^N=1, s_1^N=0\}}$
$s_2^N = 0$	Drill iff $T^{\{s_1^N=0\}} < x_L < T^{\{s_2^N=0, s_1^N=1\}}$	Drill iff $T^{\{s_1^N=0\}} < x_L < T^{\{s_2^N=0, s_1^N=0\}}$

The cutoffs are ordered as follows:

$$T^{\{s_2^N=1, s_1^N=0\}} > T^{\{s_2^N=0, s_1^N=0\}} \qquad (27)$$

$$T^{\{s_2^N=0, s_1^N=1\}} > T^{\{s_2^N=0, s_1^N=0\}} \qquad (28)$$

$$T^{\{s_2^N=1, s_1^N=0\}} \gtrless T^{\{s_2^N=0, s_1^N=1\}} \qquad (29)$$

Necessary but not sufficient condition for $T^{\{s_2^N=1, s_1^N=0\}} > T^{\{s_2^N=0, s_1^N=1\}}$ in (29) is

$$\frac{\Theta_2 + \Theta_1}{2\Theta_2} > q \qquad (30)$$

Note that condition (30) does not depend on the informativeness of the signals, a. Since informativeness of the signals is the same for F_1 and F_2, then the difference in information provided by the signals depends on their quality, not informativeness. If $\theta_2 \to 1$ or $\theta_1 \to 0$, then $T^{\{s_2^N=1, s_1^N=0\}} > T^{\{s_2^N=0, s_1^N=1\}}$ and F_2 is more likely to trust its signal than the signal of F_1. If $q \to 1$, then $T^{\{s_2^N=1, s_1^N=0\}} > T^{\{s_2^N=0, s_1^N=1\}}$ when $\theta_2 > \theta_1$, i.e., F_2 is more likely to drill in its field if the quality of its signal is better.

(27), (28) and (29) together with Table 4.4.4.5 prove Proposition 4:

Proposition 4

Let $x_L > T^{\{s_1^{N=0}\}}$. Then

1) Given that F_1 decided not to drill in its field, F_2 is more likely to drill in field 2 after receiving a high noisy signal than after receiving a low noisy signal.

2) Given that it received a low noisy signal, F_2 is more likely to drill in its field after observing F_1's decision to drill in field 1 than after observing F_1's decision not to drill.

3) F_2 is more likely to trust its signal when its quality, θ_2, is very high or when the quality of F_1's signal, θ_1, is very low. If the correlation of the reserves, q, is very high, then F_2 is more likely to trust its signal when the quality of the signal is better, $\theta_2 > \theta_1$.

4.5 COMPARISON OF FIRM 2'S DECISIONS UNDER DIFFERENT INFORMATION STRUCTURES

In this section we compare the decision rule of F_2 in the cases presented above. In particular, we will see how quality of private information and quality of information externality affects decision of F_2.

Table 4.5.1 below summarizes the decision rule of F_2:

Table 4.5.1 Decision of Firm 2 under Different Information Structures

Signal of F_2	**Case 1**		**Case 2**	
	Reserves of F_1		**Signal of F_1, $x_L > T^{\{s_1^I=0\}}$**	
	1_1	**1_2**	**$s_1^I = 1$**	**$s_1^I = 0$**
$s_2^I = 1$	Always drill	Drill if $x_L < T^{\{s_2^I=1, 0_1\}}$	Always drill	Always drill
$s_2^I = 0$	Drill if $x_L < T^{\{s_2^I=0, 1_1\}}$	Drill if $x_L < T^{\{s_2^I=0, 0_1\}}$	Drill iff $T^{\{s_1^I=0\}} < x_L < T^{\{s_2^I=0,\, s_1^I=1\}}$	Never drill
	Case 3		**Case 4**	
	Reserves of F_1		**Signal of F_1, $x_L > T^{\{s_1^N=0\}}$**	
	1_1	**1_2**	**$s_1^N = 1$**	**$s_1^N = 0$**
$s_2^N = 1$	Always drill	Drill if $x_L < T^{\{s_2^N=1, 0_1\}}$	Always drill	Drill iff $T^{\{s_1^N=0\}} < x_L < T^{\{s_2^N=1,\, s_1^N=0\}}$
$s_2^N = 0$	Drill if $x_L < T^{\{s_2^N=0, 1_1\}}$	Drill if $x_L < T^{\{s_2^N=0, 0_1\}}$	Drill iff $T^{\{s_1^N=0\}} < x_L < T^{\{s_2^N=0,\, s_1^N=1\}}$	Drill iff $T^{\{s_1^N=0\}} < x_L < T^{\{s_2^N=0,\, s_1^N=0\}}$

Let's analyze how quality of the signal affects decision of F_2 under stronger information externality, i.e. after F_2 observed deposit size in the other field (Case 1 vs. Case 3). The corresponding cutoffs are ordered as follows:

	Case 1 **(Informative Signals)**		**Case 3** **(Noisy Signals)**
1)	$T^{\{s_2^I=1,\, 0_1\}}$	$>$	$T^{\{s_2^N=1,\, 0_1\}}$
2)	$T^{\{s_2^I=0,\, 1_1\}}$	$<$	$T^{\{s_2^N=0,\, 1_1\}}$
3)	$T^{\{s_2^I=0,\, 0_1\}}$	$<$	$T^{\{s_2^N=0,\, 0_1\}}$

1) states that if F_2 observes low reserves in the neighboring field after it received a high signal, F_2 is more likely to drill in its field if the signal is informative rather than noisy. 2) and 3) imply that when F_2 received a low informative or noisy signal and observes the reserves of the other field, it is more likely to drill in its field when this signal is noisy rather than informative. In other words, F_2 is more likely to decide against its signal in the noisier environment. This suggests the following proposition:

Proposition 5

Given F_2 received a private signal and observes the reserves of the other field, it is more likely to contradict its signal when the signal is noisy rather than informative.

Proposition 5 predicts that after a successful drilling in a region, more firms are going to start exploring in their fields when their private information is noisy rather than informative. The firms with high informative or noisy signals always drill after observing high reserves in the other field. However, more firms with low signals are going to drill under noisy private information. Thus, after oil has been found in a field, we should expect more exploratory drilling in neighboring areas when private information firms receive is noisy rather than informative.

Now, let's see how quality of private information alters choice of F_2 under weaker information externality, i.e. when it only observes the decision of F_1 (Cases 2 vs. Case 4). From Table 4.5.1 it is seen that in Case 2 F_2 is able to use information externalities when $x_L > T^{\{s_1^{I}=0\}}$. Similarly, F_2 will take advantage of information externalities in Case 4 when $x_L > T^{\{s_1^{N}=0\}}$. Note that $T^{\{s_1^{N}=0\}} > T^{\{s_1^{I}=0\}}$. Hence, if parameters are such that information externalities are present in Case 4, they will be present in Case 2 as well. This allows us to compare the cases.

Table 4.5.1 shows that F_2 is more likely to contradict its high signal when both firms received noisy private information. Under informative signals (Case 2), F_2 always follows its private information after receiving a high signal. Under noisy signals (Case 4), F_2 always follows its high signal if it observes F_2's decision to drill but may contradict its high signal after it observes F_2's decision not to drill.

After F_2 received a low signal and observes that F_1 decided not to drill in its field, it will never drill under informative signals (Case 2), but may contradict its low signal under noisy signals (Case 4). Comparing the two cutoffs in the cases when F_2 received a low signal and observes F_1's decision to drill leads to the following result:

Case 2 (Informative Signals)		**Case 4** (Noisy Signals)
$T^{\{s_2^{I}=0,\, s_1^{I}=1\}}$	$\lessgtr$	$T^{\{s_2^{N}=0,\, s_1^{N}=1\}}$

iff

$$\frac{1}{\Theta_2} a(1-a)(2q-1) - \frac{1}{\Theta_1} AB > or < 0.5(1-q) \tag{31}$$

where $A = (1\text{-}a)(1\text{-}q)+aq$

$B = a(1\text{-}q)+(1\text{-}a)q$

$$\Theta_i = \frac{1-\theta_i}{\theta_i}$$

In this case, whether F_2 is more likely or less likely to drill after both firms received informative or noisy signals depends on the difference between the quality of the firm's signals. Note that $AB>a(1-a)(2q-1)$; then (31) suggests the following:

$$\frac{1}{\Theta_2} \leq \frac{1}{\Theta_1} \Rightarrow T^{\{s_2^{I=0}, s_1^{I=1}\}} < T^{\{s_2^{N=0}, s_1^{N=1}\}} \tag{32}$$

$\theta_i > \theta_j$ implies that $\frac{1}{\Theta_i} > \frac{1}{\Theta_j}$. Hence, (32) states that F_2 is more likely to contradict its low signal after observing F_1's decision to drill when both firms received noisy signals and quality of F_1's signal is either as good as or better than the quality of F_2's private signal.

Note that (32) is necessary but not sufficient condition for $T^{\{s_2^{I=0}, s_1^{I=1}\}} < T^{\{s_2^{N=0}, s_1^{N=1}\}}$. Hence, there is $\theta_2 > \theta_1$ such that $\frac{1}{\Theta_2} > \frac{1}{\Theta_1}$ and $T^{\{s_2^{I=0}, s_1^{I=1}\}} < T^{\{s_2^{N=0}, s_1^{N=1}\}}$. In other words, even if the quality of its information is better, F_2 may still be more likely to contradict its low signal and follow the decision of F_1 when both firms receive noisy signals rather than when both firms receive informative signals. For F_2 to be more likely to follow its signal under noisy private information, the quality of its low signal should be above the following threshold:

$$\frac{1}{\Theta_2} > \frac{0.5(1-q)}{a(1-a)(2q-1)} + \frac{1}{\Theta_1}\frac{AB}{a(1-a)(2q-1)}$$

Proposition 6 summarizes the analysis above:

Proposition 6.

Let $x_L > T^{\{s_1^{N=0}\}}$. *Then*

1) Given that F_2 received a high or low signal and observes F_1's decision not to drill in its field, F_2 is more likely to contradict its signal when the private information of both firms is noisy rather than informative.

2) Given that F_2 received a low signal and observes F_1's decision to drill in its field, F_2 is more likely to contradict its signal and follow the decision of F_1 when the private information of both firms is noisy rather than informative and the quality of F_1's signal is either as good as or better than the quality of F_2's private signal. For F_2 to be more likely to follow its noisy low signal, the quality of its private information should be high enough to satisfy the following condition:

$$\frac{1}{\Theta_2} > \frac{0.5(1-q)}{a(1-a)(2q-1)} + \frac{1}{\Theta_1}\frac{AB}{a(1-a)(2q-1)}$$

Proposition 6 implies that under weaker noisy private information, F_2 is more likely to contradict its signal and follow the decision of F_1. F_2 may mimic the decision of the other firm to drill even when the quality of its signal is either as good as or even better than the quality of F_1's private information. Under noisy private and public information, the second firm to decide may undervalue the information provided by its signal and give too much weight to the information provided through the information externality.

