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Abstract

During the last decade, China has evolved into the largest consumer by far and one of the largest importers of coal. The main driver for the increase in coal demand in China has been economic growth. Future Chinese growth rates, and therefore coal consumption and coal imports, are highly uncertain, which may affect profitability of new investments of international mining companies. Furthermore, China has actively employed an array of instruments to control coal trade flows in the last years. In this paper, we analyse the potential impact of increased Chinese coal import volatility and of potential exertion of Chinese market power on global mining investment decisions. For this purpose, we develop a multi-stage stochastic equilibrium model which is able to simulate investments under uncertainty and a monopolistic player in addition to a competitive fringe. We find that accounting for Chinese demand uncertainty yields significant costs for investors and also leads to a delay in investments. Additionally, the exertion of Chinese market power further reduces overall investment activity.

Keywords: Investments under uncertainty, value of perfect information, risk aversion, strategic behaviour.

JEL : L13, L71, C61, F10

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1. Introduction

The optimal sizing and timing of investments in the light of an uncertain market environment is one of the main challenges for capital intensive industries. A typical example is natural resource markets which can require large lump-sum investments for accessing and exploiting resource deposits.

Uncertainty in natural resource markets may be induced by human behaviour (e.g., economic activity or politics) or by natural effects (e.g., weather, floods). While both types of uncertainty are important, major

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mid-term uncertainty induced by human economic activity for many natural resource markets in recent years has been the speed of Asian demand growth, especially in China. According to the IMF (2011), Chinese economic growth in the first decade of the millennium was 10.2% per year on average. The resulting demand boom regarding all kinds of natural resources to build up Chinese infrastructure and industry incentivised investments into new rigs, mines and refineries on a global scale. However, it is unclear how long the Chinese economy can sustain this kind of growth rates. Investors face the challenge of correctly assessing when Chinese resource demand will flatten out in order not to built up excess capacity.

A rather representative example for a global resource market strongly influenced by Chinese economic growth and resource policies is the global steam coal market. Since 2008, China has made a market shacking shift from one of the largest steam coal exporters to the second-largest net importer of steam coal. However, it remains unclear how imports will develop in the next years. This has created a risky environment for coal mining investors which have to spend large sums upfront for mining equipment and transportation infrastructure in order to set up new capacity (IEA, 2011).

Furthermore, coal trade control regimes have recently been set up by the Chinese government which further complicates the situation for international investors; coal shipments to China face import duties and export quotas which can be reassessed on an annual basis. It remains to be seen to what extent the Chinese government applies such instrument to influence trade in a strategic way, but doubts about competitive market conduct already exist (Paulus et al., 2011; Trüby and Paulus, 2011).

The main contribution from this paper is an analysis of the projected impact of Chinese market power in the future: We analyse how the interaction between uncertain Chinese coal demand evolution and the opportunity of China to act strategically in the international market affects decisions to invest in mines or infrastructure.

Literature on investments under uncertainty and market power in other resource and commodity markets has a history dating back more than two decades. Haurie et al. (1987) proposed a stochastic dynamic model with players acting in a Cournot manner to simulate contractual agreements in the European gas sector. Murphy et al. (1982) investigated power plant investments under load uncertainty. More recent works focus on investigating how gas industry infrastructure investments are affected by uncertainty and supply-side market power (Gabriel and Zhuang, 2006; Zhuang and Gabriel, 2008; Egging, 2010). Literature on demand side market power has been scarce thus far. One example of such a work is that of Kolstad and Burris (1986) who analyse demand-side market power in agricultural markets. However, their model did not account for investment decisions under uncertainty.

Existing work on steam coal market economics has so far included the analysis of policy scenarios of different transport infrastructure investments regimes (Paulus and Trüby, 2011) and the analysis of interactions between climate policies and coal demand (Haftendorn et al., 2011). Another research venue has been potential supply-side market power. Kolstad and Abbey (1984) analysed strategic behaviour in seaborne steam coal trade on the demand and the supply side. However, since then, the steam coal trade market has changed substantially and several recent papers come to varying conclusions. Haftendorn and Holz (2010) reject the hypothesis of non-competitive market behaviour in coal trade in 2005 and 2006, while Trüby and Paulus (2011) raise doubts about competitive market conduct in 2008 and outline that market structure might have changed due to the growing importance of several major Asian players, most importantly China. Paulus et al. (2011) find that accounting for the interaction between the international market and the domestic market implies that Chinese export policies are consistent with a Cournot-Nash strategy. However, so far no article has focused on how demand side market power and uncertain demand influence investments into coal production capacity.

For our analysis, we model the investment decision problem as a multistage spatial stochastic equilibrium model with recourse. The stochastic perturbation is mapped in extensive form, meaning that possible demand evolutions are represented by a scenario tree and realisation probabilities. The model allows for simulation of competitive behaviour of actors as well as non-competitive market behaviour á la Cournot on the demand as well as on the supply side. We especially account for risk-averse investment behaviour by using stochastic discount factors to generate the deterministic equivalent of uncertain payoffs. The model is designed as a stochastic mixed complementary programme (sMCP) by deriving the first-order optimality conditions of the associated stochastic optimisation problem. Haurie et al. (1987, 1990) found that the information structure of players in such games, which they called *S-adapted Open-Loop*, lies between the adaptive closed-loop and the nonadaptive open-loop information structure and developed conditions for existence and uniqueness of the equilibrium concept (Haurie and Moresino, 2002).

Using an established coal market database described in Paulus and Trüby (2011), we simulate how coal mining investment decisions are affected by uncertain Chinese coal demand evolutions until 2020. We test two setups: in one, we extract the effect of uncertain Chinese demand on international mine investments. All players behave as price takers. In the other setup, we analyse the impact of Chinese market power on the demand uncertainty effect from setup one. Here, China behave as a monopolist/monopsonist regarding exports and imports in addition to the competitive fringe of other players. For both setups we compute the

Value of Perfect Information[1] which can be interpreted as the loss in rent for each modelled player due to uncertainty. We find that accounting for Chinese demand uncertainty yields significant costs for investors of 18% of their rents compared to a perfect foresight baseline. Investors reallocate their investments spatially and temporally to hedge themselves against risky demand outcomes. If we account for Chinese market power, China maximises its wellfare by withholding coal imports from the international market to a certain extent. Lower Chinese coal imports make international coal sector investments decrease. However, the Value of Perfect Information is lower for investors in this case.

The remainder of this paper is structured as follows: In section 2 we describe China's current energy policy and potential impacts on coal markets. Section 3 describes analytical results, the methodology and the model in detail, while 4 outlines the computational application. Section 5 shows and discusses the simulation results. Section 6 concludes.

2. China's energy policy and its potential impact on global coal markets

For decades, international coal trade has been growing at a moderate pace, involving a blend of multinational private mining companies, large state-run entities, and various smaller national players. China has a dominant role in the global coal market; during the last decade, the domestic Chinese steam coal market increased to 2,800 mt in 2010, which was five times more than the total global seaborne trade of 600 mt. Additionally, China has switched from a net exporter of 21 mt in 2008 to a net importer of 80 mt in 2010. This means that variations in domestic coal supply and demand which could be considered as 'noise' compared to the overall Chinese market size potentially amplify and feed back by an order of magnitude to international steam coal markets.

Higher uncertainty with regard to future Chinese coal imports and prices increases the risk for new coal market investments. A significant decrease in profitability could lead international mining companies to decide to allocate investments in other, less uncertain resource markets. Also, if investments are lower than expected, prices could increase and bottlenecks could arise in the global coal supply chain which would also affect energy policies in countries mainly depending on coal imports like many OECD economies. This analysis therefore tries to determine the following in the first step:

- To what extent are investments of international coal market investors affected by Chinese demand uncertainty?

[1] Which we sometimes will refer to as 'Costs of Uncertainty'.

- How large are the profit losses for international producers due to Chinese demand uncertainty?

In addition to the uncertain future Chinese coal import demand, increasingly tighter Chinese coal trade controls represent a second layer of complexity for investors. Such trade controls might be used by the Chinese state to exert market power (Paulus et al., 2011). China has increasingly made use of policy instruments (i.e., quotas and/or taxation) in recent years to tightly control coal exports and imports. As currently one of the largest coal importers, China has significant potential to exert market power through its import taxes. Profitability of investments into new mines may be negatively affected through import taxes, as China may be able to skim producer surplus. It is crucial for international mining investors to know how the potential skimming would affect their profitability and thus their investment plans. This leads us to another question within our analysis:

- To what extent will the exertion of Chinese market power affect investments given that demand is uncertain?

