Chapter 4
A real-option game approach to valuing gas value chain investments

4.1 Introduction
The merit order of investments in Russia’s large gas resource base will shape the future of regional markets and the interregional gas market for decades to come. In order to assess what factors have an impact on gas infrastructure investments and to define this merit order, a hybrid approach is employed in this research, consisting of a qualitative and a quantitative framework. Capturing the full value creation in an uncertain and competitive environment requires valuation tools from corporate finance theory that can be integrated with the ideas and principles of strategic management theory and industrial organisation. The goal is to ultimately value investments under market uncertainty and competition [Smit and Trigeorgis 2004].

The qualitative framework is essentially a ‘toolbox’ of concepts, while the quantitative framework consists of an application of the stylised real-option game model developed by Smit and Trigeorgis [2004]. The quantitative framework aims to value strategic investments in gas infrastructure, linking this valuation process with market structures and outcomes in the commodity market. The market outcomes determine the nature of competition as well as the boundary solutions for cooperation, which in turn influence the timing of investment decisions (and thus also the merit order). A stylised model, in this sense, is insufficient to explain the complex decision making in gas infrastructure. The model is centred on the notion of a volume-driven strategy through transport capacity extensions. Therefore, the toolbox acts as a supplement to the quantitative approach in that it aims to cover aspects and/or factors, which cannot be analysed directly in the quantitative approach. These include market structure, volume and price uncertainty, likelihood and nature of competition, general investment climate, transit and geopolitical factors, regulatory uncertainty, amongst others. Prices will be discussed in a qualitative manner.

As was described in Chapter 8, Gazprom aims to become an increasingly interregional gas exporter rather than merely a regional one. The company aims to do so both by means of newly emerging pipeline gas as well as LNG exports to new regional gas markets. For vertically integrated companies, infrastructures such as pipelines and LNG trains (i.e., the midstream gas transportation components of the value chain) act as options to gain access to new markets or consolidate positions in an existing one. In addition, in the case of

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Russia’s gas export path-dependency and how it influences Russia’s current strategy is also taken into account in the conceptual approach.
long-distance transport in general, the largest part of the total costs in the value chain is located in the transport component. Therefore, the economies of scale in this section help decrease the average cost of gas vis-à-vis competition both in relative and absolute terms. This relative cost advantage can endow gas infrastructure with a certain strategic value with regard to possible competitors, i.e., entry deterrence. Downside demand risk, amongst other factors, may encourage a wait-and-see approach. As a result, the corresponding investment decisions involve a trade-off between the values of postponement and pre-commitment [Smit and Trigeorgis 2004].

The quantitative model finds its foundations in a combination of game-theoretical concepts and corporate finance-oriented project valuation, in particular using real-options. Together with the conceptual toolbox, these are used to ascertain the value of a strategic investment from Gazprom’s point of view. Section 4.2 consists of the toolbox while Section 4.3 contains the real-option game model developed by Smit and Trigeorgis [2004], the foundations for which are introduced in Chapter 3. The content of this chapter is based and has been verified by interviews with experts.

4.2 Whether or not to invest strategically: A conceptual toolbox

The conceptual toolbox is essentially a supplemental instrument to the model in Section 4.3. The combination between the toolbox and the model is employed on the basis of various levels of geographical analysis, and in different parts of the gas value chain, especially gas transport infrastructure, with a focus primarily on export strategy and market orientation. Gazprom’s investment strategy will be the empirical focus point. This involves exploring and prioritising Gazprom’s investment programme. It provides an overview of Gazprom’s (historical) growth opportunities in relation to the export markets, which in the various cases can consist of countries and sub-regions such as Northwest Europe or a combination of these. Given the various market expansions in terms of demand and import-dependency, there are certain export growth options involved, which are subject to a range of complexities. This section develops a conceptual toolbox, which accounts for such complexities, i.e., a range of factors not accounted for in the model included in Section 4.3. It is therefore designed as a bridge between the quantitative approach and the real world.

4.2.1 Some definitions

Before embarking on a description of the conceptual factors influencing strategic investment decisions, it is necessary to first review a number of definitions with regard to value chain investments.\(^7\)

\(^7\) These definitions are originally used by Smit [1996] and Smit and Trigeorgis [2004] and adapted to fit the conceptual framework of the natural gas industry.
- **Economies of scale:** According to Smit [1996], so-called value drivers can result from strategic investments (see below), ranging from absolute cost advantages to developing innovative products as well as capacity expansions possessing (enhanced) economies of scale. In the case of natural gas, long-run marginal costs are a key determinant of market power and can be brought to fruition in different sections in the value chain. The long-run marginal costs are theoretically determined mainly by economies of scale upstream and in transport (and also include other costs such as transit fees). While economies of scale bring down unit costs, it depends in practice on the utilisation rate of pipelines whether these unit costs are indeed achieved.

Once infrastructures have been constructed, (especially mature) suppliers have committed themselves to market, and are set to supply on the basis of short-run marginal costs (SRMC), selling gas volumes in order to recover short-run marginal costs in the short-run. We assume that these pertain to the operational expenditures made for gas transport infrastructures (see Subsection 4.3.5). This is pursuant to the standard short-run marginal cost definition in microeconomics in which one or more cost factors of production cannot be changed, i.e., fixed inputs [Pindyck and Rubinfeld 2001]. The capital expenditures made for gas transport infrastructures, are fixed in the short-run and are thus captured by the notion of long-run marginal costs discussed above. In the long run therefore, unit costs as a whole are brought down with greater economies of scale.

Conceptually, investments along the entire chain, including the upstream, are taken into account while in the model’s application the mid-stream is the focal point. As is mentioned in Chapter 3, significant economies of scale in the value chain can deter entry, because an investor forces entrants to invest heavily in capacity, while still risking an aggressive response from the incumbent [Smit and Trigeorgis 2004a].

The transmission of gas can also have significant economies of scale, especially for long-distance gas pipelines [Correljé et al. 2009]. In the toolbox, the economies of scale are measured conceptually from total average transportation cost per unit, encompassing both capital and operating expenditures. In the application of the real-option game model only the operating expenditures (OPEX) are used to calculate the average cost per unit in transport, i.e., excluding upstream production costs, for a strategic investment. The capital expenditures (CAPEX) in excess of what is required for a commercial investment is seen as an initial expense to be made (see Subsection 4.3.5).\(^7\) As for the difference between pipeline gas and LNG infrastructures, LNG

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\(^7\) Greater economies of scale are not necessarily specific to strategic investments. Commercial investments can also benefit from high economies of scale, the difference being in the load factor or utilisation of the infrastructure (as described above).
trains and ships have lower economies of scale in terms of unit costs, only becoming economic vis-à-vis pipeline gas over longer distances.\textsuperscript{79}

• **Strategic versus commercial investments:** For the purpose of this research, commercial projects are those, which have a short technical ramp-up phase (i.e., by making the greatest possible use of capacity of ever any length of time). These are generally lower capacity infrastructures with higher average transport costs per unit (i.e., a smaller pipeline diameter). By contrast, at the conceptual level, strategic investments pertain primarily (but not exclusively) to the mid-stream segment of any given value chain, i.e., pipelines and/or LNG trains and shipping with higher capacities and thus generally lower average transport cost per unit. They are strategic only when the economies of scale resulting from their construction are proprietary to the investor and in the sense that they are made early to capture market share. During times of falling demand these high-capacity midstream projects have a greater tendency towards lower utilisation levels while in cases of strongly rising demand they are more fully and thus more optimally utilised (see Subsection 4.3 for the model definitions). In that light, strategic investments in LNG value chain components are also imaginable, though the relative cost reductions are less advantageous.\textsuperscript{80}

• **Proprietary versus shared investments:** There is a difference between proprietary investments and shared investments. Proprietary investments are wholly owned and exclusive, and as is mentioned above projects can only be strategic when their use is proprietary. This pertains to pipeline cases in which both the commodity and the capacity are exclusive to the owner of the project. This can also be the case for an LNG project, where upstream liquefaction assets are wholly owned by one single company (or brought together under a joint venture, selling it gas under one single holding).

\textsuperscript{79} Significant economies of scale gains have been made in the LNG value chain throughout the 1990s and 2000s, with trains and ships gradually increasing in terms of transport capacity. LNG travels longer distances at greater economies of scale than does pipeline gas while it has a higher threshold cost than does pipeline gas in being economic. Conversely, with shorter distances pipelines possess much greater economies of scale. Jensen [2004] describes the relationship between pipeline gas transport and LNG as such: “The costs of pipelining natural gas benefit substantially from economies of scale, since large diameter pipelines are not that much more expensive to lay than smaller lines but carry much greater volumes. Pipeline costs rise linearly with distance, but LNG—requiring liquefaction and re-gasification regardless of the distance travelled—has a high threshold cost but a much lower increase in costs with distance. Thus shorter distances tend to favour pipelining, but longer distances favour LNG […] For markets with an established pipeline grid (such as the US and much of Europe), LNG can easily alter the geographic pricing relationships or basis differentials among different points on the pipeline system” [Jensen 2004, p. 7].

