Bilateral Contracting in Multi-agent Energy Markets: Forward Contracts and Risk Management

Hugo Algarvio[1](✉), Fernando Lopes[1], and João Santana[2]

[1] LNEG – National Research Institute, Est. Paço do Lumiar 22, Lisbon, Portugal
{hugo.algarvio,fernando.lopes}@lneg.pt
[2] Instituto Superior Técnico, Universidade de Lisboa, INESC-ID, Lisbon, Portugal
jsantana@ist.utl.pt

Abstract. Electricity markets are systems for effecting the purchase and sale of electricity using supply and demand to set energy prices. Pool prices tend to change quickly and variations are usually highly unpredictable. Bilateral contracts allow market participants to set the terms and conditions of agreements independent of a market operator. This paper describes on-going work that uses the potential of agent-based technology to help addressing several important issues related to market models. Specifically, the paper is devoted to risk management in bilateral contracting of electricity. Two agents interact and trade according to the rules of an alternating offers protocol. The paper focuses on both risk attitude and risk asymmetry and how they can influence price negotiation. In particular, it describes the trading process, introduces strategies that model typical patterns of concessions, and presents several concession tactics. The article also presents a case study on forward bilateral contracting involving risk management: a producer agent and a retailer agent negotiate a three-rate tariff.

Keywords: Electricity markets · Bilateral contracts · Risk attitude · Risk asymmetry · Trading strategies · Autonomous agents

1 Introduction

The electricity industry throughout the world, which has long been dominated by vertically integrated utilities, has experienced major changes. In particular, liberalization has led to the establishment of a wholesale market for electricity generation and a retail market for electricity retailing [1].

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Spot markets provide supply for a specific period, typically one day, and involves no negotiation between the participants. In these markets, all parties who wish to either sell or buy electricity submit their price and quantity offers and bids. Each market settles simultaneously by selecting the lowest priced resources (based on the owners' bids) needed to meet load, given transmission constraints, usually following an algorithm known as locational marginal pricing (LMP). The resulting hourly locational market prices are determined by the price bid by the marginal supplier selected through this process.

Bilateral contracts are agreements between willing buyers and willing sellers for the purchase and sale of electricity-related products at negotiated terms, including duration, price, delivery location, times of performance, and any other terms which may be deemed applicable. Electricity-related products may be electric energy, capacity (including demand response), ancillary services or some combination of those. In this work we focus primarily on bilateral contracts for electrical energy.

Most market participants and analysts agree that bilateral contracts are crucial to the functioning of electricity markets, because they allow both parties to have the price stability and certainty necessary to perform long-term planning and to make rational and socially optimal investments. The revenue and cost certainty associated with bilateral contracts presents a number of benefits to sellers and buyers. Ranked roughly from near-term to longer-term, these benefits include [2]: less volatile retail prices, mitigation of market power, support for development of new resources, and more cost-effective, environmentally attractive resources in the long-term.

Short- or medium-term contracts, with durations up to a few years, are often used to supply standard offer service, and may help stabilize short-term fluctuations in prices and counteract market power. However, they are unlikely to provide much benefit in terms of supporting the development of new resources. Long-term contracts are crucial for supporting new resources, but they may be perceived as a potential source of stranded costs should market prices ultimately fall below contract prices for a prolonged period. Healthy markets, therefore, should support a range of bilateral contracts of varying durations, enabling market participants to readily hedge their obligations, giving producers opportunities to ensure long term revenue stability, and generally offering the most flexibility for all parties in mitigating risks [2].

However, while bilateral contracts are widely recognized as crucial to the functioning of truly competitive electricity markets, there are several obstacles to a vigorous, competitive, long-term bilateral contracting in energy markets. Chief among these is risk asymmetry: buyers and sellers face typically different risks in waiting to transact in spot markets, so some of them can charge risk premiums for bilateral contracts. Accordingly, for the existence of a robust bilateral market, there has to be sufficient incentives for both parties to transact in it, leading to symmetrical risks and comparable judgments of acceptable prices at which to transact.

This article presents several key features of software agents able to negotiate forward bilateral contracts, paying special attention to risk management, notably risk attitude and risk asymmetry, and introducing trading tactics based on risk parameters. The work presented here builds on our previous work in the areas of automated negotiation [3–6] and bilateral contracting [7]. It also refines and extends our previous work in the area of risk management in electricity markets [8]. The remainder of the paper is structured as follows. Section 2 introduces forward bilateral contracts and addresses the key issue of risk management during contract negotiation. Section 3 presents a case study on forward bilateral contracting involving risk management. Finally, concluding remarks are presented in Sect. 4.