Furthermore, it is not intuitively clear if rent reductions of investors due to uncertainty are higher or lower in a noncompetitive case compared to a competitive case, but this is an important fact for investors to know. If, for example, Chinese import controls would decrease costs of uncertainty, Chinese domestic coal demand fluctuations and energy policies might not have such a profound impact on coal markets as in a competitive market. If investors assume that China is exerting or will exert its market power, analysing and forecasting Chinese trade controls patterns might be more important for international investors than analysing the domestic Chinese coal market. Our last question is therefore thus:

- How will the exertion of Chinese market power affect costs of uncertainty of international producers?

3. Methodology and model

In this section, we describe the general layout of our empirical model and the relevant players. Finally, we formulate the model in terms of a simple multi-stage stochastic programme and derive the necessary first order conditions.

3.1. Layout of the model

The empirical model is structured to find the spatial and temporal equilibrium of prices, trade flows and investments between players given assumptions about their market conduct and objective functions. The model accounts for the following three different types of players:

1. Investors I maximise their profits given uncertain future demand in a competitive manner. Investments into additional capacity stock have to be decided prior to demand realisation. Production levels are recourse variables which are decided on during the period in which the demand level is revealed. Investors are risk averse in the sense that they price their systematic risk (see Section 3.2).
2. Consumers C maximise rents given a certain demand function. During recourse, they decide on their consumption level and trade flows. Consumers behave in a price-taking way.
3. Strategic player M jointly maximises both its consumer rent and producer rent through its recourse variables of consumption, supply and trade flows. M is therefore a consumer as well as a producer in its own right. The development of its demand and capacity stock is assumed to be given. Since we assume that capacity additions for producing regions of M follow a predetermined schedule, M does not have to make investment decisions. M maximises its payoff, given supply and demand of a competitive fringe of other players. It therefore acts as a monopsonist for investors I and as a monopolist for other consumers C. With this setup, we model the Chinese export and import control system under the assumption that they serve domestic welfare maximisation. It is important to note that, in our setup, we assume that M is a national player (e.g., it exerts market power through national export and import controls only vs. other players). Individual companies on the demand and the supply side do not exert market power and behave in a price-taking manner.

Figure 1 depicts the possible interactions of model players as well as the timing of investment decisions and the information structure. We assume that investors have to decide if they want to invest into new capacity before they know the precise demand level. To model this situation, we introduce uncertainty into the model by assuming that demand level of M is not foreseeable by investors I when capacity investments have to be taken. However, we assume that the distribution of future demand of M, and thus realisation probabilities, are given and known to investors. The first stage thus includes the investment decision stage for investors given a future demand distribution. In the second stage, capacity investments are realised and all players engage in a trading game in which the strategic player exerts market power both versus investors and consumers while the other actors behave as price takers. As demonstrated by Salant (1982); Kolstad and Burris (1986) and recently Lise and Krusemann (2008) and Montero and Guzman (2010), different types of Cournot games can be mapped by a term that is a producer's (consumer's) conjecture about the response of other producers (consumers) to a change in their production (consumption) volume[2]. The two-

[2]Our model formulation can be interpreted as a quota system that restricts exports or imports to the Cournot-Nash outcome. Other formulations with taxes instead of quotas of course yield the same equilibrium (see e.g.: Kolstad and Abbey, 1984).

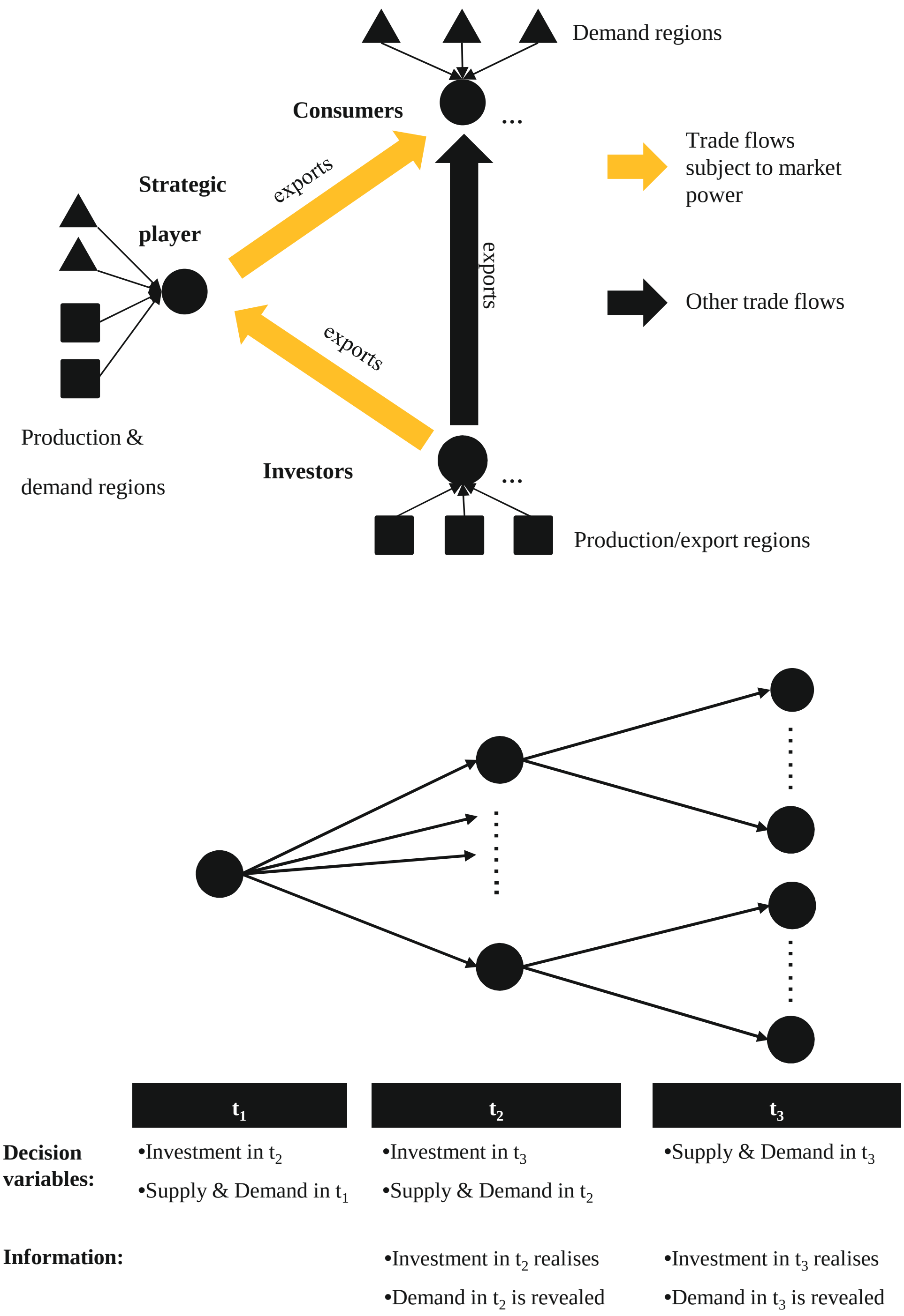

Figure 1: Setup of modelled players (top) and timing of investment decisions and information structure for a three-period example (bottom).

stage stochastic model concept can be easily generalised to a multi-stage setup as shown in Section 3.3. The model is formulated in its extensive form; e.g., all considered futures $n \in N$, or scenarios, and their respective realisation probabilities ω_n, are explicitly accounted for and known. This allows us to represent the information structure of the model as a so-called scenario tree.

Haurie et al. (1990) showed that such a stochastic equilibrium programming approach yields a special class of strategies which the authors call *S-adapted open-loop*. It can basically be regarded as an open-loop equilibrium with uncertainty, where strategies are conditional on the realisation of a stochastic underlying model parameter[3]. The equilibrium is not subgame perfect and players commit themselves to their decisions at the beginning of the game. The equilibrium concept can be useful in analysing long term supply and demand decisions under uncertainty without running into the computational challenges of determining closed-loop strategies. Genc et al. (2007) and Genc and Zaccour (2011) further analysed investment dynamics under uncertain demand and the equilibrium concept has been used in several recent empirical studies, as in Pineau and Murto (2003), Genc et al. (2007) or Bernard et al. (2008).

