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What Models Tell us about Long-term Contracts in Times of the Energy Transition

IBRAHIM ABADA,[a] GAUTHIER DE MAERE D'AERTRYCKE,[a] ANDREAS EHRENMANN,[a,c] and YVES SMEERS[b]

ABSTRACT

Uncertainty is a major hindrance to attracting investment for the energy transition. Yet European market design is mainly discussed with a focus on short-term efficiency. Based on computational results from market models for gas and power we derive lessons on the importance of contracts and the implications of incomplete markets. Specifically, we show that short-term efficiency is not sufficient to guarantee a well-functioning long-term market, whether expressed in standard welfare-maximization terms or with respect to the EU criteria (security of supply, sustainability or affordability). The end result can drastically depend on the extent to which one can deal with risk. This result is in line with economic theory.

Keywords: Investment, Risk allocation, Long-term contracts

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1. INTRODUCTION

The efficiency of short-term markets is a recurrent and major concern in EU documents on the restructuring of the gas and electricity sectors. European authorities have so far enacted three successive legal packages mainly focused on the reorganization of short-term operations. The Commission has also proposed gas and electricity target models, which also emphasizes the design of the short-term market to provide efficiency. A fourth package (the so-called "Winter Package") was proposed by the Commission in 2016 (European Commission 2016) and is currently in the legislative process. It again reinforces the same theme of improving short-term price signals. Efficient short-term energy markets are presented as steering investment[1] in the energy transition[2] as if it were implicit that short-term efficiency guarantees an efficient long-term capacity restructuring. Along the same lines, the German whitepaper (Ein Strommarkt für die Energiewende 2016) introduces the concept of an energy market 2.0 that is almost exclusively orientated towards improving the short-term market. Long-term contracts are mentioned as a hedging instrument. Unfortunately, the liquidity of such products is absent for maturities exceeding five years and are hence insufficient for investors.

1. http://ec.europa.eu/energy/sites/ener/files/documents/1_en_act_part1_v9.pdf "Adapting market rules" page 3. This language is repeated in most of the documents of the Winter Package.
2. We refer to the "energy transition" as the evolution of the energy sector away from intensive fossil fuel consumption towards the environmentally sustainable production and consumption of energy.

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Folk theorems are common in economic discussions of policies and the implicit assumption that it suffices to make the short-run market efficient to guarantee the efficiency of long-run markets seems to have become one of them in EU energy policies.[3] The reality is that an efficient short-term market does not guarantee the good functioning of the global market. The reason is that there is a long and risky path between creating value in short-term markets and appraising this value in investment calculations. The problems caused by insufficient risk-trading possibilities appear in many strands of the literature. Staum (2007) gives a particularly clear introduction to the practical problem of hedging in incomplete markets and its many facets. Coase (1937) and Williamson (1971) elaborate on market inefficiencies and failures in the context of vertical integration. The two volumes collection of papers organized by Magill and Quinzii (2008) elaborate at length on the non-trivial consequences of market incompleteness, were it only to prove the existence of equilibrium in the economy. A direct application of general equilibrium theory to standard investment theory is given in Geanakoplos and Shubik (1990). Leaving aside this technical material, the reader can probably be convinced of the dangers of neglecting risk in the analysis by the short and insightful paper of Newbery and Stiglitz (1984). Here, the authors show that a market satisfying all assumptions of perfect competition in a deterministic world may become grossly inefficient in a risky environment if the proper instruments for trading risk do not exist. In the context of this paper, this means that it may be irrelevant to construct an efficient short-term market if investors are unable to properly price today the risk of future results of that efficient market. Pricing in a risky market requires risk-trading or risk-sharing instruments. Increasing and new risk factors for which there exists little or often no hedging instrument and no hope to design them make this task impossible. This paper takes long-term demand risk as an example. This risk factor is composed of at least two elements: one is related to the overall economic growth of which both the direction and the extent have been and still remain considerably debated today; the other is the fraction of that demand growth that will go to the conventional sector or, because of regulatory and technological uncertainty, to its competitors.

Risk is today overwhelming both in the global economy in general and in the gas and power sectors in particular. It is commonly acknowledged that risk has a devastating effect on investment. This note is motivated by this situation: it reports analysis conducted with the view of improving our understanding of the phenomena underpinning Newbery and Stiglitz's example by quantifying the impact of risk-trading instruments. We concentrate on the gas and power sectors and simplify the context by assuming that their short-term markets are efficient (liquid and well-designed hubs or PXs [Power Exchanges]). These sectors offer contrasting features for our purpose: the trend in the restructuring of gas has been to reduce and sometimes abandon long-term contracts and to rely on hubs (physical, as in the US, or financial in the UK, with a quite evolving situation in continental Europe). In contrast, long-term contracts that were essentially non-existent in the power industry before restructuring are now increasingly invoked for developing new capacities.

These are typical micro-economic questions that economists usually examine using closed-form models. Our analytics is computational: we simulate markets that combine physical and financial trading. Whatever the simplifications embedded in one or the other type of model, we believe that they add insight compared to the largely verbal discussions encountered on the subject in the EU institutions literature. They also offer more precise information on the im-

3. A similar emphasis on the short -term may be found in the US, see Perez- Arriaga et al. (2017) for an analysis of the requirements for a new market design in the US.

portance of uncertainty acting as a possible hindrance to investment that would help to achieve the transition of the energy sector to a largely decarbonized world.

The paper begins with an introductory problem statement, which is followed by a summary of the methodology used to derive the computational results supporting our analysis. The models themselves and further details are discussed in more technical papers referenced in the appendix. The text focusses on the interpretation of our findings. We successively discuss gas and electricity, as the history of these sectors differs in both their industrial structure and the role played by long-term contracts in that structure. Gas markets have long been dominated by contracts that are now more and more contested: we try to extract some messages in terms of their impact on the risk exposure of supply. With the exception of Brazil, until recently power markets had generally failed to develop long-term products that would help against excessive risk exposure in supply. We summarize our findings in the last section.

2. PROBLEM STATEMENT

In contrast to short-term markets, which have received considerable attention in the restructuring of the gas and power industries, the development of long-term capacities or infrastructures has so far largely been "left to the market". This paper is motivated by a recent but growing interest in instruments, in particular, financial contracts that could mitigate the negative impact of risk on investment. The objective of the paper is to present and illustrate a methodology for assessing the extent to which those instruments might reduce this negative impact. A sketch of this methodology follows with more information given in appendix 1; full details appear in specialized papers.

Financial contracts in liquid markets are the paradigm of risk trading in microeconomics. These are also the instruments closest to the model of competition in perfect markets that underpins the Commission's target hub and PX models. We thus conduct our analysis with reference to those financial contracts. The reality is that pure financial contracts for the long term do not exist. This can be related to the general criticism of Walrasian economics found in the literature of institutional economics, transaction cost or contract theory. Brousseau and Glachant (2002) offer a compilation of important texts in the domain. Spulber (1999) gives a very readable treatise of some of these questions, including several chapters on transaction costs. The reader can look at Bolton and Dewatripont (2005) for an advanced treatment of contract theory. Some of these questions received special attention in the microstructure of financial markets (de Jong and Rindi 2009). From a practical point of view, in this policy paper, this implies that transaction costs and the complexity of long-term contracts may hamper their arrival on the market or limit their efficiency. This may, in turn, justify some public intervention, such as becoming a counterparty to the contract or providing partial guarantees in the case of exceptional events (an old practice in nuclear accidents). The "Junker Plan for Investment"[4] is meant to play that role by supporting the risky part of the cash flow of projects. It is mentioned in the Winter Package but only as a way to enhance investment in energy efficiency in buildings. This paper briefly touches on some of the difficulties encountered with long-term contracts by treating a case of the illiquid market.