\textsuperscript{80} The increase in plant (i.e., liquefaction capacity) and tanker size during the 1990s and 2000s has significantly reduced average costs. As a rule of thumb, the a plant size increase by a factor of 2 has led to a reduction of unit costs by 25 percent (e.g., from 3 bcm to 6 bcm and from 6 bcm to 10.66 bcm more recently), while a 20 percent increase in shipping capacity has led to a 5 percent reduction in shipping costs [Jensen 2004]. By that yardstick, the new 250,000 cubic meter LNG tankers reduce unit costs by 10 percent relative to 145,000 cubic meter tankers. Case study 3 in Chapter 11 includes a numerical example for Qatari LNG.
By contrast in theory, shared investments result from the investment on one supplier’s part in greater economies of scale whereupon it can be jointly used by itself and its partners (i.e., investment free rider behaviour on the part of the competitor). A shared investment in the gas industry may also be thought of as, for example, a pipeline governed by TPA rules, effectively making it a compulsory shared investment, robbing it of its strategic nature.

There is always a trade-off between the incentives to invest early versus waiting for a more opportune time to invest strategically.\(^1\) According to the model, it may be better to postpone strategic investments when the value of postponement, i.e., an option to ‘wait and see’, is greater than the value to commit early.\(^2\) In this sense, a strategic investment may be seen as a competitive ‘disadvantage’. In addition, suppliers may choose to make a commercial investment at different phases of the game’s development or defer (after having made a strategic investment or not at the beginning of the game) within the model. This is an option to wait as well, but is known as ‘managerial flexibility’.

Thus, having provided some of the basic conceptual definitions above, a step-by-step sequence of conceptual factors is discussed in the following subsections.

### 4.2.2 Market uncertainty: Volume and price risks versus likely competition

The first step in determining Gazprom’s export strategy and whether or not to invest strategically is to identify possible off-take markets.\(^3\) These markets (regional and/or sub-regional) are then analysed on the basis of their market uncertainty and the possible level and nature of competition in that market. The uncertainties in the off-take market are mainly related to the following:

a. **Oil and gas price risks**: Volatile oil prices have an impact, albeit with a time lag, on gas prices in long-term contracts. Gas hub prices may be volatile too, and these may feed into long-term oil-indexed contracts, which also include hub indexation.

b. **The availability of substitutes**: In the power generation sector especially, gas may have to compete with nuclear energy, coal and even renewable sources of energy. The demand for gas is thus affected by the availability of substitute powers sources.

c. **Government policies**: Government policies regarding the primary energy mix, regulatory issues as well as the general investment climate (e.g., property rights, rule of law) may all impact the demand for gas.

d. **Potential rival behaviour from other suppliers and/or entrants**: Other gas exporters, either through pipeline volumes or by means of LNG, may have an incentive to capture a share in that future growth. The higher the degree of possible competition and the

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\(^1\) In the model, included in Section 4.3, this trade-off is captured by the commitment versus postponement values.

\(^2\) Incomplete information can help explain why firms in practice may delay their entry beyond the breakeven trigger [Smit 2003].

\(^3\) Given the research questions posed in this study (see Chapter 1), the focus in this study is on Gazprom’s perspective.
higher the growth potential in volume terms, the greater the incentive is to make an early strategic commitment (in order to have a first mover’s advantage). However, if the level of growth potential is uncertain, varying by large degrees, the level of competition is relatively low, meaning that a wait-and-see strategy based on delaying the investment is likely to be a more prudent approach.

e. The degree of concentration: Competition may arise from a large amount of smaller players with small market shares or from few, comparatively large players with large market shares, i.e., depends on the structure of the market. Other players may also be prospecting market entry.

The matrix in Figure 4.1 illustrates the relationship between growth potential and uncertainty of demand on the one hand, and likely competition for a given market and/or shares in that market (and with that the level of concentration may vary as well) on the other. As shown in Figure 4.1, high upside demand potential may place emphasis on investing. Investing strategically in an early phase of market development is the case particularly in the presence of likely competition from existing players or entrants and/or when these include large potential players (also see the next matrix below in Figure 4.2). Conversely, low upside demand potential or downside demand risk may do the opposite: place more emphasis on postponement value. The figure above basically states that the more fragmented potential competition is, i.e., there are many other existing or potential entrants, the less strategic commitment value a project may have to deter such mostly smaller players. The game theoretical element thus becomes less pressing and postponement of the strategic investment is more likely. However, when competitors consist of few, very large players, or even only one player such that Gazprom would thus be part of a duopoly, then the greater the need to deter their entry. Hence the more oligopolistic the market structure, the greater the potential commitment value from Gazprom’s perspective.

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84 The postponement value may rise with increased upside and downside market volatility while the commitment value may also rise relative to the postponement value under increased market volatility. Ultimately, the size of the initial or strategic investment to be made (‘K’ in the model) may also make a large difference between killing a project or giving it a green light to proceed.
4.2.3 Gas suppliers: Weighing rival cost structure versus production capacity

The second consideration, which needs to be taken into account when deciding whether or not to invest strategically and thus commit to a certain market, is weighing the economies of scale in gas transport versus potential upstream gas production capacity. Economies of scale offers the possibility to reduce unit costs, though the extent to which unit costs are achieved depends on a pipeline’s utilisation rate (high utilisation rates lower unit costs):

a. High gas production capacity, low average total transportation costs: Suppliers can bring on-stream large amounts of gas at high economies of scale in transport;

b. Low gas production capacity, high average total transportation costs: Suppliers can bring on-stream smaller amounts of gas at low economies of scale in transport;

c. Mismatch between gas production and transport capacity: Suppliers may have much gas production capacity but a lack of infrastructure, or the availability of infrastructure but a lack of sufficient transport capacity at high economies of scale.

The level and intensity of competition is thus to a large extent determined by economies of scale in both up- and mid-stream production capacity. The matrix in Figure 4.2 captures this relationship; essentially it is an expression of economies of scale in transport versus upstream gas production capacity. The distance to market, especially for pipeline gas, is also an important factor: the shorter the distance, the greater the impact of pipeline gas in terms of lower unit costs, both in terms of SRMC and Long-Run Marginal Costs (LRMC).
4.2.4 Other investment variables

In addition to (1) market uncertainty and (2) possible competing gas suppliers, there are other investment variables to take into account conceptually when deciding whether or not strategic investments are viable or desirable. In addition, when the decision is being made whether or not to enter a specific market, there are other considerations at play than only the construction of mid-stream level projects. Decisions about the mid-stream are, for Russia, equally significant and interlinked with decisions about the development of upstream sources, i.e., across its entire resource base. Indeed one can think of these as ‘value chain’ level decisions involving primarily a portfolio of various ‘production’ possibilities. These value chains begin upstream and proceed mid-stream and onwards towards the final customer(s). Ultimately, Russia’s strategy hinges further on how far to integrate vertically, i.e. how close it sells its gas to the final customer. According to Barnes et al. [2006], the following factors have to be taken into account as well, in addition to market uncertainties, in order to explain investment decisions with regard to gas infrastructure:

a. The general investment climate up- and downstream: Investments in the gas industry, often involving large up-front investment costs, require a long period of predictable operation in order to recover the original investment and yield acceptable returns. Hence, investors have a large interest in the enforceability of contracts, a stable business environment (e.g., regulatory, fiscal stability and rule of law) as well as access to

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*Other considerations, regarding the rationality of decision-makers, may also have an impact on investment decisions; see Section 13.2.2 in Chapter 1.*
capital to finance investment projects via commercial banks and multilateral financial institutions. The domestic security, political and macro-economic contexts in consumer and producer countries shape the general investment climate along the value chain.

b. The involvement of transit countries: The existence of transit countries may create significant obstacles (including permit risks) in constructing viable cross-border gas pipelines, but simultaneously create the incentive to invest in transit-avoidance pipelines. Essentially, transit countries have interests that may not necessarily coincide with those of exporting or importing countries. In addition, they may behave opportunistically, because they only have their transit fees (and royalties) to lose. Conversely, transit risks may encourage additional investments in transit avoidance gas infrastructure. Certain international institutions have been established after the collapse of the Soviet Union in an effort to mitigate these risks, an example being the Energy Charter.

c. Geopolitical relationships: According to Barnes et al. [2006], another point of concern is the geopolitical relationship between states and how this influences greenfield investments. The geopolitical and geo-economic relationship between endogenous and exogenous actors can affect the feasibility of investments and thus also the likely materialisation of gas flows. International financial institutions also play a pivotal role in the overall investment framework surrounding gas infrastructure projects (also refer to Section 4.2.5).

