Investments in Renewables and Alternative Energy Markets

Can the EU influence Russia's investment in Asia?

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Exhaustible Resources as a Strategic Instrument

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Abstract

Exhaustible resources, like oil and gas, play an important strategic role in the world economy. Almost 30 years of oil domination, has resulted in acceptance of oil as a prime commodity in the transport sector, and has not been addressed as a strategic problem. The world dominance of oil creates intolerable power to those that dominates oil ownership and production, and has turned the commodity into an important strategic instrument. Political and economic consequences of resource dependency can be detected between Russia and the EU. Recently the crisis in Ukraine has spurred the need for diversification in energy mix and decreased dependency on Russian oil and gas. It is thus interesting to investigate how investments in renewable energy and new markets, can influence each other, and be effective instrument to not just to fight climate change, but also to ease the use of oil or gas as a strategic instrument.

This paper applies a game theory framework to consider a strategic interaction between an exhaustible resource seller, who faces demand from two different buyers. It is a sequential game of two periods, were the first mover is buyer E to decide on an investment in a backstop technology. The second mover is the seller who makes a decision on quantity supplied and whether or not he wants to invest in a new market, buyer A. I find that if investment cost for the seller is very high. Seller will not invest and buyer E will invest as long as surplus from the new technology are over the calculated threshold. In the case where investment cost is very low, seller will invest something which is anticipated by buyer E who will also invest. In the case where investment costs for the seller are moderate, I get an interesting result demonstrating how the two investments options work complementary. Seller will only invest in the new market if buyer E invests in the alternative resource, and if buyer E chooses not to invest, the seller will neither invest. This can demonstrate the EU's condition to invest in new technology, or renewable energy, and especially the potential power they have to influence Russia's decision on investment in new markets.

Preface

This paper marks the ending of a five year study in Economics, which has been an amazing journey. My knowledge of economics has developed from not knowing anything about standard economics, to having develop an own model. During my studying career I have found economics linked to environmental issues and development especially interesting, and wanted this to be the background for my thesis. I have really enjoyed developing the analysis, especially since I could apply it to a current world scenario. I hope others with similar interest can enjoy reading the paper.

I would like to thank my supervisor Bård Harstad who has been of great help and provided me with a critical perspective on the model.

Special thanks to my family and friends for support and feedbacks.

Content

1 Introduction

Exhaustible resources play a unique strategic role in the world economy, and especially oil. The unique strategic importance of oil stems from the fact that it has a global monopoly in the transport sector; i.e. almost all of the world's car, airplanes, trucks and ships run on petroleum products. Almost 30 years of oil domination, has resulted in acceptance of oil as a prime commodity in the transport sector and has not been addressed as a strategic problem. This monopoly power creates intolerable power to those that dominates oil ownership and production (Woolsey and Korin, 2008). The nations with the highest production, additional to obtaining the biggest proven reserves are OPEC[1], Russia and the US, which gives them power to regulate price and accessibility (EIA, 2016). Especially OPEC; since its formation in the 1960's they have had virtually world dominance in oil production and regulation of oil price. Even though the world dependency on fossil fuels has been recognized and addressed in earlier time, the focus has been restricted to the availability of oil, or efficiency of use, rather than research and development to reduce dependency

In 2004 and 2005 there was a change of focus as oil prices started to sky rocket and the Kyoto protocol went into effect. Stronger policies where implemented in importing countries, on not just efficiency, but also in regard to carbon emission. Additional to a growing concern for climate change, the recently drop in oil price, has led to hesitation on the role played by major oil producers like OPEC, Russia and the US. The oil glut has highlighted how the commodity is used as a strategic instrument for producers to maintain world dominance. This has demonstrated how vulnerable the world is to instability in oil prices, and how oil production is not just an environmental problem, but also a highly strategic issue. Production of exhaustible resources has created the world's largest market failure. It is possible that we have come to a point were increased efficiency of use is not enough, and where technology development plays an important role in changing the world demand of exhaustible resources, as well as decreasing strategic relationship between countries.

A mutual dependency on exhaustible resources is highly applicable to the relationship between the EU and Russia. The EU is dependent on gas and oil import from Russia and

[1] Stating of with the five members Islamic Republic of Iran, Iraq, Kuwait, Saudi Arabia and Venezuela. They were later joined by Qatar, Indonesia, Libya, United Arab Emirates, Algeria, Nigeria , Ecuador, Gabon and Angola (OPEC, 2016).

Russia is severely dependent on the share of export revenues in their government budget. The dependency relationship between the two neighbors stems from the post war period and plays an important strategic role in both political and economic aspects. As a principal supplier of energy, Russia has used this advantage to leverage in political disputes on especially earlier Soviet states. This illustrates how, like oil, can play a very important role when executing power between nations. The use of energy access as a political weapon highlights the importance of not just an increased mix of energy flow to the EU, but also a greener economy.

With a current sanctioned Russia, additional to increased evidence of climate change affecting temperatures, extreme weather and migration; it is more than ever important for the EU to diversify its energy resources. Russia is hurting under the strong economic sanctions, intensified by the low oil price. It is evident that both parts need a solution to the mutual dependence on gas and oil. In light of the new Paris agreement on emission targets, it is interesting to investigate the mutual dependence relationship between EU and Russia; to see how investment in new technology can be a mean to not just end dependency, but also to reduce emissions.

The development of new technology and renewable energy can send signals to the producer on future demand, and this is an important aspect. Thus, it is applicable to analyze how supply and demand reacts to possible extensions of investments in new technology. Most frameworks on resource allocation problems with the possibility of a renewable resource are based on only one seller and one buyer. But today, the market consists of more than one buyer and one seller, so what happens to the demand for exhaustible resources when a buyer has the option of investing in a new technology? How does the buyer's action, to invest in new technology, affect the seller's action?

My paper is inspired by the article on "Strategic Resource Dependency" by Gerlagh and Liski (2011). They consider an exhaustible resource seller who faces demand from a buyer who has a substitute that will appear with a time lag. In their study they find that the basic Hotelling implications are reversed, so supply does not reflect resource scarcity, but compensates buyer for delaying the substitute. In this paper I will study a strategic equilibrium of an exhaustible resource seller, but unlike Gerlagh and Liski (2011) I will introduce two possible buyers to evaluate how investments in technology by the buyer can affect sellers incentives. There is one active buyer E, who can invest in a substitute technology and one seller who has the possibility to pay a one-time investment to be able to invest in the other passive buyer A. The question of interest is whether investment by one actor my lead to investment by another, i.e.; under what condition will the buyer E invest in the new technology? And what power does this buyer have to affect seller's choice of investing in the new market A?

In my analysis I find that the decision on investment is dependent on the cost of the investments, both from the seller's and the buyer's side. I calculate to find the different thresholds for investment cost. If investment cost for the seller is very high, buyer E will invest as long as the surplus from the new technology exceeds the calculated threshold. If none of them invests they maintain the resource dependency regime. In the case where investment cost is very low, the seller will invest, and this will be anticipated by buyer E who also invests. In the case where investment costs for the seller is moderate, I get an interesting result demonstrating how the investments work complementary. Seller will only invest in the new market if buyer E invests, and if buyer E chooses not to invest, then the seller will not invest.

The limitations of the model are strongly linked to the functional form of the analysis, and thus the criticism that comes with this. The framework I use is game theoretic, i.e. a strategic equilibrium, in a sequential game which assumes that the actors are rational and acts according to profit- or utility maximization. The investments are introduced in intervals, whether costs are high, low or moderate, to reflect the different options. The reason why I chose a backstop technology, instead of for example taxes and tariffs, is because a substitute is not that flexible and most importantly it represents a permanent effect on the demand of exhaustible resources. Implying that the effect it has on a strategic relationship is a long term solution. A renewable resource that can replace exhaustible resources has for long been assumed not a realistic option. However, increased competition in technology and development has made this a more realistic solution than what it was ten years ago. In this sense I see the technology threat as a potentially more important factor than regulation instruments like taxes and subsidies.

In the next section I will discuss the motivation example, namely the resource dependence relationship between Russia and EU. In section 3, I present the background concepts that both my model and the model by Gerlagh and Liski (2011) and I explain more profoundly their analysis. In section 4 I present the model. In section 5 the results will be discussed linked to the motivation example and limitations, before I make concluding remarks in section 6.

2 Motivation Example: Russian Energy Supply vs EU's Demand

Russia is one of the biggest producers in the world of both natural gas and oil. In 2014 it was the world's biggest producer of crude oil[2], and the third largest producer of petroleum and other liquids with an average production of 10.8 million barrels per day. They were only surpassed by the United States and Saudi Arabia. Next to this, they are the second largest producer of natural gas, with a production of 20437 billion cubic feet in 2014, only outranked by United States (U.S EIA, 2015). Russia's biggest reserve is located in the west Siberian lowlands, known as the west Siberian hydrocarbon province, and contains the world larges proven oil and gas resources in the world (Gazprom, 2016).

Production of oil and gas has been part of the Russian history from late 18th century, but it was not until 1970's – 80's that hydrocarbon started to play a significant role in the Russian economy. In this period the oil price skyrocketed, additional to the initiation of the Russian – EU energy trade. Pipelines were constructed from Russia to Europe, financed by western countries to meet the increasing demand of energy in a post-war Europe. The discovery of the deposits and the construction of the pipelines accelerated the resource rent extracted from hydrocarbon, and changed the soviet economy to become increasingly dependent on rents. After region instability in late 1980's – 90's because of price drop, fall of the Soviet Union and liberal energy policies, the economy was in a poor condition. This was changed around year 2000 when President Vladimir Putin's reforms managed to gather and take state control of the energy sector under the three major production and transport companies Gazprom, Rosneft and Transneft (Goodrich and Lanthemann, 2013).

