66/2011

Raport Badawczy

Research Report

RB/21/2011

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Warszawa 2011

Pricing of uncertain Certified Emission Reductions in a China Coal Mine Methane project with the Rubinstein-Ståhl model

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Abstract

In this paper we simulate the impact of uncertainty of the Certified Emission Reductions (CERs) on CER's price in coal mine methane CDM projects. It is assumed that the buyer's willingness to accomplish price negotiations depends on CER's uncertainty. We propose models that introduce the uncertainty spread into the Rubinstein-Ståhl bargaining game. The simulation results of their application to the CDM project in Huainan coal district in China are presented.

Keywords: Clean Development Mechanism (CDM), coal mine methane (CMM) project, Certified Emission Reductions (CERs), bargaining theory, Rubinstein-Ståhl game, uncertainty, simulation.

1. Introduction

Since the moment when the Kyoto Protocol came into force on 16 February 2005, the Clean Development Mechanism (CDM) has been introduced as one of the three flexible mitigation mechanisms. The CDM allows developed countries listed in Annex 1 of the United Nations Framework Convention on Climate Change (UNFCCC) to invest in greenhouse gas (GHG) emission reduction projects in non-Annex 1 developing countries. The mechanism enables Annex 1 countries to offset this part of their emissions reduction commitments, and the host developing countries gain in return the technology and financing for GHG abatement. A review of problems connected with CDM projects can be found in Olsen (2007).

For China, the Clean Development Mechanism offers important opportunities for sustainable development, in particular, in the energy sector. China ratified the Kyoto Protocol in August 2002, making the country eligible for CDM participation. By the 1st of March 2011, 1243 Chinese CDM projects have been registered in UNFCCC, accounting for 43.25% of world total number of CDM projects. The estimated annual Certified Emission Reductions (CERs) from the above Chinese projects is 279 649 749 tCO_2eq, which is 62.63% of total CERs from all of the CDM projects (446 524 620 tCO_2eq).

Among the above Chinese CDM projects, there are 42 coal bed methane projects (CBM) and coal mine methane (CMM) projects. The difference between CBM and CMM concerns the mine process. For CBM, methane is drawn from surface, and the exploitation process is similar to that of natural gas. For CMM, a methane mine process is from underground coal, similarly to an underground coal mining. In China, the methane discharged from coal seams is usually emitted to the atmosphere without any usage. Introduction of advanced technologies enables its usage as a fuel, see e.g. (Utaki, 2010), and the process may be approved as a greenhouse gas Certified Emission Reduction. Since the 1st of March 2011, the reported annual CERs from all the China coal CDM projects was 16 454 911 tCO_2eq. In general, there exists big potential in China coal mine methane CDM projects, and the CERs amount from coal industry of China is expected to increase. Recovery and usage of coal mine methane resources is among the three main activities promoted by the Chinese government for CDM projects.

Methane is a greenhouse gas considered in the Kyoto Protocol. Its global warming potential is 21 times higher than that of carbon dioxide. Effective methods of constraining methane emissions from various sources are investigated in numerous studies, see e.g. Brown et al. (this issue); Magalhães et al. (this issue); Oh et al. (this issue). CMM projects provide one more opportunity of energy conservation and methane emission reduction.

The key issue of CDM projects development is to encourage buyers and sellers to sign the Emission Reduction Purchase Agreement (ERPA), which is a contract underlying the sale and purchase of CERs. For this, a unit price of CERs is of great importance. In the case of China CDM projects, usually, CERs price is not a spot price but a stock price, meaning that it has to be bargained at an initial point of negotiations. In this study, to simulate CERs pricing we utilize the two-player Rubinstein-Ståhl bargaining game of alternating offers, which models a negotiation process between a buyer and a seller. The methodology is applied to a particular coal mine methane CDM project in China.

The Rubinstein-Ståhl game has been applied to model practical bargaining settings, such as labor negotiation (Vannetelbosch, 1997) or conflict resolution in conjunctive use of surface and groundwater resources (Kerachian et al., 2010). As regards pricing of CERs, the Rubinstein-Ståhl game seems to be a suitable tool, since the impatience bargaining problem plays here an important role. In this kind of negotiations, buyers, usually big international or governmental agencies, are not willing to spend too much efforts for negotiations of a single project. Typically, if after 1-2 rounds parties cannot approach an agreement, a buyer decides to give up since he usually has plenty of other opportunities to invest. The problem becomes even more complex when a specific features of the traded commodity, i.e. coal mine methane, are taken into account.

In this study, we particularly focus on difficulties underlying accurate estimation of CERs amount. Quantification of CERs amount in China coal CDM projects is based upon estimates of carbon emissions from coal resources. Numerous uncertainties underlie these estimations, and as such they are subject to repeated verifications. On the other hand, verifications make it difficult to process CDM projects since any change of CERs amount affects benefit of each party. Due to highly attractive commercial benefit of CDM project, a project buyer is in pursuit of high volume of CERs. Obviously, the higher the CERs amount is, the more valuable a project becomes. Moreover, in China CDM projects, CERs price usually needs to be settled at the very initial stage of negotiations. Therefore, if the actually generated methane amount is lower than the amount considered in a negotiation period, this fact heavily affects buyer's benefit due to favourable conditions a buyer might have given to a seller at a negotiation stage. A precise estimation of CERs amount is a critical issue for both a buyer and a seller.

The most important factors influencing CERs amount from CMM are as follows. Firstly, one needs to take into account geological conditions of a coal mine, namely: methane content in coal resources, methane quality and stability, being very important for end-users, as well as saturation and coal methane reserves. The coal methane reserve factor includes thickness of a coal seam, depth of a deposit, permeability (infiltration rate) as well as a reserve pressure (Shimada et al., 2005). Especially, the permeability is a crucial factor for a successful development of coal mine methane resources (Zhang et al., 2004). Secondly, another key issue is technology of mining coal methane resources employed (Zhang et al., 2005; Xu 2007a). Estimation of CERs amount is carried out by experts based on their knowledge of geological conditions and average technology level. However, in the case of insufficient expertise, estimation of CERs amount is not accurate. To best of our knowledge, for vast majority of inaccurate estimations, CERs amount tend to be overestimated.

In this paper, we analyse influence of CERs amount uncertainty on CER price. Specifically, we focus on uncertainty related to imprecise knowledge on methane content in a bed. Thus far, this kind of uncertainty is formally not taken into account in price negotiations, nor in a buyer's compliance condition. It is, however, reasonable to assume that uncertainty of CERs amount may influence a buyer's willingness to accomplish a transaction. While inclusion of uncertainty in a buyer's compliance with his Kyoto target can be solved by a simple adaptation of the methodology proposed in Nahorski et al. (2007), and shortly presented in Nahorski et al. (this issue), influence of uncertainty on the price negotiation has not been analysed previously.