4.2.5 Organisational and financial institutionalisation
Ultimately, depending on Gazprom’s position vis-à-vis its competitors (i.e., market outcomes, see Section 4.2.6), different types of organisational institutionalisation of investments can materialise amongst Gazprom and its would-be rivals, mid-streamers, etc. Also, as mentioned above, the financial institutionalisation of projects, as to how the project in question is likely to be financed and at what rate, also has bearing on project feasibility. Financial institutionalisation pertains to the type and source of financing whereas organisational institutionalisation relates to the shape, form and structure mainly of inter-firm and -government agreements.

Besides firm-level agreements, as has been argued in Chapter 2 and 3, government-to-government agreements can help institutionalise firm-level trade and investments. In addition, such organisations can reduce risks along the value chain (e.g., transit risks or volume risks in the off-take markets). Because of the structure of the gas market (e.g., a regionally traded commodity and high upfront costs, see Chapter 2), a strong path-dependency in mutual gas relations is a reality with which both producing and consuming govern-

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* Most of the government-to-government deals are cut on a bilateral basis, although some multilateral institutions try to help institutionalise firm-level trade and investments and reducing risks along the value chain, such as the WTO, the Energy Charter Treaty (ECT) and the EU, for example via the Trans-European Network (TEN) Programs and the agreements and dialogues with third-party countries and regions (see Chapter 10 for multilateral energy cooperation between Russia and Europe).
ments must deal, by working on a bilateral basis [Goldthau 2010]. This can be done through energy diplomacy, where the government takes on an active role in supporting its (national) firms at home and abroad. The role of energy diplomacy is especially important in an oligopolistic market environment. The aim of government support is not necessarily maximising business opportunities, but can also be national security goals. Therefore, diplomatic efforts to strengthen a firm’s presence in domestic and export markets reflect not necessarily identical interests of the government and the firm; see also Chapter 3 [Goldthau 2010].

The success of its organisational and financial institutionalisation, both on government and firm level, has an impact on the ability to realise strategic investments.

a. Organisational institutionalisation: The forms of institutionalisation on firm level are determined to a large extent by the market’s phase of evolution and structure – and as far as the model is concerned – by market outcomes (see Section 4.2.6 below). As already discussed in Chapter 3, De Jong [1989] distinguishes between three forms of institutionalisation on firm level: (1) M&A, (2) joint ventures and/or collusion and (3) direct competition via greenfield investments.

To increase the success of organisational institutionalisation through energy – and more specifically in this context – gas diplomacy, we have made a distinction between ‘vertical’ and ‘horizontal’ gas diplomacy. Vertical gas diplomacy is related to pipeline diplomacy along the value chain, both in the mid- and downstream. In light of the model discussion in Section 4.3, pipeline diplomacy can help to facilitate a firm’s first-mover advantage (i.e., its proprietary position) and to improve the change that a firm captures additional market share in a scenario of demand growth. In addition, gas diplomacy can help to reduce other risks, such as transit risk. Horizontal gas diplomacy is related to governmental efforts to support firm’s (bilateral) deals with other gas-producing and exporting firms and/or governments. Horizontal energy diplomacy also pertains to multi-lateral producer organisations such as the Gas Exporting Countries Forum (GECF), OPEC and bilateral gas producer country relations. From the model’s perspective, horizontal gas diplomacy can facilitate forms of supply coordination (i.e., cooperation and/or collusion) and shared investments; see also Chapter 10 Boon von Ochssée [2010].

There is no consensus on the definition of energy diplomacy. However, according to Goldthau [2010], “[t]he term commonly connotes the way countries give their energy companies a competitive edge in bidding for resources by using the state’s power: consumer countries strengthen their supply situation by diplomatically flanking energy contracts, whereas producer countries use diplomacy to enhance access to markets or reserves”. According to Okano-Heijmans [2010], economic (energy) diplomacy includes a ‘commercial’ dimension and a ‘power play’ dimension (these dimensions are not mutually exclusive per se). For an in-depth analysis on energy and pipeline diplomacy, see for example Zhiznin [2007], Goldthau [2010], and Bahgat [2003].
b. **Financial institutionalisation:** The next issue to be considered in the value chain is the financial institutionalisation of various investment programs geared towards establishing components of the value chain: how will these multi-billion dollar projects be financed and how will the corresponding risks be mitigated? There are differences in applying various business models in up-, mid-, and downstream activities, as was mentioned in Chapter 2. Large sums of required capital are involved for even just one such large-scale production and transportation project.

A firm can finance its projects internal (tap into their own cash flow) and external (rely on external investors and lenders). In general, the government- or state-backed ultimately guarantees debt issued by national gas firms. In some cases, a government authority also guarantees the debt capital of privately owned energy firms [Myers Jaffe and Soligo 2010]. The traditional means of risk mitigation and financing of large gas supply infrastructures is via long-term take-or-pay contracts; also see Chapter 2.

Figure 4.3 The general structure of financial flows for Russian gas exports

In the specific case for Gazprom, in addition to these take-or-pay contracts, it is using higher credit ratings of Western companies in order to realise better borrowing rates for debt via the so-called ‘warehouse’ construction (see Figure 4.3). The contracts between Gazprom and European mid-streamers are incorporated

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*See Myers Jaffe and Soligo [2010] for an in-depth analysis on state-backed financing in oil and gas projects.*
into a ‘warehouse’, serving as collateral for the financing of the project as well as a source of cheaper credits.

As discussed in Chapter 2, self-contracting as a form of new business models enables companies to integrate vertically, also resulting in higher financial exposure, because they must access capital markets on the basis of their own credit rating rather on the basis of the rating of their Western partners, i.e., mid-streamers [De Jong et al. 2010].

4.2.6 Possible market outcome scenarios
In accordance with steps 1 and 2 in Sections 4.2.2 and 4.2.3, the last step taken in the conceptual toolbox is making a rough assessment of which market outcomes may result from the situation Gazprom is confronted with in terms of possible entrants and their own characteristics in terms of market power. While the quantitative model leads, in its application, to its own various game theoretic equilibria, this component of the toolbox is designed to translate those equilibria into market outcomes. The application of the toolbox in each case will lead to separate market outcome scenarios after the application of the quantitative model, which itself is preceded by the application of the steps in the toolbox listed and explained above. So while the model uses a stylised approach to describe the various market outcomes in its own game theoretic fashion, the ‘real world’ requires a more loosely defined set of scenarios, which may for example explain situations involving oversupply despite oligopolistic market structures. For example, during the early 2000s the Turkish gas market was characterised by a gas oversupply despite a limited number of players in the market. Gazprom’s decision in each case which may range from investing in commercial projects to investing strategically early on, the following corresponding range of scenarios can result: (1) a (quasi-)monopolist scenario in a given market; (2) a dominant firm scenario; and (3) non-dominant or fringe firm scenario. These market outcomes are translated into model outcomes in Section 4.3.4 below, and both the conceptual market and model outcomes are summarised in Figure 4.7.

In each of the three ‘real-world’ scenarios, Gazprom’s various potential rivals in the European market are diverse, coming in the form of pipeline gas suppliers as well as LNG, varying largely in market power terms (also see Chapter 9). The competitors in this case may involve different groupings and behaviours: they may act as a ‘competitive fringe’, for example, sharing investments together in common infrastructures or projects (also see below). These competitors can be sub-divided roughly into two loose categories: (1) Fringe and non-dominant players, both pipeline gas and LNG suppliers, and (2) potentially dominant players (pipeline gas and LNG suppliers). In all three scenarios, oversupply is a real possibility. This is particularly plausible in the case of an economic crisis, which may precipitate a collapse in demand. The possible market outcomes are fed back into the beginning of the decision-making process, as is the case through backward induction in the model, discussed below.
In conceptual terms, and in taking the market outcome scenarios a step further, Gazprom can end up in a different position in a number of different scenarios. Gazprom may end up as a dominant firm, on the one hand, and as a non-dominant firm on the other, both at regional and sub-regional levels. Simultaneously, either the industry sees the rise of a buyer’s or a seller’s market for gas as a market condition. The different market outcomes and market conditions lead to different combinations, e.g., Gazprom may become a dominant or non-dominant firm in either a buyer’s or a seller’s market. Each such different combination has differing consequences for Gazprom’s investment strategy and merit order.