One may also mention that competition authorities often saw the negotiated long-term contracts that prevailed in the gas market as foreclosing the market and hence objected to

4. http://www.eib.org/efsi/

them. They also viewed the new long-term power contracts such as Exeltium[5] or Hinckley Point[6] with suspicion, and subjected them to long scrutiny before approving them with some modifications. As a consequence, the length of the process and the uncertainty of its outcome add to risk.[7]

Lastly, the Commission often presents its energy policy with respect to the criteria of affordability, security of supply and sustainability. We thus cast the results of our analysis in those terms, too.

3. BRIEF METHODOLOGICAL NOTE

Risk is an old subject in corporate finance, and the CAPM (Capital Asset Pricing Model) is the method of choice in practice for evaluating risky investments. It is thus relevant to briefly discuss its relation with the present work. Two issues are of particular relevance. First, the practice of the CAPM essentially relies on an exogenous risk premium computed from the past. The discount factor that embeds this risk premium and drives investment is therefore also exogenous. Hence, at first sight, it is impossible to use the standard CAPM to test the impact of changing risk conditions, or the introduction of new risk-trading instruments such as financial contracts, on this risk premium.

In contrast, we make the risk premium endogenous. Second, the CAPM only considers systematic risk (risk correlated with "the market") and sets the price of idiosyncratic risk to zero. This latter step is no longer universally accepted and risk factors other than "the market" now appear in recent developments of the traditional methodology. Our approach prices both risks correlated to "the market" and prices or values other risks.

Demand is nowadays a major source of risk for investors. It is also the closest to "market risk", that is, the systematic risk considered in the CAPM. Our analysis throughout the paper is accordingly illustrated by demand risk in gas and power. This it is not a restriction: in principle, our approach can deal with a portfolio of risks that need not be related to "the market" (like the speed of cost reduction of renewables, policy choices for phasing out technologies like lignite or nuclear or changing abatement targets).

We work with equilibrium models of capacity expansion (see Ehrenmann and Smeers 2011, Abada et al. 2017a, and de Maere d'Aertrycke et al. 2017). We thus depart from the optimization found in many modeling works and simulate interactions between agents (producers, merchants, and final demand) in the market. These models are "two stages": decisions to invest and contract are made in a first stage before uncertainty is revealed; short-term physical markets (hubs or PX) efficiently clear in the second stage, leading to payments from physical and financial transactions. Our presentation of these models is very brief: we refer readers to the above references for more elaboration, and we give a structured summary of the methodology in the appendix.

The treatment of risk is through "coherent risk functions" (Artzner et al. 1999), which developed in the last decade in the finance literature. These are related to the standard mean-variance model of portfolio theory or to the value at Risk (VaR) in traditional risk management.

5. http://www.exeltium.com/project/?lang=en#enhance-visibility-electro-intensive-industry
6. http://ec.europa.eu/competition/elojade/isef/case_details.cfm?proc_code=3_SA_34947
7. The EU ishas been aware that of the dilemma of its position on long-term supply contracts. de Hauteclocque and Glachant (2009) provide a comprehensive discussion of the balance between foreclosure and transaction costs and discuss the potentially detrimental effect of risk.

They can also be interpreted as a distortion of scenario probabilities found in the insurance industry. Risk neutrality in coherent risk functions implies a straight expectation of profits; risk aversion progressively discounts higher profits, which decreases their value and reflects higher prudency in the presence of risk. Specifically, an agent invests or enters a financial position when the investment cost is covered by the risk-adjusted (by the risk function) value of the future payoffs accruing from physical and financial transactions.

4. CONTRACTS AND THE GAS MARKET

4.1 Background

The European gas market developed along a two-tiered contractual system. Long-term contracts (LTC) structured on both take-or-pay and price indexation clauses and covering 20-year periods drove physical trade between producers and merchant companies. Medium-term contracts of five years accompanied the physical trade between merchants and final demand (retail). These contracts served several purposes; our interest here focusses on risk sharing and mitigation.

European competition authorities prohibited medium-term contracts between merchants and final demand on the basis of market foreclosure. All things remaining equal, this increased the risk exposure of the merchants and, hence, also the credit risk of the clients of the producers.

But things did not remain equal, and the overall degradation of the economic environment quickly made LTCs unmanageable due to their indexation clauses and the insufficient flexibility of take-or-pay. This outcome was remarkable to the extent that instruments initially presented (at least partially) for risk sharing between the producer and merchant became the source of the dramatic losses that they had, in principle, been designed to avoid. More remarkable is that similar evolutions had been observed in the US and UK at other times. Makholm (2012) gives a thorough economics and institutional economics analysis of these events and draws important conclusions for the EU. Even if initiating events and operating and economic conditions in these three markets were not identical the similarities of outcome are sufficient to raise questions. The US and UK gas systems resolved their problems after huge losses and ended in hub-driven markets[8]. Continental merchants also incurred losses and reacted by demanding a renegotiation of the contract and a system largely based on the hub models.

Neumann et al. (2015) provide an extensive discussion of the institutional and industrial economics issues underpinning long-term gas contracts. Based on a review of existing contracts, they argue that LTCs are likely to remain important in the European gas industry, but with a shorter duration and with a higher share of hub indexation. In contrast, Jonathan Stern and his colleagues at the Oxford Institute for Energy Studies (see Stern and Rogers 2014, for instance) give an extensive analysis of the transition away from gas contracts. They argue that a large European transport and storage infrastructure has now been built that has already recovered its initial capital cost and no longer needs to be linked to contracts. They conclude that

8. The comparison between the US and UK gas markets should be performed cautiously, these "hubs" being generically different: as the Henry Hub is the necessary physical commodity delivery point for the financial industry's unregulated participation in North American gas price risk, the NBP does not serve that role for the financial industry (having no physical point to serve as the reliable delivery point to terminate commodities futures contracts). The NPB's futures trading, beyond the short term, is thus quite small compared to the Henry Hub.

take-or-pay clauses will thus progressively disappear in continental Europe, as they did in the US and the UK. This argument only holds in so far as the market no longer needs investment in the infrastructure, which as the US development of shale gas shows is not necessarily the universal rule. We perform a numerical analysis to test these ideas.

4.2 Model features

We abstract away from the detail of a particular system and try to capture fundamental mechanisms in a stylized market model comprising a producer and a merchant, each active in the contract and spot gas markets. The producer sells spot gas to a hub (which can be equally interpreted as financial or physical in this single-node model) and contract gas directly to the merchant (further details can be found in Abada et al. 2017a). The producer has increasing marginal costs of production. The merchant buys contract gas from the producer and spot gas from the hub. It has constant marginal costs.