While OPEC's largest share of oil is exported to the east, Russia's main export of both gas and crude oil is directed towards Europe. In 2014 almost 90% of Russian gas export went to European countries, whereas the export of oil in 2013 was approximated to 70 % to EU and to a smaller extent exported to Turkey and China. The revenues from the oil and gas export plays a crucial role in the Russian economy; in 2013 it accounted for almost 68% of Russia's total export revenues (U.S EIA, 2015). Most of the revenues are extracted from crude oil

[2] Including lease condensate, which are light liquid hydrocarbons recovered from lease separators or field facilities at associated and non-associated natural gas wells.

export, much due to the high petroleum price. Russia is thus heavily dependent on Europe as a market for its oil and gas production, but this is also a mutual relationship.

The EU has been increasingly dependent on import of primary energy, which accounts for 53 % of real energy consumption, and most it imported from Russia. In 2013, more than 30% of EU's import of crude oil came from Russia, - their principal supplier since 2006. Additionally, Russia's share of the EU's import was almost 40% in 2013, which makes them their biggest gas supplier, with Norway as the second largest supplier (Eurostat, 2015). Thus it is not just Russia that depends on the import from Europe, but Europe is also dependent on the constant supply of energy from Russia, especially on gas.

The dependency on energy supply from Russia varies greatly between different member countries in the EU. On one hand you have countries like Germany and Italy who imports Gas from Russia, but are more or less protected from disruptions in energy flow, due factors like storage capacity or other import options. On the other hand you have countries, in Eastern Europe, like Bulgaria, Lithuania and Hungary who are very dependent on gas supplies from Russia hence very sensitive to disruptions. The severe dependency has made these countries easy targets for price manipulations and political pressure. On the contrary, countries like Spain, Portugal and Sweden are not importing anything from Russia, and thus not dependent on the supply from Gazprom. Figure 1 gives an illustration of the relationship between European countries and the dependency of Russian energy import.

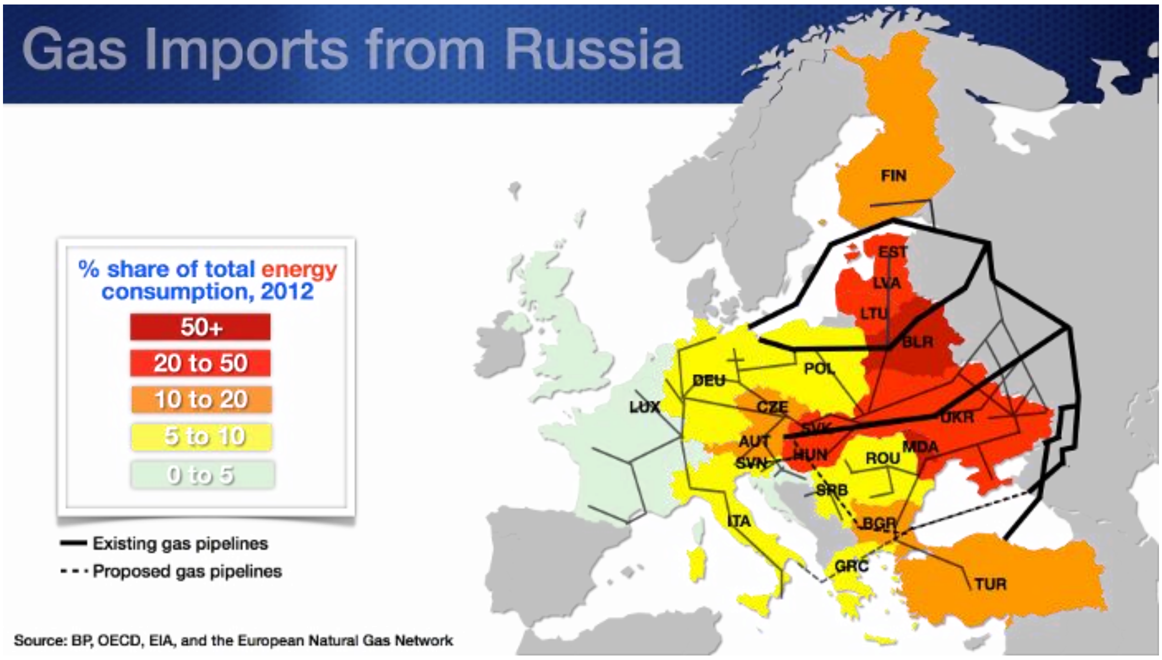

Figure 1- (Husain et al., 2014): Gas imports from Russia as a share of total energy consumption.

In recent years, this mutual interdependency between Russia and EU has created an intense debate concerning energy security for the EU and its member countries. This was drawn attention to under the Ukraine crisis in 2006 and 2008-09, when price disputes led to a cut in supply and further gas shortage, not just in the Ukraine but also in other European countries. Almost half of the gas supply to Europe travels through the Ukrainian pipe system. This makes the country a strategic element in energy disputes between EU and Russia. The Ukraine crisis in 2013 brought the conflict to a new level, and demonstrated how fragile the two parts are with respect to energy supply (Kirby, 2014).

Whereas earlier disputes in Ukraine has been price related, the crisis in 2013 started off as protests in Ukraine regarding a EU membership, and accelerated to end off as a standoff between the EU and Russia. Russia has long and close ties with Ukraine, hence a possible EU membership is considered as a threat (McMahon, 2014). After wide unrest between the south and eastern Ukraine, Russia entered and annexed Crimea. The Crimea peninsula is the part of Ukraine with most ethnic Russian’s, and considered to be a great strategic area for Russia. The annexation was, by the EU and the US, considered illegal and as a deliberate action to destabilize the sovereignty of Ukraine (EU, 2016b). This resulted in economic sanctions imposed on Russia, targeting businesses and individuals, as well as key sectors close to the ruling elite. It did not take long before Russia responded with counter sanctions on food imports, additional to threatening with supply cuts if Ukraine's gas bill was not payed. Throughout the conflict, gas supply has been a widely used weapon. On one hand Russia has been accused of supporting pro-Russian rebels with gas supplies, and sending the bill, with increased gas prices, to Ukraine. On the other hand, Ukraine has been accused of turning of gas to territories under pro-Russian rebels, and in such way also townships (Boren, 2015, Cohen, 2015).

The shut off and reduction in gas supplies into the Ukraine has a direct effect on other countries in Europe, because they all receive gas through the important pipeline, "Bratstvo" or Brotherhood. This is illustrated in figure 2. Unfortunately, it is the people that take the burden. Especially in countries that do not have any gas storage, and are in danger of facing the cold Eastern Europe winter with no heating option.

Figure 2 - (The Economist, 2014): Demonstrates existing and planned gas pipelines in Europe.

The instability around pipelines and gas flow through Ukraine has led Gazprom to invest in the newly constructed Nord Stream and the planned South Stream, which can be depicted in figure 2. These pipelines are constructed in order to supply gas from Russia to Europe without being dependent on instability in Ukraine as well as other neighboring countries.

Consequently, after the Ukraine crisis, the EU has started to talk more seriously about diversification of energy flow and other possible sources of energy. Norwegian gas is one option, but the possibility of a steady and long term increase in supply is uncertain. Norwegian hydropower is also an important and interesting option, and a new pipe connection is built between Germany and Norway, which potentially can be the beginning of an increased supply of renewables to Europe (CEDREN, 2011). The option of gas supplies from North Africa is too unstable to be a realistic option; potentially terrorist attacks and corruption makes it too risky. A more realistic option is the construction of the Trans Adriatic pipeline (TAP) which will bring gas from Caucasus through Turkey, to meet the European gas demand. TAP is estimated to start operations in 2016 and to be finished in 2020. Additionally, can the easing of sanction on Iran can increase the possible stream from this non-Russian line (The Economist, 2014, TAP, 2016).

Russia, on the other hand, has the possibility of connecting to the increased demand of energy from emerging markets in the East, like China. Increased energy demand, next to health problems from air pollution and environmental damages from coal burning, has led especially China to look for new possible energy sources. The agreement on the construction of the "Power of Siberia" line going from East Siberia to China was signed in 2014 with the construction starting the same year, and is estimated to be operational in 2018 (Gazprom, 2015). However, uncertainty in the Chinese economy and increased supply competition has led to doubt on whether the expensive investment will deliver as anticipated. In the beginning of 2016 reporters Astakhova and Aizhu (2016) wrote an article for the newsplatform Reuters on down-scaling of the planned Russian supply to China. However, the insecurity in the Russian – China relationship has been doubted earlier, much due to high investment cost and insecure demand from China (Tully, 2015).

This situation highlights the difficulties in regard to gas supply and diversification. Whereas oil can easily be transported and stored, gas supply is more complex. Gas needs an extensive investment in infrastructure, and Russia, as well as other gas suppliers, is therefore dependent on a long term and stable agreement to undertake the investments needed. This implies that Russia is tied to the European market because of challenges and costs in diversification of the gas supplies (De Micco et al., 2013). Additionally, Europe is considered a market with increased need of energy and with the decreased use of nuclear and coal, gas is an important and realistic substitute. This is taken for granted by Russia, they understand the important role they play, and can play, in Europe's future energy consumption, as Gosden (2015) in the Daily Telegraph point out, and repeated by The Russian Insider (2015).

However, while both parts seem to understand that the fragile situation needs attention; Russia is struggling with their economic situation. The sanctions imposed by the EU and the US are hitting the economy and technology sector hard, and has led to paused and delayed projects on exploration in offshore oil fields, as well as modernization in technology. This comes in addition to the plunge in oil price. The decreased oil price has hit the resource dependent economy hard, and both media and the world bank reports on "troubling" increased poverty in Russia (The Guardian, 2016). The country has been in severe need for political and economic reforms, especially in the governmental sector; this has now been pointed out as an important factor to be able to work themselves out of the crisis (Koshkin and Zubacheva, 2016). It is also clear that an economy this dependent on resource rent is sensitive towards oil prices and fluctuations, and it is now used as an argument, to start to look towards a "greener economy" (Clark, 2015, Koshkin and Zubacheva, 2016). West Siberia does not just hold the largest reserves for oil and gas, but it has also undoubtedly big potential for renewable energy like wind and hydropower. The argument still falls back on Russia's big need for technological improvement and political will to make a change, something Kremlin has not been very recognized for.