4.2.7 Interregional prices and shared investments
As was described in Chapter 2, the complexity of interregional gas trade and the nature of gas pricing (i.e., spot or ‘flexible’ volumes versus long-term oil-indexed volumes) preclude an independent pricing framework for gas. As was explained above, the framework used in this conceptual and quantitative model pertains to competition in quantities, not prices, because firms are assumed to compete in capacities before competing in prices in the longer run. In mature markets where excess or over-capacities are built up as firms compete for a stronger position in the market over time; firms ultimately are forced to compete through prices as demand growth slows down [Colell et al. 1995].

In order to avoid (interregional) price erosion, firms can engage in shared investments along the gas value chain, both at a regional level (e.g., pipelines) as well as at an interregional level (e.g., large-scale LNG projects). Indeed, according to Smit and Trigeorgis [2004] competitors may either act in a contrarian or reciprocating manner. If the competitor reciprocates and an investment is shared (such as both parties sharing the advantages of economies of scale of a shared value chain), it can lead to shared strategic benefits such as avoiding price rivalry by adopting a pricing standard, i.e., in the natural gas industry this could correspond to avoiding price competition in the long-run.

4.3 Whether or not to invest strategically: A real-option game model
As an extension of the review of the standard DCF approach, the real-options approach and the game-theoretic, entry-deterrence component captured by the overall net project value (see also equation 3.6), the scene is set to introduce the real-option game model. This is the quantitative, stylised counterpart to the toolbox included in the previous section. The model consists of a two-stage game involving a duopoly, i.e., Gazprom (the incumbent, or “firm A”) and an entrant or competitor (“firm B”). In stage I, firm A can decide whether or not to invest strategically before the game begins. In stage II, firm B is assumed to take part in the game, after which this entering firm may decide whether or not to invest. Stage II in turn consists of two periods, see Figure 4.5. The stylisation of the model implies that a wait-and-see strategy is a definitive deferral of the strategic investment, which means firm A postpones the option to compete for good.
Following these steps, four dates exist and stage II subsequently consists of two periods. Hence $t_0$ denotes the beginning of the game, stage I, which is when firm A makes a decision whether or not to invest strategically. Then, $t_1$ denotes the beginning of period 1 in stage II, which is when the market opens while $t_2$ denotes the beginning of period 2 in stage II. In this duopolistic framework, where binomial valuation is used, each player wants to have the greatest possible market share at the end of the “game” ($t_3$) in order to maximise so-called state-contingent project values, or ‘payoffs’ in game-theoretic terms (the term payoff is used in the model. These values basically represent the present values of profits derived from the different actions (i.e., of investing and not doing so, also refer to column 5 in Table 4.1 in the appendix of Section 4.5 for a mathematical explanation).

For the incumbent, the decision whether or not to invest early leads to different market outcomes on the basis of actions by the potential entrant. Following Smit [2003], we estimate the value of a firm’s growth opportunities as the sum of the outcomes of repeated expansion sub-games along an equilibrium path in the overall game. After $t_3$, the game is over and firm cash flows are assumed to continue in a ‘steady state’.

In the remainder of this section, a description of the model is provided in 6 subsections. Subsection 4.3.1 is a stylised review of the logic of early commitment and its strategic or net commitment value, which is broken down into separate components: the direct, the strategic reaction value and the strategic pre-emption value. Based on this logic, subsection 4.3.2 argues that four competitive strategies or postures can be assumed by the incumbent (and its potential competitor). Subsection 4.3.3 is an overview of the mechanics of the decision tree that comprises the possible decision paths of both the incumbent and the potential competitor, as a function of market demand swings upward and downward.

Subsection 4.3.4 is an overview of the two cases the model offers: one where the incumbent makes an early strategic investment, the so-called proprietary case, and the other where both players decide not to invest strategically early on but only make commercial investments, the so-called base case. Subsequently, subsection 4.3.5 links pipeline economics to the real-option game model concerning its input variables. Subsection 4.3.5 presents a summary of the different equilibria, which can result from each of these two scenarios where competitive strategies determine these equilibria. Subsection 4.3.6 provides an ex-
Plan explanation of how the different value components described in subsection 4.3.1 are calculated.

4.3.1 The strategic value of early commitment

Assume firm A is an incumbent firm in the European gas market and supplies gas through already existing infrastructure. It can make a first stage strategic capital investment, $K_A$, for the construction of a new gas pipeline to the European market. The present value at $t$, $(V_i)$ of second stage operating profits $(\pi)$ for firm A or B in each state of nature depends on the strategic investment of the incumbent firm, $K_A$, as well as on the firm’s ability to appropriate the benefits when investing in subsequent opportunities (i.e., non-strategic investments, as discussed in Section 8.3), which is a function of competitive reaction from an entrant or rival.

Firm A: $V_A(K_A, \alpha^*_A(K_A), \alpha^*_B(K_B))$; Firm B: $V_B(K_A, \alpha^*_A(K_A), \alpha^*_B(K_A))$  \hspace{1cm} (4.1)

where:

- $K_A$ = first-stage strategic capital investment of incumbent firm A (potentially influencing second-stage average costs, $AC$).
- $\alpha^*_i(K_A)$ = optimal \text{*} second-stage action of firm $i$ ($Q_i$ in quantity competition if investment is made in a proprietary investment by pipeline or $P_i$ in price competition), in response to first-stage strategic investment $K_A$.
- $V_i(\cdot)$ = the present value of operating profits $(\pi)$ at $t$, for firm A in the second stage of the market, given $K_A$ and the optimal actions of both firms.

Given market demand and taking the potential rival’s decision into account, player A must decide whether or not to make an upfront strategic investment commitment, $K_A$ while it must also, as in the case of its opponent, decide whether and when to invest in the second stage and select an optimal action (i.e., the quantity $Q$). In some cases, incumbent firm A may invest in a strategic pipeline capacity in order to deter entry by making firm B’s entry, thereby able to earn monopoly profits in the later stage of the market. The incremental impact of firm A’s strategic investment $(dK_A)$ on firm B’s second stage value $(dV_B)$ is generally given by:

$$\frac{dV_B}{dK_A} = \frac{\delta V_B}{\delta K_A} + \frac{\delta V_B}{\delta \alpha_A} \frac{d\alpha_A}{dK_A}$$  \hspace{1cm} (4.2)
In order to deter entry, firm A must take a ‘tough’ stance that would inflict damage to its competitor \( \frac{dV_B}{dK_A} < 0 \). If entry deterrence is too costly (i.e., the postponement value being greater than the commitment value) firm A may find it preferable in some cases to follow an accommodating strategy, in which case it would by definition not be making a strategic investment. Firm A’s incentive to make the strategic investment then depends on the impact of the incremental investment \( dK_A \) on its own value from second-stage operating profits, i.e.:

\[
\frac{dV_A}{dK_A} = \delta V_A + \frac{\delta V_B}{\delta K_A} \frac{d\alpha^*}{dK_A}
\]

(4.3)

The commitment value, which is explained in Chapter 3, can be broken up in the direct value, and the strategic reaction and pre-emption values (see Appendix 4.6 for the mathematical explanation):

- the direct value pertains to the direct incremental future cash flows resulting from the strategic investment, due mainly to lower marginal cost of production/transportations (gains from economies of scale);
- the strategic reaction value is the strategic value component of the investment which influences a potential competitor’s reaction. This enables the firm to conquer greater market share opportunities (due to a first-mover advantage);
- the strategic pre-emption value corresponds with a strategic investment which can influence the competitive equilibrium at the end of the game or, the game’s final outcome. In some cases this may even involve changing the market structure altogether by deterring entry.

The net commitment value thus has a direct effect on the investment itself by increasing economies scale and a strategic effect expressed by the effect it has on a competitor’s scale of entry, if at all. A net commitment value indicates whether a strategic investment is to be made at \( t_o \), which may be seen as pursuing a strategic growth investment. The postponement value indicates at \( t_o \) whether a strategic investment should be postponed and that therefore only commercial investments should be pursued, which may be seen as excising the postponement option rather investing strategically (see above). If the difference between the net commitment value and postponement value is positive, then the incumbent invests; if the difference is negative, then the investment is postponed. The model is an extension of what was described in Chapter 3, namely an approach where standard NPV calculations are enhanced with flexibility options value and the strategic option-game value. This overall value is recapitulated as followed:
The overall Net Project value (NPV\(^{*}\)) = ‘direct’ (static) NPV + flexibility options value + net strategic option-game value \hspace{1cm} (4.5)

As was explained in Section 4.2.7, the competitive setting used in the conceptual toolbox and above pertains to quantity competition. However, the real-option game approach can also be applied in a duopoly situation of price competition (see Smit and Trigeorgis [2004]), which goes beyond the scope of this study.