The main idea of our proposition is that the buyer is less interested in buying CERs, if they are more uncertain. Starting from this assumption, we propose models, which reflect uncertainty on the parameters of the Rubinstein-Ståhl bargaining game. The modified parameters drive the negotiation results in the direction consistent with the observation that has started the model elaboration. We use simple models, mainly linear ones. The models are used in simulations for an existing CMM project.

Organization of the paper is as follows. In section 2 methodological questions are addressed: the Rubinstein-Ståhl game is shortly described, and our extensions on uncertainty inclusion are presented. Section 3 contains description of the considered CDM project, as well as derivation and estimation of the uncertainty distribution. The uncertainty of emission reductions stems from unknown methane content in the bed. In section 4 we present and discuss simulation results. Section 5 concludes.

2. Methodology

2.1 The Rubinstein-Ståhl bargaining model

The turning point in the bargaining theory occurred in early 1950s and was related to works of John F. Nash and Lloyd S. Shapley. They initiated treatment of bargaining as a game problem and used axiomatic methods to simulate a bargaining scenario. The axiomatic theory proposes a number of properties that a solution to a bargaining problem should have, and identifies respective solutions. On the other hand, the strategic theory specifies details of negotiation protocols.

The model developed by Rubinstein (1982) adopts a strategic (noncooperative) approach to the bargaining problem. A special class of two-person bargaining is analysed as a game with alternating offers, complete information, infinite horizon, and time discounting. A finite-horizon version of the model was first proposed by Ståhl (1972). The model was extended to an infinite horizon by Rubinstein (1982), and in the sequel we refer to it as the Rubinstein-Ståhl bargaining model.

In the Rubinstein-Ståhl model, two players bargain to share a surplus of size k. In our study, the two considered players are a buyer and a seller, denoted with superscripts ^{B} and ^{S}, respectively. The bargaining process is the one of alternating offers, as illustrated in Figure 1. Time is divided into periods. Starting at an initial period $t = 0$, each player in turn makes a proposal how to divide the surplus, and the other player may agree to the offer or reject it. Acceptance of the offer terminates the bargaining process. On the other hand, rejection means that the players enter a next time period $t+1$, in which the roles of the two players are reversed and the refusing side makes a counter offer.

Consider the setting where both players discount the future at a constant rate, i.e. player i's preference is derived from the function $y_t^i \delta^i$ ($0 < \delta^i < 1$), where y_t^i denotes the part of the surplus received by player i, $i = B, S$ at a time period t. The discount factors δ^i are interpreted as cost of delay and reflect players' impatience – the closer they approach 1, the higher is patience which they represent.

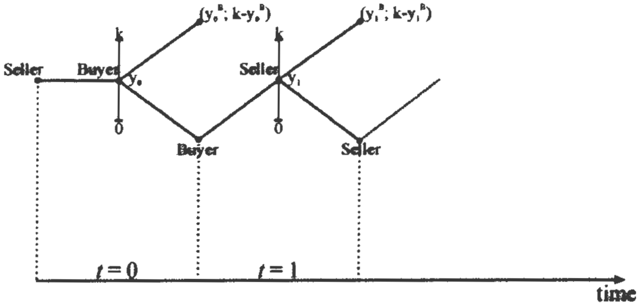

Figure 1. Scheme of bargaining game with alternating offers

Rubinstein (1982) used the subgame perfect equilibrium strategy concept to solve the negotiating problem under an assumption of infinite horizon. A subgame perfect equilibrium in a two-player game is a pair of strategies specifying the best response to each other at every point in time.

2.1.1 Complete information case

Complete information means that the preference relations of both players are assumed to be common knowledge. Here we stick to the fixed discounting factors, which values are assumed known. In such a case Rubinstein (1982) showed that there exists a unique pair of bargaining strategies that constitute a subgame perfect equilibrium. A somewhat simpler derivation of the Rubinstein result is given in Shaked and Sutton (1984).

Theorem 1. Consider the infinite horizon game of alternating offers, in which both players discount the future at fixed rates, $\delta^S$and δ^B, respectively. There exists a unique subgame perfect equilibrium, which prescribes that agreement should be reached immediately with a seller making an initial offer and receiving the fraction

$$\frac{1-\delta^B}{1-\delta^B\delta^S}$$

of the surplus k.

For a better insight, two properties of the equilibrium should be mentioned. Firstly, the more impatient the player is (i.e. the lower his discount factor is), the smaller is his share of the surplus. This reflects his limited ability to wait for a higher payoff in the next period. Secondly, note that a buyer receives the fraction

$$\frac{\delta^B(1-\delta^S)}{1-\delta^B\delta^S}$$

of the surplus k. Priority in making the first offer can be reversed. When a buyer makes an initial offer, then he receives

$$\frac{1-\delta^S}{1-\delta^B\delta^S},$$

which is more than $\frac{\delta^B(1-\delta^S)}{1-\delta^B\delta^S}$. Thus, a player always gets more when he initiates bargaining than when he does not, because making the first offer gives a player some bargaining power.

2.1.2 Incomplete information case

In what follows we weaken the critical assumption on players' complete information about each other preferences. Assume that both the players know the seller's discount factor δ^S, but the buyer's discount factor δ^B is his private information. In particular, a buyer can be one of two types: *weak* (i.e. impatient) or *strong* (i.e. patient). For fixed bargaining factors, this means that the weak buyer has a lower discount factor (δ_l) than the strong buyer, whose discount factor is denoted by δ_h, i.e. we have

$$0 < \delta_l < \delta_h < 1$$

To simplify notation we drop superscript ^{B} denoting the buyer's discount factor, both above and in the sequel.

For a seller, bargaining with a strong opponent is less favourable than bargaining with a weak opponent. A seller assesses a probability, denoted by p, that a buyer is weak, and p is common knowledge. In this situation, a seller may try to conclude from buyer's moves what kind of buyer his opponent really is. On the other hand, a buyer may try to cheat a seller by making him to believe that he is tougher than he actually is.

This model of bargaining with one-sided uncertainty has been studied by Rubinstein (1985) and re-examined by Bikhchandani (1992), see also Srivastava (2001) for an experimental testing of the setting. Rubinstein (1985) showed that for a general class of preferences there exists a unique bargaining sequential equilibrium, and for the case of fixed discounting rate the theorem takes the following form

Theorem 2. Consider the infinite horizon game of alternating offers with one-sided uncertainty and the discounting rates of two players as described above. For a game starting with a seller's offer:

(i) If p is high enough such that $y^p > \delta^S V_h$, then a seller offers x^p. The weak buyer accepts this offer, while the strong buyer rejects it and offers y^p, which is accepted. Both x^p and y^p denote the seller's share.