The EU, on the other hand, is working hard towards the new and improved European 2030 Energy and Climate Strategy, with main targets being a 40% cut in greenhouse gas emissions compared to 1990 levels, at least a 27% share of renewable energy consumption, and at least 27% energy savings compared with the business-as-usual scenario in 2030 (EU, 2016a). By increasing the share of renewables in their energy mix, they will also deal with the dependence to Russian energy supplies because of potentially decreased demand. Further, increased investment in renewables and realistic moves towards a "greener economy" will send signals to Kremlin that the EU is looking towards a long-term energy solution. Not just to decrease the use of fossil fuel, but also to the dependency relationship between the two parts. However, for the EU to start its change towards a greener economy it takes strength, willingness, and political power. There is little doubt that the Paris agreement was a diplomatic success, but it remains to see if it becomes an environmental success.

Regardless of this, the new international agreement will probably affect demand in some way. Even though enforcement of the new agreement is difficult, it does play a role in changing the use of fossil fuel by sending signals to producers. The possibility of renewable energy is much more realistic today than what it was a decade ago, and the maintaining low oil price has certainly changed the picture. The “old equation” of low oil price leading to boom seems to not hold trough; where experts expected increased demand from emerging market because of drop in oil price, there has been hesitation (IMF, 2016). This has been argued to be caused by a general slowdown in world development and growth, especially from important emerging countries like China.

The lacking reaction from emerging markets to the decreased oil price is somewhat contradicting to what Sinn implied in his article “Public policies against global warming: a supply side approach” from 2008. In the article (2008) he argues that a decrease in demand from one country will only lead to increased demand from other countries, due to lower prices. Until now, there has not been registered any increased demand from emerging markets, however there it is still likely that is arrives with a lag, i.e. when the end consumer understands that the prices are to stay low (IMF, 2016).

In relation to the strategic dependence between Russian and the EU it is of interest to apply a game theoretic model to analyze how possible investments in technology from the buyer’s side can induce seller to invest.

3 Background Model

The main inspiration behind this paper is the article “Strategic Resource Dependence” by Reyer Gerlagh[3] and Matti Liski[4]. In the article (2011) they analyze a strategic interaction between a exhaustible resource seller, facing a buyer who has an interest in ending its dependence to the resource. Their main result is that the basic implication of the Hotelling model is reversed; over time the stock declines while supply increases. The framework developed by the authors builds on the Hoteling theory of non-exhaustible resource depletion, the concept of backstop technology and the waste literature on strategic equilibrium. Further, the article is motivated by the market for cheap conventional oil. Firstly, I will introduce more thoroughly the three concepts that the framework builds, on before I explain more thoroughly the result of their analysis in section 3.2.

3.1 The Building Blocks

The standard ide and theory developed by the economist Harald Hotelling in the beginning of the 19th century, laid an important foundation for regulation in exhaustible resources. His famous article “The economics of exhaustible resources” begun by acknowledging how exhaustible resources where too cheap for the good of future generations, and that both production and consumption were wasteful and in need of conservation regulations (Hotelling, 1991). The author’s work led to what is known as The Hotelling rule; stating that the most profitable extraction path of a non-renewable resource is where the price of the resource[5], increases at the rate of interest. It is the discount rate that distinguishes markets at different times, and determines how future utility should be valued in present utility. The model assumes that markets are efficient and that owners of the resource is motivated by profits (Hotelling, 1991, Perman, 2011). The Hotelling rule is illustrated by:

[3] Department of Economics, Tilburg University
[4] Department of Economics, Aalto University School of Economics
[5] The marginal net revenue from sale

$$\rightarrow \quad r = \frac{(P_2 - c)_2 - (P_1 - c)_1}{(P_1 - c)_1} \tag{1}$$

The left hand side is the social discount rate and the right hand side is the proportional rate of growth of the resource price minus cost. Importantly, this considers a natural resource as an asset; and as all other assets they should satisfy the condition that their discounted prices should be equal at all points in time (Perman, 2011). The Hotelling model has been widely discussed and criticized, especially with respect to how empirical studies have failed to confirm the rule. There are different arguments as to how and why the empiric's are failing, but important explaining factors have been unsecure property rights, strategic interaction or market failures. Therefore different attempts have been made to expand the model and adapt it to for example technological change, and insecure property rights, others have highlighted the need for a new model (Krautkraemer, 1998, Anderson et al., 2014).

The second building block is the concept of a "Backstop technology", which is understood as an alternative resource to fossil fuel that can be found in unlimited amounts, and becomes cheaper and more accessible as exhaustible get more expensive. When the price of the exhaustible resource is the same as the backstop technology it assumed that consumers switch. Nordhaus et al. (1973) was the first to define the concept of backstop technology:

> "The concept that is relevant to this problem is the backstop technology, a set of processes that (1) is capable of meeting the demand requirements, and (2) has a virtually infinite resource base." (Nordhaus et al., 1973, pp. 547 – 548)

The concept is widely used when analyzing the effect of a substitute energy source, or renewable energy, on the extraction path of an exhaustible resource. If we consider a Hotelling model expanded to incorporate the effect of a backstop technology, or substitute introduced in the second period. It can be demonstrated that when a resource seller, know that a substitute will be introduced, the extraction rate will increase so that more of the resource is consumed in earlier periods. This implies that seller knows at some point he will not be able to sell his resource anymore so he is interested in "getting" rid of everything before the substitute takes over, and the more certain the substitute is the more the seller mind the present. The presence of a backstop technology is crucial for the production path of an exhaustible resource since it accelerates the resource extraction by a shorter planning horizon

(Perman, 2011). This reaction in extraction path to a backstop technology is demonstrated in both the model by Gerlagh and Liski (2011) and my analysis in section 5.

The concept of a backstop technology was long anticipated not realistic, but with the increased technological change and demand for renewable this is changed. The idea of an energy source that is renewable and can threaten the domination of exhaustible resources is much more realistic today than what it was ten years ago.

Additional to the Hotelling framework and Nordhaus concept of a "Backstop technology", the model by Gerlagh and Liski (2011) is based on a strategic equilibrium. This is a concept of a non-cooperative or cooperating equilibrium in game theory, and builds on an extensive literature. They present a non-cooperative strategic equilibrium of perfect information. The fundamental idea of game theory is that it deals with a situation where rational people interact with each other, i.e. when one person's action depends on what the other do. It is the mutual consistency of a player's best response that defines a "strategic equilibrium' of the game and the outcome is equilibrium if, and only if, each players anticipates correctly the behavior of the other part in the game. The use of a strategic equilibrium, assumes that players are rational, and with common knowledge of each other's action. Rationality implies that every player is motivated by maximizing own payoff. This does not necessarily have to be profit, but can be understood as maximizing utility. The concept of common knowledge implies that everybody knows all information, and that everybody knows that the other knows. The use of game theory in political and economic analysis is extensive, especially in the development of for example international agreements, trade and also conflicts (Montet and Serra, 2003, Perman, 2011).

3.2 "Strategic Resource Dependency" by Gerlagh and Liski

The model by Gerlagh and Liski (2011) considers a situation where a monopolistic seller of an exhaustible resource is facing demand from a single buyer (or group of coordinated buyers). The buyer has the possibility of investing in a backstop technology, or substitute, but there is a lag from the decision of investing until it is implemented. When the substitute is in place, it is assumed that there is no longer a need for the exhaustible resource. The lag before the investment is intended to capture the idea of having constraints on a fast transition from an exhaustible to a non-exhaustible resource. This is the crucial part of their model. It differentiates it from other bilateral monopoly models where buyer's strategic variable is to adapt a substitute technology (Gerlagh and Liski, 2011). The key question in the analysis is thus on *when* to start the process of ending the resource relationship, i.e. when to change the demand for the exhaustible resource. The time-to-build lag in the model can be presented in the following way:

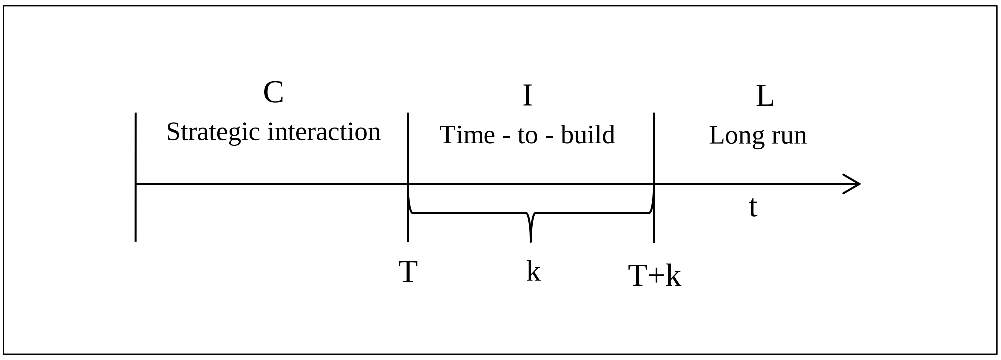

Figure 3 - Time horizon of the Gerlagh and Liski (2011) model

Figure 3 illustrates the time lap in the model, where C represents the Continuation regime where all decisions are made in the strategic interaction. Regime I represent the Intrim regime where the plyers have already made their decisions but substitute has not yet arrived. The Intrim regime is assumed to last for k unit of time. Regime L represents the long run situation when the substitute is in place. When the decision is made in regime C both parts knows that there is a transition period before buyer will change over to the substitute at time T + k.

The model is in continuous time and the authors assume no extraction cost on the exhaustible resource, built on the idea of a low cost convention oil source. They first derive the resource allocation problem before they turn to the strategic equilibria analysis. In each interval of time, their timing consists of three stages:

1) Seller chooses q_{t_i}.