### 4.3.2 Competitive strategies

This subsection conceptually links the various possible competitive strategies of each player to the market outcomes, which are described in the next subsection. An offensive strategy is directed at undermining a competitors’ payoff in a later stage of the market, seriously impacting its ability to enter the market. An accommodating strategy may involve a decision not to fully engage a potential entrant. The incumbent firm accommodates entry in that it accepts the entering firm’s entry as a fait accompli and merely tries to affect its subsequent behaviour. Conversely, as Colell et al. [1995] note, if deterrence is optimal, then even though entry does not occur, its threat nevertheless has an effect on the market outcome, raising the level of firm A’s output relative to a situation in which no entry is possible. The effects of a decision to invest early or not are expressed mathematically in equations 4.3 and 4.4. Based on these strategic effects, four competitive strategies or combinations of strategic actions can be imagined, involving competition and/or cooperation through proprietary and shared investments, respectively. The four different strategy combinations are summarised in Figure 4.6. In the left two cases, competition occurs in volume terms while in the second it occurs in price terms because the potential entrant can act in either a contrarian or reciprocating fashion, respectively. For the conceptual treatment of price games in this study, reciprocating competition is included as well, in addition to contrarian competition.

1) Committing and offensive strategy (tough position with contrarian competition): An offensive strategic investment, for example by building a large-diameter gas pipeline, can generate a proprietary advantage, translating into a tough position, hurting the competitor’s chances in the second stage of the game. Under contrarian or volume/quantity competition, competition will retreat and the incumbent firm can expand its share and gain leadership as the market grows. At lower relative demand the competitor’s profit value is negative, and the incumbent firm may even enjoy monopoly rents.

2) Flexible and offensive strategy (accommodating with contrarian competition): Under contrarian competition, a new entrant may take advantage of the incumbent’s accommodating position and capture most of the shared benefits of a strategic investment. According to the model, there is no strategic advantage to pre-commit investment since it would offer a rival firm with the opportunity to free ride on the incumbent’s initial investment, if shared (see also subsection 4.2.1). In order to prevent the creation of valuable shared opportunities for the competition, the incumbent should
maintain an offensive posture by postponing its investment (postponement value), all the while maintaining its option to invest at a later stage (maintaining managerial flexibility value). In case future demand grows, two identical competitors would choose to invest simultaneously. If demand declines, both would abandon the market.

3) **Flexible and inoffensive strategy** (tough with reciprocating competition): A tough position through a strategic investment may hurt competition but can induce a tough reaction by a reciprocating competitor, which can result in intensified rivalry. Here competition would take place through prices. To avoid such intense second-stage competition, the firm will not invest in an early strategic investment, remaining flexible and inoffensive. If demand develops later, both firms can invest, resulting in a duopolistic price equilibrium.

4) **Committing and inoffensive** (accommodating with reciprocating competition): Now suppose that early strategic investment will also benefit demand for the competitor, who is ready to reciprocate. The incumbent firm should invest in the strategic project and be accommodating in a later stage of the market development, avoiding price competition, reaping shared benefits in the process. Though maintaining high prices and higher profit margins, both firms can enjoy more profitable follow-up investments. The incumbent firm could act as a dominant player, with the competitor following suit. Compared to the base case (see subsection 4.3.3), a strategic investment has positive strategic reaction and coordination effects but at the same time implies a flexibility loss (i.e., foregoing of postponement value).

**Figure 4.5** Sign of strategic effect and competitive strategies under different position and competition

<table>
<thead>
<tr>
<th>Incumbent (Firm A)</th>
<th></th>
</tr>
</thead>
</table>
| **Tough position**<br>e.g. proprietary investment (hurt competition) | **Committing and offensive**<br>Invest (strategic effect)<br>(Monopoly profits or duopolistic quantity competition)<br>✓<br>**Postponing and inoffensive**<br>Do not invest (postponement effect)<br>(Duopolistic price competition)<br>✗
| |
| **Postponing and offensive**<br>Do not invest (postponement effect)<br>(Duopolistic quantity competition)<br>✗<br>**Committing and inoffensive**<br>Invest (strategic effect)<br>(Leader–follower/collusion or duopolistic price competition)<br>✓
| |
| **Contrarian**<br>(down-sloping reaction/substitutes)<br>e.g. quantity competition | **Reciprocating**<br>(up-sloping reaction/complements)<br>e.g. price competition |
| **Competitor or potential entrant (Firm B)** | |

Source: adapted from Smit [1996]; Smit & Trigeorgis [2001].
4.3.3 The base case versus the proprietary case

Depending on which competitive strategy the incumbent and the entrant take in quantity terms, a base case and a proprietary case may result. In the base case, both the incumbent and the entrant do not invest strategically but rather invest only commercially against relative high operating transport costs per unit (see also subsection 4.3.5).

By contrast, in the proprietary case the incumbent makes a strategic investment, for example by building a large-diameter pipeline. A large-diameter pipeline results in lower average operating transport costs per unit vis-à-vis the competition. In the case of shared investment (see subsection 4.2.1), the incumbent makes an upfront investment which it then shares with the entrant. This implies a mutual decrease in the operating transport cost per unit. For this research, shared investments are not taken into account as a possibility in the real-option game model.

4.3.4 Model outcomes, demand moves and the decision tree

Each different combination of strategic choices made by firm A, the incumbent, and firm B, the competitor, leads to various combinations of quantities supplied, profits and state-contingent project values for both firms. Table 4.1 (see the appendix in Section 4.6) contains the formulae needed to compute equilibrium quantities, the final profits and corresponding state-contingent project values. Each such combination corresponds to a different model outcome within this duopolistic market setting. It is useful to describe the essentials of these model elements in a step-by-step fashion, starting with the various model outcomes and moving on to the workings of the model’s so-called decision tree.

Model outcomes

Essentially, each market outcome (described conceptually in subsection 4.3.6) corresponds with various game-theoretic equilibria resulting from the interaction between the two firms in the model. Each equilibrium in the game is essentially a Nash equilibrium, where each firm pursues its own dominant strategy given what the other firm does. Because the game is based on interaction between two players, the market structure of the game remains duopolistic, in principal. However, at the end of the game (i.e., model outcomes), firm A and/or B may not remain in the market, which changes the overall market structure at that stage. Changed market structures are implicitly valued for both firms in the state-contingent project values.

Game theory prescribes to such situations various equilibria or outcomes, in which one or the other firm ‘ends’ the game in a certain position vis-à-vis the other firm. These equilibria in the model can be described intuitively as various market structures in a two-firm world (see also Figure 4.6). In other words, in a duopoly, these outcomes explain the balance of power between only two firms. We refer to these market structures as outcomes rather than structures, in order to avoid confusion, given the duopolistic nature of the model. Since a discussion about game-theoretic equilibria is beyond the scope of the ap-
application of the real-option game model here, an intuitive description will suffice at this stage.97

Each type of market outcome hinges on the quantities supplied respectively by the two firms. These quantities vary according to the various combinations of actions taken by the two players (in terms of investing commercially or not in stage II, or also investing strategically or not in stage I, i.e., base versus proprietary case). Following mostly textbook industrial organisation economics and game theory, this can be represented graphically by means of a figure depicting the so-called reaction curves of both firms, see Figure 4.6.

Figure 4.6 Graphical representation of quantity competition90

The two firms react to each other’s supply decisions, which are represented graphically by their reaction curves. Each firm’s reaction curve (\( R_A \) for firm A and \( R_B \) for firm B) represents what it supplies given what its competitor produces, and is determined by solving the two firms’ production functions. The reaction curves can also be derived by determining a firm’s iso-profit curve, a curve that represents the combinations of output that will

90 This is the case since essentially the research objective calls “only” calls for applications of the model, in order to provide insights that serve the research questions as mentioned in Chapter 1. The game-theoretic concepts nevertheless remain fundamental to understanding the link between model outcomes and the state-contingent project values. For a theoretical background on these game theoretic concepts, see for example, Tirole [1998] and Dixit and Nalebuff [1991], Coell et al. [1995], Rasmussen [2001] and Jacquemain [1987].