(ii) If p is low enough such that $y^p < \delta^S V_h$, then a seller offers V_h and both the weak and strong types of buyer accept it.

Here,

$$V_h = \frac{1-\delta_h}{1-\delta^S\delta_h},$$

$$x^p = \frac{(1-\delta_l)\left(1-(\delta^S)^2(1-p)\right)}{1-(\delta^S)^2+\delta^S(\delta^S-\delta_l)p}, \tag{1}$$

and

$$y^p = \frac{\delta^S(1-\delta_l)p}{1-(\delta^S)^2+\delta^S(\delta^S-\delta_l)p}. \tag{2}$$

The theorem states that the bargaining is not worth continuing beyond the second period, as it reaches there the equilibrium. Note that V_h stands for the seller's share in the complete-information equilibrium of the game where the seller starts the bargaining and it is common knowledge that the buyer is the strong one. In the case of low p, if it happens that the buyer is weak, he is better off as compared with the complete-information solution. In the case of high p, an important property of the equilibrium is that both x^p and y^p are increasing in p. This is intuitive because the more likely the buyer is weak, the more favourable the situation is for a seller.

For convenience of calculations that follow, we also determine the boundary point p^* at which $y^p = \delta^S V_h$.

$$p^* = \frac{\delta^S + 1}{\delta^S + \frac{1-\delta_l}{1-\delta_h}}. \tag{3}$$

If $p > p^*$ we are in case (i) of the theorem.

2.2 Modeling beliefs on unknown model parameters

Various kinds of risk influence CERs price negotiations. For methane CDM projects, these include: selection of a project site, supply and demand on electricity market in nearby regions or potential difficulties with CERs approval, validation, registration, monitoring, certification. See also a discussion in section 3.3.

Among other risks, uncertainty underlying estimation of CERs amount is of special importance for the methane related CDM projects. In this section, we set ourselves to the task of incorporating this specific kind of risk into the Rubinstein-Ståhl negotiation model with one-sided uncertainty, so that seller's belief on a buyer's discount factor reflects uncertainty of methane amount calculations. To clarify, it is the seller's obligation to provide an assessment of CERs amount, and this assessment tends to carry uncertainty. Both, the estimates of buyer's discount rates (δ_l, δ_h) as well as a probability p seem to be affected by this kind of risk.

To begin with, consider a distribution of uncertainty underlying estimations of CERs (methane) amount $f(x)$, depicted in Figure 2. In negotiations, usually only a point estimate of methane amount is provided, and in the sequel we denote this value as $\hat{x}$. To enable incorporation of a distribution $f(x)$ into the negotiation model, we introduce the notion of probability $\alpha, \alpha \in [0,1]$. The amount of methane corresponding to a probability α is denoted by x_α, and it is the quantile of order α of the distribution $f(x)$. Therefore, the true value of methane amount is lower than x_α with probability α, compare also Figure 2.

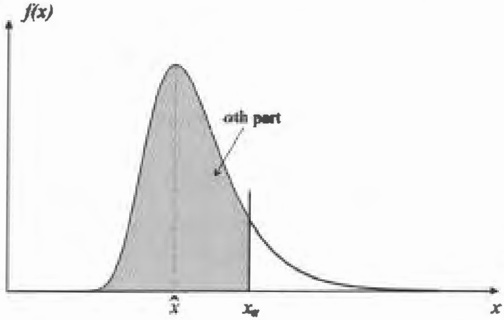

Figure 2. A distribution of uncertainty underlying methane calculations $f(x)$, a calculated methane amount $\hat{x}$, and an amount of methane x_α corresponding to a probability α.

Now we introduce the right fractional deviation $u(\alpha)$ related to a probability α with the following formula

$$\hat{x}[1 + u(\alpha)] = x_\alpha.$$

For a chosen level of probability α, fractional deviation $u(\alpha)$ is a fraction of $\hat{x}$, which has to be added to $\hat{x}$ to get the upper bound of the true emission x_α, with the probability α of its fulfilling. From the above we get

$$u(\alpha) = \frac{x_\alpha}{\hat{x}} - 1. \tag{4}$$

Note that $u(\alpha)$ is positive for $x_\alpha > \hat{x}$, and $u(\alpha)$ is negative for $x_\alpha < \hat{x}$.

2.2.1 Discount factors δ_l, δ_h

Let us denote by δ_{ll} and δ_{lh}, respectively, the lower and upper estimates of a low discount factor δ_l. Similarly, δ_{hl} and δ_{hh} stand for the lower and upper estimates of a high discount factor δ_h. Consider a straightforward linear relationship between the seller's uncertainty u and buyer's unknown discount factors δ_l and δ_h

$$\delta_l(u) = \delta_{ll} - \frac{\delta_{ll}-\delta_{lh}}{u_{max}-u_{min}}(u - u_{min}) \tag{5}$$

$$\delta_h(u) = \delta_{hl} - \frac{\delta_{hl}-\delta_{hh}}{u_{max}-u_{min}}(u - u_{min}), \tag{6}$$

where

$$u_{min} = u(\alpha = 0), \qquad u_{max} = u(\alpha = 1)$$

and $u \in [u_{min}, u_{max}]$. The functions are shown in Figure 3. The motivation behind a positive relationship is as follows. Higher fractional deviation u of CERs amount estimation strengthens a buyer's position, which is reflected in his higher discount factors. While some more sophisticated functions can be introduced, the one proposed above models the relation in a possibly simple way.

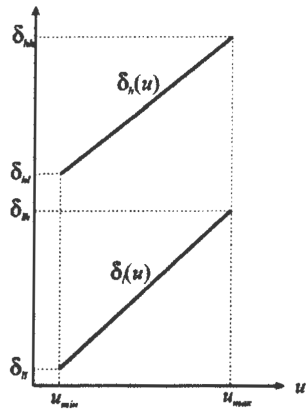

Figure 3. Discount factors $\delta_l(u)$, $\delta_h(u)$ as functions of deviation u.