3.2. Risk-adjusted discount factors

As demand realisation is risky, we allow investors I to price their systematic risk in accordance to standard CAPM theory (e.g.: Armitage, 2005). Pricing in systematic risk[4] will cause investors in our model to assume risk-averse behaviour in a sense that they will demand a higher (lower) capital return from expected payoffs of scenario nodes with high (low) market returns r_n^m and low (high) realisation probabilities ω_n. In our case, scenarios with high market returns coincide with high Chinese coal demand as both are driven by economic growth. Thus, the relative weight of expected payoffs from such high demand scenarios diminishes in our model, as they are discounted more strongly. Vice versa, the relative weight of low demand scenarios increases.

For implementation, we rely on a methodology described by Fama (1977) to compute deterministic equivalents of risky cash flows using linear stochastic discount factors. Stochastic discount factors $d^s(n)$ are defined such that a cash flow vector $X(n)$ accruing in a later time period has the value $E[d^s(n) \times X(n)]$ at time period 0. If one relies on the theories and assumptions of CAPM, such a vector may be determined ex-ante if the vector of market returns and the risk-free interest rate r^f are known. Using stochastic discount factors enables us to compute the equivalent deterministic cash flows in each scenario so that any further

[3]But not on realisations of other players decisions.

[4]Systematic risk is the not diversifiable risk that is associated with aggregate market returns. In contrast, unsystematic risk is company or industry-specific and is not correlated with market returns. It may be reduced through portfolio diversification (Armitage, 2005).

intertemporal discounting of pay-offs may be done at the risk-free interest rate. A very comprehensive overview of how to implement the notion of deterministic equivalent cash flows into stochastic equilibrium models has been provided by Ehrenmann and Smeers (2010). In this analysis, we largely follow their approach.

3.3. Model formulation

The information structure of the model is represented by a scenario tree which consists of a set of scenario nodes $n \in N$. Let $succ(n)$ represent the set of all successor scenario nodes to scenario node n and let $pred(n)$ be the set of all predecessor scenario nodes of n. The spatial topology of the model consists of export regions $e \in E$, demand regions $d \in D$ and transport routes $(e, d) \in A \subset E \times D$. Each investor $i \in I$ controls a set of export regions $e \in E_i$ and each consumer $c \in C$ controls a set of demand regions $d \in D_c$. The monopolist $M = \{m\}$ controls export regions as well as demand regions. We assume quadratic costs functions and linear demand functions as well as constant investment- and transport costs. An overview of all sets, decision variables and parameters can be found in Table 1.

The remainder of this section is organised as follows: We develop the optimisation problems and the corresponding first-order optimality conditions for each player type. The first-order conditions together with the market-clearing conditions bundled together form the stochastic equilibrium model.

The variables in parentheses on the right-hand side of each constraint are the Lagrange multipliers used when developing the first-order conditions. The complementary slackness condition is indicated by the perpendicular sign $\perp$, where $0 = x \perp y = 0 \Leftrightarrow x^t y = 0$ for vectors x and y.

The investors' problem

Each investor $i \in I$ maximises its profit which is defined as revenue minus costs of supply and minus investment costs. Investors behave as price takers in the market. The payoff function $\Pi_i^I(z_i)$ is defined as:

$$\max_{z_i \in \Omega_i} \Pi_i^I(z_i) = \sum_{n \in N} \omega_n d_n^S d_n^F \sum_{e \in E_i} \left[p_{e,n}^{Ex} s_{e,n} - \left(a_{e,n} s_{e,n} + \frac{1}{2} b_{e,n} s_{e,n}^2 + c_{e,n}^{Inv} x_{e,n} \right) \right], \tag{1}$$

where z_i is the corresponding decision vector of i. Ω_i is the set of feasible solutions of z_i and is defined by constraints for maximum supply:

$$Cap_e^{Start} + \sum_{n' \in pred(n)} x_{e,n'} - g_e \sum_{n' \in pred(n)} s_{e,n'} - s_{e,n} \geq 0, \qquad (\epsilon_{e,n}) \qquad \forall\, e \in E_i,\ n \in N, \tag{2}$$

and by constraints for maximum investments:

Table 1: Model sets, variables and parameters.

Sets	
$e \in E$	export regions
$d \in D$	demand regions
$i \in I$	Investors
$c \in C$	Consumers
$e \in E_i$	export regions controlled by investor i
$d \in D_c$	demand regions controlled by consumer d
$d \in D_M$ and $e \in E_M$	demand and export regions of strategic player M
$n \in N$	scenario nodes
$n \in succ(n')$	set of all scenario nodes which are successor nodes to n'
$n \in pred(n')$	set of all scenario nodes which are predecessor nodes to n'
Primal variables	
$x_{e,n}$	investments
$s_{e,n}$	supply
$t_{(e,d),n}$	trade flows
$y_{c,d,n}$	consumption
$p^{Ex}_{e,n}$	export price
$p^{Im}_{d,n}$	consumer price
$a_{e,n}$	marginal cost intercept
$b_{e,n}$	marginal cost slope
$k^M_{d,n}$	total sales volume of M
$l^M_{e,n}$	total import volume of M
Dual variables	
$\epsilon_{e,n}$	dual variable for investments
$\lambda_{e,n}$	dual variable for supply
$\mu_{e,n}$	dual variable for maximum capacity
$\rho_{d,n}$	dual variable for consumption
$\sigma_{d,n}$	dual variable for total sales volume
$\delta_{e,n}$	dual variable for total import volume
Parameters	
ω_n	probability of scenario node n
d^S_n	stochastic discount factor of scenario node n
d^F_n	risk-free discount factor of scenario node n
Cap^{Start}_e	initial capacity of export region e
Cap^{Max}_e	maximum capacity of export region e
$Cap^M_{e,n}$	capacity of strategic player M in export region e
a^{Start}_e	initial marginal cost intercept of export region e
b^{Start}_e	initial marginal cost slope of export region e
g_e	exploitation factor of export region e
h_e	investment effect on marginal costs of export region e
$u_{e,n}$	input cost increase of export region e
$c^{Inv}_{e,n}$	investment costs for export capacity of export region e
$c^T_{(e,d)}$	transport costs on transport route (e,d)
$v_{d,n}$	demand intercept for demand region d
$w_{d,n}$	demand slope for demand region d

$$Cap_e^{Max} + g_e \sum_{n' \in pred(n)} s_{e,n'} - Cap_e^{Start} - \sum_{n' \in pred(n)} x_{e,n'} \geq 0,\ (\mu_{e,n})\ \forall\ e \in E_i,\ n \in N. \qquad (3)$$

Each investor thus faces a dynamic multistage investment problem where investments have to be decided upon before demand is realised in later scenario nodes. The first-order conditions of the investors' problem can then be summarised by constraints (2) and (3) as well as the following:

$$\omega_n d_n^S d_n^F \left(p_{e,n}^{Ex} - a_{e,n} - b_{e,n} s_{e,n}\right) - \epsilon_{e,n} - \mu_{e,n} \leq 0 \perp s_{e,n} \geq 0, \qquad \forall\ e \in E_i,\ n \in N, \qquad (4)$$

$$\omega_n d_n^S d_n^F c_{e,n}^{Inv} - \sum_{n' \in succ(n)} \epsilon_{e,n'} \leq 0 \perp x_{e,n} \leq 0, \qquad \forall\ e \in E_i,\ n \in N. \qquad (5)$$

We implement the concept of dynamic short run marginal costs functions which has first been described by Haftendorn et al. (2010). In their work, the authors model marginal costs endogenously as a function of cumulative supply and investments. Increases in cumulative supply increases the marginal cost intercept as the cheapest reserve deposits get exhausted. Increases in cumulative investments may have ambiguous effects depending on the age of the mining basin and the remaining reserves. In their paper, Haftendorn et al. (2010) apply their methodology to a linear marginal cost function, and we follow the same approach. The endogenous evolution of the marginal cost intercept is then described by:

$$a_{e,n} = u_{e,n} \left(a_e^{Start} + g_e \sum_{n' \in pred(n)} b_{e,n} s_{e,n} \right), \qquad \text{(free)} \qquad \forall\ e \in E_i,\ n \in N, \qquad (6)$$

and the evolution of the marginal cost slope by:

$$b_{e,n} = u_{e,n} \left(b_e^{Start} + h_e \sum_{n' \in pred(n)} x_{e,n} \right), \qquad \text{(free)} \qquad \forall\ e \in E_i,\ n \in N. \qquad (7)$$

We assume that there is no arbitrage between supply and trade and that the mass balance in all export regions of investors always has to be satisfied:

$$s_{e,n} = \sum_{d \in D} t_{(e,d),n}, \qquad \text{(free)} \qquad \forall\ e \in E \backslash E_M,\ n \in N. \qquad (8)$$