97 In a situation of reciprocating (Bertrand) competition, the reaction curves would be upward-sloping (e.g., price competition), see also Smit and Trigeorgis [2004]. For a more complete explanation of the various model outcomes and a more detailed explanation of the graph produced in Figure 4.8, see Figure 4.6 in Smit and Trigeorgis [2004], p. 195.
generate the same level of profit (iso-profit) for each firm. The farther a firm’s reaction curve is from the axes in the graph, the greater is its share of the market, and hence the greater its profits. The model outcomes should be interpreted at the end of stage II, where investment actions by firm A in stage I or by either of the two firms in stage II can lead to:

1) A duopoly outcome with two firms that roughly supply a similar portion of the market (which is represented by point C in Figure 4.6) because they both end up investing accordingly in such an outcome. This is represented in the decision tree (see Figure 4.8) and elsewhere by the letter ‘C’ (i.e., C for Cournot duopolists).

2) A monopoly for firm A on the one hand, where firm B is deterred from the market entirely, or on the other hand, where the converse is the case (which is represented by point M in Figure 4.6). This is represented in the decision tree and elsewhere by the letter M. For firm A, a monopoly for B means firm A deferred investment in both stages of the game while firm B invested, a market outcome denoted by the letter ‘D’ for deferral (also see Table 4.1 in the appendix).

3) A leader-follower outcome for firm A where it ends as a dominant firm (i.e., the leader) and where firm B invests in such a way that it ends as a non-dominant firm (i.e., the follower). This model outcome is represented by ‘S’ for firm A in Figure 4.6 and in the decision tree in Figure 4.8. In Figure 4.6, an outward shift of firm A’s reaction curve is a result of quantity competition in stage II, based on a strategic investment made in stage I by firm A. Elsewhere in the text and throughout text pertaining to applications of the model, this outcome is represented by S-L for the leading firm and S-F for the following firm (this is applicable to both firms).

4) An outcome in which both firms defer their investments in both stages of the game, denoted by the letter ‘A’ in Figure 4.8 (i.e., A for abandon).

Figure 4.7 provides an overview of the different possible scenario market outcomes as discussed in Section 4.2.6 and their translation into model outcomes, which was discussed above. While Figure 4.7 includes the game-theoretic terms associated with these model outcomes, they are used here merely to illustrate the link between the toolbox and the model in terms of the outcomes.

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" There is a different iso-profit curve for each level of profit. The parabolic iso-profit curves drawn above are combinations with a higher quantity for the competitor (firm B), and consequently a lower profit for firm A.

" This corresponds with a Nash-Cournot model outcome, see Figure 4.7.

" This corresponds with a von Stackelberg Leader-Follower model outcome, see Figure 4.7.
Figure 4.7 Gazprom’s market outcomes in scenarios and model terms

<table>
<thead>
<tr>
<th>Market outcomes – scenarios</th>
<th>Market outcomes – model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>(Quasi-) monopolist</strong></td>
<td><strong>Monopolist</strong></td>
</tr>
<tr>
<td>• Market share of between 70-100 percent</td>
<td>• The incumbent builds capacity early such that it is unprofitable for the competitor to enter</td>
</tr>
<tr>
<td>• Competitor(s) are either non-dominant or fringe players with a share of between 0 and 30 percent</td>
<td></td>
</tr>
<tr>
<td><strong>Dominant position</strong></td>
<td><strong>Von Stackelberg leader (S-L) or Nash-Cournot (C)</strong></td>
</tr>
<tr>
<td>• Market share of between 30-70 percent</td>
<td>• S-L: The incumbent invests first in a project and its competitor invests in a later period.</td>
</tr>
<tr>
<td>• Competitor(s) can be dominant, non-dominant or fringe players with a share of between 30 and 70 percent</td>
<td>• C: Both firm invest simultaneously</td>
</tr>
<tr>
<td><strong>Fringe/non-dominant position</strong></td>
<td><strong>Von Stackelberg follower (S-F)</strong></td>
</tr>
<tr>
<td>• Market share is less than 30 percent</td>
<td>• S-F: The incumbent ends up investing later in a (commercial) project while the entrant itself invests commercially before the incumbent does so.</td>
</tr>
<tr>
<td>• Competitor(s) take a quasi-monopolist, dominant and/or non-dominant firm position</td>
<td>• This outcome is the converse case of S-L (see above)</td>
</tr>
</tbody>
</table>

Note: the model-based market outcomes refer to equilibrium results from economic game theory. Section 4.3 provides an explanation of these results. Source: own analysis, based on Smit and Trigeorgis [2004]; De Jong [1989].

The decision tree

Through the use of a decision tree (Figure 4.8), each of the strategy combinations mentioned above in Subsection 4.4.2 and the model outcomes can be visualised. Each of these outcomes is tied to the valuations of the relevant investments (valued through the state-contingent project values), both initial as well as follow-up ones. The tree uses binomial real option valuation to compute the state-contingent project values. Figure 4.8 contains the binomial valuation tree, the letters at the bottom of which (i.e., at the ends of the branches at \( t_j \)) correspond with the model outcomes.

Demand moves

The values or numbers lodged at the bottom of the decision tree are the state-contingent project values resulting from the competitive strategies each of the two firms can take (see Figure 4.6 for an overview of the various competitive strategies the two firms can take). The tree structure conveys the two-stage uncertainty and decision structure of the model, which has been described in subsection 4.3.1. The nodes at the bottom end of the branches in the tree contain the values of the various actions as a function of resulting model outcomes at the end of each period in the second stage, which in turn result from the decisions of each player (as described above). These values ultimately determine whether or not firm A is to make a strategic investment decision or not.
The state-contingent project values are factored into risk-neutral backward valuation formulae used to calculate values of investing and/or deferring under binomial upward and downward movements of demand between periods 1 and 2 (these formulae are included in the bottom half of Table 4.1 in the appendix, Section 4.5), discounted using a risk-free interest rate, $r$. This is the relevant rate within the applied approach of risk-neutral valuation. The approach has been described in Section 3.7.2 and is visualised by means of the decision tree in Figure 4.8 below. The state project values themselves are based on the equilibrium quantities derived from the relevant calculation framed in Table 4.1 (see Section 4.5) and are discounted back to $t=0$ as long-term expected cash flow annuities at end of period 2 (at a risk-adjusted discount rate $k$).

**Figure 4.8** The two-stage game in extensive form under different market structures

---

When both firms decide to invest simultaneously, $(I,I)$, the game ends in a duopolistic competitive equilibrium $(C)$. When both firms choose to defer, $(D,D)$, under low realisations of demand, the nature of demand $(\theta)$ moves again and the game is repeated in a sub-game. The different outcomes of each game and sub-game imply different state-contingent project values (for the different sets of firm actions, investing or not) at the end of each branch (node) in the binomial valuation tree, representing equilibrium outcomes: duopolistic competitive equilibrium competition, a duopolistic leader/follower outcome,
monopoly, a deferral in period 1 (which is ‘not yet’ a market outcome), and an abandon outcome; see also subsection 4.3.6.

In the end, the model aims to answer the question as to whether the incumbent is to invest strategically or not at the outset of the first stage of the game. The final equilibrium outcomes resulting from strategic interaction at the end of each sub-game (i.e., each “path” through the tree) are used to reason backwards towards the first branches in order to provide outcomes for the net commitment and flexibility values of the strategic investment. The stage II sub-game equilibrium outcomes are dealt with first, used to calculate optimal actions along the different branches of the tree backwards towards the initial point of decision in stage I. The direct, strategic and postponement values of the strategic investment are then calculated on the basis of various quantity outputs and corresponding profit levels; see the appendix in Section 4.6. The stylised model formalises the relationship between the notions and attaches to the net commitment value its own components.

### 4.3.5 Input variables from the perspective of the gas industry

Pipeline economics are based on CAPEX, OPEX and are also subject to the pipeline’s utilisation rate and ramp-up period, see also Chapter 2. The CAPEX cover mainly the costs of building a pipeline (e.g., steel costs etc.), and the costs of building compressor facilities. The OPEX covers mainly the costs of maintaining the compressor and pipeline facilities for operational use. In addition fuel costs are taken into account. The economic lifetime of a pipeline investment is assumed to be 25 years. Below one can find an explanation and a calculation approach of a number of input variables from the perspective of the gas industry, in order to make gas infrastructure investments useable for a real-option game model.

- **Calculation of the average operating transport cost (c):** In order to calculate the average operating transport cost, the cash flows of operating costs (i.e., OPEX and fuel costs) are discounted over 25 years with the cost of capital (i.e., WACC). The present value of the operating costs is divided by the present value of the pipeline’s volumes multiplied by the price index (i.e., in order to correct it for economies of scale). Both the price index, and the cash flows of costs are corrected partially for inflation.\(^94\) For simplicity, the calculations exclude any form of taxation. We assume the OPEX at 1.5 percent of the CAPEX of the pipeline and 3 percent of the CAPEX of the compression facilities at yearly basis. The fuel costs per year are calculated through the fuel usage by full capacity (i.e., 1160 mcm/y\(^95\); corrected with the utilisation rate) to the

\(^94\) According to expert interviews, inflation is partially passed on, defined as the indexation tariff (in this research assumed at 25 percent). This tariff increases marginally during time according to a specific formula.