Proposition 6 predicts that under noisy public and private information, we can expect more firms to start drilling after the first firm has decided to drill in its track. The firms with high noisy or informative signals will always drill after observing the first firm's decision to explore in its field. As for the firms with low signals, they will be more likely to choose to drill under noisy information if the quality of their private information is either worse or the same as the quality of the signal of the firm that decided to drill first.

Both propositions 5 and 6 suggest that after receiving a low signal, F_2 is more likely to contradict its private information in the noisier environment. The next natural step is to check whether it is more likely to contradict its noisy low signal under weaker or stronger information externalities, i.e. after observing reserves in the other field or after just observing the decision of F_2 (Case 3 vs. Case 4). The corresponding thresholds are ranked as follows:

	Case 3 **(Stronger Information Externality)**		**Case 4** **(Weaker Information Externality)**
1)	$T^{\{s_2^{N=0}, 1_1\}}$	>	$T^{\{s_2^{N=0}, s_1^{N=1}\}}$
2)	$T^{\{s_2^{I=0}, 0_1\}}$	<	$T^{\{s_2^{N=0}, s_1^{N=0}\}}$

This proves Proposition 7:

Proposition 7

1) After receiving a low noisy signal, F_2 is more likely to contradict its private information after observing the high reserves in the other field than after observing F_1's decision to drill.

2) After receiving a low noisy signal, F_2 is more likely to contradict its private information after observing F_1's decision not to drill that after observing the low reserves in the other field.

Part 1 of Proposition 7 together with part 2 of Proposition 6 suggest an explanation to the spike of investment in the Caspian region. In particular, part 2 of proposition 6 explains why more companies entered the Caspian region despite their relatively low private information after the first contract had appeared. The first company to invest was a major; its decision could have influenced the drilling decisions of the companies of the same or lower level of expertise. Part 1 of proposition 7 suggests why more companies appeared in the region after the first major's successful exploration efforts became public. Positive drilling results could have affected decision of the companies with high signals as well as the companies with low signals and different levels of expertise.

Part 2 of Proposition 7 suggests why almost no companies came to the region after two projects found no oil. After bad drilling results became known, only companies with low noisy signals became less likely to contradict its private information and invest in the region.

4.6 CONCLUSION

In the essay we attempt to explain why in the environment with information externalities and sequential decision-making the oil companies tend to drill more. As an example, we use the exploration of the Caspian region. we show that under noisy available public and private information, the oil companies are more likely to follow the decision of the first company if its level of expertise is as good or better. The companies will be even more likely to follow the decision of the first firm after it released results of successful exploratory efforts. However, the result of poor exploratory efforts will make companies more cautious in making their investment decision.

5.0 CONCLUSION

It has been widely documented that after 1998 the GDP in Russia has grown at an impressive average annual rate of more than 6%; the GDP of the Caspian states has been growing even faster: 9% in Kazakhstan and 19.7% in Azerbaijan (CIA World Fact Book, 2005). One of the major concerns with this growth record, however, is that it is driven primarily by high oil prices rather than deep structural reform (see Berglöf et al., 2003). In the first essay, we have documented that the Russian oil sector is in need of substantial restructuring. In particular, the privatization of the crude oil sector has been partial because the federal government as of 2003 has both retained monopoly control over the transport of crude oil onto world markets and has also obtained substantial positions and influence on some oil company boards. This has created major inefficiencies in the allocation of scarce export capacity because the federal government has used its control over the pipeline to provide privileged access to those companies over which it has influence. In particular, by 2003 fully private companies had to be much more productive than state-influence companies to receive comparable access to world markets; state-influence companies had preferential access to routes with more capacity; and, the allocation of route capacity was sensitive to transport costs only among those companies in which the state has substantial representation on boards.

The second and the third essays argue that the influx of foreign investment into the Caspian region in 1997-1998 was largely influenced by available noisy information. However, a vast increase in foreign direct investment did not promote sustainable economic development in the region because its inflow turned out to be quite fragile: the foreign investors stopped coming to the country as soon as bad news on the size of the Caspian reserves came in. The decision to enter Caspian oil development projects turned out to be costly for many investors because they paid too much attention to publicly available information and too little to their private signals. On the other hand, the Caspian states were hurt by the release of negative information because it prevented further expansion of oil development projects in the region.

There is another interesting question that has not been addressed in this dissertation. The Caspian states are landlocked. The Russian federal government has near monopoly power over the shipping of the oil produced there. However, since 2003 the Russian federal government's near monopoly position as the regional transporter of crude oil exports has been threatened. Starting in 2003, substantial progress has been made in establishing routes for oil companies located in Azerbaijan and Kazakhstan that would enable them to bypass Russia as they pump their oil onto world markets.

This development during 2003-2006 is important for several reasons. First, it is important to understand and document the extent to which state monopolies such as the Russian oil transport sector adapt to international competition. In particular, does the threat of some entry encourage the Russian government to compete with potential entrants by taking measures such as providing additional capacity clients, lowering tariffs and providing more transparent access? Or, do bureaucrats in the energy sector believe that they can ignore the threat of entry? Second, the Caspian region is becoming a major source of world oil and gas, and we need a better understanding of just how the transport of oil from the landlocked countries surrounding the Caspian is evolving.

In our future research (joint with Daniel Berkowitz), we plan to collect company level corporate governance data, company-subsidiary level crude oil export data, company-subsidiary level productivity data, company-subsidiary level capacity data, route level cost data, capacity data, and regional specific price data for 2004, 2005 and 2006 to test whether or not the Russian federal government has continued its practice (that we documented in 2003) of providing privileged access to the companies over which it has influence. However, taking advantage of new data sources, we will add companies located in Azerbaijan and Kazakhstan to our data set. If the Russian federal energy bureaucracy is ignoring the real threat of the emergence of a non-Russian oil pipeline bypass, then we would observe that the Azeri and Kazakh companies have received the same limited access to the oil pipeline that other state-independent companies such as Tatneft and Yukos received during 2003. However, if the Russian federal energy bureaucracy is responding to this threat of entry, we would observe two possible outcomes: 1) the Azeri and Kazakh companies get the privileged access to the pipeline that has been given to state-influence companies such as LUKoil and Rosneft in 2003; and 2) the Russian government eliminates the entire system of privileges and increases the overall transparency of its pipeline system.

APPENDIX A

LIST OF INTERVIEWS

Interviewee #	Date	Country	Category	Company/Organization
1	03.02.2004	Azerbaijan	NGO, Academy, Politics	Azerbaijan's Center for Economic and Political Research, Entrepreneurship Development Foundation
2	03.03.2004	Azerbaijan	NGO	Center for Civil Initiatives
3	03.03.2004	Azerbaijan	NGO	Open Society Institute-Assistance Foundation, Azerbaijan
4	03.04.2004	Azerbaijan	NGO	Public Finance Monitoring Center
5	03.04.2004	Azerbaijan	Politics	Budgetary Committee in the Parliament
6	03.05.2004	Azerbaijan	Company	Exxon Azerbaijan
7	03.05.2004	Azerbaijan	Company	BP Group Azerbaijan
8	03.05.2004	Azerbaijan	NGO	Public Finance Monitoring Center
9	03.09.2004	Azerbaijan	Academy	Azerbaijan State Oil Academy, Azerbaijan National Academy of Science
10	03.10.2004	Azerbaijan	Company	BP Group Azerbaijan
11	03.15.2004	Azerbaijan	Company	BP Group Azerbaijan

APPENDIX B

MATHEMATICAL APPENDIX FOR ESSAY 3

B.1 A MODEL OF SEQUENTIAL EXPLORATION

B.1.1 P. 85

1) $\mathbf{Pr(s_i^I = r_i|r_i) > Pr(s_i^I \neq r_i|r_i)}$

(a) $Pr(s_i^I = 1_i|1_i) > Pr(s_i^I = 0_i|1_i)$

$\Phi(f(1_i)) > 1 - \Phi(f(1_i))$

True since $\Phi(f(1_i)) >0.5$

(b) $Pr(s_i^I = 0_i|0_i) > Pr(s_i^I = 1_i|0_i)$

$1 - \Phi(f(0_i)) > \Phi(f(0_i))$

True since $\Phi(f(0_i)) <0.5$

2) $\mathbf{Pr(\{s_i^I,s_j^I \}= \{1,1\}|1_i,1_j) > Pr(\{s_i^I,s_j^I \}\neq \{1,1\}|1_i,1_j)}$

(a) $Pr(s_i^I = 1, s_j^I = 1|1_i,1_j) > Pr(s_i^I =1, s_j^I =0|1_i,1_j)$

$\Phi(f(1_i))^2 > \Phi(f(1_i)) [1 - \Phi(f(1_i))]$

True since $\Phi(f(1_i)) >0.5$

(b) $Pr(s_i^I = 1, s_j^I = 1|1_i,1_j) > Pr(s_i^I, = 0, s_j^I = 1|1_i,1_j)$

$\Phi(f(1_i))^2 > [1 - \Phi(f(1_i))] \Phi(f(1_i))$

True since $\Phi(f(1_i)) > 0.5$

(c) $Pr(s_i^I = 1, s_j^I = 1|1_i,1_j) > Pr(\{s_i^I = 0, s_j^I = 0|1_i,1_j)$

$\Phi(f(1_i))^2 > [1 - \Phi(f(1_i))]^2$

True since $\Phi(f(1_i)) > 0.5$

$Pr(\{s_i^I,s_j^I\} = \{1,0\}|1_i,0_j) > Pr(\{s_i^I,s_j^I\} \neq \{1_i,0_j\}|1_i,0_j)$

(a) $Pr(s_i^I = 1, s_j^I = 0|1_i,0_j) > Pr(s_i^I= 1, s_j^I = 1|1_i,0_j)$

$\Phi(f(1_i)) [1 - \Phi(f(0_i))]> \Phi(f(1_i)) \Phi(f(0_i))$

True since $\Phi(f(1_i)) > 0.5$; $\Phi(f(0_i)) < 0.5$

(b) $Pr(s_i^I = 1, s_j^I = 0|1_i,0_j) > Pr(s_i^I = 0, s_j^I = 1|1_i,0_j)$

$[1 - \Phi(f(0_i))] \Phi(f(1_i)) > \Phi(f(1_i)) \Phi(f(0_i))$

True since $\Phi(f(1_i)) > 0.5$; $\Phi(f(0_i)) < 0.5$

(c) $Pr(s_i^I = 1, s_j^I = 0|1_i,0_j) > Pr(s_i^I = 0, s_j^I = 0|1_i,0_j)$

$[1 - \Phi(f(0_i))] \Phi(f(1_i)) > \Phi(f(0_i)) \Phi(f(0_i))$

True since $\Phi(f(1_i)) > 0.5$; $\Phi(f(0_i)) < 0.5$

$Pr(\{s_i^I,s_j^I\}=\{0,0\}|0_i,0_j) > Pr(\{s_i^I,s_j^I\}\neq\{0_i,0_j\}|0_i,0_j)$