2 Bilateral Contracting and Risk Management

Either physical or financial, bilateral contracts are typically negotiated weeks or months prior to their delivery and can include the following specifications: (i) starting date and time, (ii) ending date and time, (iii) price per hour over the length of the contract, (iv) variable megawatt amount over the length of the contract, and (v) range of hours when the contract is to be delivered.

Software agents are computer systems capable of flexible, autonomous action and able to communicate, when appropriate, with other agents to meet their design objectives. Specifically, each agent has the following key features [3]:

- A set of *beliefs* representing information about the agent itself, the market, and other agents trading in the market.
- A set of *goals* representing world states to be achieved.
- A library of *plan templates* representing simple procedures for achieving goals. A plan template *pt* has an header and a body. The header defines a name for *pt*. The body specifies either the decomposition of a goal into more detailed subgoals or some numerical computation.
- A set of *plans* for execution, either immediately or in the near future. A plan is a collection of plan templates structured into a hierarchical and temporally constrained And-tree. The nodes of the tree are instantiated plan templates retrieved from the library. The header of each instantiated plan template is referred to as *intention*.

The generation of a plan p from the simpler plan templates stored in the library is performed through an iterative procedure involving four main tasks: (i) plan retrieval, (ii) plan selection, (iii) plan addition, and (iv) plan interpretation. In brief, plan retrieval consists of searching the library for any plan template whose header unifies with the description of a goal. Plan selection consists of selecting the preferred plan template (from the set of retrieved plan templates). Plan addition consists of adding the preferred plan template to p. Plan interpretation consists of selecting a composite plan template from p, establishing a temporal order for the elements of its body, and picking the first ordered element (which is interpreted as a new goal).

The agents are broadly classified into risk-averse ($\lambda > 0$), risk neutral ($\lambda = 0$), and risk-seeking ($\lambda < 0$), where λ is a risk preference parameter. They interact and trade according to an alternating offers protocol [9]. In particular, they bargain over $n \geq 2$ issues by alternately submitting offers at times in $\mathcal{T} = \{1, 2, \dots\}$. This means that one offer is made per time period $t \in \mathcal{T}$, with an agent offering in odd periods and the other agent offering in even periods. An offer (or proposal) is a vector specifying a division of the surplus of all the issues. After receiving an offer, an agent can either accept it, reject it and opt out of the negotiation, or reject it and continue bargaining. In the first two cases, negotiation ends. In the last case, negotiation proceeds to the next time period, in which the other agent makes a counter-proposal. The tasks just described are then repeated.

The agents are equipped with an additive function for rating offers and comparing counter-offers [10]. They pursue negotiation strategies that model typical patterns of concessions. Generally speaking, concession making involves reducing negotiators' demands to accommodate the opponent. This behaviour can take several different forms. For instance, negotiators can start with ambitious demands, well in excess of limits and aspirations, and concede slowly. High demands and slow concessions, also referred to as starting high and conceding slowly, are often motivated by concern about position loss and image loss [11]. A formal definition of a negotiation strategy that models this and other existing forms of concession making is presented elsewhere [7].

Furthermore, negotiation strategies are computationally tractable functions that define the negotiation tactics to be used during the course of negotiation. In particular, concession tactics model the concessions to be made throughout negotiation. A formal definition of a generic concession tactic follows (without loss of generality, we consider that an agent a_i wants to maximize an issue x).

Definition 1 (Concession Tactic [7]). Let $\mathcal{A} = \{a_b, a_s\}$ be the set of negotiating agents, $\mathcal{I} = \{x_1, \dots, x_n\}$ the negotiating agenda (i.e., the set of issues under discussion), and $\mathcal{D} = \{D_1, \dots, D_n\}$ the set of issue domains. A concession tactic $Y_i : D \times [0, 1] \rightarrow D$ of an agent $a_i \in \mathcal{A}$ for an issue $x \in \mathcal{I}$ is a function with the following general form:

$$Y_i(x, C_f) = x - C_f(x - lim) \tag{1}$$

where $C_f \in [0, 1]$ is the concession factor of a_i for issue x and *lim* is the limit of a_i for x (i.e., the fallback position).

The following three levels of concession magnitude are commonly discussed in the negotiation literature [12]: large, substantial, and small. To this we would add two other levels: null and complete. Accordingly, we consider the following five concession tactics: (i) stalemate (models a null concession on an issue x), tough (models a small concession), moderate (models a substantial concession), soft (models a large concession), and accommodate (models a complete concession on x). These and other similar tactics can be defined by considering specific values for the concession factor C_f.