\(^95\) The fuel usage by full capacity is calculated as follows: (MW\text{power}/\text{efficiency of compression in percentage}) \times (\text{number of hours generator is working yearly}/\text{caloric value of gas in MJ/cm}^3) \times 0.0036 = (564/0.35) \times (8000/40) \times 0.0036 = 1160 \text{ mcm/\text{y}}.
power of the fuel versus flow ration (i.e., 1.5), multiplied by the gas price (corrected partially for inflation). In order to determine the gas volumes per year, we assume a technical ramp-up phase with an utilisation rate of 20 percent at year 1; 40 percent at year 2; 60 percent at year 3; 80 percent at year 4; and 100 at year 5.

- **Calculation of the strategic investment (K) and commercial investment (I) from the theoretical and project CAPEX:** As mentioned above, a large part of the investment has to be realised upfront via the CAPEX of pipeline and compressor facilities. Generally speaking, it can be assumed that the CAPEX of a pipeline is 70 percent of the total CAPEX, while the CAPEX of compression 30 percent.

In order to define the CAPEX, public data will be used when applicable. In other cases, a theoretical CAPEX will be calculated for the pipeline section, and added with a CAPEX component of compression. In general, the CAPEX of a pipeline scales with the diameter of the pipeline, while the capacity of a pipeline scales with more than the square of the diameter [Correljé et al. 2009]. The throughput of a natural gas pipeline is thus a function of a pipeline’s diameter. An increase in the diameter of the pipeline generates an exponential rise in additional throughput capacity. This is an important determinant of economies of scale in pipeline economics; see above. According to expert interviews, a constant factor (i.e., an average theoretical derivation) is derived from the relation between the diameter and the capacity (i.e., 0.0013). The average CAPEX of a pipeline is assumed to be 43 euro/inch/meter.

The next step is to define the variables K and I. In the model, the variable I corresponds with investments pertaining to small-diameter pipelines with a short, technical ramp-up phase, i.e., a 8 bcm/y pipeline (with the same distance in case of a proprietary investment). By contrast, in the proprietary case the incumbent makes a strategic investment by building a large-diameter pipeline in order to lower the average operating transport costs. The strategic investment, with a lower potential utilisation level under various market conditions, is denoted by K. As such, in modelling terms, a strategic investment K can be defined as the difference between the total CAPEX for the

\[ \text{Throughput capacity} = \frac{\text{CAPEX}}{0.0013} \]

The theoretical formula according to Davis [1984], \( T(d) = d^{3.5} = d^{3.5} \), is adjusted by the constant factor, so that

\[ \text{diameter of a pipeline is: } d = \left[ \frac{\text{Cap}}{0.0013} \right]^{1/3}, \text{ where Cap = throughput capacity; and } d = \text{the diameter of the pipeline).} \]

\[ \text{For simplicity, offshore and onshore pipelines are assumed to bear the same costs in terms of euro/inch/meter in this analysis.} \]
large-diameter pipeline investment (e.g., the Nord Stream) and the 'theoretical' CAPEX for the investment of a 8 bcm/y pipeline (I), i.e., K – I.\textsuperscript{98}

In a specific case, when the incumbent does not invest commercially (I=0) in either periods 1 or 2, a deferral and/or abandon outcome results, respectively. However, the incumbent invests in K at the beginning of the game. If in the end, the incumbent has invested K but did not actually use this strategic investment, K may be seen for the future as a comparatively cheap option, which requires a correction in the model. For this reason the incumbent is 'punished' in the model's outcomes with the subtraction of a commercial investment amount (I) from the state-contingent project values at the end of period 2, at $t_2$. This substraction is also made in order to come to a 'correct' total CAPEX for the gas pipeline project. This exception holds for situations in which firm A did not invest commercially in periods 1 and 2.\textsuperscript{99}

- **Calculation of the theta at t=0 (θ₀) and u and d:** For the purpose of this research, the initial market demand $θ₀$ is a function of the increasing gap between gas market demand and volumes supplied through long-term contracts and indigenous production. As long-term gas contracts expire and indigenous production declines, combined with possible increase demand, additional demand or market opportunities are manifested, thus increasing $θ₀$. New capacity (e.g., in the form of pipelines to be built by firm A and/or firm B) is built based on and designed to capture this ‘widening gap in the market’. In the model’s applications, $θ₀$ is computed by taking an average of the difference between the level of demand and contracted volumes added to indigenous production per year. This amount is then discounted at the risk free rate. This is done in order to account for time value differences in market demand since satisfying demand today is worth more than doing so tomorrow.

In the model, demand is assumed to be stochastic, moving up or down with binomial parameters $u$ and $d$ (where $d = 1/u$). In light of the conceptual discussion above, we assume the upward potential (which in the model as $2 \times u$) to coincide with an upward demand scenario after 25 years. For simplicity in the model, we define $2 \times u$ as the highest level of demand ($θ_2$) reached at $t_2$ (see Figure 4.4). Starting at $t_1$, there is

\textsuperscript{98} Other options for defining K in gas industry terms have also been considered. This includes the aggregated opportunity costs arising from lower infrastructure utilisation levels under lower market demand conditions within the model (as a result of upward and downward moves in market demand). These opportunity costs in all the various outcomes at the end of the first and second periods of the game would then be valued back up through the tree through binomial risk-neutral valuation. This results in an amount, which is equal to ‘K’. For simplicity after consulting experts, the ‘total CAPEX-I’ approach was opted for.

\textsuperscript{99} In reality, when a firm did not actually use a strategic investment, it can possibly abandon investments in compression facilities.
a ‘steady state’ over 25 years, i.e., no more upward and downward moves. The data used as input in conceptual reasoning act as an annuity involving approximately linear growth. However, for simplicity given the purpose of the model, this is translated into the binomial evolution of demand periods 1 and 2 in stage II, with a steady state after $t_3$.

- **Maximum capacity of new pipeline investments and $Q$:** In a number of market outcomes in period 1 and/or 2, quantities supplied by both the incumbent (e.g., for firm A’s strategic investment in a proprietary case), and the competitor (e.g., for firm B’s commercial investment) may exceed the pipeline capacity of their investment, i.e., $Q_{A,B} > Q_{\text{Max}}$. For example, as a dominant firm or a monopolist in a market outcome, firm A may supply a quantity greater than the theoretical capacity of its strategic pipeline investment in order to achieve this market position. As is explained in the conceptual sections of the cases in Chapter 11, both the incumbent and its competitor are assumed to be supplying a given market through existing infrastructure. With the fall in flows provided through long-term contracts, existing pipeline infrastructure utilisation falls gradually. When additional infrastructure is built, and $Q_{A,B} > Q_{\text{Max}}$ in various market outcomes, it is assumed that firm A and/or B can supply gas through already existing infrastructure (because of falling, already contracted supplies). When an action on the part of the incumbent squeezes the competitor out of the market, it is also assumed that the competitor’s infrastructure hereby becomes redundant.

Ultimately this formalised combination is a quantitative assessment of strategic investments in the face of demand uncertainty and the impact of potential entry (and/or other actions) by a competitor. The stylised model fits into the toolbox where its quantitative essence is lodged inside a qualitative framework. A schematic overview of the conceptual toolbox and its relationship with the stylised model is provided in the Figure 4.9.
4.4 Conclusion

The conceptual toolbox and the stylistic real option game model comprise a framework designed to analyse the issue of strategic investments. The real-option game model shows that pipelines with high economies of scale over longer distances can serve as tools to preserve or expand market share. Strategic investments are fundamentally different from commercial investments, the latter pertaining to pipelines with a more optimal utilisation profile. Investments may be proprietary or shared.

The conceptual toolbox is designed to take into account those factors which cannot be taken into account quantitatively when assessing whether or not to invest strategically. These include the general investment climate, geo-economic and geopolitical relationships, difficulties involved in transit countries as well as organisational and financial feasibility of investments. Market demand uncertainty in terms of volumes and prices, as well as the nature of competition is also taken into account conceptually in the toolbox. The stylised real-option game model acts as a supplement where demand uncertainty and rival moves are taken into account more formally by quantitative means. The model’s added value lies in its mathematical underpinning for a more intuitive understanding of strategic investments. This value lies in its exact application, where the toolbox is more conceptual. The various outcomes yield preferences, expressed by large-scale investments from the perspective of this model, the ultimate aggregation of which helps determine the merit.
order. Ultimately, the model also helps explain how gas suppliers may lean towards a tendency to compete on the one hand and cooperate on the other.