(a) $Pr(s_i^I = 0, s_j^I = 0|0_i,0_j) > Pr(s_i^I= 1, s_j^I = 1|0_i,0_j)$

$[1 - \Phi(f(0_i))]^2 > \Phi(f(0_i))^2$

True since $\Phi(f(0_i)) < 0.5$

(b) $Pr(s_i^I = 0, s_j^I = 0|0_i,0_j) > Pr(s_i^I = 0, s_j^I = 1|0_i,0_j)$

$[1 - \Phi(f(0_i))]^2 > \Phi(f(0_i)) [1 - \Phi(f(0_i))]$

True since $\Phi(f(0_i)) < 0.5$

(c) $Pr(s_i^I = 0, s_j^I = 0|0_i,0_j) > Pr(s_i^I = 1, s_j^I = 0|0_i,0_j)$

$[1 - \Phi(f(0_i))]^2 > [1 - \Phi(f(0_i))]\Phi(f(0_i))$

True since $\Phi(f(0_i)) < 0.5$

B.1.2 P. 87

Pr(s_i^I = 1,s_j=1)=Pr(s_i^I=0,sj=0) > Pr(s_i^I=1,s_j=0)=Pr(s_i^I=0,s_j=1)

$$0.5a^2q + 0.5(1-a)^2q + a(1-a)(1-q) > 0.5a^2(1-q) + 0.5(1-a)^2(1-q) + a(1-a)q$$

$$\Leftrightarrow a^2\frac{q}{1-q} + (1-a)^2\frac{q}{1-q} + 2a(1-a) > a^2 + (1-a)^2 + 2a(1-a)\frac{q}{1-q}$$

$$\Leftrightarrow [a^2 + (1-a)^2 - 2a((1-a)]\frac{q}{1-q} > a^2 + (1-a)^2 - 2a(1-a)$$

$$\Leftrightarrow \frac{q}{1-q} > 1$$

True since

$q > 0.5$ and

$$a^2 + (1-a)^2 - 2a((1-a) > 0$$

since $\frac{\partial[a^2 + (1-a)^2 - 2a((1-a)]}{\partial a} = 8a - 4 \geq 0$

forall $a \geq 0.5$

B.2 CASE 1

B.2.1 P. 88

$$E\Pi_2 \mid \{s_2^{\,I}, r_1\} = \Pr(1_2 \mid s_2^{\,I}, r_1\} x_H - \Pr(0_2 \mid s_2^{\,I}, r_1) x_L$$

$$= \frac{\Pr(s_2^{\,I}, 1_2, r_1)}{\Pr(r_1, s_2^{\,I})} x_H - \frac{\Pr(s_2^{\,I}, 0_2, r_1)}{\Pr(r_1, s_2^{\,I})} x_L$$

$$= \frac{\Pr(s_2^{\,I} \mid 1_2, r_1)\Pr(1_2, r_1)}{\Pr(s_2^{\,I})\Pr(r_1)} x_H - \frac{\Pr(s_2^{\,I} \mid 0_2, r_1)\Pr(0_2, r_1)}{\Pr(s_2^{\,I})\Pr(r_1)} x_L$$

$$= \frac{\Pr(s_2^{\,I} \mid 1_2, r_1)\Pr(1_2 \mid r_1)\Pr(r_1)}{\Pr(s_2^{\,I})\Pr(r_1)} x_H - \frac{\Pr(s_2^{\,I} \mid 0_2, r_1)\Pr(0_2 \mid r_1)\Pr(r_1)}{\Pr(s_2^{\,I})\Pr(r_1)} x_L$$

$$= \frac{\Pr(s_2^{\,I} \mid 1_2, r_1)\Pr(1_2 \mid r_1)}{\Pr(s_2^{\,I})} x_H - \frac{\Pr(s_2^{\,I} \mid 0_2, r_1)\Pr(0_2 \mid r_1)}{\Pr(s_2^{\,I})} x_L$$

B.2.2 P. 89. Table 4.4.1.1

1) $\mathbf{T}^{\{s_2^{I}=1;\ 1_1\}}$

$$E\Pi_2 \mid \{s_2^{\,I} = 1, 1_1\} = 2aqx_H - 2(1-a)(1-q)x_L$$

$$> 0 \Rightarrow x_L < \frac{a}{1-a}\frac{q}{1-q} x_H$$

2) $\mathbf{T}^{\{s_2^{I}=1;\ 0_1\}}$

$$E\Pi_2 \mid \{s_2{}^I = 1, 0_1\} = 2a(1-q)x_H - 2(1-a)qx_L$$

$$> 0 \Rightarrow x_L < \frac{a}{1-a}\frac{1-q}{q}x_H$$

3) $\mathbf{T^{\{s_2{}^{I=0};\ 1_1\}}}$

$$E\Pi_2 \mid \{s_2{}^I = 0, 1_1\} = 2(1-a)qx_H - 2a(1-q)x_L$$

$$> 0 \Rightarrow x_L < \frac{1-a}{a}\frac{q}{1-q}x_H$$

4) $\mathbf{T^{\{s_2{}^{I=0};\ 0_1\}}}$

$$E\Pi_2 \mid \{s_2{}^I = 0, 0_1\} = 2(1-a)(1-q)x_H - 2aqx_L$$

$$> 0 \Rightarrow x_L < \frac{1-a}{a}\frac{1-q}{q}x_H$$

B.2.3 P. 89

$\mathbf{x_L < T^{\{s_2{}^{I=1};\ 1_1\}}}$ for all *a, q* > 0.5

$$x_L < \frac{a}{1-a}\frac{q}{1-q}x_H$$

$$a, q > 0.5 \Rightarrow aq > (1-a)(1-q)$$

$$\Rightarrow \frac{a}{1-a}\frac{q}{1-q} > 1$$

B.2.4 P. 90

1) $\mathbf{T}^{\{s_2{}^{I=1,0}{}_1\}} > \mathbf{T}^{\{s_2{}^{I=0,0}{}_1\}}$

$$\frac{a}{1-a}\frac{1-q}{q}x_H > \frac{1-a}{a}\frac{1-q}{q}x_H$$

$$\Leftrightarrow a^2 > (1-a)^2$$

True since $a > 0.5$

2) $\mathbf{T}^{\{s_2{}^{I=0,1}{}_1\}} > \mathbf{T}^{\{s_2{}^{I=0,0}{}_1\}}$

$$\frac{1-a}{a}\frac{q}{1-q}x_H > \frac{1-a}{a}\frac{1-q}{q}x_H$$

$$\Leftrightarrow q^2 > (1-q)^2$$

True since $q > 0.5$

3) $\mathbf{T}^{\{s_2{}^{I=1,0}{}_1\}} \gtrless \mathbf{T}^{\{s_2{}^{I=0,1}{}_1\}}$ **iff** $\frac{a}{1-a} > or < \frac{q}{1-q}$

$$\frac{a}{1-a}\frac{1-q}{q}x_H > or < \frac{1-a}{a}\frac{q}{1-q}x_H$$

$$\Leftrightarrow \frac{a}{1-a} > or < \frac{q}{1-q}$$

B.3 CASE 2

B.3.1 P. 92: Table 4.4.2.1

1) $\mathbf{T}^{\{s_1^I=1\}}$

$$E\Pi_1 \mid \{s_1^I = 1\} = ax_H - (1-a)x_L$$

$$> 0 \Rightarrow x_L < \frac{a}{1-a}x_H$$

2) $\mathbf{T}^{\{s_1^I=0\}}$

$$E\Pi_1 \mid \{s_1^I = 1\} = (1-a)x_H - ax_L$$

$$> 0 \Rightarrow x_L < \frac{1-a}{a}x_H$$

B.3.2 P. 92

$$E\Pi_2 \mid \{s_2^I, s_1^I\} = \Pr(1_2 \mid s_2^I, s_1^I\}x_H - \Pr(0_2 \mid s_2^I, s_1^I)x_L$$

$$= \frac{\Pr(s_2^I, 1_2, r_1)}{\Pr(r_1, s_2^I)}x_H - \frac{\Pr(s_2^I, 0_2, r_1)}{\Pr(r_1, s_2^I)}x_L$$

$$= \frac{\Pr(s_2^I, s_1^I \mid 1_2)\Pr(1_2)}{\Pr(s_2^I, s_1^I)}x_H - \frac{\Pr(s_2^I, s_1^I \mid 0_{21})\Pr(0_2)}{\Pr(s_2^I, s_1^I)}x_L$$

$$= \frac{\Pr(s_2^I, s_1^I \mid 1_2, 1_1)\Pr(1_1 \mid 1_2)\Pr(1_2) + \Pr(s_2^I, s_1^I \mid 1_2, 0_1)\Pr(0_1 \mid 1_2)\Pr(1_2)}{\Pr(s_2^I, s_1^I)}x_H$$

$$- \frac{\Pr(s_2^I, s_1^I \mid 0_2, 1_1)\Pr(1_1 \mid 0_2)\Pr(0_2) + \Pr(s_2^I, s_1^I \mid 0_2, 0_1)\Pr(0_1 \mid 0_2)\Pr(0_2)}{\Pr(s_2^I, s_1^I)}x_L$$

B.3.3 P. 93: Table 4.4.2.2

1) $\mathbf{T}^{\{s_2^I=1;\ s_1^I=1\}}$

$$E\Pi_2 \mid \{s_2{}^I = 1, s_1{}^I = 1\} = \frac{a^2 q + a(1-a)(1-q)}{a^2 q + (1-a)^2 q + 2a(1-a)(1-q)} x_H - \frac{a(1-a)(1-q) + (1-a)^2 q}{a^2 q + (1-a)^2 q + 2a(1-a)(1-q)} x_L$$

$$> 0 \Rightarrow x_L < \frac{a^2 q + a(1-a)(1-q)}{a(1-a)(1-q) + (1-a)^2 q} x_H$$

$$\Leftrightarrow x_L < \frac{a}{1-a}\left[\frac{aq + (1-a)(1-q)}{a(1-q) + (1-a)q}\right] x_H$$

2) $\mathbf{T}^{\{s_2^I=1;\ s_1^I=0\}}$

$$E\Pi_2 \mid \{s_2{}^I = 1, s_1{}^I = 0\} = \frac{a(1-a)q + a^2(1-q)}{a^2(1-q) + (1-a)^2(1-q) + 2a(1-a)q} x_H - \frac{(1-a)^2 q + a(1-a)q}{a^2(1-q) + (1-a)^2(1-q) + 2a(1-a)q} x_L$$

$$> 0 \Rightarrow x_L < \frac{a(1-a)q + a^2(1-q)}{(1-a)^2 q + a(1-a)q} x_H$$

$$\Leftrightarrow x_L < \frac{a}{1-a}\left[\frac{(1-a)q + a(1-q)}{(1-a)(1-q) + aq}\right] x_H$$

3) $\mathbf{T}^{\{s_2^I=0;\ s_1^I=1\}}$

$$E\Pi_2 \mid \{s_2{}^I = 0, s_1{}^I = 1\} = \frac{a(1-a)q + (1-a)^2(1-q)}{a^2(1-q) + (1-a)^2(1-q) + 2a(1-a)q} x_H - \frac{a^2(1-q) + a(1-a)q}{a^2(1-q) + (1-a)^2(1-q) + 2a(1-a)q} x_L$$

$$> 0 \Rightarrow x_L < \frac{a(1-a)q + (1-a)^2(1-q)}{a^2(1-q) + a(1-a)q} x_H$$

$$\Leftrightarrow x_L < \frac{1-a}{a}\left[\frac{aq + (1-a)(1-q)}{a(1-q) + (1-a)q}\right] x_H$$