2) The buyer chooses d_{t_i} to be either 0 for no investment, or 1 for the decision that starts the process of changing to the new substitute.

3) Markets clear, dependent on the decision on variable *d* from stage 2.

The analysis is calculated first without discounting and then with discounting. They find that over time the resource stock declines but supply increases up to the point where the buyer decides to start the transition over to the substitute. That is at the point in figure 3 where regime C changes to regime I, at time T + k.

This result is the opposite as to what is depicted by the traditional Hoteling model revised in first paragraph of section 3.1, and can be understood as a reaction to the threat of demand change. Implying, that the supply in this framework does not reflect the scarcity cost, but the idea that seller wants to postpone the buyer's decision on investing in the new substitute. In a sense seller compensates for the scarcity felt under the Intrim regime when the decision to invest is taken, but while buyer still is dependent on the resource. The equilibrium of the game is thus based on the strategy from the seller to keep the buyer indifferent between investing today and consume the remaining stock during the transition. They also suggest that the analysis gives a prospective of the cost of resource dependence (Gerlagh and Liski, 2011).

The transition time plays a huge role on this result, and acts like a commitment device; the threat of demand change leads the producer to increase his supply to be able to postpone the buyer's action. This implies, and which also is highlighted in their paper (2011), that the size of the stock is an important aspect, since it determines the seller's ability to postpone the buyer's switching point. It is likewise critical for the buyer in the game to observe how much stock is left for the transition time, if not seller can take advantage of this imperfect information. The scenario of imperfect information is studied more thoroughly in a former paper by Gerlagh and Liski (2007).

The strategic relationship is important to understand how one action in affects the other, or how a change in demand affects the production. Introducing the time lag in the model creates a different and new perspective of the reaction towards an investment choice, or a backstop technology. This can thus be linked up towards the debate on an exhaustible resource as a weapon, or treat, because by investing (or threatening to invest) the buyer can force seller to sell faster and thus cheaper. As Gerlagh and Liski (2011) point out in their paper, the energy technology in exhaustible resource importing countries can act as an increasingly effective strategic instrument, especially due to increased credibility in technology development and renewable resources.

What is thus interesting is the potential power of the buyer. In the model where there is only one seller and one buyer, the seller does not have any leverage against the threat of the buyer and thus has to sell at a fast speed and due to low prices binds the buyer to keep up the dependency regime. Increased production due to threats of renewable resources, or ‘greener’ policies, creates what is referred to as a “green paradox”. A green paradox was first used by the economist Hans – Werner Sinn, who explain how the increased price path may lead the acceleration of global warming, due to the acceleration of the extraction path. The paradox demonstrates that good intentions does not always led to good results (Sinn, 2008).

The resource market is today controlled by a few sellers and many buyers, so what happens if a seller faces demand from different buyers? In this scenario the seller might not be forced to sell to the principal buyer, but has the option of selling to others if the principal buyer threatens to invest in a new technology. Thus the green paradox might be evited, as well as the dependency relationship between the two players. Another interesting point is how the option of investing in a new technology for a buyer will affect the investment decision for the seller. Be it an investment in a new market or a new technology. This is the idea behind the model that I have develop, which will be introduced in the next section.

4 The Model

In the model I consider a framework where a monopolistic seller, s, of an exhaustible resource, namely gas and oil, faces demand from two possible buyers or markets. The buyers are differentiated in the sense that there is one active buyer E, which can be understood as the European market, and one passive buyer A, which can be understood as the Asian market.

Buyer E has the option of a one-time investment in a substitute or a backstop technology (e.g. hydropower, solar power or nuclear). The investments option is represented by a binary variable, k which takes either value *1* or *0*. For k = *1* buyer E decides to develop the substitute technology, and for k = *0* buyer E does not choose to invest. The implementation of the decision variable arrives with a time lag, i.e. he makes the decision in period 1 and it is implemented in period 2. If buyer E decides to invest in the renewable resource in period 1 the country gains the surplus of $\bar{u}$ in period 2, assumed also to include the investment cost. After the substitute is in place buyer E no longer requires resource supply from the seller.

Buyer A is characterized as a passive buyer because he does not have any option of a substitute technology. For seller to supply to this market he has to pay a one-time investment cost, *C,* which is determined by the binary decision variable *I*. For *I = 1* the seller chooses to invest in the Asian market, and will have to pay the investment cost, C. For *I* = 0 seller does not invest, and he remains in the dependence regime with buyer E. The investment cost symbolizes costs linked to expansion of infrastructure necessary to supply to the new market A. The cost of the investment, *C,* is defined under two different thresholds, which gives us three cost intervals: Low cost, moderate cost and high cost. The effect of the different cost intervals on the investment decision will be analyzed in section 4.3.

The game is set in a two period model, where decisions are made in period 1 and implemented in period 2, with the exception of seller's decision on supply for period 1. Where nothing else is specified it is assumed that the seller wants to use all of its known stock by the second period such that $S = q_1 + q_2$.

Buyer E is the first mover and decides on investment choice, k, before seller decides his supply strategy, q, and whether he wants to invest in the Asian market or not, *I*. Seller's strategy is dependent on the size of the stock, which is exogenous determined, and the decision from buyer E on variable *k*. The investment decision *I*, determined by the seller is dependent on the cost of the investment, *C*.

The seller is rational and only interested in maximizing profit, defined by $\pi(q_t) = \tilde{u}'(q_t)q_t$. The inverse demand function is assumed linear and to be equal between the two countries, it is represented by the following:

$$p = \tilde{u}'(q_t) = (a - bq_t), \text{ where } a \text{ and } b \text{ are positive constants.} \tag{2}$$

The demand is equal to $q_t = D(p_t)$. The stock is depleted by q_1 in period 1 and by q_2 in period 2, and it is assumed no extraction cost of the exhaustible resource. The buyer's surplus from consuming the exhaustible resource is defined by $u(q)$. The surplus function is associated with consumer's utility $\tilde{u}\,(.)$ satisfying $u(q_t) = \tilde{u}(q_t) - \tilde{u}'(q_t)q_t$. Inserting the demand function from (2) into the consumer's utility function gives us the buyer's surplus from consuming the resource:

$$\tilde{u}(q) = \int(a - bq) = aq - 1/2\,bq^2 \tag{3}$$

$$u(q_t) = \tilde{u}(q_t) - \tilde{u}'(q_t)q_t = aq - 1/2\,bq^2 - (a - bq_t)q = 1/2\,bq^2 \tag{4}$$

Because this is a two period model, utility and profits are equally weighted over the two periods, meaning that discount rate is set to r = 0 when calculating the equilibrium results. Notation and formulas in this based on the article by Gerlagh and Liski (2011), with exception of the linear demand.

The timing of the game:

1. Buyer E makes a decision on $k \in [0,1]$
2. Seller decides on quantity supplied, q, and investment variable, $I \in [0,1]$

Unlike the model by Gerlagh and Liski (2011), the buyer is the first mover to choose whether to invest or not, before the seller makes his move.

In section 4.1 it is assumed that the cost to reach the new market, buyer A, is too expensive and therefore not an option, I thus only look at buyers condition to invest in the new technology given suppliers strategy on *q*. In section 4.2 the cost of the investment option has decreased and seller therefore has the opportunity to invest in the Asian market. In section 4.3 I will analyze the effect the thresholds has on the investment option by seller and buyer E.

4.1 Asian Market - Not Accessible

First I analyze a scenario where the investment option for expansion into the Asian market is assumed to be so expensive that it is not a choice, i.e. $I = 0$[6].

As this is a sequential game, buyer E's investment decision depends on seller's strategy. Buyer E moves first and decides if he wants to invest in the new technology or not. After this seller decides the amount of *q* supplied. The solution to a sequential game of full information is found by backward induction: First I investigate the seller's strategy, dependent on *k* and the exogenous decided stock, than the seller's strategy is inserted into the buyer's value function. The game when the Asian market is excluded can be illustrated by:

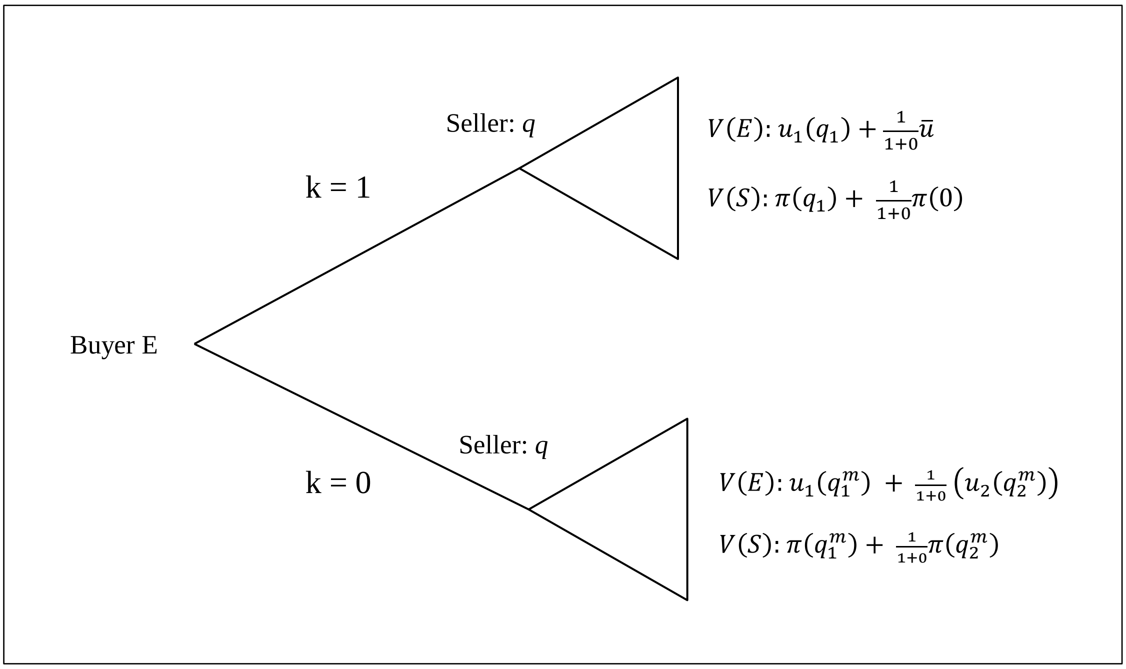

Figure 3 – The game in extensive form, with no alternative to invest in Asia, $I = 0$

[6] The threshold for this choice will be derived in section 4.2.2.