The consumers' problem

We assume that consumers behave in a competitive manner such that they take prices as given[5]. We further assume that consumers cannot generate savings or build up coal stocks. Therefore, in each scenario node $n \in N$ each consumer faces a static maximisation problem, as there are no intertemporal decisions to be taken. Consumer payoff is defined as gross surplus less costs of procurement. The payoff function $\Pi_c^C(z_c)$ is defined as:

$$\max_{z_c \in \Omega_c} \Pi_{c,n}^C(z_c) = \sum_{d \in D_c} \Bigg[\int_0^{y_{d,n}} p_{d,n}^{Im}(u)\mathrm{d}u \\ - \sum_{e \in E \setminus E_M} \left(p_{e,n}^{Ex} + c_{(e,d)}^T \right) t_{(e,d),n} - \sum_{e \in E_M} p_{d,n}^M t_{(e,d),n} \Bigg], \qquad \forall\, n \in N. \tag{9}$$

Each consumer procures his consumption directly from the investors I (first term of second line (9)), thus paying export prices plus shipping costs. In case of procurements from M, consumers pay the respective import price $p_{d,n}^M$ that M is setting. This will later become important when we derive the conditions for the equilibrium. Linear inverse demand is defined as $p_{d,n}^{Im}(y_{d,n}) = v_{d,n} + w_{d,n} y_{d,n}$. We compute the parameters of the demand function using a reference demand level D_{ref}, a reference price p_{ref}, and elasticity e. The slope of the demand function can then be expressed as $w_{d,n} = \frac{p_{ref}}{D_{ref}} \frac{1}{e}$ and the demand intercept through $v_{d,n} = p_{ref} - w_{d,n} D_{ref}$. Assumptions on reference volumes, prices and elasticities can be found in the Appendix. Consumers face the constraint that inbound trade flows have to be greater or equal to consumption:

$$\sum_{e \in E} t_{(e,d),n} - y_{d,n} \geq 0, \qquad (\rho_{d,n}) \qquad \forall\, d \in D_c,\ n \in N. \tag{10}$$

First-order conditions for consumer c are equation (10) and:

$$p_{d,n}^{Im}(y_{d,n}) - \rho_{d,n} \leq 0, \perp y_{d,n} \leq 0, \qquad \forall\, d \in D_c,\ n \in N, \tag{11}$$

$$\rho_{d,n} - p_{e,n}^{Ex} - c_{(e,d)}^T \leq 0 \perp t_{(e,d),n} \leq 0, \qquad \forall\, d \in D_c,\ n \in N,\ e \in E \setminus E_M, \tag{12}$$

$$\rho_{d,n} - p_{d,n}^M \leq 0 \perp t_{(e,d),n} \leq 0, \qquad \forall\, d \in D_c,\ n \in N,\ e \in E_M. \tag{13}$$

[5]As consumers represent a large number of national utility companies as well as many different energy-intensive industries we conclude that there is little potential for consumers to exercise market power on the international coal market.

The strategic player's problem

The strategic player M controls demand regions as well as export regions. Demand regions of M are specified through linear demand functions (similarly as for consumers), and supply regions are specified by quadratic cost functions and a capacity limit. Potential imports or exports balance M's supply and demand. M uses its imports and exports as strategic variables to maximise its total welfare, the joint surplus of production and consumption. Its maximisation problem is static, as we assume a fixed trajectory for its export capacity evolution[6], therefore no intertemporal decisions are taken[7]. Its payoff $\Pi^M(z_M)$ is defined as:

$$\begin{aligned}\max_{z_M \in \Omega_M} \Pi_n^M(z_M) = &\sum_{d \in D \setminus D_M} p_{d,n}^M(.)\, k_{d,n}^M - \sum_{e \in E_M} \left(\sum_{d \in D} c_{(e,d)}^T t_{(e,d),n} + a_{e,n} s_{e,n} + \frac{1}{2} b_{e,n} s_{e,n}^2 \right) \\ &+ \sum_{d \in D_M} \int_0^{y_{d,n}} p_{d,n}^{Im}(u)\mathrm{d}u - \sum_{e \in E \setminus E_M} \left(\sum_{d \in D_M} c_{(e,d)}^T t_{(e,d),n} + p_{e,n}^{Ex} l_{e,n}^M \right) \\ &\forall n \in N. \end{aligned} \tag{14}$$

M's total welfare is defined as export sales to consumers C less transport costs for outbound flows and production costs (first line of (14)) plus total gross consumer surplus minus transport costs for imports and procurement costs from investors I (second line of (14)). M's production capacity constraint is:

$$Cap_{e,n}^M - g_e \sum_{n' \in pred(n)} s_{e,n'} - s_{e,n} \geq 0, \qquad (\epsilon_{e,n}) \qquad \forall\, e \in E_M,\ n \in N. \tag{15}$$

The energy balance for M's production regions is:

$$s_{e,n} - \sum_{d \in D} t_{(e,d),n} \geq 0, \qquad (p_{e,n}^{Ex}) \qquad \forall\, e \in E_M,\ n \in N. \tag{16}$$

The energy balance for M's demand regions is:

$$\sum_{e \in E} t_{(e,d),n} - y_{d,n} \geq 0, \qquad (\rho_{d,n}) \qquad \forall\, d \in D_M,\ n \in N. \tag{17}$$

The energy balance for all exports of M to consumers I is:

[6] This will be explained in more detail in Section 4.

[7] We therefore neglect that M might be able to anticipate how production cost functions of investors I are affected given M's consumption and import decisions. If M decides to import more in earlier periods production costs among investors increase as the cheapest seams get exploited (modelled through equation (6)). This would increase M's cost for importing in later periods. While this mechanism seems to be worthwhile to investigate further, it is beyond the scope of this analysis.

$$\sum_{e\in E_M} t_{(e,d),n} - k^M_{d,n} \geq 0, \qquad (\sigma_{d,n}) \qquad \forall\, d\in D\backslash D_M,\ n\in N, \tag{18}$$

and the energy balance for all imports of M from investors I is:

$$\sum_{d\in D_M} t_{(e,d),n} - l^M_{e,n} \geq 0, \qquad (\delta_{e,n}) \qquad \forall\, e\in E\backslash E_M,\ n\in N. \tag{19}$$

The first-order conditions of M with respect to supply, physical trade flows and consumption are:

$$p^{Ex}_{e,n} - \epsilon_{e,n} - (a_{e,n} + b_{e,n}s_{e,n}) \leq 0 \perp s_{e,n} \geq 0, \qquad \forall\, e\in E_M,\ n\in N, \tag{20}$$

$$\sigma_{d,n} - c^T_{(e,d)} - p^{Ex}_{e,n} \leq 0 \perp t_{(e,d),n} \geq 0, \qquad \forall\, e\in E_M,\ d\in D\backslash D_M,\ n\in N, \tag{21}$$

$$\rho_{d,n} - c^T_{(e,d)} - p^{Ex}_{e,n} \leq 0 \perp t_{(e,d),n} \geq 0, \qquad \forall\, e\in E_M,\ d\in D_M,\ n\in N, \tag{22}$$

$$\delta_{e,n} - c^T_{(e,d)} - p^{Ex}_{e,n} + \rho_{d,n} \leq 0 \perp t_{(e,d),n} \geq 0, \qquad \forall\, e\in E\backslash E_M,\ d\in D_M,\ n\in N, \tag{23}$$

$$p^{Im}_{d,n}(y_{d,n}) - \rho_{d,n} \leq 0 \perp y_{d,n} \geq 0, \qquad \forall\, e\in E\ , d\in D_M,\ n\in N. \tag{24}$$

The first-order condition w.r.t export sales $k^M_{d,n}$ of M is given by:

$$p^M_{d,n} + \frac{\partial p^M_{d,n}}{\partial k^M_{d,n}} k^M_{d,n} - \sigma_{d,n} \leq 0 \perp k^M_{d,n} \geq 0, \qquad \forall\, d\in D\backslash D_M.\ n\in N, \tag{25}$$