Besides the spot market, we also consider two types of contracts both with inflexible take-or-pay clauses. In contrast with the negotiated contracts of the past, we work with tradeable commodity contracts whose prices are determined on an exchange (thus, different from the hub). One is a fixed price contract (which is then analogous to a forward contract) where both prices and quantities are determined by the market in the model. The second contract is indexed on some fuel taken as oil. The indexation clause is exogenous so that the market only determines the volume of the contract in the model.

The market is affected by demand risk that appears here in different forms. Risk on the spot gas market is described by a random demand function: one needs to pay more for a given quantity of gas if the economy is doing well (correlation with "the market"). The final consumer is also represented by a random demand function, which encompasses both economic conditions and its switching possibilities (a mix of supply and fuel-burning substitution that is left as a parameter). Demand on the spot and final consumer markets are correlated, as one can expect. We also consider an oil price correlated to gas demand. We assume both high and low correlations to capture the opinions on the relevance of maintaining price indexations clauses.

Both the producer and the merchant are risk-averse. We seek a market equilibrium where both agents select their portfolio of contracts and spot gas subject to the sole constraint that quantities match (sales and supply are equal for both spot and contract markets). There is no contract between the merchant and the final demand. Our model is thus different from a gas system optimization or a system operating under policy constraints. The model is small but, being computational, it can easily be adapted to more complex situations. More details about the data, the representation of the risk of the agents' profit and the distribution of the spot market prices are given in Appendix 2.

4.3 Results

4.3.1 Long-term contracts and business-as-usual conditions

We use the gas spot market data of the year 2012 to calibrate our model (see appendix 2 for more details) and test whether it is useful to retain some long-term contracts in the supply of a market otherwise driven by a hub. In other words, we check whether long-term contracts provide an incremental economic surplus that would help develop the market (in case of an increasing role of gas in the energy transition or as a result of technological innovation, as

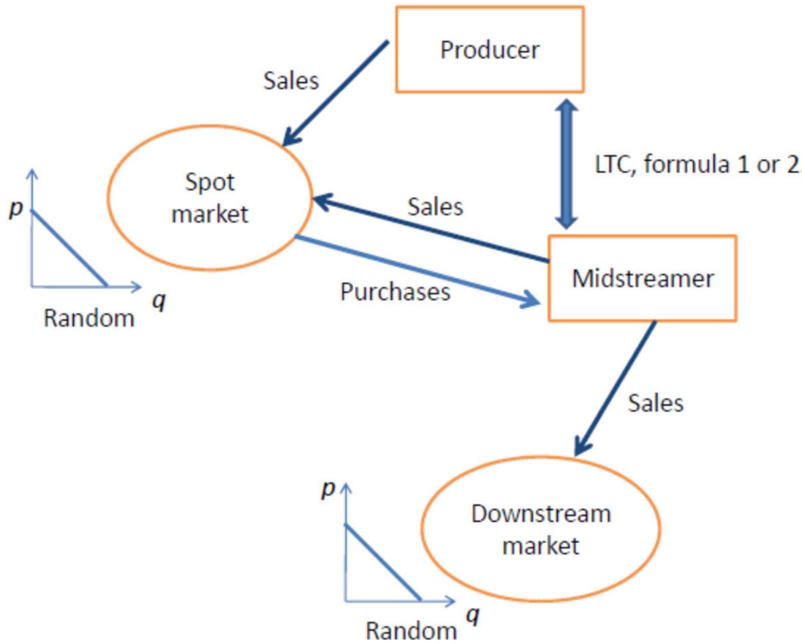

FIGURE 1

A schematic description of the gas model.

Source: Own Illustration.

with US shale gas) or simply maintain it (help develop production and trade under steady or declining conditions).

We observe the usual portfolio effect: it is better to diversify supplies in the sense of letting contracted gas mitigates the risk of the pure spot supply. Here, “better” means that global market welfare (particularly the total gas market) increases with contracts compared to a pure hub supply. This positive outcome seems intuitive (diversification should improve things in a portfolio), but it is not necessarily so in our case. We are searching for an equilibrium portfolio of spot and contracts that satisfy both the producer and the merchant, and the usual argument of diversification coming from the optimization of a portfolio does not automatically apply. As is often the case with market imperfections (lack of risk trading in this case), a partial remedy (some, but not a complete risk trading) does not necessarily improve the situation (a “second best” phenomenon): the final outcome must be checked. This was done and led to an improvement of welfare in all tested cases, not only globally but also for each agent (producer, merchant and final consumer: in more formal terms, the “core” is not empty). The main driver of this increase is the diversification of risk allowed by the contracts. In case oil and gas prices are effectively correlated (which is a matter of observation on the global market), we also observe that contracts that include price indexation clauses perform better for all agents. Allowing for long-term contracts is thus beneficial at least in the cases tested. Or in other words, an evolution towards a pure hub supply system would be detrimental to all agents.

The economic interpretation of these results is that contracts between the producer and the merchant offer a valuable risk-sharing activity that induces the development of the market and hence benefits the final demand. This effect is best illustrated by focusing on the opposite situation when the risk-sharing activity disappears in a pure hub-supplied market. The merchants' role boils down to reselling what it bought on the hub after adding its constant marginal cost. This activity is a pure spatial (LNG) or temporal (storage) arbitrage. This can be a quite attractive business, but it can also be worthless in the case of plentiful transportation and storage capacities. This discussion falls outside of this study.

Interestingly, mixing spot activities with fixed-price and oil-indexed contracts when there is a good correlation between gas and oil prices brings the system very close to the complete market with a full set of Arrow Debreu securities, which serves as a benchmark.[9] In the complete market case, it appears that the consumer side captures all the risk trading activity, which leaves very few trading opportunities for the merchant (mid-streamer). This suggests that the mid-stream activity could disappear if the market becomes complete. The fate of this activity thus depends on the emergence of a liquid financial market capable of supporting the needs for resource developments with different risk exposures and correlations.

4.3.2 Long-term contracts and extreme conditions

As effectively observed in various geographic markets, long-term contracts, while improving the situation for all risk-averse agents of the markets do not exclude the possibility of high losses and real credit risk for some of them. We indeed observe that the merchant almost goes bankrupt in some scenarios of our simulations. This is the type of situation that occurred in the year 2008 in the EU and previously in the US and UK (with effective bankruptcies). This induced an increase of risk aversion on the merchant side (and possibly also on the producer side, which could not avoid contract renegotiation). This, in turn, decreased the proportion of long-term contracts in the supply at the same time as it decreased the overall supply of gas.