Now, concession tactics can generate new values for each issue at stake by considering specific criteria. Typical criteria include [13]: the time elapsed since the beginning of negotiation, the quantity of resources available, and the previous behavior of the opponent. In this work, we consider two different criteria directly related to risk management, namely risk attitude (modelled by $\lambda \in [-1, 1]$) and risk asymmetry (modelled by $\beta \in [0, 1]$).

Specifically, the concession factor is modeled as a function of the attitude towards risk, taking into account the following: greater negotiation flexibility means more concessions, and a greater chance to reach agreement. As noted earlier, market participants have several choices to transact power and manage risk, including the spot market and forward bilateral contracts. The price stability and certainty associated with bilateral contracts have positive effects on the functioning of electricity markets, and can benefit both producers and consumers. In particular, these contracts are important to hedge against short-term price fluctuations.

Risk-averse agents show typically more flexibility to secure a deal, and therefore, concede more to avoid that negotiation ends prematurely without agreement. If an agreement is reached, these agents will probably buy (sell) energy at a higher (lower) price compared to agents that are not averse to risk. Conversely, risk-seeking agents are more willing to be firm and rigid, tending to win negotiation without great regard to its success or failure, and thus conceding less to get a deal. Despite this, if negotiation ends successfully with agreement, risk-seeking agents will probably benefit more than risk-averse agents in similar situations. Hence, considering "success/failure to agree" as the key concern of the negotiating parties, we postulate that risk-averse agents tend to adopt higher concession factors than risk-seeking agents.

Furthermore, the concession factor is also modeled as a function of risk asymmetry: buyers and sellers typically face disproportionate risks by waiting to transact in the spot market and also bear different risks by entering into bilateral contracts. Sellers typically face bid-based clearing prices and the potential for windfall profits. Buyers also face substantial risks in waiting to trade in the spot market, since they must procure energy to meet their obligations to serve load (to avoid severe sanctions). Also, buyers bear the risk of being held to account for misjudgment in making contracts than in failing to do so when it would have been prudent. If they enter into contracts that later turn out to be "out of the market" they risk being left without cost recovery for the excess [2].

The terms and conditions of bilateral contracts can vary significantly, leading to a myriad of potential categories, although the following two are of particular importance: contract duration and contract pricing terms. There is no standard definition of short-, medium- or long-term with respect to bilateral contracts. However, contracts of five years or more are often referred to as long-term contracts. They are required to provide the level of revenue guarantee that developers need to finance new resources. Short- and medium-term contracts (five years or less) also have an important role to play in electricity markets. Their primary function is to smooth out year-to-year and shorter-term price volatility.

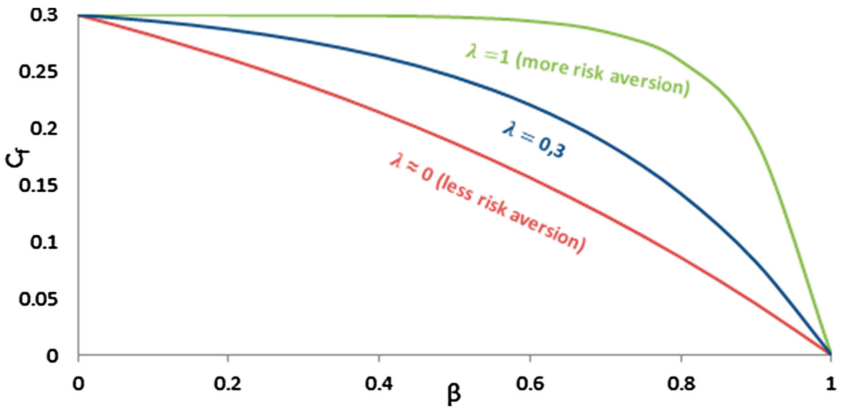

Fig. 1. Risk-averse seller: concession factor vs. risk asymmetry

Regarding contract price, an important distinction is between fixed-price and indexed price contracts [2]. In particular, some contracts (often referred to as "tolling" contracts) provide agents with the right to convert fuel into electricity, but no protection from variations in fuel prices, unless load-serving entities (LSEs) procure all or a portion of their fuel supply through contracts as well. This can still have benefits, including protecting purchasers from scarcity rents in times of very high prices, supporting needed resources with a guaranteed stream of revenue, and providing some protection from market power as purchase prices are based on a formula instead of supply offers. Further, an emerging issue of importance for bilateral contracts is the treatment of future carbon emissions costs: will these be the responsibility of generators, or flowed through to buyers?