Explanation figure 4: Buyer E moves first and decides if he wants to invest in the new technology or not, $k = 1$ or $k = 0$. After this seller decides the amount of q that he wants to supply, given that $I = 0$. When the game is solved backwards it gives us the value functions V(S) for seller S, and V(E) buyer E.

4.1.1 The Seller's Problem

The seller, s, has a strategy q and I, which is a function of buyer E's decision on its investment in the new technology, k. Because the investment I is considered too expensive in this section, seller only has to decide supply strategy, q, which is dependent on buyer E's choice of investment into the backstop technology, k. I first calculate sellers two strategies, or reaction function (RF), for whether $k = 0$ or $k = 1$.

For k = 0: Seller maximizes profit over the two periods

As a monopoly resource producer the seller, is interested in maximizing profits over the two periods, given that the stock is depleted after the two periods. The seller's reaction function, given that buyer E does not invest in the new technology, i.e. $k = 0$, is calculated from the profits in the two periods. Assuming no discounting, i.e. r = 0, then:

$$RF_s\,\{k = 0\} = \pi(q_1^m) + \tfrac{1}{1+0}\pi(q_2^m) \tag{5}$$

We calculate sellers profit by multiplying the inverted demand function from (2), with quantity in each period. It is assumed that seller wants to sell all of the stock, so we insert the value $q_2 = S - q_1$ in the maximization problem. This gives us the following calculations:

$$\mathrm{Max}_q \left[(a - bq_1)(q_1) + \left[\left(a - b(S - q_1)\right)(S - q_1)\right]\right] \qquad \text{a,b} > 0 \tag{6}$$

$$\frac{dMax}{dq_1} = a - 2bq_1 + bS - (a - Sb + 2bq_1) = 0 \tag{7}$$

$$a - 2bq_1 + Sb - a + Sb - 2bq_1 = 0 \tag{8}$$

Solving for *q* in equation (8), we get the following optimal quantities and price:

$$q_1^m = q_2^m = \frac{S}{2} \tag{9}$$

$$p_1^m = p_2^m = \left(a - b\left(\frac{S}{2}\right)\right) = \frac{2a-Sb}{2} \tag{10}$$

When the discount factor is equal to zero, profits are equally weighted, therefore optimal quantity supplied and prices are the same for the two periods. In contrary, with a positive discount rate, i.e. 0< r < 1; than period 1 would be preferred to period 2, because the seller prefers the present to the future. In line with the predictions from the Hotelling model in section 3, and demonstrated by equation (1).

Given that buyer E has not invested in the new technology, *k = 0*, and by the assumption that seller does not want anything left in the ground, seller's strategy will be to sell at quantities q_1^m in period 1, and q_2^m in period 2. From this we calculate seller's profits and reaction function:

$$RF_S\,\{k=0\} = p_1^m * q_1^m + \frac{1}{1+0}\, p_2^m * q_2^m \tag{11}$$

$$= \left(\frac{S}{2}\right)\left(\frac{2a-Sb}{2}\right) + \left(\frac{S}{2}\right)\left(\frac{2a-Sb}{2}\right) = \left(\frac{2Sa-S^2b}{4}\right) + \left(\frac{2Sa-S^2b}{4}\right) = \frac{2Sa-S^2b}{2} \tag{12}$$

The total profit for the two periods, $\frac{2Sa-S^2b}{2}$, is dependent upon the size of the stock, capital S, and the constant positive demand variables a and b.

<u>For k = 1: Seller will only be able to sell in period 1</u>

When *k = 1*, buyer E has decided in period 1 to invest in the new technology, which will be effective in period 2. By assumption, the investment option in the Asian market is too expensive in this scenario, so seller has no other choice than only selling to buyer E in period 1. Seller will try to sell everything, and if assumed that he does not want resource left in the ground, he will sell everything in period 1. This is represented by the following maximizing problem:

$$\underset{q}{\text{Max}}\ \pi(q_1) + \tfrac{1}{1+0}[\pi(0)] \ = \ \text{Max}_q(a - bq_1)(q_1) \tag{13}$$

$$\frac{dMax}{dq} = a - \ 2bq_1 = 0 \tag{14}$$

$$q_1 = \frac{a}{2b} \quad \text{and} \ \ p_1 = a - b * \frac{a}{2b} = \frac{a}{2} \qquad \pi(q_1) = \ q_1 p_1 = \ \frac{a^2}{4b} \tag{15}$$

Here quantity supplied will be high relative to if he could sell in two periods, because seller realizes he will have to sell everything in period 1. Under the condition that seller does not want any of the stock left in the ground, which implies $q_2 = 0$; then the quantity in period 1 will be equal the entire stock, if and only if, $S = \ q_1 + \ q_2$ where $q_2 = 0$:

$$q_1 = \ S - \ q_2 \ \ when\, q_2 = 0 \ \ \text{it implies} \ \ \overline{q_1} = S. \tag{16}$$

When the quantity in period 1 equals the entire stock, i.e. $\overline{q_1} = S$, it implies a larger supply relative to the option of selling in both periods, i.e. S > S/2. This supply is favorable to buyer E, as he will get a lower price. It is convenient to differentiate the values for quantity supplied in first period as:

$$q_1 \ \text{ takes value } \ \begin{cases} \overline{q_1} \ \text{ for S} = q_1 \\ \qquad \overline{q_1} \ > \ q_1^m \\ q_1^m \ \text{ for S} < q_1 \text{ and } q_2 > 0 \end{cases} \tag{17}$$

I will use the value $\overline{q_1}$ when the seller only have the option of supplying in period 1, and assuming he wants to deplete the stock. Thus for *k = 1*, the reaction function for the seller becomes:

$$RF_S\,\{k = 1\} = \ \pi(\overline{q_1}) + \ \tfrac{1}{1+r}\pi(0) \tag{18}$$

$$RF_S\,\{k = 1\} = \ \overline{\frac{a^2}{4b_1}} \tag{19}$$

Importantly if seller has the option of selling in period 2, i.e. $q_2 > 0$, he will sell quantity q_1^m in period 1 equal to the optimal supply calculated from equation (9). Seller's profits in period 1 is higher when he has the possibility of selling in both period because $\overline{q_1} \ > \ q_1^m$. A high quantity supplied will give low prices and thus low profits to the seller. This is favorable for buyer E, but not for the seller.

4.1.2 Buyer E's Problem

In the next step, the reaction functions from the seller are inserted into the buyers payoff function. First I analyze buyer E's utility under *k = 0* and *k = 1*, before I calculate under what condition buyer E will invest in the new technology. I insert the seller's strategy into buyer E's value functions:

For k = 0: Inserting seller's quantity in buyer E's utility:

$$V_E\,\{k = 0\} = u_1(q_1^m) + \tfrac{1}{1+0}\big(u_2(q_2^m)\big) \tag{20}$$

For k = 1: Inserting seller's quantity in buyer E's utility:

$$V_E\,\{k = 1\} = u_1(\overline{q_1}) + \tfrac{1}{1+0}\,\bar{u} \tag{21}$$

Under what condition will buyer E choose to invest in the new technology?

We must have that equation (21) is greater than equation (20) for buyer E to decide to implement the investment option, if we insert the optimal supply values for *k = 0* and *k = 1*, calculated in section 4.1.1 it gives us the following condition:

$$V_E\,\{k = 0\} < V_E\,\{k = 1\} \tag{22}$$

$$u_1\left(\tfrac{S}{2}\right) + u_2\left(\tfrac{S}{2}\right) < u_1\left(\tfrac{\overline{a}}{2b}\right) + \bar{u} \tag{23}$$

For buyer E to invest in the new technology the utility from supply in period 1 given that *I = 0*, and the utility from the new technology in period 2, must be greater than the utility from the optimal supply in both periods.

Under the condition that buyer E chooses to invest, seller can only sell in period one and because seller does not have the option of selling any in period 2, this will be equal the favorable supply $\overline{q_1}$.

To calculate the buyer's utility functions, given the supplies from seller, I utilize equation (4), i.e. $u(q_t) = 1/2\, bq^2$, to calculate buyer E's utility:

$$1/2\, b\left(\frac{S}{2}\right)^2 + 1/2\, b\left(\frac{s}{2}\right)^2 < 1/2\, b\left(\frac{\overline{a}}{2b}\right)^2 + \bar{u} \tag{24}$$

This gives us the following:

$$\frac{S^2 b}{8} + \frac{S^2 b}{8} < \frac{\overline{a^2}}{8b} + \bar{u} \tag{25}$$

$$\frac{S^2 b}{4} - \frac{\overline{a^2}}{8b} < \bar{u} \tag{26}$$

$$\frac{2(Sb)^2 - a^2}{8b} < \bar{u} \tag{27}$$

From eq. (27)[7] we see that for Buyer E to invest it means that the utility, or surplus from the new technology, plus the utility from the high quantity in period 1 must me greater than utility from under the resource regime, where *k = 0*. From eq. (27) this means that surplus from the new technology must be greater than the left hand side, i.e. the payoff from the scenario where buyer does not invest, *k = 0*, minus the utility from the supply in first period if buyer E chooses to invest, *k = 1*.