4.3.3 Long-term contracts and investment costs

Lastly, we also mention the result of tests specifically dedicated to assessing the impact of risk on investment in capital-intensive development. We did so by changing the proportions of CAPX and OPEX in the cost of gas production. This (roughly but simply) simulates the impact of risk on high capital cost supply (whether for conventional gas or shale gas) and possibly illustrates some of the differences between the US and EU gas markets. The investment is modeled as a first-stage decision that is taken by the producer (at a cost) when contracting. Given this investment and the set of contracts the producer has signed, he will subsequently produce gas and sell it either on the spot market or via the contracts he has with the merchant. The link between contracts and investment is hence modeled in an implicit way, in the sense that these variables are jointly calculated so that the risk-adjusted profit of the producer is optimized. The representation of the merchant remains unchanged. Here again the results are clear: a higher CAPEX requires a higher proportion of long-term contracts. Otherwise upstream investment is jeopardized.[10]

9. More details about the notion of complete market will be given in the section dedicated to power markets.

10. This being said, it is important to highlight that the US and EU gas systems have different evolutions of regulation that could also explain the differences in the contracts structure. In US, contracts also played an important role in the past but mainly for the development of pipelines: the US pipeline system was built thanks to regulations that allowed local distributors to sign long-term contracts. Indeed, the strong risk aversion inherent to these CAPEX intensive projects required a solid system of regulatory guarantees that helped finance the rapid expansion of the US pipeline system in the 1940s–1960s. We refer the reader to Makholm (2012) for more information on this subject.

4.3.4 Conclusion

These results are directly interpretable in terms of investment and their consequences on affordability, security of supply and sustainability. The driving economics is simple: risk decreases investment and hence reduces the amount of gas put on the market. This increases prices in all scenarios and hence decreases affordability. Security of supply is affected in two senses: a first effect is that the overall supply decreases and one becomes more vulnerable to interruption on the remaining market. Whether this is any different from less affordability depends on whether one is talking in economic or geopolitical terms. The second effect is purely in terms of security of supply and is not interpretable in terms of affordability: the increased credit risk of the merchant increases its risk of bankruptcy, which would definitely disturb the security of supply.

To the extent that gas is essential at least for some time in the energy transition (because of the remaining difficulties with integrating renewables), risk also deteriorates sustainability by making gas more expensive and coal more competitive.

Long-term contracts bring some relief to these problems, and particularly so if the gas and oil price continue to be correlated.

5. CONTRACTS AND THE POWER MARKET

5.1 Background

Long-term contracts have not played a significant role in the history of the European power market, at least until recently. Because the system was geographically segmented at the time of regulation, actors built their own capacity fitted to the market to which they could sell with minimal risk. Except possibly for excess capacity there was no real issue of investment. Restructuring did not cause much worry either, at least at the beginning. The common wisdom was that an efficient, competitive market would in the short-run send the right signal for investment. Things turned out differently: European institutions are still struggling to make the short-run market efficient and today's risk hampers our appraisal of the value that will be collected from short-term markets in the future. The result is that, except for subsidized equipment, investment has now come to a complete halt. Some in the industry and academia are now proposing reinforcing the incentive to invest through additional instruments. These, such as a high price cap in case of curtailment, target short-run market imperfections. Others, such as capacity payment or capacity markets, create a direct investment signal that bypasses the short-term market. A more recent idea is to improve risk trading through long-term contracts with the view of facilitating the transfer and pricing of short-term market uncertainty to investment decisions. This section is devoted to these latter instruments.

Risk trading ideally takes place through financial markets. It has accordingly been proposed to extend common instruments found in short- to medium-term financial markets, namely forward (or Contract for Differences) and Option (named as Reliability Options in this case) to the investment problem. There are only a few examples of the implementation of these instruments. Specifically, the Hinkley Point contract between EdF and the UK government is meant to facilitate the construction of two EPRs in the UK. Financial contracts should be tradeable between agents, and this is our initial assumption in the following. It should, however, be noted that the UK government is the counterpart of the Hinkley contract (which is thus not tradeable) because it was well acknowledged that no private party would be ready to enter that transaction. Because of this important discrepancy between the paradigm of the contract and its implementation, it is also relevant to mention the Exeltium contract, which is also long-term but not financial, concluded between EdF and large electricity users to recover the cost of nuclear units.

Investment in renewable energy is no different from conventional investment when it comes to the negative impact of risk. PV and wind, with high investment costs and low operating costs, ask for long-term contracts to reduce the cost of capital (Brattle 2013). This has mainly been achieved in Europe through special measures such as feed-in tariffs or premium, the priority of dispatch, exemption from balancing costs. The literature has treated the question of risk of the right support mechanisms for renewable developers. Butler and Neuhoff (2006) find that the 15-year feed-in tariff in Germany has been more effective in attracting investment than the (much higher) support mechanism through the ROCs scheme in Britain. In practice, Caplan (2011) analyzed the US power generation projects completed in 2011 and found that almost all of them were conducted under the (financial) protection of either vertical integration or long-term contracts (whether renewable[11] or conventional). According to the author, the real-world analysis shows that short-term price signals play a minor role in driving investments.

In Europe, renewable support has since shifted to auctions that guarantee long-term stability. In the US we observe the emergence of long-term contracts between companies that have committed to green energy (like Microsoft, Google) with wind and PV developers.[12]

5.2 Model features

5.2.1 The market

We consider a stylized market consisting of a producer and a final consumer with price inelastic demand (further details in de Maere d'Aertrycke et al. 2017). As in the discussion of natural gas, we suppose that this market is affected by long-term demand risk. We classically assume that the producer invests in different types of plants. Less classically, we also assume that the producer and the consumer take positions in long-term financial contracts to hedge the risk created for them by demand (revenue risk for the producer and electricity payment risk for the consumer). Very much like virtual trading in the short-term US electricity market, one expects that other purely financial agents would also intervene in those contracts, but this extension falls outside of this illustrative example. We simplify things by taking linear investment and operating costs of the producer (constant marginal costs) and assuming that the consumer is willing to be curtailed at some VOLL that we assimilate to a price cap. We also interpret the price cap as the usual correction of the missing money in a deterministic market or as a technical limitation in the software clearing the spot market. All this is relatively easy to relax. The producer and the consumer are the sole agents in the physical and financial markets. This means that production is equal to consumption possibly minus interruption and that the financial position of both agents' net out to zero.

The global market can be decomposed in its short- and long-term parts. The short-term market is cleared in a PX that implements a simple merit order. This means that we overlook inefficiencies due to bloc bids or complex orders in the EU or uplift in the US. The PX is thus perfectly efficient. Investment in the long-term market is driven by a risk-modified version of

11. In the US, investment in renewables is often driven by state-level RES schemes or tax benefits.
12. Insurance groups (Allianz 2016) have started to offer tailored hedging contracts for such arrangements.

the standard corporate finance criterion: one invests if the expectation, in a risk-adjusted probability, of future payoffs covers the investment cost. As in the gas model, the exogenous risk premium of the CAPM is replaced by an endogenous risk premium derived from risk aversion and the changing risk conditions of the market. This latter correction is the novel feature of the work: as in the gas model, it depends on risk trading, as we will now discuss.

5.2.2 Focus on the financial market

We organize the discussion around the particularly important case of a contract for difference (CfD) for baseload electricity. We consider these contracts to be financial (which is the paradigm of risk trading) but comment on divergences with respect to this paradigm that may occur in practice. We also note here that some of the promoters of these contracts (in fact, of reliability option contracts) had suggested at the outset that it might be necessary for public authorities to intervene as counterparties before the market could take off on its own. These two comments are directly motivated by the liquidity issue and are important parts of the analysis. Like all markets, but possibly more so for financial markets, trading indeed requires liquid markets. We thus explore the liquidity needed for the good functioning of the CfD markets. Lastly, we compare these contracts to more commonly discussed instruments, such as capacity markets. In all cases, we assume that the price cap corrects the missing money in the usual sense of the energy-only market and hence never invoke missing money as a possible reason for the lack of investment in our analysis.