We can now further simplify this pricing equation. We know due to equations (11) and (13) that $p^M_{d,n} = p^{Im}_{d,n}\left(y_{d,n}\right)$ if $t_{(e,d),n}$ and $y_{d,n}$ are greater zero. Both $y_{d,n}$ and $k^M_{d,n}$ can be substituted by $t_{(e,d),n}$ (see (18) and (10). As we also know the functional form of $p^{Im}_{d,n}\left(y_{d,n}\right)$, we can substitute:

$$\frac{\partial p^M_{d,n}}{\partial k^M_{d,n}} = \frac{\partial p^{Im}_{d,n}\left(\sum_{e\in E} t_{(e,d),n}\right)}{\partial k^M_{d,n}} = w_{d,n} \qquad \forall\, d\in D\backslash D_M,\ n\in N, \tag{26}$$

which is the usual result that monopolists perceive demand downward sloping and can thus extract a rent by withholding volumes. As we assumed a linear inverse demand function, M's markup is a function of the demand slope $w_{d,n}$ in each demand region. Given equilibrium condition (21) we can now rewrite (25):

$$p^{Im}_{d,n}\left(y_{d,n}\right) + w_{d,n}k^M_{d,n} - c^T_{(e,d)} - p^{Ex}_{e,n} \leq 0 \perp k^M_{d,n} \wedge t_{(e,d),n} \geq 0,\ \forall\, d\in D\backslash D_M,\ e\in E_M,\ n\in N. \tag{27}$$

The first order condition w.r.t import procurements $l^M_{e,n}$ of M is given by:

$$-\frac{\partial p_{e,n}^{Ex}}{\partial l_{e,n}^{M}} l_{e,n}^{M} - \delta_{e,n} \leq 0 \perp l_{e,n}^{M} \geq 0, \qquad \forall\, e \in E \backslash E_M,\ n \in N. \tag{28}$$

Equation (28) can be simplified in a similar manner as (26). According to (4), $p_{e,n}^{Ex}$ is, among others, a function of $s_{e,n}$. $s_{e,n}$ and $l_{e,n}^{M}$ can both be substituted through $t_{(e,d),n}$ (equations (8) and (19)) so that we may write:

$$\frac{\partial p_{e,n}^{Ex}}{\partial l_{e,n}^{M}} = \frac{\partial p_{e,n}^{Ex}\left(\sum_{d \in D} t_{(e,d),n}\right)}{\partial l_{e,n}^{M}} = b_{e,n} \qquad \forall\, e \in E \backslash E_M,\ n \in N. \tag{29}$$

Oligopsonists perceive the production cost function upward sloping and can thus extract a rent by consuming less (e.g., through implementing import taxes (Kolstad and Abbey, 1984)). For a linear marginal cost function, M's markup depends on the marginal cost slope $b_{e,n}$. Given equilibrium conditions (23) and (24), (28) may be written as:

$$p_{d,n}^{Im}\left(y_{d,n}\right) - b_{e,n} l_{e,n}^{M} - c_{(e,d)}^{T} - p_{e,n}^{Ex} \leq 0 \perp l_{e,n}^{M} \wedge t_{(e,d),n} \geq 0,\ \forall\, e \in E \backslash E_M,\ d \in D_M,\ n \in N. \tag{30}$$

The combined equilibrium conditions of investors, consumers, and the strategic player yield a unique equilibrium. The resulting set of inequalities is known as a mixed complementarity problem.

4. Computational application

To illustrate how uncertainty and demand side market power affect investors, we conduct a case study for the global steam coal market for reference years 2015 and 2020. China takes over the role of the strategic player M. Other coal importers are modelled as consumers and the major coal exporters as investors. We use a large existing database on global coal markets which has been extensively presented in Paulus and Trüby (2011); Trüby and Paulus (2011) and which has also been used by IEA (2011). Based on the present data, we make assumptions on the projected evolution of parameters such as reference demand and reference prices in consumer regions, and mining input factor prices. The model consists of more than 30 demand and export regions. A detailed overview of these parameter assumptions can be found in the Appendix.

The model has been implemented in GAMS and is solved using the PATH solver (Ferris and Munson, 1998).

4.1. Scenario tree definition

Evolution of China's demand is described by a set of scenarios which describe a wide range of possible trajectories. The basis for developing the demand scenarios is the Chinese 12th 5-Year Plan. The plan sets very challenging targets to be reached by 2015, including a reduction of energy intensity by 16% and an increase of non-fossil energy production to 11%. Most importantly, the target for economic growth was set to 7% p.a., down by 2% from the last 5-year plan (real economic growth rates were even higher, according to IMF (2011), more than 10% between 2005-2010). Chinese coal demand is driven by economic growth, energy intensity, and the ramp-up speed of renewables and other energy sources in China. Therefore, achieving the plan's targets would significantly reduce coal demand growth. However, reaching these goals would also be very challenging. Additionally, these targets are not considered 'binding' in the plan and therefore may be demoted to achieve other targets (e.g., inflation containment).

Taking the Chinese 12th 5-Year Plan as the reference scenario for the lowest coal demand evolution until 2015 (scenario node l in Figure 2), we construct two further scenarios for 2015. In one scenario, we assume economic growth to be 9% (scenario node m) and in another other scenario, we also assume 9% economic growth and additionally reduced gains in energy efficiency (scenario node h). Coal demand[8] is derived from multiplying the different GDP trajectories with energy intensity assumptions and deducting the projected expansion of renewables and other fossil fuels. The remainder of energy demand has to be covered by coal. In the next time step until 2020, we assume economic growth to either be 8% p.a. (scenario nodes hh, mh and lh) or 6% (scenario nodes hl, ml and ll). Altogether, the ten scenario nodes form six scenarios paths, which we label *s1* to *s6*. We assume realisation probabilities are uniformly distributed. A summary of the Chinese energy balances can be found in the Appendix.

The expansion of coal supply of China is outlined in the 12th 5-Year Plan. We assume that the ambitions and incentives of the Chinese coal industry to fulfil the plan's targets are a more important driver than just pure market economics. Therefore, Chinese coal supply capacity in the model follows the production targets of the 12th 5-Year Plan. Supply is projected to increase by another 30% between 2010 and 2015. This is already an ambitious target, as the Chinese coal industry is currently undergoing a profound restructuring process. Thus, China is expanding its domestic capacity at the fastest rate possible.

To compute stochastic discount factors, we assume a risk-free interest rate of 3.5%. Market returns are assumed to be correlated with Chinese economic growth. For details regarding the stochastic discount factors please refer to the Appendix.

[8]The term 'coal demand' refers to a reference coal demand that is consumed at a certain reference price. Together with an assumption on demand elasticity, it is possible to construct linear demand functions. Reference coal demand, reference prices, and elasticities for all regions are provided in the Appendix.

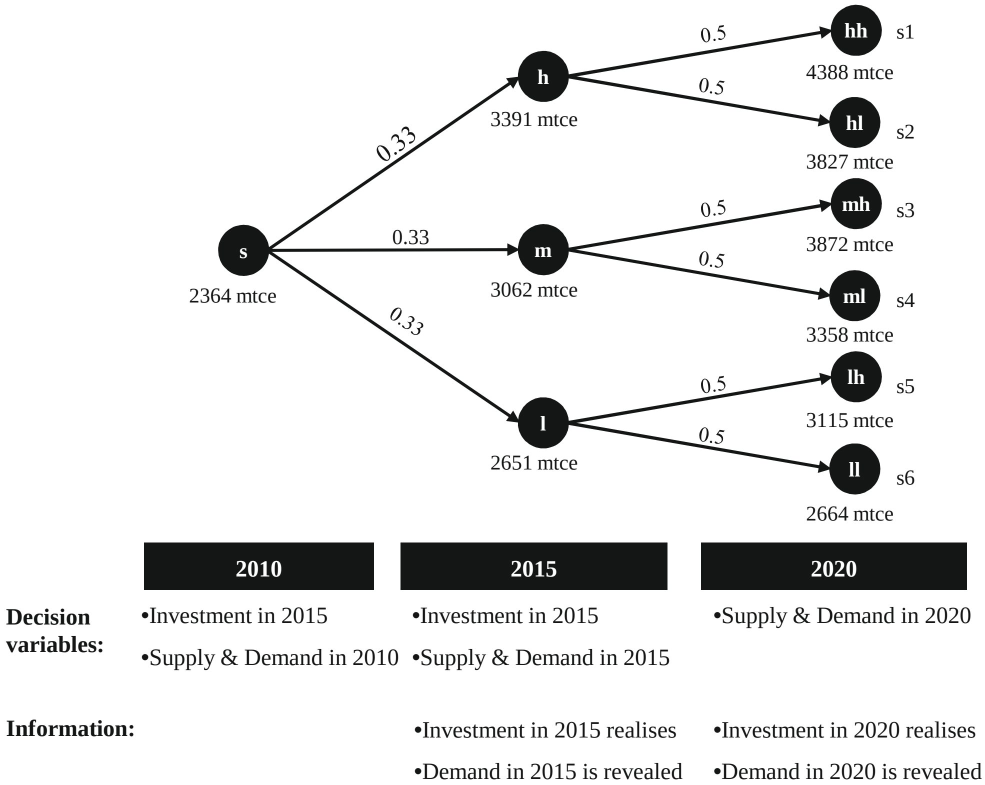

Figure 2: Scenario tree structure and information structure of the model. Demand figures are given in million tonnes of coal equivalent [mtce] and have to be understood as reference demand levels given a certain reference price.