The above model of a discount factor is relevant for a single uncertainty distribution $f(x)$. In general, however, we would like to have a possibility to compare several distributions describing uncertainty of CERs amount estimations. Let us start with a comparison of two distributions, and denote their fractional deviations as $u^0(\alpha)$ and $u(\alpha)$, where $u^0(\alpha) > u(\alpha)$ for $\alpha = 1$. In our model, we would like to have $\delta_j^0(u) > \delta_j(u)$, for $j = l, h$. Thus, we introduce a value $\gamma > 0$ and define

$$\delta_j(u) = \delta_j^0(u) - \gamma.$$

Further, we require that $\gamma \to 0$ when $u(\alpha) \to u^0(\alpha)$, and use for this a simple linear relation

$$\gamma = (1 - \zeta)\gamma_d$$

where

$$\zeta = \frac{u(\alpha)}{u^0(\alpha)}$$

and γ_d is a freely selected constant. To simplify notation we introduce a new variable

$$v = \frac{u-u_{min}^0}{u_{max}^0-u_{min}^0},$$

where $u_{max}^0 = u^0(\alpha = 1)$ and $u_{min}^0 = u^0(\alpha = 0)$. Then the model of the discount factors (5) - (6) changes into

$$\delta_l(v) = (1-v)\delta_{ll} + v\delta_{lh} - (1-\zeta)\gamma_d \quad (7)$$

$$\delta_h(v) = (1-v)\delta_{hl} + v\delta_{hh} - (1-\zeta)\gamma_d \quad (8)$$

$$\frac{u(0)-u_{min}^0}{u_{max}^0-u_{min}^0} \leq v \leq \frac{u(1)-u_{min}^0}{u_{max}^0-u_{min}^0}. \quad (9)$$

An example of using this model is given in Section 4.

To use this model for comparison of several distributions, one has to choose a default distribution, denoted by the superscript ^{0}, with the highest value of the fractional deviation u for $\alpha = 1$, and then apply the discount factor models following from equations (7) – (9).

2.2.2 Probability p

Consider probability p that the buyer is weak. Here, we model p as a function of u. We require that

$$p(u_{min}) = 1, \quad p(u_{max}) = 0.$$

In addition, we require that these limit values are approached smoothly

$$p'(u_{min}) = 0, \quad p'(u_{max}) = 0,$$

where $p'(\cdot)$ denotes the first derivative.

The above constraints imposed on the 3rd order polynomial provide the following formula for the function $p(u)$

$$p(u) = 2\left(\frac{u-u_{min}}{u_{max}-u_{min}}\right)^3 - 3\left(\frac{u-u_{min}}{u_{max}-u_{min}}\right)^2 + 1, \; u \in [u_{min}, u_{max}], \quad (10)$$

which is illustrated in Figure 4. The function is monotonically decreasing, expressing an intuition that the higher the uncertainty of methane calculations is, the stronger is the buyer's position, and thus the lower is the probability that he is weak.

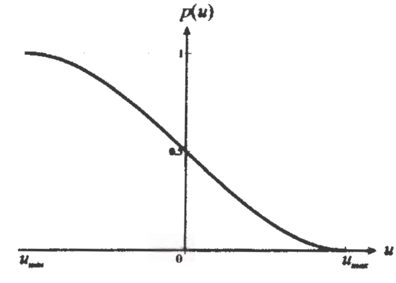

Figure 4. A probability $p(u)$ that player 2 is weak as a function of deviation u.

Similar as for the discount factors, we would like to compare several distributions describing uncertainty of CERs amount estimations. Thus, let us consider the same two cases considered for the discount factor, with $u^0(\alpha) > u(\alpha)$. We postulate the following conditions:

1. $p(u) \geq p^0(u)$
2. $p(u_{max}) = p^0(u_{max}) + \gamma$
3. $\gamma \to 0$ for $u \to u_{min}$

4. $\gamma \to 0$ for $\zeta \to 1$.

Using the earlier introduced variable v, we can write equation (10) as

$$p^0(u) = 2v^3 - 3v^2 + 1 \qquad u \in [u^0_{min}, u^0_{max}].$$

Let us introduce a variable

$$\xi = u - u_{min}$$

and model the condition 3 as $v = \xi\gamma_1$.To satisfy the condition 4 we apply the same type of a linear model as before, i. e. $\gamma_1 = (1-\zeta)\gamma_p$. Finally,

$$p(u) = 2v^3 - 3v^2 + 1 + (1-\zeta)\xi\gamma_p \qquad u \in [u_{min}, u_{max}] \tag{11}$$

An example of using this model is given in Section 4.

Analogously to the discount factor model, the case with fractional deviation $u^0(\alpha)$ could be chosen as a default one, if it satisfies $u^0(\alpha) > u(\alpha)$ for $\alpha = 1$.

As a final remark, we stress that the two proposed approaches, i.e. modeling discount factors δ_f and δ_h, as well as modeling probability p, do not need to be applied jointly. Each of these can be used as a separate piece of analysis, driving the search for proper estimates.

3. Case study of ERPA negotiation in a China coal mine methane CDM project

3.1 Huainan coal mine methane project

The considered coal mine methane (CMM) capture and utilization project is located in Huainan, Anhui province of China. This coal mine belongs to Huainan Coal Mining Group Co., Ltd. Huainan Coal Mining Group is situated in the north central part of Anhui Province, and Anhui province is located in Eastern China (Figure 5).

Figure 5.The project location map.

Huainan coal mining district is an old coal mining area with a mining history of more than 100 years. Its length is 100 km from East to West, and the width is 30 km from South to North. The total land area is 3 000 km^2. The considered coal mining is located 500 km away from Shanghai city and 100 km from Heifei city, the capital of Anhui province.

Coal resources of Huainan coal mining area are very rich - the total coal reserves in this area account for 74% of Anhui province and 50% of Eastern China. The recoverable deposits of coal reserves within 1 000 meters amount 20 billion tons.

However, the geological conditions of Huainan coal mining area are very complex. All the coal mines in the area suffer from high content of mine gas (with major composition of methane) and/or coal and gas burst. With a depth of coal mining resources, a risk of accidents increases. In order to decrease a risk of coal gas burst and to guarantee safety of coal production, the CMM utilization project was initiated in Huainan Coal Mining Group Co., Ltd. The CMM capture and utilization project drew methane from the mine and enabled its further utilization. Emission reductions were achieved through combustion of CMM by end-use technologies, as well as through replacement of fuel usage in more than 15 000 households. The latter switched from coal to gas-fired boilers, and thereby offset emissions from coal-based electricity generation.

3.2 Negotiating CERs price: no uncertainty case

The main concern of ERPA negotiations is to establish CERs unit price. The aim of the negotiations is to divide the margin between the highest price that a buyer is willing to pay (a buyer's conservative price) and the lowest price that a seller is willing to accept (a seller's conservative price).

We assume there are only two players: a buyer and a seller (Huainan Coal Mining Group Co., Ltd.), while a broker function is incorporated into either the buyer's or seller's side. Furthermore, regulations of Chinese government set the minimum unit price of CERs for coal mine methane projects at 70 Yuan/ton, and we treat this value as the seller's conservative price. The buyer's conservative price is assumed to be 170 Yuan/ton. Thus, the surplus to be divided among the players amounts to $k = 100$ Yuan/ton.