4) $\mathbf{T}^{\{s_2{}^{I}=0;\ s_1{}^{I}=0\}}$

$$E\Pi_2 \mid \{s_2{}^I=0, s_1{}^I=0\} = \frac{(1-a)^2 q + a(1-a)(1-q)}{a^2 q + (1-a)^2 q + 2a(1-a)(1-q)} x_H - \frac{a(1-a)(1-q) + a^2 q}{a^2 q + (1-a)^2 q + 2a(1-a)(1-q)} x_L$$

$$> 0 \Rightarrow x_L < \frac{(1-a)^2 q + a(1-a)(1-q)}{a(1-a)(1-q) + a^2 q} x_H$$

$$\Leftrightarrow x_L < \frac{1-a}{a}\left[\frac{(1-a)q + a(1-q)}{(1-a)(1-q) + aq}\right] x_H$$

B.3.4 P. 93

1) $\mathbf{x_L} < \mathbf{T}^{\{s_2{}^{I}=1,\ s_1{}^{I}=1\}}$ **for all *a, q* > 0.5**

$$x_L < \frac{a}{1-a}\left[\frac{aq + (1-a)(1-q)}{a(1-q) + (1-a)q}\right] x_H$$

$$a, q > 0{,}5 \Rightarrow aq + (1-a)(1-q) > a(1-q) + (1-a)q$$

$$aq - a(1-q) > (1-a)q - (1-a)(1-q)$$

$$a(2q-1) > (1-a)(2q-1)$$

$$a > (1-a)$$

Then $a(aq + (1-a)1-q) > (1-a)[a(1-q) + (1-a)q]$

$$\Rightarrow \frac{a}{1-a}\left[\frac{aq + (1-a)(1-q)}{a(1-q) + (1-a)q}\right] > 1$$

2) $\mathbf{x_L} < \mathbf{T}^{\{s_2{}^{I}=1,\ s_1{}^{I}=0\}}$ **for all *a, q* > 0.5**

$$x_L < \frac{a}{1-a}\left[\frac{(1-a)q + a(1-q)}{(1-a)(1-q) + aq}\right] x_H$$

$$a, q > 0.5 \Rightarrow a(1-a)q + a^2(1-q) > (1-a)^2(1-q) + a(1-a)q$$

$$a^2 > (1-a)^2$$

$$\Rightarrow \frac{a}{1-a}\left[\frac{(1-a)q + a(1-q)}{(1-a)(1-q) + aq}\right] > 1$$

B.4 CASE 3

B.4.1 P. 96: Table 4.4.3.1

1) $\mathbf{T}^{\{s_2^{N}=1;\ 1_1\}}$

$$E\Pi_2 \mid \{s_2^{N}=1,1_1\} = \theta_2\left(\frac{\Pr(s_2^{I}=1 \mid 1_2,1_1)\Pr(1_2,1_1)}{\Pr(s_2^{I}=1)\Pr(1_1)}x_H - \frac{\Pr(s_2^{I}=1 \mid 0_2,1_1)\Pr(0_2,1_1)}{\Pr(s_2^{I}=1)\Pr(1_1)}x_L\right)$$

$$+(1-\theta_2)\left(\frac{\Pr(s_2^{U}=1 \mid 1_2,1_1)\Pr(1_2,1_1)}{\Pr(s_2^{U}=1)\Pr(1_1)}x_H - \frac{\Pr(s_2^{U}=1 \mid 0_2,1_1)\Pr(0_2,1_1)}{\Pr(s_2^{U}=1)\Pr(1_1)}x_L\right.$$

$$=[2\theta_2 a+(1-\theta_2)]qx_H - [2\theta_2(1-a)+(1-\theta_2)](1-q)x_L$$

$$>0 \Rightarrow x_L < \frac{[2\theta_2 a+(1-\theta_2)]q}{[2\theta_2(1-a)+(1-\theta_2)](1-q)}x_H$$

$$\Leftrightarrow x_L < \left[\frac{2\theta_2 a+(1-\theta_2)}{2\theta_2(1-a)+(1-\theta_2)}\right]\frac{q}{1-q}x_H$$

2) $\mathbf{T}^{\{s_2^{N}=1;\ 0_1\}}$

$$E\Pi_2 \mid \{s_2^{N}=1,0_1\} = \theta_2\left(\frac{\Pr(s_2^{I}=1 \mid 1_2,0_1)\Pr(1_2,0_1)}{\Pr(s_2^{I}=1)\Pr(0_1)}x_H - \frac{\Pr(s_2^{I}=1 \mid 0_2,0_1)\Pr(0_2,0_1)}{\Pr(s_2^{I}=1)\Pr(0_1)}x_L\right)$$

$$+(1-\theta_2)\left(\frac{\Pr(s_2^{U}=1 \mid 1_2,0_1)\Pr(1_2,0_1)}{\Pr(s_2^{U}=1)\Pr(0_1)}x_H - \frac{\Pr(s_2^{U}=1 \mid 0_2,0_1)\Pr(0_2,0_1)}{\Pr(s_2^{U}=1)\Pr(0_1)}x_L\right.$$

$$=[2\theta_2 a+(1-\theta_2)](1-q)x_H - [2\theta_2(1-a)+(1-\theta_2)]qx_L$$

$$>0 \Rightarrow x_L < \frac{[2\theta_2 a+(1-\theta_2)](1-q)}{[2\theta_2(1-a)+(1-\theta_2)]q}x_H$$

$$\Leftrightarrow x_L < \left[\frac{2\theta_2 a+(1-\theta_2)}{2\theta_2(1-a)+(1-\theta_2)}\right]\frac{1-q}{q}x_H$$

3) $\mathbf{T^{\{s_2{}^{N=0};\ 1_1\}}}$

$$E\Pi_2 \mid \{s_2{}^N = 0, 1_1\} = \theta_2\left(\frac{\Pr(s_2{}^I = 0 \mid 1_2, 1_1)\Pr(1_2, 1_1)}{\Pr(s_2{}^I = 0)\Pr(1_1)} x_H - \frac{\Pr(s_2{}^I = 0 \mid 0_2, 1_1)\Pr(0_2, 1_1)}{\Pr(s_2{}^I = 0)\Pr(1_1)} x_L\right)$$

$$+ (1-\theta_2)\left(\frac{\Pr(s_2{}^U = 0 \mid 1_2, 1_1)\Pr(1_2, 1_1)}{\Pr(s_2{}^U = 0)\Pr(1_1)} x_H - \frac{\Pr(s_2{}^U = 0 \mid 0_2, 1_1)\Pr(0_2, 1_1)}{\Pr(s_2{}^U = 0)\Pr(1_1)} x_L\right.$$

$$= [2\theta_2(1-a) + (1-\theta_2)]q x_H - [2\theta_2 a + (1-\theta_2)](1-q) x_L$$

$$> 0 \Rightarrow x_L < \frac{[2\theta_2(1-a) + (1-\theta_2)]q}{[2\theta_2 a + (1-\theta_2)](1-q)} x_H$$

$$\Leftrightarrow x_L < \left[\frac{2\theta_2(1-a) + (1-\theta_2)}{2\theta_2 a + (1-\theta_2)}\right]\frac{q}{1-q} x_H$$

4) $\mathbf{T^{\{s_2{}^{N=0};\ 0_1\}}}$

$$E\Pi_2 \mid \{s_2{}^N = 0, 0_1\} = \theta_2\left(\frac{\Pr(s_2{}^I = 0 \mid 1_2, 0_1)\Pr(1_2, 0_1)}{\Pr(s_2{}^I = 0)\Pr(0_1)} x_H - \frac{\Pr(s_2{}^I = 0 \mid 0_2, 0_1)\Pr(0_2, 0_1)}{\Pr(s_2{}^I = 0)\Pr(0_1)} x_L\right)$$

$$+ (1-\theta_2)\left(\frac{\Pr(s_2{}^U = 0 \mid 1_2, 0_1)\Pr(1_2, 0_1)}{\Pr(s_2{}^U = 0)\Pr(0_1)} x_H - \frac{\Pr(s_2{}^U = 0 \mid 0_2, 0_1)\Pr(0_2, 0_1)}{\Pr(s_2{}^U = 0)\Pr(0_1)} x_L\right.$$

$$= [2\theta_2(1-a) + (1-\theta_2)](1-q) x_H - [2\theta_2 a + (1-\theta_2)]q x_L$$

$$> 0 \Rightarrow x_L < \frac{[2\theta_2(1-a) + (1-\theta_2)](1-q)}{[2\theta_2 a + (1-\theta_2)]q} x_H$$

$$\Leftrightarrow x_L < \left[\frac{2\theta_2(1-a) + (1-\theta_2)}{2\theta_2 a + (1-\theta_2)}\right]\frac{1-q}{q} x_H$$

B.4.2 P. 96

$\mathbf{x_L < T^{\{s_2{}^{N=1},\ 1_1\}}}$ for all *a*, *q* > 0.5

$$x_L < \left[\frac{2\theta_2 a + (1-\theta_2)}{2\theta_2(1-a) + (1-\theta_2)}\right]\frac{q}{1-q} x_H$$

$$a, q > 0.5 \Rightarrow 2\theta_2 a + (1-\theta_2) > 2\theta_2(1-a) + (1-\theta_2)$$

$$\Rightarrow q[2\theta_2 a + (1-\theta_2)] > (1-q)[2\theta_2(1-a) + (1-\theta_2)]$$

$$\Rightarrow \left[\frac{2\theta_2 a + (1-\theta_2)}{2\theta_2(1-a) + (1-\theta_2)}\right]\frac{q}{1-q} > 1$$

B.4.3 P. 96-97

1) $\mathbf{T}^{\{s_2^{N=1};\ {}^{0}_{1}\}} > \mathbf{T}^{\{s_2^{N=0};\ {}^{0}_{1}\}}$

$$\left[\frac{2\theta_2 a+(1-\theta_2)}{2\theta_2(1-a)+(1-\theta_2)}\right]\frac{1-q}{q}x_H > \left[\frac{2\theta_2(1-a)+(1-\theta_2)}{2\theta_2 a+(1-\theta_2)}\right]\frac{1-q}{q}x_H$$

$$\Leftrightarrow [2\theta_2 a+(1-\theta_2)]^2 > [2\theta_2 a+(1-\theta_2)]^2$$

True since $a > 0.5$

2) $\mathbf{T}^{\{s_2^{N=0};\ {}^{1}_{1}\}} > \mathbf{T}^{\{s_2^{N=0};\ {}^{0}_{1}\}}$

$$\left[\frac{2\theta_2(1-a)+(1-\theta_2)}{2\theta_2 a+(1-\theta_2)}\right]\frac{q}{1-q}x_H > \left[\frac{2\theta_2(1-a)+(1-\theta_2)}{2\theta_2 a+(1-\theta_2)}\right]\frac{1-q}{q}x_H$$

$$\Leftrightarrow q^2 > (1-q)^2$$

True since $q > 0.5$

1) $\mathbf{T}^{\{s_2^{N=1};\ {}^{0}_{1}\}} \gtrless \mathbf{T}^{\{s_2^{N=0};\ {}^{1}_{1}\}}$ **iff** $\frac{2\theta_2 a+(1-\theta_2)}{2\theta_2(1-a)+(1-\theta_2)} > or < \frac{q}{1-q}$

$$\left[\frac{2\theta_2 a+(1-\theta_2)}{2\theta_2(1-a)+(1-\theta_2)}\right]\frac{1-q}{q}x_H > or < \left[\frac{2\theta_2(1-a)+(1-\theta_2)}{2\theta_2 a+(1-\theta_2)}\right]\frac{q}{1-q}x_H$$

$$\Leftrightarrow \frac{2\theta_2 a+(1-\theta_2)}{2\theta_2(1-a)+(1-\theta_2)} > or < \frac{q}{1-q}$$