4.2. Scenarios and outline of result discussion

For model discussion, we test two setups. In the first scenario, we assume that the strategic player M behaves as a simple price taker both on the export and the import side (*competitive setup*). Thus, M basically becomes a player of the consumer type with an attached supply base. In the second setup, M behaves as a monopolistic/monopsonistic player for exports and imports (*Monop setup*). We will structure the comparison of the scenario results into two steps. First, we will investigate how investment decisions of investors change. Second, we will analyse how costly uncertainty is for investors by computing the Value of Perfect Information (VPI). In both steps we will compare the stochastic model to its deterministic version.

5. Simulation results and discussion

Model results for investments and payoffs are summarised in Tables 2 and 3. We first compare the stochastic *competitive setup* with its deterministic equivalent. For this, we compute the expected model results under perfect information, which means we sum up the weighted outcomes of the deterministic model run for each of the scenarios *s1* to *s6* and compare them to the stochastic model run. The weighted deterministic results for the *competitive setup* are referred to as 'comp-det' and for the *Monopoly setup* as 'mon-det', respectively. The results of of the stochastic model are referred to as 'comp-stoch' and 'mon-stoch'.

5.1. Investments

Two effects are noteworthy if we look at the model results for investments: In the *competitive setup*, the expected total amount of investments of 395 mtpa does not essentially change compared to the deterministic baseline (see 'weighted sum' and lines 'comp-det.' and 'comp-stoch.' in Table 2). However, investments change with respect to their spatial as well as their temporal allocation. In the first investment stage s, total investments with 198 mtpa are 8% lower in the stochastic model compared to those of its deterministic counterpart. The investors hedge themselves against risky demand by delaying investments until a later stage where they have a higher certainty that their investments will become profitable. This effect is strengthened by the fact that investors price their systematic risk and thus emphasise asset returns of the lower demand scenario nodes higher than the ones from the higher demand nodes.

The picture becomes somewhat more complex in the second investment stage (scenario nodes l, m, and h). In scenario nodes m and h, where higher demand has been realised investors in the stochastic model catch up their investments which they have been delaying thus far. Investments in m and h are 36% and 52% higher than in the deterministic model, respectively. On the contrary, investments in the stochastic

Table 2: Investments in export capacity in mtpa, stochastic model runs and deterministic equivalents.

Countries[a]:		IR	VN	SA	CO	PL	VE	QLD	NSW	R e.	R w.	US	$\sum$
s^b	comp-det	90	11	10	32	1	10	0	59	2	0	0	**214**
(2010)	comp-stoch	76	11	0	32	0	11	0	69	0	0	0	**198**
	mon-det	30	11	0	32	0	10	0	39	0	0	0	**122**
	mon-stoch	12	11	0	32	0	11	0	20	0	0	0	**85**
l	comp-det	81	2	18	5	2	1	0	38	0	0	0	**146**
(2015)	comp-stoch	0	2	0	5	0	1	0	0	0	0	0	**8**
	mon-det	80	2	2	5	0	1	0	50	0	0	0	**140**
	mon-stoch	12	2	0	5	0	1	0	46	0	0	0	**66**
m	comp-det	50	2	35	5	7	1	34	8	31	16	8	**196**
(2015)	comp-stoch	72	2	35	5	9	1	53	7	44	24	14	**267**
	mon-det	102	2	8	5	2	1	0	32	0	0	0	**151**
	mon-stoch	132	2	35	5	4	1	0	54	0	0	0	**233**
h	comp-det	21	2	4	5	7	1	53	8	37	30	26	**194**
(2015)	comp-stoch	72	2	35	5	11	1	55	7	44	34	28	**295**
	mon-det	105	2	16	5	3	1	0	26	0	0	0	**157**
	mon-stoch	132	2	22	5	4	1	0	54	0	0	0	**219**
wtd.	comp-det	140	12	30	36	6	12	30	76	26	15	11	**395**
$\sum$	comp-stoch	127	12	25	36	7	11	38	74	31	20	14	**395**
	mon-det	126	12	8	36	2	12	0	75	0	0	0	**272**
	mon-stoch	108	12	21	36	3	11	0	72	0	0	0	**263**

[a]Country abbreviations: IR - Indonesia, VN - Viet Nam, SA - South Africa, CO - Colombia, PL - Poland, VE - Venezuela, QLD - Queensland (Australia), NSW - New South Wales (Australia), R e. - Russia east coast, R w. - Russia west coast, US - United States.

[b]Investments take place with a time lag of one time period: investment decisions taken in 2010 (scenario node s) become available in 2015 (scenario nodes l, m, and h). Investments decisions taken in 2015 become available in 2020 (scenario nodes ll, lh, ml, mh, hl and hh).

model in scenario node l, where low demand is realised, are close to zero and significantly below those of the deterministic counterpart. This is also due to the hedging decision investors faced in s; as investors do not want to forego possible returns from m and h completely, they invest at a level in s which is above the optimal value for scenario node l. In contrast, investors in the deterministic models invest 40% less in s for the low demand trajectory.

In addition to the intertemporal hedging effect changing spatial allocation of investments is also driven by a technological hedging effect. Export regions are characterised by their (linear) marginal cost function and their investment costs for capacity additions. Roughly, export regions can be classified as either belonging to a low-cost type or a high-cost type; low-cost types have low investment costs, low marginal cost intercepts but higher marginal cost slopes (marginal costs rising fast). High-cost types have high investment costs, higher marginal cost intercepts but lower marginal cost slopes. Naturally, the low-cost type regions are more suited to handle low demand scenarios and the high-cost type regions are better fitted for high demand scenarios. Of course, some regions are a mix of both types. Investors in the stochastic model invest in a portfolio of export capacities given their valuation of expected payoffs to hedge against different potential demand levels. This can be seen from the distribution of investments over regions (see lines 'comp-det.' and 'comp-stoch.' in Table 2): Indonesia and South Africa capture smaller shares of investments in the stochastic model, while investments in Queensland, Russia and the US increase by 20% to 30%.

Expected investments in the *Monopoly setup* are 272 mtpa and 263 mtpa - around 30% lower than in the *Competitive setup* (in the deterministic and in the stochastic case). In the *Monopoly setup*, China behaves in a Monopolistic fashion both on the export and the import side. Due to high demand compared to supply in practically all scenarios nodes, exports of China are mostly negligible; this means that supply-side market power potential is low. On the other hand, imports of China vary widely between the *Competitive setup* and the *Monopoly setup*, indicating the demand-side market power potential of China. This leads to a reduction of its procurements from investors, lower export prices, and thus a reduced incentive for investors to invest in new capacity. Also, the temporal hedging effect is even stronger here; in the first investment stage s, total investments are 31% lower in the stochastic model compared to its deterministic counterpart, while they were 8% lower in the *Competitive setup*.

The driver for lower investments in the *Monopoly setup* is that China accrues monopolistic rents by withholding consumption from the market. This reduces rents of investors due to lower overall seaborne demand and trade market prices (an overview of import region prices is provided in the Appendix). It is thus less attractive for investors to invest in new capacity in the *Monopoly setup*, as they anticipate that China will adjust its imports and thus reduces payback for their investments. The amount of monopolistic rents accrued by China depends on the slope of investors' marginal cost functions and the slope of the Chinese demand functions, which both vary by region.

In summary, we may therefore conclude that investors reallocate their investments spatially and temporally to hedge themselves against risky Chinese demand outcomes. However, under the assumed parameter setup, the amount of investments is not affected. On the other side, the exertion of Chinese market power in fact leads to lower investments, as China's welfare maximising strategy is to withhold foreign imports, thus lowering seaborne prices and trade market demand and making investments less profitable.

5.2. Value of Perfect Information

As described, investors in the stochastic model adapt their investment decisions to risky demand outcomes. This means that the portfolio of investment decisions generates the highest returns, given all demand scenarios and their respective realisation probabilities. However, investment decisions are not optimal with respect to each individual scenario. The associated costs are commonly referred to as the value of perfect information, or VPI[9], and are calculated by subtracting the payoff of the stochastic model from the probability weighted sum of payoffs of the deterministic models for each scenario (Birge and Louveaux, 1997). Table 3 shows the VPI as a ratio of deterministic payoffs of the different models and players.