Consider first a situation of complete information, that is, discount factors of both players constitute common knowledge. In particular, the buyer and seller have asymmetric impatience degree since delay in negotiations is more harmful to the seller. The buyer's discount factor is $\delta^B = 0.97$, and the seller's discount factor is $\delta^S = 0.94$. Assume that it is the buyer who makes an initial offer. Applying Theorem 1, we calculate the buyer's benefit

$$k\,(1 - \delta^S) / (1 - \delta^S \delta^B{}_B) = 68.03 \text{ (Yuan/ton)},$$

which yields the CERs price of 170 – 68.03 = 101.97 (Yuan/ton). The seller's benefit equals 31.97 (Yuan/ton).

When, on the other hand, the negotiations are initiated by the seller, his benefit equals

$$k\,(1 - \delta^B) / (1 - \delta^S \delta^B \delta) = 34.01 \text{ (Yuan/ton)},$$

the associated CERs price becomes 70 + 34.01 = 104.01 (Yuan/ton), and the buyer's benefit is 65.99 (Yuan/ton). This illustrates that, according to the Rubinstein-Ståhl theory, the player who initiates negotiations is in a favourable situation.

In practice, however, assessment of discount factors becomes a challenging task. This is particularly true for a buyer's discount rate, which remains basically unknown. Looking from the seller's perspective, we assume that the seller's discount δ^S is known. In Chinese CDM projects the sellers are more concerned to sell the CERs than the buyers are to buy them. This is due to opportunity of the buyers to find a more profitable option, as he usually has good knowledge of international market in CDM projects. In this situation, the buyers are more patient in negotiations than the sellers. Based on the personal experience of the first author, we assume δ^B in the range of 0.9 – 0.97. Therefore, in this study, we adopt the incomplete information extension of the Rubinstein-Ståhl model, which corresponds to unknown buyer's discount rate.

Suppose the seller estimates that the buyer is either a weak player with a discount rate $\delta_l = 0.9$, or that he is a strong player with a discount rate $\delta_h = 0.97$. Additionally, the seller assumes that these two instances have equal probabilities, i.e. $p = 0.5$. The seller's discount factor $\delta^S = 0.94$ remains common knowledge.

Negotiations start with the seller's offer. From (3) we calculate $p^* = 0.45$, and since $p > p^*$, we follow case (i) of Theorem 2. The seller proposes that his benefit is

$$k * x^p = k \frac{(1-\delta_l)\left(1 - (\delta^S)^2(1-p)\right)}{1-(\delta^S)^2+\delta^S(\delta^S-\delta_l)p} = 41.29 \text{ (Yuan/ton)}$$

from where the CERs price is 70 + 41.29 = 111.29 (Yuan/ton). The weak buyer accepts this offer, whereas the strong buyer rejects it. In a next step, the strong buyer offers to the seller a benefit of

$$k * y^p = k \frac{\delta^S(1-\delta_l)p}{1-(\delta^S)^2+\delta^S(\delta^S-\delta_l)p} = 34.76 \text{ (Yuan/ton)},$$

yielding the CERs price of 70 + 34.76 = 104.76 (Yuan/ton). Based on the real CERs price negotiated for the Huainan project, the buyer was a weak one.

3.3 Risks in the project

Numerous uncertain factors underlie CERs estimation in coal mine methane projects. At the beginning, high risk is related to the selection of a project site, which in turn determines factors such as methane reserves, geological mining conditions, gas quality, local demand, etc. In addition, the amount of methane directed for CDM projects depends on national requirements and sustainable development policy, as well as on gas prices on a local market. Also currency exchange rate and its fluctuations highly influence project profitability (Xu, 2007b). These uncertainties and risks, although important for both the seller and buyer, are not considered in this paper. Here we focus on uncertainty related to calculation of CERs due to inaccuracies in assessment of methane amount for an already selected site.

To assess the certified emission reduction, typically ACM0008 methodology is applied. This methodology was designed for coal mine methane projects as an integration of five earlier proposed methodologies, and approved in the 22nd meeting of UNFCCC Executive Board in November 2005. The detailed description can be found in ACM (2010) and UNECE (2010).

According to ACM0008 methodology, the annual (Certified) Emission Reductions ER, in tCO_2eq, of a CDM project, are calculated as

$$ER = BE - PE - LE$$

where BE are the baseline emissions, saved due to implementation of the project; PE are the project emissions; and LE are the leakage emissions, all in tCO_2eq per year. Baseline emissions BE form the basic component of this reduction. In the CMM case study of Huainan Coal Mining Group Co., the baseline emissions are represented by mined methane, which substitutes usage of other fuels, for example in heating or electricity production. Uncertainty of emission reduction is mainly caused by baseline emissions BE, since project emissions PE can be estimated with much better accuracy, and leakage emissions LE are small. Therefore, we neglect uncertainty of the project and leakage emissions, and assume that uncertainty of the overall emission reduction is caused by uncertainty of the amount of methane for mining, or more precisely by the methane content in the coal bed. Two indices characterizing this content are used: the highest methane content and relative methane content, measured in m^3/t. Both of them will be discussed in the sequel.

3.4 Estimating uncertainty distribution of methane content

Uncertainty of methane emission estimation is characterized with two indices: the highest methane content in coal bed seam (m^3/t) and relative methane emission (m^3/t). The former index is typically reported in China to estimate CERs production in the future, while the latter one accounts for adopted technology and provides more accurate estimation. Distributions of these two indices, based on data from 25 coal mines, are shown in Figures 6 and 7. These coal mines extract coal from similar beds. Thus, the histograms show distributions of the indices in China coal mines of the type similar to the one considered in the paper. We fit lognormal distributions to the data for both indices, and test the results with the Kolmogorov-Smirnov test.

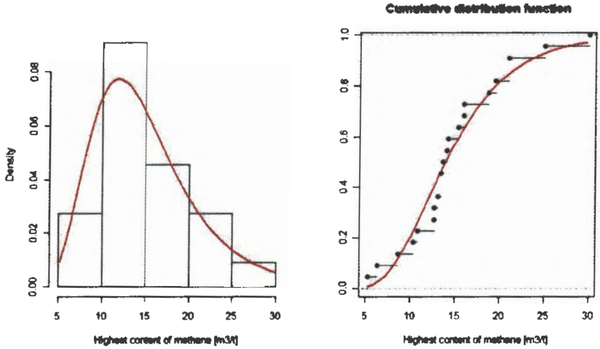

Figure 6.Distribution of highest methane content with a fitted lognormal density function.

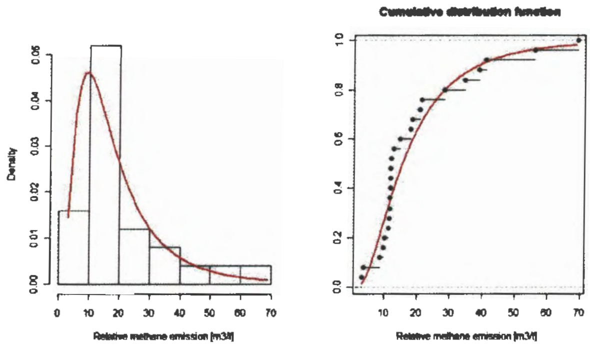

Figure 7. Distribution of relative methane content with a fitted lognormal density function.