4.5 Appendix to Section 4.3

In Table 4.1, the equilibrium quantities, profits and state project values are included for the various market structures under contrarian (Cournot) quantity competition, based on the equilibria outcomes mentioned in Section 4.3.6 and 4.4.5. The formulae are derived from Smit and Trigeorgis [2004].

Smit and Trigeorgis [2004] attain higher values for the state-contingent project values due to the fact that they discount profits (see column 4 in Table 4.1 below) simply by the variable $k$, which implies that profits are discounted as perpetuities. The state-contingent project values have thus been adjusted because infrastructural investments in the gas world typically have a lifetime of 25 years. Therefore, rather than allowing the cash flows to take place in the form of a perpetuity, the state-contingent project values are discounted for that length of time by multiplying the contingent state project value by:

$$1 - \left(\frac{1}{(1+k)^{25}}\right)$$

where $k$ is the risk-adjusted discount rate.

The total net commitment value and the overall NPV

The total net commitment value of gas infrastructure investments is broken down into three parts and calculated as follows:

1. a direct value resulting from direct reduction in future operating costs (i.e., economies of scale). The direct value is calculated from the reaction curves as explained in Section 4.4. (see Figure 4.7 of Section 4.3.6), reducing $c_i$ to the cost level derived from the strategic investment (for the incumbent):

$$R_A(Q_B) = \frac{1}{2}(\theta_i - c_A - Q_B)$$

for $Q_A$ ($Q_B$ is known from the base case), then solve the Cournot proprietary profit function:

$$\pi_A = ([\theta_i - c_A - Q_B]Q_A - Q_A^2)$$

where $c_A < c_B$.

---

100 A constant perpetuity is an annuity that has no definite end, that is, a stream of expected cash flows that continues forever.

101 For the exact mathematical application and breakdown of the commitment and postponement values, refer to the quantitative numerical application of the model in Case study 1 in Chapter 11.
Then $\frac{\pi}{k} = V_\pi$ determines the direct profit value while subtracting from this the base case profit value determines the direct value (because the base case reflects the situation in which both parties do not invest strategically).

2. a strategic reaction value reflecting the impact of the strategic investment made by the incumbent on the competitor’s reaction curve and profit value for a given market structure. It is obtained by subtracting the direct profit value from the total profit value (the total profit value function used depends on the dominant equilibrium in question):

$$E.g., \left( \frac{\theta_l - 2c_A + c_B}{9} \right) / k - \frac{\pi}{k} \quad (4.6)$$

3. a strategic pre-emption value resulting from deterring competitive entry and causing a change in the market structure altogether (i.e., gaining a Stackelberg leader or monopoly position instead of a Nash-Cournot one). It is calculated simply by subtracting the resulting project value from the project value under a Nash-Cournot outcome.

Ultimately, the overall net project value described conceptually in Chapter 3, in the value components of expression 3.7, translates in model terms to the overall NPV ($NPV^*$):

$$NPV^* = \text{base case NPV} + [-K_A + (\text{direct value} + \text{strategic reaction value} + \text{pre-emption value})] + \text{postponement value}$$

Remember that the model assumes a duopoly. This implies that the total value to be gained by players in the market is to be distributed exclusively among the two firms (firm A, the incumbent and firm B, the competitor).

Also see Chapter 11 for an application of the formula described above.
### Table 4.1: Equilibrium quantities, profits and state project values for various market structures under contrarian (Cournot) quantity competition in the second stage

<table>
<thead>
<tr>
<th>Action</th>
<th>Model outcome</th>
<th>Equilibrium quantity</th>
<th>Equilibrium profit</th>
<th>State-contingent project value</th>
<th>Demand state</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A, B)</td>
<td>C/M/S/A/D</td>
<td>$Q_i^*$</td>
<td>$\pi_i^*$</td>
<td>$NPV_i$</td>
<td>$\theta_i$</td>
</tr>
</tbody>
</table>

**Second-stage game in period 2 (continued on the next page)**

- **Nash Cournot (N)**
  - (DI, DI): $\frac{(\theta_i - c_i)(2 + q_j) - (\theta_i - c_j)}{(2 + q_i)(2 + q_j) - 1}$
  - (II, II): $\frac{\theta_i - c_i}{2 + q_i}$, $Q_i = 0$

- **Monopolist (M)**
  - (DI, DD): $\frac{\theta_i - c_i}{2 + q_i}$, $Q_i = 0$
  - (II, DD): $\frac{\theta_i - c_i}{4k} - l$ < $3\sqrt{k}l + 2c_i - c_j$

- **Stackelberg Leader (S-L) / Monopolist (M)**
  - (II, DI): $\frac{(\theta_i - c_i)(2 + q_j) - (\theta_i - c_j)}{(2 + q_i)(2 + q_j) - 2}$
  - (II, DD): $\frac{(\theta_i - c_i)(2 + q_j) - (\theta_i - c_j)}{(2 + q_i)(2 + q_j) - 2}$

---

104 During period 1, the denotation (A, B) means that firm A took action A while competition firm B took action B. During the entire second stage the denotation (AA', BB') means that firm A took action A in period 1 and A' in period 2, while firm B took action B in period 1 and B' in period 2.

105 Calculated from $\pi_i = PQ_i - C(Q_i)$, assuming for simplicity $q_i = q_j = q = 0$. In the application of the model, $q_i, q_j \geq 0$, that is: when model outcomes are negative, they are assumed to equal zero, because firms do not produce negative quantities.

106 This state-contingent project value is determined in the last stage from $NPV_i = \max(\pi_i / k - l, 0)$, where $\pi_i$ is a perpetuity cash flow stream, $l$ is the required outlay and $k$ the risk-adjusted discount rate. In the first period, the state-contingent project value may be determined from future expanded (strategic) net present value in the up and down states using backward binomial risk-neutral valuation. When A or B make an investment (I) in the second period, I must be subtracted in order to calculate the state-contingent project value otherwise this does not apply.

107 Model outcome symbols: C: Cournot duopoly, M: Monopoly, S: Stackelberg Leader or Stackelberg Follower, A: Abandon, D: Defer.
<table>
<thead>
<tr>
<th>Action</th>
<th>Model outcome</th>
<th>Equilibrium quantity</th>
<th>Equilibrium profit</th>
<th>State-contingent project value</th>
<th>Demand state</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A, B)</td>
<td>C/M/S/A/D</td>
<td>$Q^*_i$</td>
<td>$\pi^*_i$</td>
<td>$NPV^*_i$</td>
<td>$\theta_i$</td>
</tr>
<tr>
<td>(D1, D2)</td>
<td>Stackelberg</td>
<td>$\frac{\theta_i - 3c_j + 2c_i}{4}$</td>
<td>$(\theta_i - 3c_j + c_i)^*$</td>
<td>$\frac{\theta_i - 3c_j + 2c_i}{16}$</td>
<td>$\geq 4\sqrt{k/l + 3c_j - 2c_i}$</td>
</tr>
<tr>
<td></td>
<td>Follower (S-F)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(DD, DD)</td>
<td>Abandon (A)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

**Period 1**

<table>
<thead>
<tr>
<th>Action</th>
<th>Model outcome</th>
<th>Equilibrium quantity</th>
<th>Equilibrium profit</th>
<th>State-contingent project value</th>
<th>Demand state</th>
</tr>
</thead>
<tbody>
<tr>
<td>(I, I)</td>
<td>Nash Cournot (N)</td>
<td>$\frac{(\theta_i - c_j)(2 + q_j) - (\theta_i - c_j)}{(2 + q_j)(2 + q_j) - 1}$</td>
<td>$(\theta_i - 2c_j + c_i)^*$</td>
<td>$\frac{\theta_i - 2c_j + c_i}{9}$</td>
<td>$l$</td>
</tr>
<tr>
<td>(I, D)</td>
<td>Monopolist (M)/Stackelberg Leader (S-L)</td>
<td>$\frac{\theta_i - c_j}{2 + q_j}$</td>
<td>$\pi_m = (\theta_i - c_j)^*$</td>
<td>$\frac{pV^<em>_w + (1 - p)V^</em>_d}{1 + r} + \frac{\pi_m}{1 + k}$</td>
<td></td>
</tr>
<tr>
<td>(D, D); (D, I)</td>
<td>Defer (D)</td>
<td>0</td>
<td>0</td>
<td>$pNPV^<em>_w + (1 - p)NPV^</em>_d$</td>
<td>$\frac{1}{1 + r}$</td>
</tr>
</tbody>
</table>

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