In the *Competitive setup*, all players exhibit a positive VPI. Investors have the highest VPI, making up 17.6% of the payoffs in the deterministic models (see Table 3 section 'Comp', line 'Investors' right hand column), as they have to decide on investments under risky demand. The high costs of uncertainty for investors is explained by the range of Chinese coal demand evolutions and their underlying assumptions; as China continues to expand its coal mining capacity at the fastest rate possible, any excess demand has to be covered by imports. However, given the very large market size of China and the strong correlation between economic growth and energy demand Chinese imports vary widely, between 123 mtce in the *ll* scenario node and 519 mtce in the *hh* scenario node in the *Competitive setup.* These variations in imports are very large compared to the relatively small size of the seaborne trade market, which is composed of the investors and consumers. In the *ll* scenario node, Chinese imports make up 15% of total trade against 46% in the *hh* scenario node. As investors have to decide on their investments ex-ante, they hedge against this very large spread of Chinese import demand by delaying investments and forgoing a part of the payoffs that they would realise in the deterministic models.

The hedging effect of investors can also be seen in Table 3; the VPI for most investors is strongly *negative* in scenarios with low demand evolutions (*l*, *ll*, *ml* and *hl*), meaning that investors actually have *higher* payoffs in the stochastic model. However, the VPI for these investors is also strongly positive in the scenarios with high demand evolutions (*h*, *lh*, *mh* and *hh*). If we observe the demand scenarios belonging to each model stage ('2015', '2020'), the effect is partly netted away. Investment costs accrue in the predecessor scenario node, and investors adapt to risky demand by investing more in the low scenario nodes than in the deterministic baseline, and vice versa. As the higher investment costs are not represented in the VPI of nodes where investments are realised, the VPI in low demand nodes can be negative. Additionally, risk aversion strengthens this effect; investors maximise risk-adjusted payoff streams, which means they evaluate

[9] In the following we will use the terms *VPI* and *costs of uncertainty* interchangeably.

payoffs from 'negative' demand scenarios more highly than from more favourable demand scenarios.

At first thought, consumers and China should actually have zero costs of uncertainty, as they face static payoff maximisation problems, which means a lack of intertemporal decision variables. Nevertheless, consumers and China have a positive VPI making up 2% and 4% of deterministic payoffs, respectively. The reason for this lies in the interaction of consumers and China with the investors through imports, which leads to a spillover of costs of uncertainty from investors to the other players. Investors hedge their investment portfolio against risky demand in the stochastic model by delaying investments and changing their spatial allocation. This leads to higher costs of supply as well as a tighter trade market, which both increase imports costs for consumers and for China. The VPI is high in the high-demand scenario nodes, because investments in the stochastic model are lower than in the deterministic ones for high capacity ('s1' and 's2'). This means that capacity is scarcer and consumers are paying a higher scarcity rent for constrained export capacity to investors. Vice versa, the VPI is negative in the low-demand scenario nodes, because investments in the stochastic model are higher in this case.

If we now compare the *Monopoly setup* with the *Competitive setup*, we can observe that the distribution of costs of uncertainty among market players change. In the *Monopoly setup*, the VPI of investors makes up only 10.2% of payoffs compared to 17.6% in the *Competitive setup*. In absolute terms this difference makes up around USD_{2010}10 billion. On the other side, the VPI of China is 7.3%, significantly higher in the *Monopoly setup* compared to perfect competition. The absolute increase in VPI for China makes up USD_{2010}27 billion. Total costs of uncertainty for all market players are USD_{2010}14 billion or USD_{2010}7 billion higher in the *Monopoly setup*.

The increase of the VPI for China is driven by the risk aversion of investors; in the stochastic model, investors require a risk premium on the paybacks of their investments. This means that, in the high-demand scenario nodes, prices have to be higher to generate investments compared to the deterministic model. In other words, investment costs are basically higher. China reduces trade market prices through exertion of market power in the deterministic and the stochastic cases by withholding coal imports. However, a similar reduction of prices in the stochastic model and the deterministic model will lead to a stronger reduction of investments in the stochastic case. This effect can be also seen in the investment figures in Table 2; in scenario node 's' investments between the *Competitive setup* and the *Monopoly setup* change by -43% in the deterministic model and by -57% in the stochastic model. Lower investments in the stochastic model may lead to lower payoff for China, which is shown by the VPI.

To conclude, losses of investors due to uncertain Chinese demand are significant. Investors adapt to risky

Table 3: VPI as a ratio of deterministic payoffs in [%] (a positive number means the VPI is greater zero).

		2015			2020						
Country[a]:		l	m	h	ll	lh	ml	mh	hl	hh	sum
comp	JA	-2.6	2.9	11.0	1.3	11.2	-1.6	0.7	-0.6	1.2	1.9
	KR	-2.4	2.7	10.3	1.2	10.5	-1.5	0.7	-0.6	1.1	1.8
	TW	-2.4	2.7	10.1	1.1	10.3	-1.4	0.7	-0.6	1.1	1.8
	OA	-2.2	2.5	9.5	1.1	9.8	-1.4	0.6	-0.6	1.0	1.8
	IN	-2.6	3.0	11.2	1.3	11.5	-1.6	0.7	-0.7	1.3	2.4
	EU	-3.0	3.4	12.9	1.5	12.0	-1.8	0.9	-1.7	1.4	2.2
	US	-3.1	3.5	13.0	1.5	12.1	-1.8	0.9	-1.6	1.5	1.0
	LA	-3.1	3.5	13.1	1.5	12.2	-1.8	0.9	-1.5	1.5	2.3
	Consumer	-2.6	3.0	11.2	1.3	11.1	-1.6	0.7	-0.9	1.2	**2.0**
mon	JA	0.5	2.2	2.6	3.9	6.6	-2.0	-1.0	-0.4	-0.2	1.0
	KR	0.5	2.0	2.5	3.7	6.2	-1.9	-0.9	-0.4	-0.2	0.9
	TW	0.5	2.0	2.4	3.6	6.0	-1.8	-0.9	-0.3	-0.2	0.9
	OA	0.4	1.9	2.3	3.4	5.7	-1.7	-0.9	-0.3	-0.2	0.9
	IN	0.5	2.2	2.7	3.9	6.7	-2.0	-1.0	-0.4	-0.2	1.2
	EU	0.6	2.6	3.1	4.3	7.6	-1.7	-1.2	-0.4	-0.3	1.2
	US	0.6	2.6	3.1	4.3	7.6	-1.3	-1.1	-0.4	-0.3	0.6
	LA	0.6	2.6	3.1	4.3	7.7	-1.4	-1.2	-0.5	-0.3	1.3
	Consumer	0.5	2.2	2.7	3.9	6.7	-1.9	-1.0	-0.4	-0.2	**1.1**
comp	IR	-106.3	75.8	28.0	-16.9	49.8	2.1	61.8	-9.1	61.7	17.9
	AU	-102.1	73.5	6.6	-19.9	36.7	0.9	61.8	-9.5	61.6	18.3
	VN	-74.2	74.5	18.1	-19.3	43.7	30.0	62.0	20.8	61.9	18.1
	RU	-18.4	69.8	-8.7	-56.2	-8.9	-19.9	62.1	-10.4	61.2	18.9
	SA	-86.2	72.9	45.4	-21.6	58.8	-3.0	61.8	-8.9	61.7	18.3
	CO	-72.6	74.3	16.2	-19.9	44.0	-2.8	61.8	-4.7	61.8	14.3
	US	-26.6	70.3	-54.7	-46.5	-20.1	-10.7	59.6	-15.3	65.1	16.3
	PL	-85.8	75.0	51.5	-29.4	53.2	-4.8	60.3	-5.3	60.8	20.9
	VE	-66.0	73.6	11.9	-24.0	37.0	13.5	61.6	36.5	61.6	20.0
	Investors	-88.3	74.4	20.0	-20.1	43.5	1.0	61.8	-6.5	61.8	**17.6**
mon	IR	-115.6	77.1	37.9	-23.6	59.0	-0.7	65.3	-9.3	63.2	10.7
	AU	-98.7	77.8	41.0	-47.4	44.2	6.0	65.6	-8.9	63.3	12.3
	VN	-98.6	74.9	30.9	-36.9	49.5	0.0	64.7	-9.5	63.2	9.4
	RU	-112.0	72.0	19.9	-155.7	23.9	-2.3	65.0	-9.2	63.2	6.7
	SA	-103.0	78.0	30.2	-43.0	49.0	-28.6	54.7	-17.8	61.4	6.1
	CO	-98.8	74.8	30.6	-36.3	49.2	-4.3	64.7	-9.6	63.2	9.6
	US	-108.9	72.8	25.7	-129.2	-2.6	24.6	65.0	-8.2	63.4	16.0
	PL	-116.7	80.0	21.2	-65.7	43.4	-16.7	60.2	-21.2	62.0	5.4
	VE	-100.2	74.1	28.5	-50.9	42.4	-1.1	65.5	-8.8	63.3	9.1
	Investors	-105.8	76.2	34.5	-38.9	50.0	-1.7	64.3	-10.0	63.0	**10.2**
comp	CH	-4.4	5.7	9.3	-1.0	12.3	-1.6	9.2	-1.2	13.2	**3.6**
mon	CH	-13.3	19.4	16.2	-1.5	19.2	-3.2	19.6	-3.6	26.3	**7.3**

[a]Country abbreviations: JA - Japan, KR - South Korea, TW - Taiwan, OA - Other Asia, IN - India, EU - Europe, US - United States, LA - Latin America. Scenario abbreviations: comp - *Competitive setup*, mon - *Monopoly setup*.