B.5 CASE 4

B.5.1 P. 98: Table 4.4.4.1

1) $\mathbf{T}^{\{s_1{}^N=1\}}$

$$E\Pi_1 \mid \{s_1^N = 1\} = \theta_1[\Pr(s_1^I = 1 \mid 1_1)x_H - \Pr(s_1^I = 1 \mid 0_1)x_L] + (1-\theta_1)[\Pr(s_1^U = 1 \mid 1_1)x_H - \Pr(s_1^U = 1 \mid 0_1)x_L]$$

$$= [2\theta_1 a + (1-\theta_1)]x_H - [2\theta_1(1-a) + (1-\theta_1)]x_L$$

$$> 0 \Rightarrow x_L < \frac{2\theta_1 a + (1-\theta_1)}{2\theta_1(1-a) + (1-\theta_1)} x_H$$

2) $\mathbf{T}^{\{s_1{}^N=0\}}$

$$E\Pi_1 \mid \{s_1^N = 0\} = \theta_1[\Pr(s_1^I = 0 \mid 1_1)x_H - \Pr(s_1^I = 0 \mid 0_1)x_L] + (1-\theta_1)[\Pr(s_1^U = 0 \mid 1_1)x_H - \Pr(s_1^U = 0 \mid 0_1)x_L]$$

$$= [2\theta_1(1-a) + (1-\theta_1)]x_H - [2\theta_1 a + (1-\theta_1)]x_L$$

$$> 0 \Rightarrow x_L < \frac{2\theta_1(1-a) + (1-\theta_1)}{2\theta_1 a + (1-\theta_1)} x_H$$

B.5.2 B.5.2 P. 100

$\Pr(s_i^I = 1, s_j^U=1) = \Pr(s_i^I=1, s_j^U 0) = \Pr(s_i^I=0, s_j^U=1) = \Pr(s_i^I=0, s_j^U=0)$

$= [0.5a + 0.5(1-a)]\ 0.5q + [0.5a + 0.5(1-a)]\ 0.5(1-q) = 0.25$

$\Pr(s_i^U = 1, s_j^U=1) = \Pr(s_i^U=1, s_j^U 0) = \Pr(s_i^U=0, s_j^U=1) = \Pr(s_i^U=0, s_j^U=0)$

$= (0.5)\ 0.5q + (0.5)\ 0.5(1-q) = 0.25$

B.5.3 P.100: Table 4.4.4.4

$$E\Pi_2 \mid \{s_2{}^N, s_1{}^N\} = \theta_2\theta_1 E\Pi_2 \mid \{s_2{}^I, s_1{}^I\} + \theta_2(1-\theta_1)E\Pi_2 \mid \{s_2{}^I, s_1{}^U\}$$
$$+(1-\theta_2)\theta_1 E\Pi_2 \mid \{s_2{}^U, s_1{}^I\} + (1-\theta_2)(1-\theta_1)E\Pi_2 \mid \{s_2{}^U, s_1{}^U\}$$

1) $\mathbf{T}^{\{s_2{}^{N=1},\, s_1{}^{N=1}\}}$

$$E\Pi_2 \mid \{s_2{}^N = 1, s_1{}^N = 1\} = \Bigg[\theta_2\theta_1 \frac{a^2q + a(1-a)(1-q)}{a^2q + (1-a)^2q + 2a(1-a)(1-q)}$$
$$+\theta_1(1-\theta_2)[aq + (1-a)(1-q)] + (1-\theta_1)\theta_2 a + 0.5(1-\theta_2)(1-\theta_1)\Bigg]x_H$$
$$-\Bigg[\theta_2\theta_1 \frac{(1-a)^2q + a(1-a)(1-q)}{a^2q + (1-a)^2q + 2a(1-a)(1-q)}$$
$$+\theta_1(1-\theta_2)[a(1-q) + (1-a)q] + (1-\theta_1)\theta_2(1-a) + 0.5(1-\theta_2)(1-\theta_1)\Bigg]x_L$$

$>0 \Rightarrow$

$$x_L < \frac{\theta_2\theta_1[a^2q + a(1-a)(1-q)] + [a^2q + (1-a)^2q + 2a(1-a)(1-q)]\{\theta_1(1-\theta_2)[aq + (1-a)(1-q)] + (1-\theta_1)\theta_2 a + 0.5(1-\theta_2)(1-\theta_1)\}}{\theta_2\theta_1[(1-a)^2q + a(1-a)(1-q)] + [a^2q + (1-a)^2q + 2a(1-a)(1-q)]\{\theta_1(1-\theta_2)[a(1-q) + (1-a)q] + (1-\theta_1)\theta_2(1-a) + 0.5(1-\theta_2)(1-\theta_1)\}} x_H$$

Divide both sides of the above expression by $\theta_2\theta_1$:

$$\Rightarrow x_L < \frac{[a^2q + a(1-a)(1-q)] + [a^2q + (1-a)^2q + 2a(1-a)(1-q)]\{\frac{(1-\theta_2)}{\theta_2}[aq + (1-a)(1-q)] + \frac{(1-\theta_1)}{\theta_1}{}_{2}\, a + 0.5\frac{(1-\theta_1)}{\theta_1}\frac{(1-\theta_2)}{\theta_2})\}}{[(1-a)^2q + a(1-a)(1-q)] + [a^2q + (1-a)^2q + 2a(1-a)(1-q)]\{\frac{(1-\theta_2)}{\theta_2}[a(1-q) + (1-a)q] + \frac{(1-\theta_1)}{\theta_1}(1-a) + 0.5\frac{(1-\theta_2)}{\theta_2}\frac{(1-\theta_1)}{\theta_1}\}} x_H$$

Let $\Theta_i = \frac{1-\theta_i}{\theta_i}$. Then the above expression can be re-written as:

$$\Rightarrow x_L < \frac{[a^2q + a(1-a)(1-q)] + [a^2q + (1-a)^2q + 2a(1-a)(1-q)]\{\Theta_2[aq + (1-a)(1-q)] + \Theta_1 a + 0.5\Theta_2\Theta_1\}}{[(1-a)^2q + a(1-a)(1-q)] + [a^2q + (1-a)^2q + 2a(1-a)(1-q)]\{\Theta_2[a(1-q) + (1-a)q] + \Theta_1(1-a) + 0.5\Theta_2\Theta_1)\}} x_H$$

Recall that A = (1-a)(1-q)+aq

B = a(1-q)+(1-a)q.

The above threshold can be further simplified as:

$$\Rightarrow x_L < \frac{aA + [aA + (1-a)B]\{\Theta_2 A + \Theta_1 a + 0.5\Theta_2\Theta_1\}}{(1-a)B + [aA + (1-a)B)]\{\Theta_2 B + \Theta_1(1-a) + 0.5\Theta_2\Theta_1\}} x_H$$

$$\Leftrightarrow x_L < \frac{\frac{aA}{aA + (1-a)B} + \Theta_2 A + \Theta_1(a + 0.5\Theta_2)}{\frac{(1-a)B}{aA + (1-a)B} + \Theta_2 B + \Theta_1[(1-a) + 0.5\Theta_2]} x_H$$

Let

$$C = \frac{aA}{aA + (1-a)B},$$

$$D = \frac{(1-a)B}{aA + (1-a)B}.$$

Then the threshold becomes:

$$\Leftrightarrow x_L < \frac{C + \Theta_2 A + \Theta_1(a + 0.5\Theta_2)}{D + \Theta_2 B + \Theta_1[(1-a) + 0.5\Theta_2]} x_H$$

2) $\mathbf{T}^{\{s_2^{N=1},\, s_1^{N=0}\}}$

$$E\Pi_2 \mid \{s_2^N = 1, s_1^N = 0\} = \Bigg[\theta_2\theta_1 \frac{a(1-a)q + a^2(1-q)}{a^2(1-q) + (1-a)^2(1-q) + 2a(1-a)q}$$

$$+\theta_1(1-\theta_2)[(1-a)q + a(1-q)] + (1-\theta_1)\theta_2 a + 0.5(1-\theta_2)(1-\theta_1)\Bigg]x_H$$

$$-\Bigg[\theta_2\theta_1 \frac{(1-a)^2(1-q) + a(1-a)q}{a^2(1-q) + (1-a)^2(1-q) + 2a(1-a)q}$$

$$+\theta_1(1-\theta_2)[(1-a)(1-q) + aq] + (1-\theta_1)\theta_2(1-a) + 0.5(1-\theta_2)(1-\theta_1)\Bigg]x_L$$

$$>0 \Rightarrow$$

$$x_L < \frac{\theta_2\theta_1[a(1-a)q + a^2(1-q)] + [a^2(1-q) + (1-a)^2(1-q) + 2a(1-a)q]\{\theta_1(1-\theta_2)[(1-a)q + a(1-q)] + (1-\theta_1)\theta_2 a + 0.5(1-\theta_2)(1-\theta_1)\}}{\theta_2\theta_1[a(1-a)q + (1-a)^2(1-q)] + [a^2(1-q) + (1-a)^2(1-q) + 2a(1-a)q]\{\theta_1(1-\theta_2)[(1-a)(1-q) + aq] + (1-\theta_1)\theta_2(1-a) + 0.5(1-\theta_2)(1-\theta_1)\}}x_H$$

Following the steps in (1), the above threshold can be re-written as:

$$\Rightarrow x_L < \frac{aB + [(1-a)A + aB]\{\Theta_2 B + \Theta_1 a + 0.5\Theta_2\Theta_1\}}{(1-a)A + [(1-a)A + aB)]\{\Theta_2 A + \Theta_1(1-a) + 0.5\Theta_2\Theta_1\}}x_H$$

$$\Leftrightarrow x_L < \frac{\dfrac{aB}{(1-a)A + aB} + \Theta_2 B + \Theta_1(a + 0.5\Theta_2)}{\dfrac{(1-a)A}{(1-a)A + aB} + \Theta_2 A + \Theta_1[(1-a) + 0.5\Theta_2]}x_H$$