To avoid confusion in notation, we recall that the lognormal distribution has the probability density function

$$g(x) = \frac{1}{\sqrt{2\pi}\sigma x} \exp\left[-\frac{(\ln x - \mu)^2}{2\sigma^2}\right], \quad x > 0. \qquad (12)$$

Its mean is $E(X) = \exp\left(\frac{1}{2}\sigma^2 + \mu\right)$, and the variance is $Var(X) = \exp\,(\sigma^2 + 2\mu)(\exp\sigma^2 - 1)$. In Table 1, apart from the estimated parameters μ and σ with its standard errors in brackets, we report also the mean $E(X)$ and standard deviation $\sqrt{Var(X)}$ of the fitted distributions. High p-values of the Kolmogorov-Smirnov test support the null hypothesis that the samples were drawn from the reference distributions.

Table 1. Parameters of fitted lognormal distributions and results of the Kolmogorov-Smirnov test.

	μ	σ	$E(X)$	$\sqrt{Var(X)}$	Test statistic	p-value
Highest methane content	2.636 (0.08)	0.399 (0.06)	15.121	6.293	0.174	0.519
Relative methane content	2.746 (0.14)	0.713 (0.10)	20.099	16.360	0.163	0.471

We use these distributions to infer on uncertainty of the observation $\hat{x}$. More precisely, we want to obtain the probability that the actual value of observation x is in a given interval $I(\hat{x})$ around $\hat{x}$

$$P\{x \in I(\hat{x})|g,\hat{x}\} = \int_{I(\hat{x})} f(x|g,\hat{x})dx.$$

For this, we need to find the conditional distribution $f(x|g,\hat{x})$, which provides probability density function of x given the observation $\hat{x}$ and the probability density function $g(x)$. The exact result will depend on our knowledge of the distribution $g(x)$. In the situation at hand, the value $\hat{x}$ actually adds information to previous measurements (from 25 mines). Here, we assume that we know the family of distributions, to which $g(x)$ belongs (the lognormal distributions in our case), and the distribution parameter σ^2. On the other hand, about the parameter μ we only know that it belongs to a given set M, i.e. $\mu \in M$.

Thus, using the law of total probability we have

$$f(x|g,\hat{x}) = \int_M g(x|\mu)\pi(\mu|\hat{x})d\mu \qquad (13)$$

where $\pi(\mu|\hat{x})$ is the conditional probability density function of μ when $\hat{x}$ is known. However, we know that, when $\hat{x}$ has been observed, both $\hat{x}$ and μ are deterministic values. Thus, $\pi(\mu|\hat{x})$ is simply a deterministic function $\mu(\hat{x})$. We insert formally $\pi(\mu|\hat{x}) = \delta(\mu - \mu(\hat{x}))$ into (13), where δ is the Dirac delta function and $\mu(\hat{x})$ is a deterministic value. This gives

$$f(x|g,\hat{x}) = g(x|\mu(\hat{x})).$$

To find the function $\mu(\hat{x})$ we estimate μ in (12) using the maximum likelihood method with one observation $\hat{x}$. We have

$$\ln g(x|\mu) = -\ln\sqrt{2\pi}\sigma - \ln x - \frac{1}{2\sigma^2}(\ln x - \mu)^2.$$

The maximum of this function with respect to μ is for

$$\mu(\hat{x}) = \ln\hat{x}.$$

Inserting this value into (12) we finally get

$$f(x|g,\hat{x}) = \frac{1}{\sqrt{2\pi}\sigma x}\exp\left[-\frac{\left(\ln\frac{x}{\hat{x}}\right)^2}{2\sigma^2}\right], \quad x > 0.$$

The maximum of this function is for $x_{max} = \hat{x}e^{-\sigma^2}$. Thus, in this case $\hat{x}$ is not the modal point of the distribution. In fact, $\hat{x}$ is the median.

Actually, our knowledge of the distribution $g(x)$ here is slightly more complicated than the one assumed above. A more advanced analysis of the considered case will be provided elsewhere. We note, however, that a full analysis may not provide a nice analytic solution, as with the assumptions taken above.

3.5 Determining the fractional deviation function

Before the method proposed in section 2.2 will be applied, we determine the fractional deviation function $u(\alpha)$. Note that the function $u(\alpha)$, defined in (4), does not depend on $\hat{x}$. For this case study, where the function $f(x|g,\hat{x})$ has lognormal distribution with parameters μ and σ, the cumulative distribution function (cdf) is

$$F(q_\alpha) = \phi\left(\frac{\ln q_\alpha - \mu}{\sigma}\right) = \alpha,$$

where q_α is the quantile of order α, and ϕ is cdf of the standard normal distribution[1]. We obtain

$$q_\alpha = \exp[\mu + \sigma\phi^{-1}(\alpha)].$$

Since in our case x_α is the quantile of order α, and $\mu = \ln\hat{x}$, it follows

$$u(\alpha) = \frac{x_\alpha}{\hat{x}} - 1 = \frac{\exp[\mu + \sigma\phi^{-1}(\alpha)]}{\hat{x}} - 1 = \exp[\sigma\phi^{-1}(\alpha)] - 1,$$

and $u(\alpha)$ no longer depends on $\hat{x}$. This fact becomes especially advantageous when information on a point estimate $\hat{x}$ is not revealed to the public.

For the considered indices of highest and relative methane content, the above relation is shown in Figure 8. For this purpose we also calculate $u_{min} = u(\alpha = 0) = -1$. Due to the fact that the support of lognormal distribution is unbounded from above, we set $u_{max} = u(\alpha = 0.995)$, which provides $u_{max} = 1.79$ for the highest methane content, and $u_{max} = 5.27$ for the relative methane content.

Note that the deviation u equals 0 for $\alpha = 0.5$, meaning that $x_\alpha = \hat{x}$. This is a consequence of the fact that $\hat{x}$ is the median of the distribution $f(x|g,\hat{x})$. In other words, when $\alpha = 0.5$ is adopted, the uncertainty is neglected ($u = 0$). For the probability $\alpha < 0.5$ the upper bound with risk α on the true emission moves the deviation $u(\alpha)$ to the left of $\hat{x}$, and then $u(\alpha)$ is negative. And contrary, for $\alpha > 0.5$ the deviation $u(\alpha)$ is positive.