As in the gas analysis, we first consider the situation where investors decide whether to invest on the sole basis of the outcome of the efficient short-term market (here a PX). We refer to that case as "no risk trading". We also consider the opposite case, which is implicitly assumed in the folk theorem underpinning the discussion of the internal market, namely that a perfect physical market is accompanied by a perfect financial market where all risk can be traded. Economists refer to that market as "complete": it is never realized in practice but, like the standard model of perfect competition in a deterministic world, it provides an upper bound on the efficiency that a risky market can achieve. The complete market basically requires a full set of Arrow Debreu securities that can allow one to hedge any risk in the market. The relevant question is then whether we can come close to it by introducing tradable contracts.

We then consider "in-between cases" where CfD are the sole contracts in the market. Because of its potential importance, we also explore the impact of limited liquidity. Finally, we compare these results to those obtained with more classical instruments, such as capacity markets. The results are depicted in figure 2 with comments following below. The welfare is calculated as the sum of the profit of the producer and the consumer's surplus. It is reported in M€ so that it can be compared to a standard yearly profit of a producer.

5.3 Results

5.3.1 On the importance of risk trading

The comparison between the "complete" and "no risk trading" cases illustrates the impact of risk trading. Notwithstanding the efficiency of the short-term market (a PX with pure merit order and correction for the missing money), the long-term market is inefficient compared to the complete market in building adequate capacities. This can be seen both from the evolution of the welfare and the investments. The phenomenon is not surprising: it is simply a transposition to the investment of the mechanism pointed out by Newbery and Stiglitz. This lack of

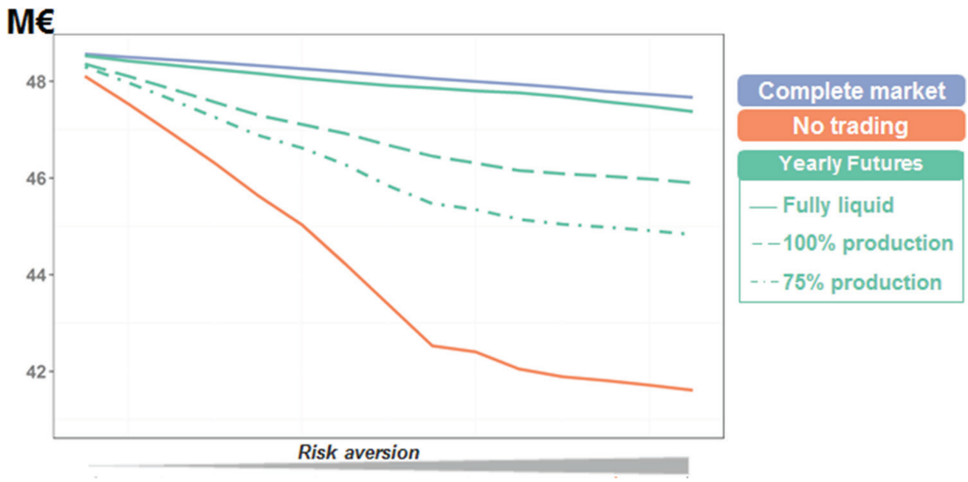

FIGURE 2
Welfare as a function of risk-aversion.
Source: Own Illustration.

capacity in the no-trading case jeopardizes both the affordability (by increasing prices) and the security of supply (by increasing curtailment).

5.3.2 On contracts for difference

A single contract for difference remarkably corrects the shortcoming of the "no trading case". While a single contract far from makes the market "complete" in the economic sense, it brings it closer to the outcome of this market in terms of total investment and welfare. As expected, a contract for difference for baseload electricity reduces the risk on baseload plants and hence favors their development with respect to partial load units. There is thus a distortion of the capacity mix that can be detrimental to sustainability if these partial load plants are thermal units that are competing with coal plants. But this is only a particular case that would be reversed in the case of competition with nuclear units or an import of centralized solar power. Each situation needs be assessed on the basis of the mix of plant types in competition.

As the history of the Hinkley Point contract shows, it is very unlikely that the financial market would develop contracts for differences for such capital-intensive plants because of the amount of money at risk involved. This was the justification for the UK government intervening directly as a counterparty in the transaction, making the contract non-tradeable. We tried to relate that outcome to the risk trading observed in the simulation of the CfD and found that the liquidity implied by our calculation exceeded anything that had been observed so far in short- and medium-term financial electricity markets. A long-term market could only do worse in terms of liquidity, implying that the recourse to some public help or counterparty is indeed unavoidable. On the positive side, we also found that the forward price emerging from an assumed tradeable CfD is very similar to a cost-covering contract such as in Exeltium. Even if the financial market would probably not develop spontaneously, one could expect that physical contracts based on cost coverage would be efficient, but they would be interpreted as a return to a full cost-based regulation.

A related question is whether a less liquid market could still be useful. We limit the hedging possibilities of illiquid CfDs to between 75 and 100% of expected energy consumption.

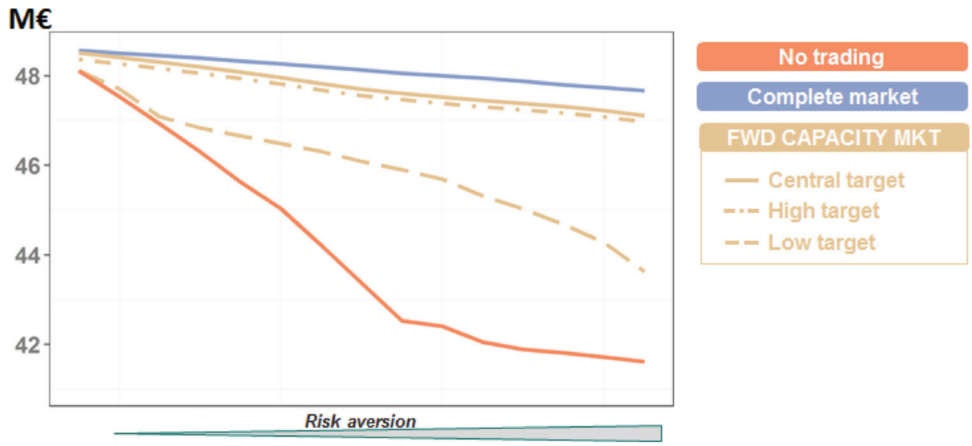

FIGURE 3
Welfare as a function of risk aversion.
Source: Own Illustration.

We found that the contracts still had some benefit compared to the "no risk trading" case but to a much smaller extent.