Let

$$E = \frac{(1-a)A}{(1-a)A + aB},$$

$$F = \frac{aB}{(1-a)A + aB}.$$

Then the threshold becomes:

$$\Leftrightarrow x_L < \frac{F + \Theta_2 B + \Theta_1(a + 0.5\Theta_2)}{E + \Theta_2 A + \Theta_1[(1-a) + 0.5\Theta_2]}x_H$$

3) $\mathbf{T}^{\{s_2^{N=0},\, s_1^{N=1}\}}$

$$E\Pi_2 \mid \{s_2{}^N = 0, s_1{}^N = 1\} = \Bigg[\theta_2\theta_1 \frac{a(1-a)q + (1-a)^2(1-q)}{a^2(1-q) + (1-a)^2(1-q) + 2a(1-a)q}$$

$$+ \theta_1(1-\theta_2)[aq + (1-a)(1-q)] + (1-\theta_1)\theta_2(1-a) + 0.5(1-\theta_2)(1-\theta_1)\Bigg]x_H$$

$$-\Bigg[\theta_2\theta_1 \frac{a^2(1-q) + a(1-a)q}{a^2(1-q) + (1-a)^2(1-q) + 2a(1-a)q}$$

$$+ \theta_1(1-\theta_2)[(a(1-q) + (1-a)q] + (1-\theta_1)\theta_2 a + 0.5(1-\theta_2)(1-\theta_1)\Bigg]x_L$$

$$> 0 \Rightarrow$$

$$x_L < \frac{\theta_2\theta_1[a(1-a)q + (1-a)^2(1-q)] + [a^2(1-q) + (1-a)^2(1-q) + 2a(1-a)q]\{\theta_1(1-\theta_2)[(aq + (1-a)(1-q)] + (1-\theta_1)\theta_2(1-a) + 0.5(1-\theta_2)(1-\theta_1)\}}{\theta_2\theta_1[a(1-a)q + a^2(1-q)] + [a^2(1-q) + (1-a)^2(1-q) + 2a(1-a)q]\{\theta_1(1-\theta_2)[a(1-q) + (1-a)q] + (1-\theta_1)\theta_2 a + 0.5(1-\theta_2)(1-\theta_1)\}} x_H$$

Following the steps in (1), the above threshold can be re-written as:

$$\Rightarrow x_L < \frac{(1-a)A + [(1-a)A + aB]\,\{\Theta_2 A + \Theta_1(1-a) + 0.5\Theta_2\Theta_1\}}{aB + [(1-a)A + aB)]\,\{\Theta_2 B + \Theta_1 a + 0.5\Theta_2\Theta_1\}} x_H$$

$$\Leftrightarrow x_L < \frac{\dfrac{(1-a)A}{(1-a)A + aB} + \Theta_2 A + \Theta_1[(1-a) + 0.5\Theta_2]}{\dfrac{aB}{(1-a)A + aB} + \Theta_2 B + \Theta_1(a + 0.5\Theta_2)} x_H$$

Let

$$E = \frac{(1-a)A}{(1-a)A + aB},$$

$$F = \frac{aB}{(1-a)A + aB}.$$

Then the threshold becomes:

$$\Leftrightarrow x_L < \frac{E + \Theta_2 A + \Theta_1[(1-a) + 0.5\Theta_2]}{F + \Theta_2 B + \Theta_1(a + 0.5\Theta_2)} x_H$$

4) $\mathbf{T}^{\{s_2{}^{N=0},\, s_1{}^{N=0}\}}$

$$E\Pi_2 \mid \{s_2{}^N = 0, s_1{}^N = 0\} = \Bigg[\theta_2\theta_1 \frac{a(1-a)(1-q)+(1-a)^2 q}{a^2 q+(1-a)^2 q+2a(1-a)q}$$

$$+\theta_1(1-\theta_2)[(1-a)q+a(1-q)]+(1-\theta_1)\theta_2(1-a)+0.5(1-\theta_2)(1-\theta_1)\Bigg]x_H$$

$$-\Bigg[\theta_2\theta_1 \frac{a(1-a)(1-q)+a^2 q}{a^2 q+(1-a)^2 q+2a(1-a)q}$$

$$+\theta_1(1-\theta_2)[(1-a)(1-q)+aq]+(1-\theta_1)\theta_2 a+0.5(1-\theta_2)(1-\theta_1)\Bigg]x_L$$

$$>0 \Rightarrow$$

$$x_L < \frac{\theta_2\theta_1[a(1-a)(1-q)+(1-a)^2 q]+[a^2 q+(1-a)^2 q+2a(1-a)q]\{\theta_1(1-\theta_2)[(1-a)q+a(1-q)]+(1-\theta_1)\theta_2(1-a)+0.5(1-\theta_2)(1-\theta_1)\}}{\theta_2\theta_1[a(1-a)(1-q)+a^2 q]+[a^2 q+(1-a)^2 q+2a(1-a)q]\{\theta_1(1-\theta_2)[(1-a)(1-q)+aq]+(1-\theta_1)\theta_2 a+0.5(1-\theta_2)(1-\theta_1)\}} x_H$$

Following the steps in (1), the above threshold can be re-written as:

$$\Rightarrow x_L < \frac{(1-a)B+[aA+(1-a)B]\{\Theta_2 B+\Theta_1(1-a)+0.5\Theta_2\Theta_1\}}{aA+[aA+(1-a)B)]\{\Theta_2 A+\Theta_1 a+0.5\Theta_2\Theta_1\}} x_H$$

$$\Leftrightarrow x_L < \frac{\dfrac{(1-a)B}{aA+(1-a)B}+\Theta_2 B+\Theta_1[(1-a)+0.5\Theta_2]}{\dfrac{(1-a)A}{aA+(1-a)B}+\Theta_2 A+\Theta_1[a+0.5\Theta_2]} x_H$$

Let

$$D = \frac{(1-a)B}{aA+(1-a)B},$$

$$C = \frac{aA}{aA+(1-a)B}.$$

Then the threshold becomes:

$$\Leftrightarrow x_L < \frac{D+\Theta_2 B+\Theta_1[(1-a)+0.5\Theta_2]}{C+\Theta_2 A+\Theta_1[a+0.5\Theta_2]} x_H$$

B.5.4 P. 101

$x_L < T^{\{s_2^{N=1}, s_1^{N=1}\}}$ for all *a*, *q* > 0.5

$$x_L < \frac{C+\Theta_2 A+\Theta_1(a+0.5\Theta_2)}{D+\Theta_2 B+\Theta_1[(1-a)+0.5\Theta_2]} x_H$$

$$1) A > B$$

$$\Leftrightarrow (1-a)(1-q)+aq > a(1-q)+(1-a)q$$

$$\Leftrightarrow aq - a(1-q) > (1-a)q-(1-a)(1-q)$$

$$\Leftrightarrow a(2q-1) > (1-a)(2q-1)$$

$$\Leftrightarrow a > (1-a)$$

$$2) C > D$$

$$\Leftrightarrow \frac{aA}{aA+(1-a)B} > \frac{(1-a)B}{aA+(1-a)B}$$

$$a > 0.5 \quad \text{and} \quad A > B \Rightarrow aA > (1-a)B$$

$$\Rightarrow C+\Theta_2 A+\Theta_1(a+0.5\Theta_2) > D+\Theta_2 B+\Theta_1[(1-a)+0.5\Theta_2]$$

$$\Rightarrow \frac{C+\Theta_2 A+\Theta_1(a+0.5\Theta_2)}{D+\Theta_2 B+\Theta_1[(1-a)+0.5\Theta_2]} > 1$$

B.5.5 P. 102

1) **$T^{\{s_2^{N=1}, s_1^{N=0}\}} > T^{\{s_2^{N=0}, s_1^{N=0}\}}$**

$$\frac{F+\Theta_2 B+\Theta_1(a+0.5\Theta_2)}{E+\Theta_2 A+\Theta_1[(1-a)+0.5\Theta_2]} x_H > \frac{D+\Theta_2 B+\Theta_1[(1-a)+0.5\Theta_2]}{C+\Theta_2 A+\Theta_1[a+0.5\Theta_2]} x_H$$

True since *a* > 0.5 and

$$1) F+\Theta_2 B+\Theta_1(a+0.5\Theta_2) > D+\Theta_2 B+\Theta_1[(1-a)+0.5\Theta_2]$$

$$\Rightarrow F > D$$

$$\Leftrightarrow \frac{aB}{(1-a)A+aB} > \frac{(1-a)B}{aA+(1-a)B}$$

$$\Leftrightarrow a^2AB+a(1-a)B^2 > (1-a)^2AB+a(1-a)B^2$$

$$\Leftrightarrow a^2 > (1-a)^2$$

$$2) E+\Theta_2 A+\Theta_1[(1-a)+0.5\Theta_2] < C+\Theta_2 A+\Theta_1[a+0.5\Theta_2]$$

$$\text{since } E < C$$

$$\Leftrightarrow \frac{(1-a)A}{(1-a)A+aB} < \frac{aA}{aA+(1-a)B}$$

$$\Leftrightarrow a(1-a)A^2+(1-a)^2AB < a(1-a)A^2+a^2AB$$

$$\Leftrightarrow (1-a)^2 < a^2$$

2) $\mathbf{T^{\{s_2{}^{N=0}, s_1{}^{N=1}\}} > T^{\{s_2{}^{N=0}, s_1{}^{N=0}\}}}$

$$\frac{E+\Theta_2 A+\Theta_1[(1-a)+0.5\Theta_2]}{F+\Theta_2 B+\Theta_1(a+0.5\Theta_2)} x_H > \frac{D+\Theta_2 B+\Theta_1[(1-a)+0.5\Theta_2]}{C+\Theta_2 A+\Theta_1[a+0.5\Theta_2]} x_H$$

True since $a > 0.5$, $q > 0.5$ and

$$1) A > B$$

$$\Leftrightarrow (1-a)(1-q)+aq > a(1-q)+(1-a)q$$

$$\Leftrightarrow aq-a(1-q) > (1-a)q-(1-a)(1-q)$$

$$\Leftrightarrow a(2q-1) > (1-a)(2q-1)$$

$$\Leftrightarrow a > (1-a)$$

$$2) E+\Theta_2 A+\Theta_1[(1-a)+0.5\Theta_2 > D+\Theta_2 B+\Theta_1[(1-a)+0.5\Theta_2]$$

$$\text{True since } A > B \text{ and}$$

$$E > D$$

$$\Leftrightarrow \frac{(1-a)A}{(1-a)A+aB} > \frac{(1-a)B}{aA+(1-a)B}$$

$$\Leftrightarrow a(1-a)A^2+(1-a)^2AB > a(1-a)B^2+(1-a)^2AB$$

$$\Leftrightarrow A^2 > \mathrm{B}^2$$

$3) F + \Theta_2 B + \Theta_1 (a + 0.5\Theta_2) < C + \Theta_2 A + \Theta_1 [a + 0.5\Theta_2]$