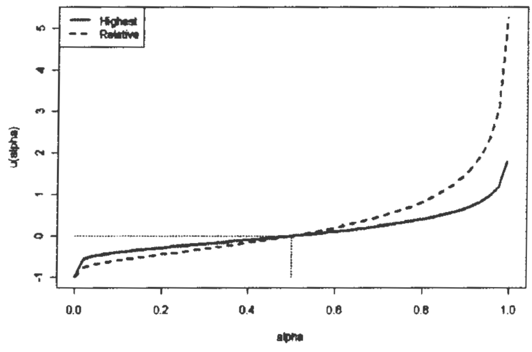

Figure 8. The fractional deviation u as a function of probability α.

The scale parameter σ is responsible for the difference between the two lines. This parameter is associated with the dispersion, and therefore higher σ increases uncertainty. This way, higher σ drives higher absolute values of fractional deviation $u(\alpha)$. When interpreting

[1] To see this, recall that if $Z \sim N(\mu,\sigma)$, then $X = \exp(\mu + \sigma Z) \sim LN(\mu,\sigma)$. Denoting probability with P, we have $F_X(q_\alpha) = P(X < q_\alpha) = P(\exp(\mu + \sigma Z) < q_\alpha) = P\left(Z < \frac{\ln q_\alpha - \mu}{\sigma}\right) = \phi\left(\frac{\ln q_\alpha - \mu}{\sigma}\right). = \phi\left(\frac{\ln q_p - \mu}{\sigma}\right)$

curves depicted in Figure 8, recall that σ = 0.399 for the highest methane content, and σ = 0.713 for the relative methane content (see Table 1).

4. Simulating negotiation outcome under uncertainty

In this section, the estimated uncertainty of methane calculations is applied for the Huainan CMM project. We extend the incomplete information setting of the Rubinstein-Ståhl negotiation model, so that the seller's belief on the buyer's discount factor reflects CERs uncertainty. The results of CERs price negotiations for the Huainan project are presented in terms of the seller's share of the surplus. Recall that the surplus amounts to k = 100 Yuan/ton. To calculate a final CERs price, a seller's share is to be multiplied by k, and added to the seller's conservative price of 70 Yuan/ton, compare section 3.2.

We begin with modeling the unknown buyer's discount factors δ_l and δ_h, while the probability of the weak buyer is kept constant ($p = 0.5$). The discount factors functions, described in section 2.2.1, are depicted in Figure 9 for both the highest and relative methane content indices. The left hand-side figure presents the linear dependence on deviation u, while the right one presents the dependence on probability α. The two upper lines refer to δ_l, and the two lower ones to δ_h.The linear functions illustrate equations (7) – (9), where the distribution of the relative methane content index is the one denoted in section 2.2.1 by the superscript ^{0}. In addition, the following lower and upper limits of discount factors were assigned: δ_{ll}= 0.88, δ_{lh} = 0.94, δ_{hl}= 0.96, δ_{hh}= 0.99, and we set γ_d= 0.05.

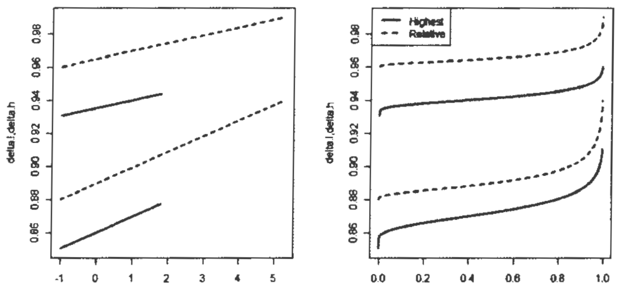

Figure 9. Discount factors δ_l, δ_h as functions of uncertainty u and probability α.

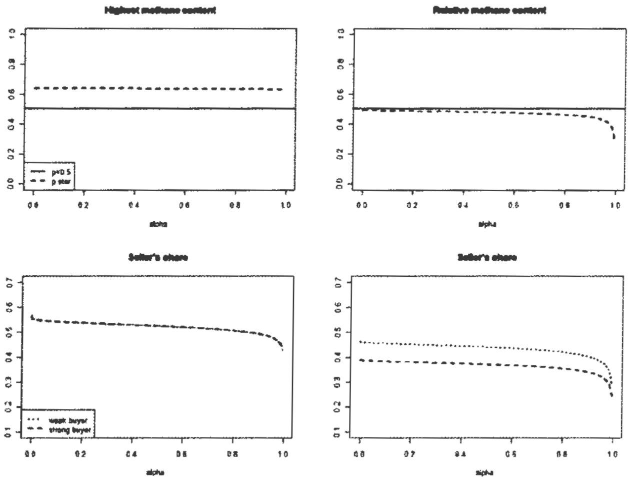

Figure 10. Negotiation outcome versus probability α (constant p=0.5).

Next, Theorem 2 is applied, and the results are presented in Figure 10. The upper graphs depict, for a range of α, the probability p that the buyer is weak, and the boundary point p^* distinguishing between the cases (i) and (ii) of the theorem. With probability p assumed constant and equal 0.5 for the entire range of α, we get $p < p^*$ in the case of the highest methane content index, and $p > p^*$ in the case of the relative one. Therefore, for the former index the case (ii) of Theorem 2 applies, and this is illustrated in the lower left graph. Here, the seller's share is the same, no matter if the buyer is weak or strong. On the other hand, for the relative methane content, the case (i) of Theorem 2 applies, and the weak buyer accepts higher seller's share than that which the strong buyer does (see the right lower graph). Note that the difference between the shares accepted by a strong and weak buyer is quite remarkable. Naturally, the higher the probability α is accounted for, the lower share of the surplus the seller gets. Comparison of the two lower graphs provides one more information. Namely, for a fixed level of probability α, the seller is better off in the case of the highest methane content index, regardless of the type of the buyer (weak or strong) he is negotiating with. This fact confirms intuition, also because the uncertainty distribution of the highest methane content has lower dispersion. It is also an interesting observation that the highest methane content is more often used in China.

Following the proposition of section 2.2.2, we further model the probability p that the buyer is weak. Equation (11), applied for the Huainan project, is depicted in Figure 11. The discount factors are kept constant: if the buyer is weak, his discount factor is δ_l=0.91, and if he is strong, his discount factor is $\delta_h = 0.975$. These values are set as the middles of the previously assigned δ_{ll},δ_{lh}, and δ_{hl}, δ_{hh}, respectively.