4.2 Introducing the Asian market, $I \in \{0, 1\}$

The investment cost, *C*, for entering the Asian market has decreased, so seller has the option of supplying to the Asian market in period 2. This implies that seller no longer has to settle with the low price he gets from supplying everything to buyer E in period 1, if k = 1. He can now choose to invest and sell to the Asian market.

[7] If we set that $\bar{q_1} = \frac{a}{2b} = S$ directly in the equation we can get the same result expressed as $\frac{(Sb)^2 - 2S^2 b}{4} < \bar{u}$

The same game as from previous section is utilized to solve the game again; with the exception that seller now has the option of investing in the Asian market. The decision of quantity supplied, *q*, and whether or not he invests, *I*, are decided simultaneously by seller.

4.2.1 The Sellers Problem

As in section 4.1.1 we start by solving the last stage, i.e. the seller's strategy in the two different subgames before we turn towards the action of the buyer.

<u>*Subgame k = 0*</u>

Given that buyer E has not invested in the new technology, seller has to decide if he wants to invest in the Asian market and quantities supplied. Seller has the option of suppling in two periods to buyer E, i.e. *I = 0*, or supply the stock between the two buyers over the two periods, i.e. *I = 1*. The strategy of the seller is represented in reaction function, RF_S, which now also includes the strategic variable *I* and the investment cost *C*.

For I = 0: We have the same result as in section 4.1.1, namely that seller will sell quantity q_1^m in period 1 and q_2^m in period 2 to buyer E:

$$RF_S\,\{I = 0 | k = 0\} = \pi(q_1^m) + \frac{1}{1+0}\pi(q_2^m) = \frac{2Sa - S^2 b}{2} \tag{28}$$

For I = 1: Given that buyer does not want to invest in the new technology and seller does choose to do so, seller will maximize its profit by dividing the stock by three. Since we do not have any discounting he will sell 1/3 to buyer E in period 1, 1/3 to buyer E in period 2 and 1/3 to buyer A in period 2, minus the investment cost. Because I assumed the same linear demand for the Asian market we can utilize quantities from section 4.1.1, just dividing the stock on three instead of two. The quantities produced to buyer E under this scenario will be referred to as $q_t^m = q_t^E$ where optimal quantities now are given by: q_1^E = q_2^E = q_2^A = S/3. This gives the following reaction function:

$$RF_S\,\{I = 1|k = 0\} = \pi(q_1^E) + \frac{1}{1+0}\,[\pi(q_2^E) + \pi(q_2^A) - C\,] \tag{29}$$

For the subgame where k = 0, the seller will choose to invest in the new market, if:

$$\pi(q_1^m) + \pi(q_2^m) < \pi(q_1^E) + \pi(q_2^E) + \pi(q_2^A) - C \tag{30}$$

$$\frac{2Sa - S^2b}{4} + \frac{2Sa - S^2b}{4} < \frac{3Sa - S^2b}{6} + \frac{3Sa - S^2b}{6} + \frac{3Sa - S^2b}{6} - C \tag{31}$$

$$C < \frac{9Sa - 3S^2b}{6} - \frac{4Sa - 2S^2b}{4} = \frac{Sa}{2} \tag{32}$$

This condition implies that seller will invest in the new market A, if the investment costs are smaller than $\frac{Sa}{2}$. This gives us a definition of seller threshold on the investment condition in market A, when k = 0:

Definition 1: The seller's threshold, C, for k = 0 is defined as I(0).

<u>Subgame k = 1</u>

Given that Buyer E decides to invest in the new energy, under what condition will seller invest in the Asian market?

For I = 0: This is the same expression for the payoff as we saw in section 4.1.1 where seller sells quantity $\overline{q_1}$ to buyer E, and cannot sell anything in period 2:

$$RF_S\,\{I = 0|k = 1\} = \pi(\overline{q_1}) + \frac{1}{1+0}[\pi(0)] \tag{33}$$

Not a favorable position for seller since quantity supplied is high, and thus price and profits for seller are low.

For I = 1: Now seller has the opportunity to invest and sell to the Asian market in period 2, this means that we can no longer assume $q_1 = S$, since seller will supply in period 2, i.e.

$q_2 > 0$. This implies that quantity produced in period 1 will be referred to as q_1^m by definition stated in eq. (15):

$$RF_S\,\{I = I|k = 1\} = \pi(q_1^m) + \tfrac{1}{1+0}[\pi(q_2^A) - C] \tag{34}$$

We can utilize the same calculations as above, because the linear demand function is assumed to be equal between the two countries, next to the assumption that seller wants to sell all the stock during the two periods:

$$\operatorname*{Max}_{q}\ \pi(q_1^m) + \tfrac{1}{1+0}[\pi(q_2^A) - C] \quad where \quad q_2 = S - q_1 \tag{35}$$

$$q_1^m = q_2^A = \tfrac{S}{2} \tag{36}$$

For the subgame where k = 1, seller will choose to invest in the new market if:

$$RF_S\,\{I = 0|k = 1\} < RF_S\,\{I = I|k = 1\} \tag{37}$$

$$\pi(\overline{q_1}) + 0 < \pi(q_1^m) + \pi(q_2^A) - C \tag{38}$$

$$C < \frac{2Sa - S^2b}{4} - \frac{\overline{a^2}}{4b} + \frac{2Sa - S^2b}{4} = \frac{4Sa - 2S^2b}{4} - \frac{\overline{a^2}}{4b} = \frac{4Sba - 2S^2b^2 - a^2}{4b} \tag{39}$$

This demonstrates that in subgame *k = 1,* as long as investment cost, *C,* is smaller than the profits from opening up minus the profits if otherwise, seller will choose to invest in the new market A, i.e. *I=1,* if *k =1*. This gives us the following definition:

Definition 2: The threshold, C, for k = 1 is defined as I(1).

Importantly, if seller chooses to invest it will have an impact on quantity supplied to buyer E in period 1, because opening for market A in period 2 makes $\overline{q_1} \rightarrow q_1^m$. Thus quantity supplied to buyer E in period 1 will decrease since seller now has the option of selling in period 2. Instead of selling the whole stock in period 1, seller divides the stock on two periods. Seller gets a higher price from decreasing quantity supplied in period 1 to buyer E, and sells rest of the stock in period 2.

The key to this possibility lies in the investment cost, *C*. If k =1, and the investment costs are lower than the threshold, seller will choose $I = 1$. If Investments costs are high (but still below the threshold, seller will prefer to sell when $k = 0$, but if $k= 1$, as here, he will choose $I =1$, because this is at least better than $I = 0$, if $k = 1$. If the investment cost exceeds the threshold seller will not have incentives to invest in the Asian market. This can be demonstrated by comparing seller's threshold.

4.2.2 Comparing Seller's Thresholds

From the investment cost thresholds in the previous section we have three different intervals, which I will rank and analyze to easier understand how buyer E will react. Firstly, it can be demonstrated that the cost threshold for the investment when $k = 0$ is lower than the threshold cost for when $k = 1$.This because seller can accept a bigger cost of investing in market A when $k = 1$, since the alternative (of not investing when buyer invests) is more expensive. This can be demonstrated as follows:

$$I(0) < I(1) \tag{40}$$

$$\frac{Sa}{2} < \frac{4Sba - 2S^2b^2 - a^2}{4b} \tag{41}$$

This gives us the following ranking of investment cost for seller:

- <u>*For C < I(0):*</u> Than $I =1$ when $k = 0$ or $k = 1$. Implying that seller will choose to invest in the new market if investment costs are lower than threshold *I(0)*. This gives seller the possibility of decreasing supply to buyer E in first period, and hence receives a higher profit. Seller will invest even if buyer E does not invest.

- *For: $I(0) < C < I(1)$*: Than $I = 1$ if, and only if, $k = 1$, and $I = 0$ if $k = 0$. When the investment cost is between the two thresholds seller will only invest if buyer E does. If buyer E invests and seller don't, seller will get a low profit from period 1 and nothing from period 2, this implies that even though costs are moderate seller will invest if buyer E does, - costs are still under threshold $I(1)$. On the other hand, if buyer E does not invest seller will neither invest since he has a good profit option of selling to buyer E in two periods without any cost, - cost is over $I(0)$. In this middle threshold buyer E has power to affect seller investment decision, whatever buyer E chooses, seller will follow. Interestingly, in this cost interval the investment options for the two players works complementary: If buyer E invests, seller invests, and contrary.

- *For $I(1) < C$*: Than $I = 0$, if $k = 1$ or $k = 0$. When the investment cost is higher than threshold $I(1)$ the seller will never invest in the Asian market because it is too expensive, which is the same result as presented in section 4.1.1. Thus, in this scenario buyer E can choose to invest and get a favorable price in period 1, due to the necessity for seller to sell everything in period 1.

The interval can be illustrated as follows:

$C < I(0)$	$I(0) < C < I(1)$	$I(1) < C$
Low costs	*Moderate costs*	*High costs*

Figure 4 – Overview of threshold intervals of investment cost, C

4.2.3 Buyer E's Problem

The seller's thresholds are inserted into buyer E's value function to see how he would react under the different thresholds of the seller.