True since $A > B$ and

$$F < C$$

$$\Leftrightarrow \frac{aB}{(1-a)A + aB} < \frac{aA}{aA + (1-a)B}$$

$$\Leftrightarrow a^2 AB + a(1-a)B^2 < a^2 AB + a(1-a)A^2$$

$$\Leftrightarrow B^2 < A^2$$

3) $\mathbf{T}^{\{s_2^{N=1}, s_1^{N=0}\}} \gtrless \mathbf{T}^{\{s_2^{N=0}, s_1^{N=1}\}}$

$$\frac{F+\Theta_2 B+\Theta_1(a+0.5\Theta_2)}{E+\Theta_2 A+\Theta_1[(1-a)+0.5\Theta_2]}x_H > or < \frac{E+\Theta_2 A+\Theta_1[(1-a)+0.5\Theta_2]}{F+\Theta_2 B+\Theta_1(a+0.5\Theta_2)}x_H$$

$$\Leftrightarrow F+\Theta_2 B+\Theta_1(a+0.5\Theta_2) > or < E+\Theta_2 A+\Theta_1[(1-a)+0.5\Theta_2]$$

Note that $F > E$

$$\Leftrightarrow \frac{aB}{(1-a)A+aB} > \frac{(1-a)A}{(1-a)A+aB}$$

$$\Leftrightarrow a^2(1-q)+a(1-a)q > (1-a)^2(1-q)+a(1-a)q$$

$$\Leftrightarrow a^2 > (1-a)^2$$

And $\Theta_2 B+\Theta_1(a+0.5\Theta_2) > or < \Theta_2 A+\Theta_1[(1-a)+0.5\Theta_2]$

$$\Leftrightarrow \Theta_2 B+a\Theta_1+0.5\Theta_1\Theta_2 > or < \Theta_2 A+(1-a)\Theta_1+0.5\Theta_1\Theta_2$$

$$\Leftrightarrow a(1-q)\Theta_2+(1-a)q\Theta_2+a\Theta_1 > or < (1-a)(1-q)\Theta_2+aq\Theta_2+(1-a)\Theta_1$$

$$\Leftrightarrow (2a-1)(1-q)\Theta_2+(2a-1)\Theta_1 > or < (2a-1)q\Theta_2$$

$$\Leftrightarrow \Theta_2+\Theta_1 > or < 2\Theta_2 q$$

So, for $\frac{F+\Theta_2 B+\Theta_1(a+0.5\Theta_2)}{E+\Theta_2 A+\Theta_1[(1-a)+0.5\Theta_2]}x_H > \frac{E+\Theta_2 A+\Theta_1[(1-a)+0.5\Theta_2]}{F+\Theta_2 B+\Theta_1(a+0.5\Theta_2)}x_H$,

it is necessary (but not sufficiant) that $\frac{\Theta_2+\Theta_1}{2\Theta_2} > q$

Note that

$$\frac{\Theta_2+\Theta_1}{2\Theta_2} \Leftrightarrow \frac{\theta_2-\theta_1(2\theta_2-1)}{2\theta_1(1-\theta_2)}$$

$\Rightarrow \theta_2 \to 1$ or $\theta_1 \to 0 \Rightarrow \frac{\Theta_2+\Theta_1}{2\Theta_2} \to \infty$ and $\frac{F+\Theta_2 B+\Theta_1(a+0.5\Theta_2)}{E+\Theta_2 A+\Theta_1[(1-a)+0.5\Theta_2]} > \frac{E+\Theta_2 A+\Theta_1[(1-a)+0.5\Theta_2]}{F+\Theta_2 B+\Theta_1(a+0.5\Theta_2)}x_H$;

$\Rightarrow$ q $\to$ 1 and $\theta_2 > \theta_1 \Rightarrow \frac{F+\Theta_2 B+\Theta_1(a+0.5\Theta_2)}{E+\Theta_2 A+\Theta_1[(1-a)+0.5\Theta_2]} > \frac{E+\Theta_2 A+\Theta_1[(1-a)+0.5\Theta_2]}{F+\Theta_2 B+\Theta_1(a+0.5\Theta_2)}x_H$

B.6 COMPARISON OF FIRM 2'S DECISIONS UNDER DIFFERENT INFORMATION STRUCTURES

B.6.1 P. 105

1) $\mathbf{T^{\{s_2^{I=1},\, 0_1\}} > T^{\{s_2^{N=1},\, 0_1\}}}$

$$\frac{a}{1-a}\frac{1-q}{q}x_H > \left[\frac{2\theta_2 a+(1-\theta_2)}{2\theta_2(1-a)+(1-\theta_2)}\right]\frac{1-q}{q}x_H$$

$$\Leftrightarrow \frac{a}{1-a} > \frac{2\theta_2 a+(1-\theta_2)}{2\theta_2(1-a)+(1-\theta_2)}$$

$$\Leftrightarrow 2\theta_2 a(1-a)+a(1-\theta_2) > 2\theta_2 a(1-a)+(1-a)(1-\theta_2)$$

$$\Leftrightarrow a > (1-a)$$

True since $a > 0.5$

2) $\mathbf{T^{\{s_2^{I=0},\, 1_1\}} < T^{\{s_2^{N=0},\, 1_1\}}}$

$$\frac{1-a}{a}\frac{q}{1-q}x_H < \left[\frac{2\theta_2(1-a)+(1-\theta_2)}{2\theta_2 a+(1-\theta_2)}\right]\frac{q}{1-q}x_H$$

$$\Leftrightarrow \frac{1-a}{a} < \frac{2\theta_2(1-a)+(1-\theta_2)}{2\theta_2 a+(1-\theta_2)}$$

$$\Leftrightarrow 2\theta_2 a(1-a)+(1-a)(1-\theta_2) < 2\theta_2 a(1-a)+a(1-\theta_2)$$

$$\Leftrightarrow (1-a) < a$$

True since $a > 0.5$

2) $\mathbf{T}^{\{s_2^{I=0},\, 0_1\}} < \mathbf{T}^{\{s_2^{N=0},\, 0_1\}}$

$$\frac{1-a}{a}\frac{1-q}{q}x_H < \left[\frac{2\theta_2(1-a)+(1-\theta_2)}{2\theta_2 a+(1-\theta_2)}\right]\frac{1-q}{q}x_H$$

$$\Leftrightarrow \frac{1-a}{a} < \frac{2\theta_2(1-a)+(1-\theta_2)}{2\theta_2 a+(1-\theta_2)}$$

$$\Leftrightarrow 2\theta_2 a(1-a)+(1-a)(1-\theta_2) < 2\theta_2 a(1-a)+a(1-\theta_2)$$

$$\Leftrightarrow (1-a) < a$$

True since $a > 0.5$

B.6.2 P. 106-107

$T^{\{s_2^{I=0},\, s_1^{I=1}\}} \lesseqgtr T^{\{s_2^{N=0},\, s_1^{N=1}\}}$

$$\frac{1-a}{a}\frac{A}{B}x_H > or < \frac{E+\Theta_2 A+\Theta_1[(1-a)+0.5\Theta_2]}{F+\Theta_2 B+\Theta_1(a+0.5\Theta_2)}x_H$$

$$\Leftrightarrow (1-a)A\{F+\Theta_2 B+\Theta_1(a+0.5\Theta_2)\} > or < aB\{E+\Theta_2 A+\Theta_1[(1-a)+0.5\Theta_2]\}$$

$$\Leftrightarrow (1-a)A\{\frac{aB}{(1-a)A+aB}+\Theta_2 B+\Theta_1(a+0.5\Theta_2)\} > or < aB\{\frac{(1-a)A}{(1-a)A+aB}+\Theta_2 A+\Theta_1[(1-a)+0.5\Theta_2]\}$$

$$\Leftrightarrow \frac{a(1-a)AB}{(1-a)A+aB}+\Theta_2(1-a)AB+\Theta_1(1-a)A(a+0.5\Theta_2) > or < \frac{a(1-a)AB}{(1-a)A+aB}+a\Theta_2 AB+\Theta_1 aB[(1-a)+0.5\Theta_2]$$

$$\Leftrightarrow (1-a)\Theta_2 AB+a(1-a)\Theta_1 A+0.5(1-a)\Theta_1\Theta_2 A > or < a\Theta_2 AB+a(1-a)\Theta_1 B+0.5a\Theta_1\Theta_2 B$$

$$\Leftrightarrow a(1-a)\Theta_1(A-B) > or < (2a-1)\Theta_2 AB+0.5\Theta_1\Theta_2[aB-(1-a)A]$$

Now, devide both sides of the inequality by $\Theta_1\Theta_2$:

$$a(1-a)(A-B)\frac{1}{\Theta_2} > or < (2a-1)AB\frac{1}{\Theta_1}+0.5\ [aB-(1-a)A]$$

Now,

$$1) A-B=(1-a)(1-q)+aq-a(1-q)-(1-a)q=(2a-1)q-(2a-1)(1-q)$$

$$=(2a-1)(2q-1)$$

$$2) aB-(1-a)A=a^2(1-q)+a(1-a)q-(1-a)^2(1-q)-a(1-a)q=(a^2-1+2a-a^2)(1-q)$$

$$=(2a-1)(1-q)$$

Then

$$a(1-a)(A-B)\frac{1}{\Theta_2} > or < (2a-1)AB\frac{1}{\Theta_1} + 0.5\ [aB-(1-a)A]$$

$$\Leftrightarrow a(1-a)(2a-1)(2q-1)\frac{1}{\Theta_2} > or < (2a-1)AB\frac{1}{\Theta_1} + 0.5(2a-1)(1-q)$$

$$\Leftrightarrow a(1-a)(2q-1)\frac{1}{\Theta_2} > or < AB\frac{1}{\Theta_1} + 0.5(1-q)$$

$$\Leftrightarrow a(1-a)(2q-1)\frac{1}{\Theta_2} - AB\frac{1}{\Theta_1} > or < 0.5(1-q)$$

Note that

$$AB > a(1-a)(2q-1)$$

$$\Leftrightarrow [(1-a)(1-b)+ab][a(1-q)+(1-a)a] > a(1-a)(2q-1)$$

$$\Leftrightarrow a(1-a)(1-q)^2 + (1-a)^2 q(1-q) + a^2 q(1-q) + a(1-a)q^2 > a(1-a)(2q-1)$$

$$\Leftrightarrow a(1-a)[(1-q)^2 + q^2 - 2q - 1] + (1-a)^2 q(1-q) + a^2 q(1-q) > 0$$

$$\Leftrightarrow a(1-a)[1-2q+q^2+q^2-2q-1] + (1-a)^2 q(1-q) + a^2 q(1-q) > 0$$

$$\Leftrightarrow a(1-a)[2-4q+2q^2] + (1-a)^2 q(1-q) + a^2 q(1-q) > 0$$

$$\Leftrightarrow 2a(1-a)[1-2q+q^2] + (1-a)^2 q(1-q) + a^2 q(1-q) > 0$$

$$\Leftrightarrow 2a(1-a)(1-q)^2 + (1-a)^2 q(1-q) + a^2 q(1-q) > 0$$

Then

$$\frac{1}{\Theta_1} > \frac{1}{\Theta_2} \Rightarrow a(1-a)(2q-1)\frac{1}{\Theta_2} - AB\frac{1}{\Theta_1} < 0.5(1-q)$$