5.3.3 Comparison with capacity markets

Financial contracts, therefore, emerge as an ideal instrument (as they should be according to theory), were it not for the liquidity issue, which is an empirical question to be handled separately in each case. It is worthwhile noting in this context that the classical capacity markets perform well provided the capacity target had been well-chosen (that means on the high side) as can be seen from figure 3 where we compare a CRM with a capacity target in line with the highest possible demand (central target) with two counterfactuals that set the target above (high target) or below (low target) the highest realized peak in our model.

Specifically, we found that they come close to the result of the "complete" market. As expected, low-capacity targets imply low welfare and curtailment otherwise. These effects bring to mind similar phenomena obtained with security margins in capacity expansion models in the regulated period.

5.3.4 On credit risk

As for the gas market, risk trading through contracts mitigates the impact of risk but does not eliminate it. One cannot exclude that particularly unfavorable conditions lead to expositions that can jeopardize the sustainability of the companies. Bankruptcies have been observed in the US power market, and the threat of bankruptcies (losses amounting to the equities required for the investment) occurs in our tests. This can only reinforce risk aversion and reduce investment.

6. CONCLUSION

Economists have pointed out the importance of risk trading for achieving efficient markets in the presence of risk. This directly applies to restructured markets in need of investment for the energy transition. Whatever the efficiency achieved in the short term, these benefits may not be conveyed to the investment decision stage if the risk is too high and there is no risk trading through adequate instruments in place.

Efficient risk trading, notwithstanding its potential, should not be taken for granted. The market may not develop these instruments, at least not with the required liquidity. Institutional economics invalidates the common wisdom that the market would develop these instruments if they were useful. The reality is that transaction costs and complexity may hamper these developments. This justifies some intervention to reduce these barriers. National entities have realized the problem, as evidenced by the debate between "energy only" and "capacity markets". But these measures raise State aid issues. The Commission introduced the so-called Investment Plan for Europe[13] to directly reduce the risk borne in strategic projects. This directly bears on the cost of capital and is thus directly relevant to our problem.[14] But the Winter Package only mentions the intervention of this plan for financing renewable energy and efficiency in buildings. Physical risk sharing through portfolios of plant ownership may also help and be simulated. But one must be certain that it would not contravene competition law. Last, as discussed here, a market partially covered by physical contracts based on cost recovery and inspired by the simulation of risk trading could reduce the need for risk trading and, hence, the liquidity requirement for the rest of the market. Analyzing these questions goes beyond the scope of this note but seems accessible by powerful computational tools.

The objective of our research is to develop a methodology to treat the issue of investments in the context of energy transition, in the presence of risk in an incomplete market where there are insufficient instruments to fully hedge any risk. We model risk-averse agents interacting in both physical and financial markets who have to take investment decisions in a risky environment but can partially hedge or trade their risk using a portfolio of contracts. Our models are applied to simplified representations of gas and power markets, and different types of contracts are considered.

Our simulations suggest that huge risk trading may be necessary to effectively incentivize investment at the central (transmission) level. This may need more drastic measures than the above proposals. The restructuring of the US gas market stands out as a possible source of inspiration to solve these harder problems. The whole value chain in the US gas market, including the transportation infrastructure, which raises most of the risk in that market, was privately financed, leading to a very dynamic and competitive gas market. The reason for the success lies in transportation contracts with well-defined tradeable property rights but no third party access. These took care of the risk and allowed (and still allows in the current developments of the US gas market) the massive risk transfer necessary for investors (Makholm 2012). Needless to say, property rights are not the same in gas and electricity (Adamson 2018) and what was possible with gas may remain difficult in the evolving power sector. But it is worth looking at that market, if for nothing else than to assess, for a better understanding of the issue.

Summing up, the important message is that risk has an obvious detrimental impact on investment and achieving short-term efficiency is pointless if this cannot be transferred to long-term efficiency. It is an important component of energy security and can also jeopardize the energy equity by preventing investments and driving up the cost of the transition to more environmentally sustainable sources. A first task is thus for policymakers to not unduly increase

13. The European Fund for Strategic Investment (EFSI) https://ec.europa.eu/commission/priorities/jobs-growth-and-investment/investment-plan-europe-juncker-plan/european-fund-strategic-investments-efsi_en

14. This mechanism can indeed be simulated with the type of model presented here (at the cost of technical work).

a risk (especially regulatory risk) for which it is highly unlikely one would have risk-trading instruments.

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References

Abada, I., A. Ehrenmann, and Y. Smeers. 2017a. "Modeling Gas Markets with Endogenous Long-Term Contracts." *Operations Research 65* (4): 856–877. https://doi.org/10.1287/opre.2017.1599.

Abada, I., G. de Maere d'Aertrycke, and Y. Smeers. 2017b. "On the multiplicity of solutions in generation capacity investment models with incomplete markets: a risk-averse stochastic equilibrium approach." *Mathematical Programming 165* (1): 5–69. https://doi.org/10.1007/s10107-017-1185-9.

Adamson, S. 2018. "Comparing interstate Regulation and Investment in US Gas and Electric Transmission." *Economics of Energy and Environmental Policy* 7 (1): 7–24. https://doi.org/10.5547/2160-5890.7.1.sada.

Allianz Press release 2016. http://www.agcs.allianz.com/about-us/news/art-innovative-swap-solution-wind-farms/.

Artzner, P., F. Delbaen, J.-P. Eber, and D. Heath. 1999. "Coherent Measures of Risk", *Mathematical Finance* 9 (3): 203–228. https://doi.org/10.1111/1467-9965.00068.

BMWI 2016. "Ein Strommarkt für die Energiewende" http://www.bmwi.de/Redaktion/DE/Publikationen/Energie/weissbuch.pdf?__blob=publicationFile&v=31.

Bolton, P. and M. Dewatripont 2005. "Contract Theory." Cambridge, MA: The MIT Press.

Brattle Group. 2013. "The importance of long-term contracting for facilitating renewable energy project development." http://www.brattle.com/system/publications/pdfs/000/004/927/original/The_Importance_of_Long_term_Contracting_for_Facilitating_Renewable_Energy_Project_Development_Weiss_Sarro_May_7_2013.pdf?1380317003.

Brousseau, E., and J.-M. Glachant 2002. "The Economics of Contracts and the Renewal of Economics" in *The Economics of Contracts, Theories and Applications,* E. Brousseau. and J.-M. Glachant Ed. Cambridge, UK: Cambridge University Press. Cambridge.

Butler, L., and K. Neuhoff. 2006. "Comparison of Feed in Tariff, Quota and Auction Mechanisms to Support Wind Power Development" Cambridge University, CWPE 0503, and Massachusetts Institute of Technology. CMI Working Paper 70. http://www.econ.cam.ac.uk/electricity/publications/wp/ep70.pdf, visited January 3.

Caplan, E. 2012. "What Drives New Generation Construction? An Analysis of the Financial Arrangements behind New Electric Generation Projects" *Electricity Journal* 25 (6): 48–61. https://doi.org/10.1016/j.tej.2012.06.012.