<u>*In the interval C < I(0): Low cost*</u>

As previously illustrated, with an investment cost, C < *I(0),* then *I = 1.* Seller will choose to invest whether buyer E chooses to invest or not. This leads to decreased quantity supplied to buyer E in period one. Remember from above that we defined the quantity supplied to buyer E when *I =1* and *k = 0* for $q_t^m = q_t^E$ when S/3. Here I calculate to find the value buyer E needs from the new technology, to decide on investing, given that seller invests. This means that for buyer E to invest he needs:

$$V_E\ \{k = 0|I = 1\} < V_E\ \{k = 1|I = 1\} \tag{42}$$

$$u_1(q_1^E) + \frac{1}{1+r}\left(u_2(q_2^E)\right) < u_1(q_1^m) + \frac{1}{1+r}\bar{u} \tag{41}$$

$$1/2\, b\left(\frac{S}{3}\right)^2 + 1/2\, b\left(\frac{S}{3}\right)^2 < 1/2\, b\left(\frac{S}{2}\right)^2 + \bar{u} \tag{43}$$

$$\frac{S^2 b}{9} - \frac{S^2 b}{8} < \bar{u} \quad \rightarrow \quad -\frac{S^2 b}{72} < \bar{u} \tag{44}$$

If the payoff from the new technology is greater than $-\frac{S^2 b}{72}$, it means that buyer E will choose to invest when seller invests if costs are low, i.e. *C < I(0).* Buyer E anticipates that the seller will invest; implying that buyer E will get a lower supplied amount in period 1and 2, because of the supply to the Asian market. Thus, buyer E will choose to invest as long as he receives more than $-\frac{S^2 b}{72}$ from the new technology.

<u>*In the interval: I(0)< C < I(1): Moderate cost*</u>

Seller will invest in the new market if, and only if, buyer E invests in the new technology. If *k = 1* than *I = 1*, and if *k = 0* than *1 = 0*. Buyer E will invest as long as:

$$V_E\ \{k = 0|I = 0\} < V_E\ \{k = 1|I = 1\} \tag{45}$$

$$u_1(q_1^m) + \frac{1}{1+r}\big(u_2(q_2^m)\big) < u_1(q_1^m) + \frac{1}{1+0}\bar{u} \tag{46}$$

$$1/2\, b\left(\frac{S}{2}\right)^2 + 1/2\, b\left(\frac{S}{2}\right)^2 < 1/2\, b\left(\frac{S}{2}\right)^2 + \bar{u}$$

$$\rightarrow \quad \frac{S^2 b}{8} < \bar{u} \tag{47}$$

For the situation where *I = 1*, if *k = 1*, buyer E understands that if he chooses to invest, so will seller, and if he chooses not to invest seller will neither. Thus, the surplus from the new technology in period 2 has to be greater than what buyer would get in period 2 by staying in the resource regime.

For I(1) < C: High cost

Seller will not invest, because of too high expenses. This is similar to the scenario in 4.1.2, given *I = 0,* I found that, buyer E will invest in the new technology if:

$$V_E\ \{k = 0|I = 0\} < V_E\ \{k = 1|I = 0\} \tag{48}$$

$$u_1(q_1^m) + \frac{1}{1+r}\big(u_2(q_2^m)\big) < u_1(\overline{q_1}) + \frac{1}{1+r}\bar{u} \tag{49}$$

$$\rightarrow \quad \frac{2(Sb)^2 - a^2}{8b} < \bar{u}. \tag{50}$$

This gives us three different values of, $\bar{u}$, the surplus from the new technology, which can be ranked in the following way:

$$-\frac{S^2 b}{72} < \frac{2(Sb)^2 - a^2}{8b} < \frac{(Sb)^2}{8} \tag{51}$$

These results can be illustrated in figure 5 in the next section.

4.3 The Equilibrium Strategies

The result of the different strategies of buyer and seller is illustrated in figure 5. The figure provides an overview over the different thresholds for buyer E's surplus from the new technology, in each interval of seller's investment costs, *C*.

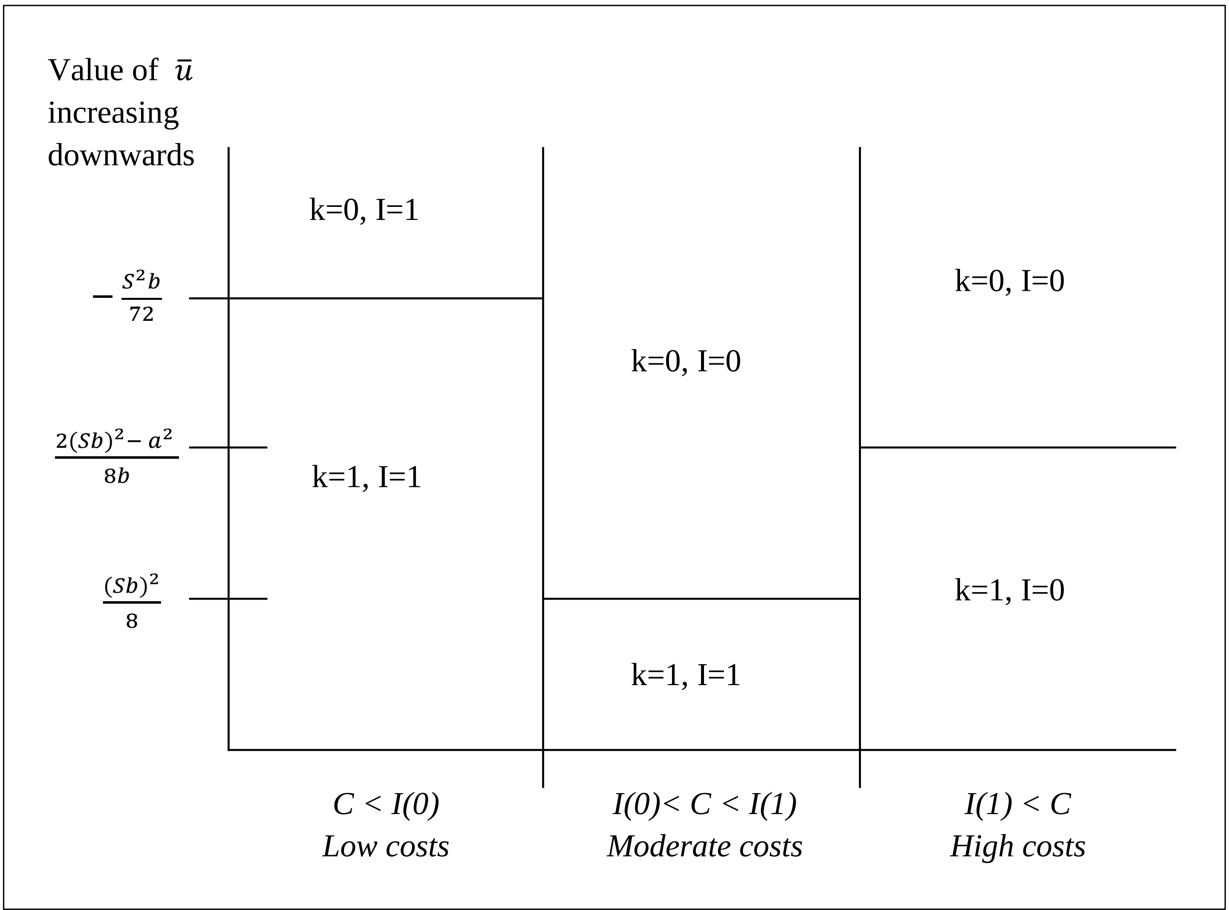

Figure 6 – Sellers investment cost, vs Buyer E's value of the new technology

The horizontal axis of the figure demonstrates the three different intervals for the investments cost, *C*, of the seller. The vertical axis demonstrates values for $\bar{u}$, where the value is increasing downwards on the axis, i.e. the lowest value is on the top of the axis. This is in line with equation (51) which states that threshold $-\frac{S^2 b}{72}$ is lower than $\frac{2(Sb)^2 - a^2}{8b}$, which is lower than $\frac{(Sb)^2}{8}$. To exemplify, will a $\bar{u}$ lower than $-\frac{S^2 b}{72}$, in the interval $C < I(0)$ lead to no investments by buyer E, even if seller invests.

The model further demonstrates that in the scenario when investment cost are high, i.e. *I(1) < C*, seller will never invest. When $I = 0$, buyer E will get a higher supply than in the scenario where seller invests, $I = 1$, which means that buyer E will need a higher surplus from the new technology, $\bar{u}$, to invest than for the interval where *C < I(0).* This means that the threshold for buyer E to invest when seller doesn't invest is higher than if seller invests, demonstrated by $-\frac{S^2 b}{72} < \frac{2(Sb)^2 - a^2}{8b}$.

In the moderate interval, where *I(0)< C < I(1)*, interestingly the investments work complementarian: seller invests only if buyer invests, $I = 1$ if $k = 1$, and will not invest if buyer does not invest, $I = 0$ if $k = 0$. Since buyer E anticipates that seller will invest if he invests, he understands that he will get a higher price in period 1 by investing. Thus for buyer E to invest the surplus has to be higher than the alternative where no one invests. This is therefore the "most expensive" scenario for buyer E to invest, and makes it more probable that buyer E will not invest, i.e. $I = 0$. If the surplus from the new technology is so high that $\frac{(Sb)^2}{8} < \bar{u}$, than buyer E will invest in the new technology regardless of what seller chooses. However, if the surplus is lower than the threshold, $\frac{(Sb)^2}{8} > \bar{u}$, in the moderate interval, than they will maintain the mutual resource dependence.

In the next section I will discuss the result in relation to the motivation example of this paper and its limitations.

5 Discussion and Limitations

The analysis in section 4.3 demonstrate how the costs of investment in the new market affects buyer E's decision on investing in the new technology. Dependent on the investments costs of the seller, buyer E anticipates his action and makes up his strategy based on quantities supplied and the surplus from the new technology that he might get in the second period. This creates a connection between the two investments, as well as demonstrates the power of the first mover in the game, which is buyer E.

For the situation where the investment cost is high, *I(1) < C,* then buyer E will invest, *k = 1,* given that *I = 0,* because buyer E will get a very favorable price in period 1 due to the high quantity supplied when q_1 = stock. On the contrary if the investments costs are low, *C < I(0),* the seller will invest, which will be anticipated by buyer E who will get an increased price in period 1, so buyer E will be better off investing as well given that surplus form the new technology is under the threshold. Thus they will end up in the equilibrium where *k = 1* and *I = 1,* given that $\frac{2(Sb)^2 - a^2}{8b} < \bar{u}$.