Also note that

$$a(1-a)(2q-1)\frac{1}{\Theta_2} - AB\frac{1}{\Theta_1} > 0.5(1-q) \Rightarrow \frac{1}{\Theta_2} > \frac{0.5(1-q)}{a(1-a)(2q-1)} + \frac{AB}{a(1-a)(2q-1)}\frac{1}{\Theta_1}$$

B.6.3 P. 109

1) $\mathbf{T}^{\{s_2^{N=0},\, 1_1\}} > \mathbf{T}^{\{s_2^{N=0},\, s_1^{N=1}\}}$

$$\left[\frac{2\theta_2(1-a)+(1-\theta_2)}{2\theta_2 a+(1-\theta_2)}\right]\frac{q}{1-q}x_H > \frac{E+\Theta_2 A+\Theta_1[(1-a)+0.5\Theta_2]}{F+\Theta_2 B+\Theta_1(a+0.5\Theta_2)}x_H$$

Recall that $\Theta_i = \frac{1-\theta_i}{\theta_i}$. Then

$$\left[\frac{2\theta_2(1-a)+(1-\theta_2)}{2\theta_2 a+(1-\theta_2)}\right]\frac{q}{1-q}x_H \Leftrightarrow \left[\frac{2(1-a)+\Theta_2}{2a+\Theta_2}\right]\frac{q}{1-q}x_H$$

So

$$\left[\frac{2(1-a)+\Theta_2}{2a+\Theta_2}\right]\frac{q}{1-q}x_H > \frac{E+\Theta_2 A+\Theta_1[(1-a)+0.5\Theta_2]}{F+\Theta_2 B+\Theta_1(a+0.5\Theta_2)}x_H$$

$$\Leftrightarrow q[2(1-a)+\Theta_2[F+\Theta_2 B+\Theta_1(a+0.5\Theta_2)]>(1-q)(2a+\Theta_2)[E+\Theta_2 A+\Theta_1[(1-a)+0.5\Theta_2]]$$

$$\Leftrightarrow[2(1-a)q+\Theta_2 q][\frac{aB}{(1-a)A+aB}+\Theta_2 B+\Theta_1(a+0.5\Theta_2)]>(2a(1-q)+(1-q)\Theta_2)[\frac{(1-a)A}{(1-a)A+aB}+\Theta_2 A+\Theta_1[(1-a)+0.5\Theta_2]]$$

$$\Leftrightarrow\frac{2a(1-a)qB}{(1-a)A+aB}+2(1-a)q\Theta_2 B+2a(1-a)q\Theta_1+(1-a)q\Theta_1\Theta_2+\frac{aq\Theta_2 B}{(1-a)A+aB}+q\Theta_2{}^2B+aq\Theta_1\Theta_2+0.5q\Theta_1\Theta_2{}^2$$

$$>\frac{2a(1-a)(1-q)A}{(1-a)A+aB}+2a(1-q)\Theta_2 A+2a(1-a)(1-q)\Theta_1+a(1-q)\Theta_1\Theta_2$$

$$+\frac{(1-a)(1-q)\Theta_2 A}{(1-a)A+aB}+(1-q)\Theta_2{}^2A+(1-a)(1-q)\Theta_1\Theta_2+0.5(1-q)\Theta_1\Theta_2{}^2$$

$$\Leftrightarrow\frac{2a(1-a)qB}{(1-a)A+aB}+2(1-a)q\Theta_2 B+2a(1-a)q\Theta_1+\frac{aq\Theta_2 B}{(1-a)A+aB}+q\Theta_2{}^2B+aq\Theta_1\Theta_2+0.5q\Theta_1\Theta_2{}^2$$

$$>\frac{2a(1-a)(1-q)A}{(1-a)A+aB}+2a(1-q)\Theta_2 A+2a(1-a)(1-q)\Theta_1+\frac{(1-a)(1-q)\Theta_2 A}{(1-a)A+aB}+(1-q)\Theta_2{}^2A+a(1-q)\Theta_1\Theta_2+0.5(1-q)\Theta_1\Theta_2{}^2$$

Recall that $a,q>0.5$ and note that

$$qB>(1-q)A$$

$$\Leftrightarrow aq(1-q)+(1-a)q^2>(1-a)(1-q)^2+aq(1-q)$$

$$\Leftrightarrow q^2>(1-q)^2$$

Then $\left[\frac{2\theta_2(1-a)+(1-\theta_2)}{2\theta_2 a+(1-\theta_2)}\right]\frac{q}{1-q}x_H > \frac{E+\Theta_2 A+\Theta_1[(1-a)+0.5\Theta_2]}{F+\Theta_2 B+\Theta_1(a+0.5\Theta_2)}x_H$ since

$$1)\frac{2a(1-a)qB}{(1-a)A+aB} > \frac{2a(1-a)(1-q)A}{(1-a)A+aB}$$

$$\Leftrightarrow qB < (1-q)A$$

$$2) 2(1-a)q\Theta_2 B > 2a(1-q)\Theta_2 A$$

$$3) 2a(1-a)q\Theta_1 > 2a(1-a)(1-q)\Theta_1$$

$$\Leftrightarrow q > (1-q)$$

$$4) aq\Theta_1\Theta_2 > a(1-q)\Theta_1\Theta_2$$

$$\Leftrightarrow q > (1-q)$$

$$5)\frac{aq\Theta_2 B}{(1-a)A+aB} > \frac{(1-a)(1-q)\Theta_2 A}{(1-a)A+aB}$$

$$\Leftrightarrow qB > (1-q)A$$

$$6) 0.5q\Theta_1{\Theta_2}^2 > 0.5(1-q)\Theta_1{\Theta_2}^2$$

$$\Leftrightarrow q > (1-q)$$

2) $\mathbf{T}^{\{s_2^{N=0},\, 0_1\}} < \mathbf{T}^{\{s_2^{N=0},\, s_1^{N=0}\}}$

$$\left[\frac{2\theta_2(1-a)+(1-\theta_2)}{2\theta_2 a+(1-\theta_2)}\right]\frac{1-q}{q}x_H < \frac{D+\Theta_2 B+\Theta_1[(1-a)+0.5\Theta_2]}{C+\Theta_2 A+\Theta_1[a+0.5\Theta_2]}x_H$$

Recall that $\Theta_i = \frac{1-\theta_i}{\theta_i}$. Then

$$\left[\frac{2\theta_2(1-a)+(1-\theta_2)}{2\theta_2 a+(1-\theta_2)}\right]\frac{1-q}{q}x_H \Leftrightarrow \left[\frac{2(1-a)+\Theta_2}{2a+\Theta_2}\right]\frac{1-q}{q}x_H$$

So

$$\left[\frac{2(1-a)+\Theta_2}{2a+\Theta_2}\right]\frac{1-q}{q}x_H < \frac{D+\Theta_2 B+\Theta_1[(1-a)+0.5\Theta_2]}{C+\Theta_2 A+\Theta_1[a+0.5\Theta_2]}x_H$$

$$\Leftrightarrow (1-q)[2(1-a)+\Theta_2[C+\Theta_2 A+\Theta_1[a+0.5\Theta_2]] < q(2a+\Theta_2)[D+\Theta_2 B+\Theta_1[(1-a)+0.5\Theta_2]]$$

$$\Leftrightarrow [2(1-a)(1-q)+(1-q)\Theta_2][\frac{aA}{aA+(1-a)B}+\Theta_2 A+\Theta_1(a+0.5\Theta_2)] < (2aq+q\Theta_2)[\frac{(1-a)B}{aA+(1-a)B}+\Theta_2 B+\Theta_1[(1-a)+0.5\Theta_2]]$$

$$\Leftrightarrow \frac{2a(1-a)(1-q)A}{aA+(1-a)B}+2(1-a)(1-q)\Theta_2 A+2a(1-a)(1-q)\Theta_1+(1-a)(1-q)\Theta_1\Theta_2$$

$$+\frac{(1-a)(1-q)\Theta_2 A}{aA+(1-a)B}+(1-q)\Theta_2^{\,2}A+a(1-q)\Theta_1\Theta_2+0.5(1-q)\Theta_1\Theta_2^{\,2}$$

$$<\frac{2a(1-a)qB}{aA+(1-a)B}+2aq\Theta_2 B+2a(1-a)q\Theta_1+aq\Theta_1\Theta_2+\frac{(1-a)q\Theta_2 B}{aA+(1-a)B}+q\Theta_2^{\,2}B+(1-a)q\Theta_1+0.5q\Theta_1\Theta_2$$

$$\Leftrightarrow \frac{2a(1-a)(1-q)A}{aA+(1-a)B}+(1-q)\Theta_2 A[2(1-a)+\Theta_2]+2a(1-a)(1-q)\Theta_1+(1-q)\Theta_1\Theta_2+\frac{(1-a)(1-q)\Theta_2 A}{aA+(1-a)B}+0.5(1-q)\Theta_1\Theta_2^{\,2}$$

$$<\frac{2a(1-a)qB}{aA+(1-a)B}+q\Theta_2 B(2a+\Theta_2)+2a(1-a)q\Theta_1+q\Theta_1\Theta_2+\frac{(1-a)q\Theta_2 B}{aA+(1-a)B}+0.5q\Theta_1\Theta_2$$

Recall that $a, q > 0.5$ and note that

$$qB > (1-q)A$$

$$\Leftrightarrow aq(1-q)+(1-a)q^2 > (1-a)(1-q)^2+aq(1-q)$$

$$\Leftrightarrow q^2 > (1-q)^2$$

Then $\left[\frac{2(1-a)+\Theta_2}{2a+\Theta_2}\right]\frac{1-q}{q}x_H < \frac{D+\Theta_2 B+\Theta_1[(1-a)+0.5\Theta_2]}{C+\Theta_2 A+\Theta_1[a+0.5\Theta_2]}x_H$ since

$$1)\frac{2a(1-a)(1-q)A}{aA+(1-a)B} < \frac{2a(1-a)qB}{aA+(1-a)B}$$

$$\Leftrightarrow (1-q)A < qB$$

$$2)(1-q)\Theta_2 A[2(1-a)+\Theta_2] < q\Theta_2 B(2a+\Theta_2)$$

$$\Leftrightarrow (1-q)A[2(1-a)+\Theta_2] < qB(2a+\Theta_2)$$

$$3)2a(1-a)(1-q)\Theta_1 < 2a(1-a)q\Theta_1$$

$$\Leftrightarrow (1-q) < q$$

$$4)(1-q)\Theta_1\Theta_2 < q\Theta_1\Theta_2$$

$$\Leftrightarrow (1-q) < q$$

$$5)\frac{(1-a)(1-q)\Theta_2 A}{aA+(1-a)B} < \frac{(1-a)q\Theta_2 B}{aA+(1-a)B}$$

$$\Leftrightarrow (1-q)A < qB$$

$$6)0.5(1-q)\Theta_1{\Theta_2}^2 < 0.5q\Theta_1\Theta_2$$

$$\Leftrightarrow (1-q) < q$$

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