Coase, R. H. 1937. "The nature of the firm." *Economica* 4 (16): 386–405. https://doi.org/10.1111/j.1468-0335.1937.tb00002.x.

de Jong, F., and B. Rindi. 2009. "The Microstructure of Financial Markets." Cambridge, UK: Cambridge University Press. https://doi.org/10.1017/CBO9780511818547.

de Maere d'Aertrycke, G., and Y. Smeers. 2013. "Liquidity risk on power exchanges: A Generalized Nash Equilibrium model." *Mathematical Programming Serie B* 140 (2): 381–414. https://doi.org/10.1007/s10107-013-0694-4.

de Maere d'Aertrycke, G., A. Ehrenmann, and Y. Smeers. 2017. "Investment with incomplete markets for risk: The need for long-term contracts." *Energy Policy* 105: 571–583. https://doi.org/10.1016/j.enpol.2017.01.029.

de Hauteclocque, A., and J.-M. Glachant. 2009. "Long-term energy supply contracts in European competition policy: Fuzzy not crazy." *Energy Policy* 37 (12): 5399–5407. https://doi.org/10.1016/j.enpol.2009.07.054.

Ehrenmann, A., and Y. Smeers. 2011a. "Generation capacity expansion in a risky environment: a stochastic equilibrium analysis." *Operations research* 59 (6): 1332–1346. https://doi.org/10.1287/opre.1110.0992.

Ehrenmann, A., and Y. Smeers. 2011b. "Stochastic Equilibrium Models for Generation Capacity Expansion." In Marida Bertocchi, Giorgio Consigli, and Michael A. H. Dempster, eds, Stochastic Optimization Methods in Finance and Energy. *International Series in Operations Research & Management Science* 163: 273–310. Springer New York.

European Commission (2016): Clean Energy for All Europeans—unlocking Europe's growth potential. Press release, November 30.

Geanakoplos, J., and M. Shubik. 1990. "The capital asset pricing model as a general equilibrium with incomplete markets." *The Geneva Papers on Risk and Insurance Theory* 15 (1): 55–71. https://doi.org/10.1007/BF01498460.
Lise, W., B. F. Hobbs, and F. Van Oostvoorn. 2008. "Natural gas corridors between the EU and its main suppliers: Simulation results with the dynamic GASTALE model." *Energy Policy* 36 (6): 1890–1906. https://doi.org/10.1016/j.enpol.2008.01.042.
Magill, M., and M. Quinzii. 2008. "Incomplete Markets." Cheltenham, UK: Edward Elgar Publishing.
Makholm, J.D. 2012. "The Political Economy of Pipelines" The University of Chicago Press. https://doi.org/10.7208/chicago/9780226502120.001.0001.
Neumann, A., S. Ruester, and C. von Hirschhausen. 2015. "Long-term contracts in the natural gas industry: Literature survey and data on 426 contracts (1965–2014)." Berlin: Data Documentation DIW 77.
Newbery, D., and J. Stiglitz. 1984. "Pareto Inferior Trade." *The Review of Economic Studies* 51 (1): 1–12. https://doi.org/10.2307/2297701.
Perez-Arriaga, I., J. Jenkins, C. Brattle. 2017. "A Regulatory Framework for an Evolving Electricity Sector: Highlights of the MIT Utility of the Future Study." *Economics of Energy and Environmental Policy* 6 (1): 71–92.
Ralph, D., and Y. Smeers. 2015. "Risk trading and endogenous probabilities in investment equilibria." *SIAM Journal on Optimization* 25 (4): 2589–2611. https://doi.org/10.1137/110851778.
Spulber, D.F. 1999. "Market Microstructure, Intermediaries and the Theory of the Firm." Cambridge, UK: Cambridge University Press. https://doi.org/10.1017/CBO9780511625930.
Staum, J. 2007. "Incomplete markets". *Handbooks in Operations Research and Management Science* 15: 511–563. https://doi.org/10.1016/S0927-0507(07)15012-X.
Stern, J., and H.V. Rogers. 2014. "The Dynamics of a Liberalised European Gas Market: Key Determinants of Hub Prices, and Roles and Risks of Major Players." Oxford Institute for Energy Studies NG94.
Williamson, O. E. 1971. "The vertical integration of production: market failure considerations." *The American Economic Review* 61 (2): 112–123.

APPENDIX 1

The methodology involves three major parts that we briefly summarize below. The steps are essentially identical for the gas and power problems. Except for a few remarks we conduct the discussion on the power problem.

Modeling

Optimization step 1: The methodology takes stock of the numerous optimization models developed for different sectors (here, the capacity expansion type for gas and power). These models minimize the investment and operating costs of satisfying demand, or in a slightly more general version with flexible demand (as used in the gas problem), maximize total welfare accruing to the system from these investment and operations. These problems always involve discounting operations. These are conducted in the usual way (standard computation of annuities and residual values on the basis of annuities). Discounting is done at the risk-free rate, the risk premium being taken care of by risk functions in the equilibrium models as discussed later. This first step applies to both the gas and power model; it embeds the usual engineering detail of technologies that one wishes to represent in sectoral models. This is standard.

We give a stylized version of the overall problem:

$$\min_{x,y} Ix + C(y)$$
$$\text{s.t.}\, 0 \le y \le x$$
$$y = D$$

The parameters I is the investment cost, C is the operating cost and D is the demand to satisfy. The variable x is the capacity invested a, d y is the production of the technology. The first constraint of the problem imposes a capacity level to which production is bounded.

Optimization step 2: We construct a stochastic programming version of the sectoral model. This requires a stochastic process of risk factors (event tree in mathematical programming or discrete finance) and a representation of the evolution of the system along the different paths of the process (taking into account non-anticipative constraints or the filtration depending on the language used) and replacing the deterministic cost minimization by expectation. This is standard. The following adapts the deterministic objective function to the stochastic one.

$$\begin{aligned} &\min_{x,y} Ix + \mathbb{E}[C(y(\omega))] \\ &\text{s.t.}\, 0 \le y(\omega) \le x \\ &\qquad y(\omega) = D \end{aligned}$$

In this stochastic problem, ω is an index for the stochastic scenarios.

Optimization step 3: we transform the risk-neutral problem into a risk-adverse one. This follows the recent developments of risk-adverse stochastic optimizations that are themselves based on the development of coherent and convex risk functions developed in the finance literature. This requires replacing the risk-neutral expectations with risk functions and nesting the constraints of the problem according to the filtration of the problem (producing a recursion formulation where a problem in stage t is defined recursively with respect to the problems of stage t+1; this is similar to dynamic programming). This step is unnecessary in risk-neutral optimization but is of the essence in risk-averse optimization. This step is less standard but can be found in the literature. We report here the new formulation of the objective function.

$$\begin{aligned} &\min_{x,y} \rho(Ix + \mathbb{E}[C(y(\omega))]) \\ &\text{s.t.}\, 0 \le y(\omega) \le x \\ &\qquad y(\omega) = D \end{aligned}$$

The function $\rho(\cdot)$ is the risk function.

Equilibrium step 1: It is known that the KKT conditions of the risk-neutral stochastic problem can be interpreted as an equilibrium problem where each agent maximizes its expected profit or welfare (with dual variables interpreted as prices, as is well known). This leads to the standard corporate finance investment criterion: for each plant in which there is an investment, the investment cost is equal to the discounted cash flow generated by the investment. The KKT conditions of the risk-averse model are similar except for the replacing of the expectation by a risk-adjusted valuation of the cash flow (the adjustment is done by the risk function and takes care of the risk premium, as discussed later): in other words, for each plant in which there is an investment, the investment cost is equal to the discounted risk-adjusted value of the cash flow. This transformation is not really standard, but it is buried in the literature.