Against this background, this work considers a parameter β to model risk asymmetry, placing emphasis on price risk (mainly related to high price volatility at times of peak demand and supply shortages). The concession factor $C_f(\lambda, \beta)$ is, therefore, modeled as a function of both risk attitude and risk asymmetry.

In situations where sellers face less risks than buyers (e.g., $\beta = 0.30$), risk-averse sellers are willing to be flexible to secure a deal, typically making substantial concessions to avoid ending negotiation prematurely without agreement. Also, in situations where sellers face more risks than buyers (e.g., $\beta = 0.80$), risk-averse sellers can work hard toward an effective agreement, but tend to adopt a more moderate stance, making smaller concessions during the course of negotiation. Simply put, as risk asymmetry increases, the likelihood of risk-averse sellers adopting small concession factors increases (but see Fig. 1).

Risk-seeking sellers tend to be more rigid and firm than risk-averse sellers, typically adopting a tougher, more competitive stance, and thus conceding less throughout negotiation. They are more willing to show a weak concern for negotiation success. For these agents, the willingness to make substantial concessions decreases with risk asymmetry, increasing the likelihood of adopting small concession factors (but see Fig. 2).

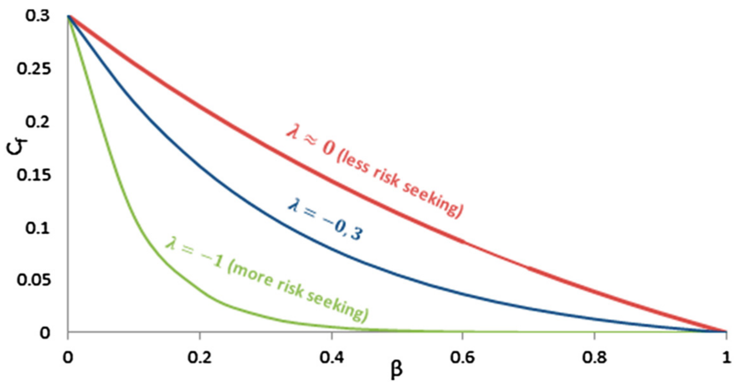

Fig. 2. Risk-seeking seller: concession factor vs. risk asymmetry

Buyers exhibit a negotiation behavior similar to the aforementioned behavior of sellers. For a reasonable value of β, say 0.45, meaning reduced risk asymmetry, risk-averse buyers are willing to adopt a position of moderateness and understanding, to secure profits. Also, for larger levels of risk asymmetry, say $\beta = 0.20$, meaning that buyers expect to face more risks than sellers, risk-averse buyers are willing to adopt a tougher, more competitive bargaining position.

Risk-seeking buyers are more willing to show a strong interest in substantive outcomes—winning this negotiation, getting this deal—with little regard for the success or failure of negotiation. For a reduced level of risk asymmetry, they can make a few substantial concessions that typically seek reciprocal concessions. Higher levels of risk asymmetry typically mean smaller concessions throughout negotiation, i.e., the adoption of smaller concession factors.

The concession factor can be represented by considering either a polynomial or an exponential function. In this work, we consider an exponential function. A formal definition of $C_f(\lambda, \beta)$ for a seller agent follows (the definition of $C_f(\lambda, \beta)$ for a buyer agent is essentially identical, and details are therefore omitted).

Definition 2 (Risk dependent concession factor). Let $a_i \in \mathcal{A}$ be a negotiating agent (i.e., a buyer or seller agent) and $x \in \mathcal{I}$ an issue at stake. The concession factor $C_f : [-1, 1] \times [0, 1] \to [0, 1]$ of a_i for x is modelled as a function depending on both risk attitude and risk asymmetry as follows:

$$C_f(\lambda, \beta) = \begin{cases} \frac{C_{f_n} - e^{ln(C_{f_n}) + k\lambda(1-\beta)}}{1-e^{\lambda}}, & \text{for } \lambda \neq 0 \\ C_{f_n} & \text{for } \lambda = 0 \end{cases} \tag{2}$$

where $\lambda \in [-1, 1]$ is the value of a_i's risk aversion, $\beta \in [0, 1]$ is the level of risk asymmetry, $C_{f_n} \in [0, 1]$ is the concession factor of a risk-neutral agent ($\lambda = 0$), and k is a constant that shapes the function's curvature.