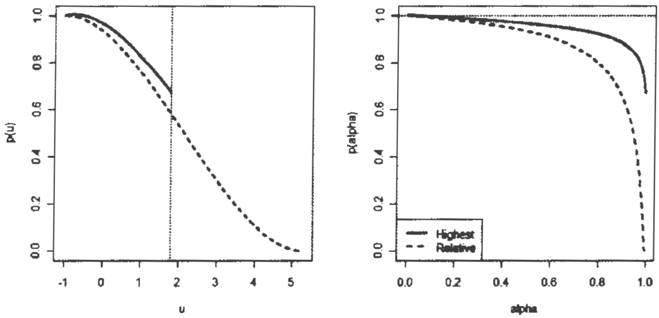

Figure 11. Probability p that player 2 is weak as a function of deviation u and probability α.

Unlike in the previous setting, we get $p > p^*$ in the case of the highest methane content for the whole range of α (see Figure 12). Also for the relative methane content index, we have $p > p^*$ for almost full range of α. The resulting seller's share of the surplus do not differ much between the two methane content indices (see the lower graphs). We only note that for high values of $\alpha > 0.8$, the seller's share decreases quickly in the case of the relative methane content index. In general, when only the probability p is modelled and the discount factors remain constant, the dependence of the negotiation results on α changes very slowly, except for higher values of α, forming a kind of plateau.

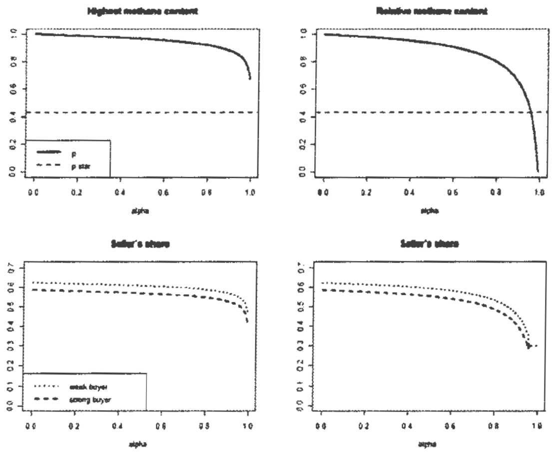

Figure 12. Negotiation outcome versus probability α (constant $\delta_l = 0.91$, $\delta_h = 0.975$).

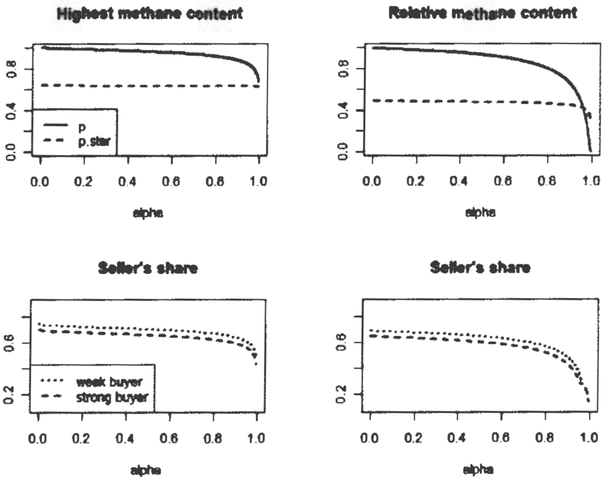

Figure 13. Negotiation outcome versus probability α (both p and δ_l, δ_h modeled).

Finally, we model both the buyer's discount factors and the probability that buyer is weak, see Figure 13. Here, for almost full range of uncertainty parameter α, the case (i) of Theorem 2 applies, and the seller gets different share depending on the type of buyer he is dealing with. The obtained graphs of seller's share seem to resemble rather the results from modeling solely p than the results from modelling solely the discount factors. Also the difference between the two methane content indices is more pronounced in this setting. For the relative methane content, the seller's share of the surplus decreases even to 0.2 when the whole of uncertainty distribution is to be included, i.e. for α close to 1. For the highest methane content, the seller's share does not drop below 0.45.

5. Summary and conclusions

The paper addresses the problem of uncertainty in methane content for a Chinese coal mine methane project, and its impact on a negotiated price of the Certified Emission Reductions. The Rubinstein-Ståhl bargaining game model is used to simulate the negotiation of the CERs price. To incorporate uncertainty into the negotiation process, the bargaining model has been extended by introducing dependence of parameters on a methane content uncertainty distribution, and more precisely on its quantile of order α. Simulations have been performed for a coal mine methane CDM project designed for the Huainan Coal Mining Group Company, Ltd. The company is located in the Anhui Province, in Eastern China. Three parameters of the Rubinstein-Ståhl model have been made dependent on the uncertainty. These are: (i) the lower and upper discount factors of a buyer, representing the patience in negotiation of a weak or strong buyer, respectively, and (ii) the probability that the buyer is a weak negotiator. The discount factors have been chosen as simple linear functions of the fractional deviation. The fractional deviation is defined in the paper in connection with an interval, to which the true value of the methane content belongs with a preselected probability. The discount factor functions have been designed to cover different uncertainty distributions, while keeping intuitively motivated relations among them. The probability that the buyer is weak is designed as a third order polynomial of the fractional deviation, and it satisfies a few intuitive conditions. Also in this case, a proper relation between different uncertainty distributions has been considered.

To estimate uncertainty distribution of the methane content in the project considered, first, the data on methane contents have been gathered from 25 Chinese coal mines having similar geological conditions. A lognormal distribution has been fitted to these data. The resulting distribution has been used to estimate the uncertainty distribution of the given methane content in the project.

These theoretical and experimental investigations were finally used for simulation of the impact of uncertainty on negotiation results. The investigations revealed a few interesting results, fully compatible with the intuition, and also with current practise in negotiation. The most important findings can be summarized as follows.

The uncertainty has impact on the negotiation results and the seller's share of the surplus, albeit this dependence is not very strong, at least for the values of α up to 0.8-0.9, that is for a reasonable inclusion of the uncertainty distribution range. In this interval the dependence of seller's share on α is decreasing almost linearly with rather slight slope. Still, the difference in the seller's share between the small and high values of α are of the same order as the difference between the strong and weak buyer. For α in the range 0.8-1, the seller's share decrease quite rapidly.

Quick decrease of the seller's share starts much earlier for the relative methane content index than for the highest one. For the former index quick decrease starts around $\alpha = 0.8$, while for the latter one around $\alpha = 0.9$. In this respect, the highest methane content is more robust to uncertainty, and therefore more convenient for usage in negotiations.

The gain of the seller's share, when negotiated with a weak buyer instead of a strong one is about 5% of the surplus, almost independently of the uncertainty parameter α. This result certainly depends on model parameters adopted in simulations. However, this fact indicates that a seller can earn a considerable amount of money by getting a chance of negotiations with a weak buyer.

9. Acknowledgements

The study was conducted within: (i) the Joint China-Poland Intergovernmental Science and Technology Cooperation project No.33-2, (ii) the National Science Foundation of China project No. 70941035, and (iii) the Fundamental Research Funds for the Central Universities project No. 2010YG06.

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