Equilibrium step 2: The equilibrium formulation of the risk-adverse optimization can be interpreted as equilibrium in a complete market (Ralph and Smeers 2015) that is in a market where all risks can be traded between agents. This is not standard and is mainly the result of the previous work of the authors and their colleagues.

Equilibrium step 3: The case of incomplete market involves models where there exist financial contracts and those where there is no risk trading.

The no-trading case is obtained by replacing the risk-neutral valuation of the cash flow with the risk-adjusted value of this cash flow. The investment criterion is then the same as in the complete market (for each plant for which there is an investment, the investment cost is equal to the risk-adjusted value of the cash flow) but the risk-adjusted value is evaluated at a different position because of the absence of risk trading. This is not standard.

Consider last the case where there is some risk trading, but the market is not complete. Contracts can be of different types and are such that their price at the time of the contact being concluded is equal to the risk-adjusted payoff of the payment that it gives during the horizon. This is the standard definition: it implies that the contract prices are endogenous. The model is then obtained by adding those conditions to the KKT conditions of the no-trading model. This is not standard and is a direct result of the work of the Abada et al. (2017a), de Maere d'Aertrycke et al. (2017) and Ehrenmann and Smeers (2011a, 2011b).

Economics

The standard investment criterion is based on the equality of the investment cost and the discounted cash flow when the discount factor is constructed on the basis of the CAPM model, that is, with a risk premium estimated econometrically on the basis of the past risk exposure. The risk-adjusted value of the cash flow in our models is also computed as a discounted cash flow, but the CAPM risk premium is replaced by a premium derived from the risk functions. In contrast with the CAPM, this risk premium depends on the risk implied by the endogenous investment obtained by the model. This is not standard and is discussed in the above-mentioned literature.

Computation

All models are formulated and solved as complementarity problems, but the risk-neutral equilibrium and the complete market model can also be formulated and solved as an optimization problem (provided the discount factor of the different agents in the risk-neutral case are equal). As is well known from economic theory, models of incomplete markets can be non-convex, which may raise an existence and uniqueness problem. This is reflected in the computational work. The first finding is that these problems are numerically non-trivial and we had to resort to regularization techniques to achieve convergence. We could prove the existence of the solutions, but these solutions are not necessarily unique. More work is necessary to fully explore these technical aspects. We refer the reader to Abada et al. (2017b) for a discussion on the multiplicity of equilibria in investment problems with risk.

APPENDIX 2

This appendix gives more details about the representation of the interaction between the producer and the merchant to assess the role of long-term contracts in gas.

Randomness is described using a tree representation (see Figure 4). Contracts are concluded in the root node of the tree. Uncertain demand appears in the second and third stages and is represented in our example by a three-state probability distribution, with demand in the third stage (in general t+1) conditional on the level of the demand in the second stage (in general t). Demand curves in the spot and downstream markets are random and correlated. Randomness is modeled through the intercept of the inverse demand functions (in the spot and downstream markets) as follows: starting from a node in the tree that corresponds to time t, the intercept in t+1 can either reflect a high, medium or low evolution with respect to the initial value in period t, with the same probability. The intercepts of the downstream and spot market inverse demand functions are supposed to be perfectly correlated in this example with the result that their states (high, low or medium) always occur simultaneously. Imperfect correlation can be modeled at the cost of additional formulation and computation.

We modeled a stylized hypothetic transaction between a gas producer and a European gas mid-streamer serving the French gas demand, for which we could compare the results on the basis of public sources. We use the PEG Nord (Point d'Echange de Gaz au Nord in France) price as a reference French market price. The NBP (National Balancing Point in the UK) plays the role of the spot market. The time scope of the study is [2012–2021], and each time-step corresponds to five years. The calibration of the inverse demand functions is done in node 0 (the year 2012) as in Lise and Hobbs (2008): we estimate the intercept and slope of an inverse demand function using a reference (price, demand) point and an estimation of the elasticity of the demand over the price. We use elasticities of 0.15 for the spot market and 0.05 for the downstream market. Such a small value of the elasticity of the demand implies that we assume the downstream demand is quasi-inelastic with respect to the price. The reference consumption and prices are taken from the BP Statistical Review of World Energy (2015) and the Natural Gas Information of the IEA (2013).

The production cost function is quadratic: it has been calibrated on a typical Asian production field (source: World Energy Outlook of the IEA 2011). This cost also includes the transportation cost to Europe.

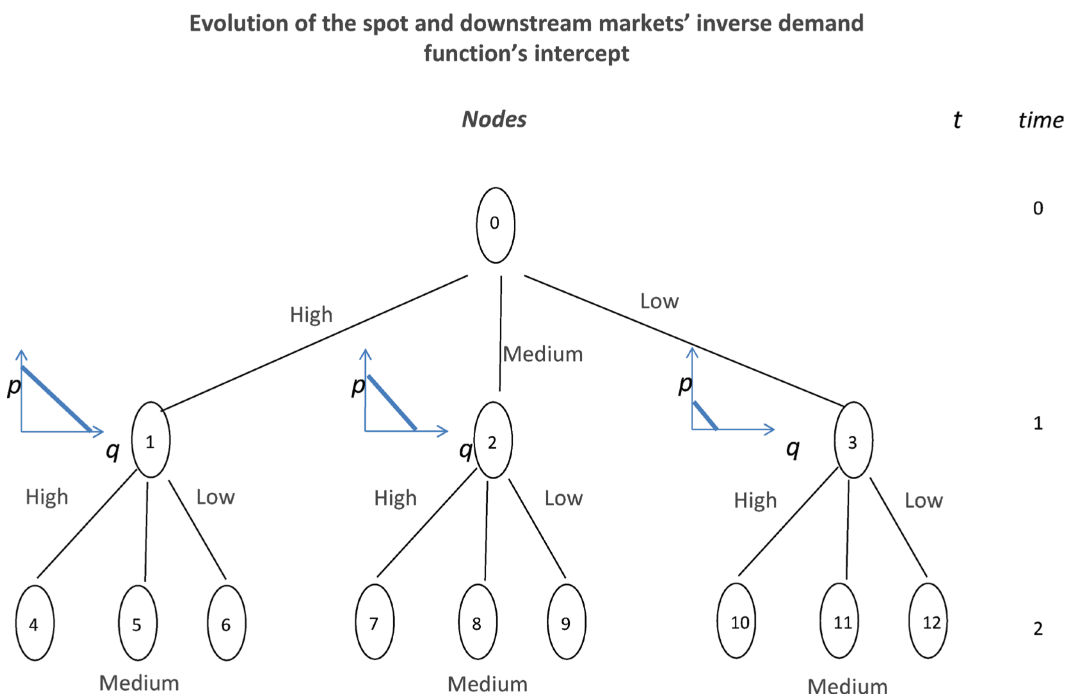

FIGURE 4
The scenario tree of the gas model.
Source: Own Illustration.