Figures 1 and 2 depict several exponential functions for the computation of the concession factor. For each Figure, the ordinate represents the concession

Table 1. Initial offers and price limits (€/MWh)

	Producer		Retailer	
Period	Price	Limit	Price	Limit
peak	50.99	47.99	49.48	52.48
mid-peak	44.43	42.04	42.62	45.05
off-peak	40.99	38.16	40.06	41.74

factor and the abscissa the risk asymmetry. The solid lines correspond to different levels of risk aversion. To keep multi-agent negotiation as close as possible to real-world negotiations, functions that give values for C_f larger than 30 % were not considered, as these values do not represent reasonable negotiation stances.

3 Case Study

A multi-agent energy market system, involving a wholesale market and a retail market, is currently being developed. Market participants are able to exhibit goal-directed behavior and interact, when appropriate, with other agents to meet their design objectives. In particular, buyer and seller agents can negotiate the terms and conditions of forward bilateral contracts. This sections presents a case study to illustrate the behavior of concession strategies and tactics, particularly tactics based on the aforementioned exponential function for computing the concession factor. The case study has several similarities with the case study presented in [8], and thus we emphasize the differences below (rather than the commonalities).

A producer or seller agent (a_s) and a retailer or buyer agent (a_b) negotiate a three-rate tariff. The agents are moderately risk-averse (λ is set to 0.5). Also, they face slightly different risks (β is set to 0.6, meaning that the buyer faces greater risks than the seller). The initial prices and the limits of both agents are shown in Table 1. The energy quantities are set as follows: 2.47 for peak-load, 2.64 MWh for medium-load, and 1.99 MWh for off-peak. These quantities remain fixed during the course of negotiation.

The agents iteratively exchange offers and counter-offers over energy prices. They pursue starting reasonable and conceding moderately strategies [4]. The producer's offers decrease monotonically and the retailer's offers increase monotonically. Also, the agents employ concession tactics based on functions 1 and 2 (see above). The parameter C_{f_n} (i.e., the concession factor of a risk-neutral agent) is set to 0.15.

The acceptability of a proposal is determined by a negotiation threshold: an agent $a_i \in \mathcal{A}$ accepts a proposal $p^{t-1}_{j \to i}$, submitted by $a_j \in \mathcal{A}$ at $t-1$, when the difference between the benefit provided by the proposal $p^t_{i \to j}$ that a_i is ready to send in the next time period t is lower than or equal to the negotiation threshold. The agents are allowed to exchange only a maximum number of offers denoted by p_{max}.

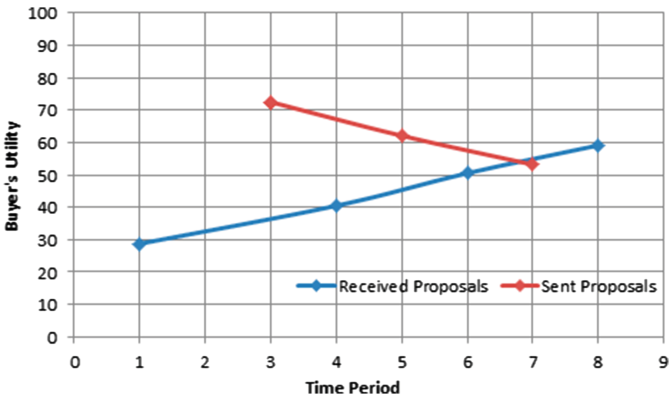

Fig. 3. Utility of the exchanged offers to the retailer agent

Agreement is reached after the exchange of 7 proposals. The agents agree on the following prices: 49.87 €/MWh for peak-load, 43.54 €/MWh for medium-load, and 39.94 €/MWh for off-peak. Figure 3 depicts the proposals sent and received by the retailer agent (i.e., the negotiation dance). The abscissa represents the utility of each proposal to this agent, and the ordinate the time when the proposals were submitted or received. The benefit of the agreement to the agents are as follows: 53.30 for the producer and 59.16 for the retailer.

4 Conclusion

This article has presented several key features of software agents able to negotiate bilateral contracts in energy markets, paying special attention to risk management. In particular, it has described several concession tactics that generate values for each issue at stake by considering two criteria directly related to risk management, namely risk attitude (modelled by $\lambda \in [-1, 1]$) and risk asymmetry (modelled by $\beta \in [0, 1]$). The article has also presented a case study on forward bilateral contracting involving risk management: a producer and a retailer negotiate a three-rate tariff.

In the future, we intend to perform a number of inter-related experiments to to empirically evaluate the concession tactics in different negotiation situations. Also, we intend to refine and extend the framework for contract negotiation with risk management. Specifically, to associate risk asymmetry with the main risks faced by buyers and sellers of electrical energy.

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