When the investment cost is moderate it gives a very interesting scenario, because buyer E here has power to affect whether they end up in the same dependence equilibrium or in a scenario where both have to invest. Seller will choose *I = 1* only if buyer E decides to invest, and *I = 0* if buyer decides to not invest. The decision of buyer E, to invest in the new technology or not, is thus dependent on the surplus from the new technology, $\bar{u}$. If the surplus from the new technology in period 2 is greater than the surplus from the resource supply in period 2, that is: $\frac{(Sb)^2}{8} < \bar{u}$, then buyer E will choose *k = 1* and seller will follow with *I = 1.* This is an interesting scenario because it opens up for the possibility of negations and agreements between the seller and buyer E, on the decision to stay in the resource dependence regime. On the other hand, if something happens to the agreements, or for example political instabilities provokes buyer E to invest, then this will also lead seller to investment. This demonstrates an interesting pattern; how one player's decision on investing makes the other player investments more likely.

Further it is interesting to analyze how this result can be linked to the motivation example of this study; the mutual dependence in exhaustible resources between Russia and EU. In the introduction I raised the attention on the issue of a possible green paradox, and investment decision by the EU and Russia, linked to possible emissions reduction and power relations.

Section 4.1 provides an illustration of a possible ‘green paradox’. When seller’s investments costs are high, so entering a new market is unrealistic, and buyer E chooses to invest; the extraction path would increase because seller will sell everything in period 1. This provides a good example of how a good deed, like the decision on investing in a new technology, not necessarily leads to a good result for the environment, as discussed in the end of section 3.2. However, it is important to recognize that this result is dependent on the anticipation that the seller wants to sell all the stock, something which is also a crucial assumption in Gerlagh and Liski (2011). This assumption is the reason why seller chooses to sell everything fast, because it is assumed that he wants to deplete the resource, even though this gives him an unfavorable price. On the contrary, if the resource seller could choose to sell the amount he wanted, independently of stock, this could change the outcome of a green paradox. If seller is not tied to the necessity of depleting the resource, he would probably adjust the quantity supplied to get highest possible price for it. This cancellation of assumption would change the result, and the whole model, and goes beyond the scope of this study.

As section 4.2 demonstrates, if there are more buyers in the market the result of a green paradox, or increased supply path, would change. If one buyer decides to invest in a new technology, this would imply that the demand of the resource is just changed over to new markets. This is an issue highlighted in the article by Sinn (2008), where he exemplifies how the Kyoto protocol may not have any effect on emission, or even worse, have a negative effect. Stricter emission rules may lead to a lower demand from the countries involved in the agreement, but can be outweighed by possible increased demand from new emerging markets. Thus investment in technology, or restriction on consumption of exhaustible, creates a demand change, and might not have any effect on the environment. Sinn (2008) investigates this from a supply side effect, and highlights how suppliers might feel threatened from an increased initiative towards lower emissions and renewable resources, and counteracts by increasing supply. Interestingly, this can be linked to the current world situation in resource extraction, with a severe drop in oil prices due to overproduction. It has to be acknowledged that there are several important factors behind the glut in the oil market, like increase competition from US shale oil, drop in exploration due to low price, additional to a decreased demand from important markets like Europe and emerging countries.

The question of whether investments in one country trigger investments in another is closely linked to the costs of investments, - as well as important factors like politics, geography, economy, power etc. However, concerning the relationship between Russia and the EU, it is interesting to see how the instability now has led Russia to take up a huge investment in pipelines to the East, the “Power to Siberia line”, in relation to the EU’s increased focus on diversifying its energy sources. The EU has been involved in emission reduction and climate related initiatives since 1991, and lately the need of a diversified energy source has led to the investment in the Trans Adriatic pipeline, as well as increased share of renewables (EU, 2016c). These clear environmental signals from the EU over many years can be seen as one of the causes for Russia’s investment in the east. Importantly, the crisis in Ukraine might have caused a new increased attention to the power Europe has to affect Russia’s investment action. Thus, the relationship between the EU and Russia can be applied to the scenario from the model developed in section 4, where I demonstrated how an investment in effort to exit the dependency regime, can lead to the same effort by the other part.

The investments in renewable energy to decrease emission by the Paris Agreement can thus be seen as an alternative instrument of power, and not just a way to decrease emissions. By investing in renewable energy sources, especially inside the borders of Europe, a country can debilitate the dependency relationship with their energy trading partner. Investments in new technology and initiative to diversify energy sends signal of a decreased necessity of importing energy. Interestingly this can also demonstrates how a political relationship may change the incentives for investments in renewable energy and technology development.

From an environmental view, investment in renewable energy is first and foremost implemented to reduce emissions. However, this is difficult to initiate since investment costs often are high and emissions are a public good problem, i.e. they are non-rivalrous and non-excludable. This implies that there are huge challenges in enforcement of environmental agreements as well as who’s to start reduction, which is why international agreements and enforcements are necessary. If investments in renewables, or technology, can be understood as means to independencies its energy mix or exiting a dependency regime, then buyers investment might lead to seller investing as well, as demonstrated in this paper. Regarding this, investments in new technology, or markets, can thus be linked to the dependency relationship between the EU and Russia, where the supply of energy to the EU is highly linked to political and economic power.

When discussing the model and its application to a real life scenario it is important to recognize that the analysis is restricted to the assumptions of the model. Game theory demonstrates interaction between rational actors. Thus it is assumed that actors are rational; that they act according to profit or utility maximization. This does not necessary mean that they act to maximize their own monetary gain, it can also signify to maximize others utility or monetary gain. Rational decision making also requires an understanding of the other players motivations, this is not always true in the real world (Watson, 2008).

The understanding of the other player's action is an important assumption when using backwards induction in a sequential game. Additional to this, many firms have other goals than profit maximization, especially in no-single firms[8]. There can be many different persons managing a firm, which not necessarily own it, so there is a big possibility that they have other agendas than profit maximization. Thus we have a principal – agent problem[9].

The game used in this paper is a non-cooperative game with perfect information, because the players need complete information of the other to anticipate its strategy. This is an assumption that makes this scenario unrealistic when applied to a real world setting; perfect information is highly unrealistic and exists only in a theoretical world. This can especially be linked to the issue of exhaustible resource reserves. These reserves are difficult to prove the size of, there are for example space overview over territory which might give an insight into how big reserves are, but this is highly discussable and linked to estimates. Even though we have estimates over how much oil there is in Saudi Arabia, they are still only estimates, and the suppliers are sure to keep information tight to the chest. The future availability of low-cost fossil fuel is thus a highly discussed concern among world leaders (Gerlagh and Liski, 2011). The argument concerning imperfect information also illuminates a problem with the maximization of profit or utility by an actor. Many firms don't even have perfect information about their own production and costs, and less about others.

The calculation of the profits and utility are based on economic modeling and maximization problem, which is linked to critical assumptions. It is based on a simplified framework with mathematical techniques to demonstrate a rather complex solution. One of the main problems with the general maximization problem is that it is static; it does not tell anything about the duration of a period, for example for how long period 1 or/and period 2 lasts. Next to this, I

[8] A firm with more than one worker, or employed.

[9] When one person or entity can make decision on behalf of another.

used the connection between surplus utility for the buyer and the profit function of the seller calculated from a Gerlagh and Liski (2011), and applied to the linear demand function, which I chose rather arbitrary.

In regard to this criticism of the economic modeling and calculations of the player's strategy and motivation, it is thus reasonable to assume that there is a gap between the results and the real world; therefore I do not expect the result of the analysis to be a perfect indicator of the scenario in real life. The question is however linked to how approximated it can fit the question in the analysis.

6 Concluding Remarks

In this paper I have considered a strategic equilibrium between a seller and two buyers of an exhaustible resource, both part facing different investment options to be able to end their resource dependence. The study is partly based on the model develop by Gerlagh and Liski (2011) but has been adjusted and ended up differently than first expected. The model I have developed has been motivated by the mutual dependence on gas and oil between EU and Russia. EU is highly dependent on the energy import, and Russia is in return very much dependent on the export revenues from the exhaustible resource which makes up a remarkable part of their budget.

The framework I have developed is a standard model of resource allocation in two periods with no discounting, where seller gains profit from suppling an exhaustible resource and buyer from the utility of the resource. The seller has the possibility of investing in a second market in period 2 for an investment cost, C, and the active buyer E, thought of as the European market, has the option of investing in a backstop technology, or alternative energy source. The key questions in the analysis are focused on the investments options, under what condition would buyer E invest in the new technology, and what power does buyer E have to affect seller's choice of investing in the new market.

The key insight from the study is that the decision on investment is how investments can work complementary given that investment costs are moderate. Figure 5 illustrates how the two investments affect each other. If investment cost, C, for the seller are very high, buyer E will invest depending on the surplus from the new technology. If buyer E also invests there will be a green paradox, since seller will have to sell everything possible in period 1. If none of them invests they will end in the same resource dependence. In the case where investment cost, C, is very low, seller will invest, something which will be anticipated by buyer E who will also invest as long as surplus from the new technology are over buyers threshold. In the case where investment costs, for the seller are moderate, I get an interesting result demonstrating how the investments work complementary. Buyer E has the possibility to impact seller's decision to invest in the new market. If buyer E invests, then seller will also invest, but if buyer E does not invest, seller will neither invest.

What are the main take away from the result to understand the mutual dependence between Russian and EU on Russian oil and gas? I believe that the study gives an understanding of how one countries investment can bring the other to invest, or the contrary. As in the model by Gerlagh and Liski (2011), it gives an insight on how investments in new technology can work as a strategic instrument in resource importing countries. From the analysis, it is illustrated how the EU can affect Russia's decision on investment, by threatening with investments in new technology. When the EU is investing in new technology and renewable energy sources they send signals to Russia, which might also invest as long as costs are under the threshold. The analysis on how investments can work complementary can give an interesting insight in how new technology or renewable energy can be an instrument of easing political pressure, additional as a way of reducing pollution.

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