Chinese demand evolutions through different investment plans. This adaption process comes at a price; investors' rents are around 18% lower than in the deterministic baseline. Total costs of uncertainty slightly increase if we account for Chinese market market power. Interestingly though, it seems that monopsonistic behaviour causes that costs of uncertainty are transferred from the investors' side to China. The exertion of market power reduces investor's profitability, and therefore investments, significantly more in the stochastic model due to the increase of costs of capital for investments compared to the deterministic case. Overall reduced investment activity raises prices and thus also affects consumer rents in China.

6. Conclusions

The optimal timing and sizing of investments given uncertain future market evolutions is an important challenge for capital-intensive industries. This decision problem gets even more complex if we account for demand-side market power. We empirically investigated these questions for investors in the global steam coal market. In this market, investors currently face high uncertainty with respect to future evolution of Chinese import demand. Additionally, China has realigned its resource strategy in recent years and keeps coal imports and exports under tight control through quotas and taxes.

In the scope of this paper, we develop a multi-stage stochastic equilibrium model which allows us to model uncertain Chinese demand in extensive form and where all players maximise their individual payoff functions either subject to a price-taking strategy or a setting in which a single player behaves as a monopolist/monoposonist and the other players act as competitive fringe. The model accounts for risk aversion in the CAPM sense by implementing the concept of stochastic discount factors. We use an established large coal market database and empirically test for four hypotheses regarding the change of investment plans and changes of the VPI. We find that accounting for uncertainty will make investors hedge their investment decisions by delaying investments and by spatially reallocating them. This results in costs of uncertainty for investors of 18% in relation to their deterministic payoffs. If we enable China to exert market power, trade market prices will be lower, thus leading to lower investments into export capacity. Chinese market power also increases the total costs of uncertainty and its allocation among players. In such a setup, costs of uncertainty are higher for China as withholding consumption leads to a comparatively stronger reduction of investments due to risk-averse investment behaviour of investors.

The results show that delaying of additional capacity investments even if faced with probably rapidly rising coal demand is a consistent strategy for coal exporting nations in an economic sense. Such delays are hard to identify in the real world but might already be observable in recent investment figures (ABARES, 2005-2011). Uncertain Chinese coal import demand increases the capital costs for coal mining investments significantly, which may lead to lower investment activity and bottlenecks in the export supply chain. Exporters accrue scarcity rents in the short run in this case, which may help to explain the high margins in the coal mining business in recent years (IEA, 2007-2011).

For China it would actually be beneficial to try to reduce uncertainty in the market as it will also be affected by the related costs. This is especially true if it chooses to make use of its demand-side market power potential. While this may seem difficult even for Chinese government executives, more transparency in general on Chinese micro- and macroeconomics might help market players to better foresee Chinese coal demand. This is especially true for data availability of Chinese domestic coal consumption and supply.

Further research could focus on two-sided market power where investors also follow non-competitive strategies, or on testing other concepts of risk aversion.

Appendix

Table 4: Scenario tree data and stochastic discount factors.

Year	**2009**	**2015**			**2020**					
scenario node		**l**	**m**	**h**	**ll**	**lh**	**ml**	**mh**	**hl**	**hh**
GDP bn \$ (2009 PPP)	9449	14602	16019	16287	18636	20480	21436	23536	21796	23932
Intensity (gce/\$ PPP)	343	288	288	309	245	245	245	245	262	262
TPED (mtce)	3241	4208	4616	5028	4564	5016	5250	5765	5720	6280
fossil (mtce)	2986	3745	4154	4566	3880	4331	4567	5081	5036	5597
coal (mtce)	2175	2651	3062	3474	2671	3123	3358	3872	3827	4388
non-fossil (mtce)	255	462	462	462	684	684	684	684	684	684
market returns	1.00	0.80	1.25	1.50	0.90	1.30	0.90	1.30	0.90	1.30
Stoch. discount factor	1.00	1.84	0.86	0.31	1.5	0.5	1.5	0.5	1.5	0.5

Table 5: Supply assumptions.

	a	b	Cap	c^{Inv}	mine life	g	h	Cap^{max}
Shanxi	61.11	0.28	117	189	20	0.05	-0.001	180
Shaanxi	56.45	0.27	106	203	20	0.05	-0.0009	240
Quinhuangdao	82.73	0.09	354	163	20	0.05	-0.0001	650
Other	70.00	0.59	36	224	20	0.05	-0.003	150
Shandong	82.73	0.16	118	178	20	0.05	-0.0005	150
IR	35.71	0.18	203	129	15	0.07	-0.0003	320
QLD	66.67	0.56	50	240	20	0.05	-0.0025	100
NSW	55.56	0.19	86	172	20	0.05	-0.0005	150
VN	40.83	0.45	26	128	20	0.05	0	35
RU east	83.33	0.58	29	172	20	0.05	-0.006	70
RU west	78.36	0.42	62	204	20	0.05	-0.002	90
SA	40.83	0.67	61	222	20	0.05	-0.005	90
CO	27.78	0.50	67	150	20	0.05	-0.004	95
APP1	72.22	0.99	23	200	20	0.05	-0.009	55
APP2	94.44	1.23	23	244	20	0.05	-0.015	70
PL	81.67	2.72	4	210	20	0.05	0	15
VE	50.00	1.00	10	110	20	0.05	-0.01	20

Table 6: Demand assumptions (Elasticity e, reference demand D_{ref} and reference price p_{ref}).

scenario	s	s	s	l	l	l	m	m	m	h	h	h	ll	ll	ll
demand region	e	D_{ref}	p_{ref}	e	D_{ref}	p_{ref}	e	D_{ref}	p_{ref}	e	D_{ref}	p_{ref}	e	D_{ref}	p_{ref}
Shandong	-0.3	308	123	-0.3	345	143	-0.2	398	143	-0.3	452	143	-0.3	348	166
Jiangsu	-0.3	232	127	-0.3	261	148	-0.2	301	148	-0.3	342	148	-0.3	263	171
Zhejiang	-0.3	117	127	-0.3	131	148	-0.2	151	148	-0.3	172	148	-0.3	132	171
Guangdong	-0.3	41	134	-0.3	46	155	-0.2	53	155	-0.3	60	155	-0.3	46	180
Fujian	-0.3	58	134	-0.3	65	155	-0.2	75	155	-0.3	86	155	-0.3	66	180
JA	-0.3	119	121	-0.3	124	140	-0.3	124	140	-0.3	124	140	-0.3	130	162
KR	-0.3	76	127	-0.3	80	148	-0.3	80	148	-0.3	80	148	-0.3	84	171
TW	-0.3	48	129	-0.3	50	150	-0.3	50	150	-0.3	50	150	-0.3	53	174
OA	-0.3	34	134	-0.3	45	156	-0.3	45	156	-0.3	45	156	-0.3	51	180
IN-West	-0.3	23	119	-0.3	57	138	-0.3	57	138	-0.3	57	138	-0.3	85	160
IN-East	-0.3	23	119	-0.3	57	138	-0.3	57	138	-0.3	57	138	-0.3	85	160
EU-MED	-0.3	37	107	-0.3	37	124	-0.3	37	124	-0.3	37	124	-0.3	33	144
EU-ARA	-0.3	80	107	-0.3	82	124	-0.3	82	124	-0.3	82	124	-0.3	74	144
EU-East	-0.3	42	107	-0.3	53	124	-0.3	53	124	-0.3	53	124	-0.3	53	144
US	-0.3	13	105	-0.3	3	122	-0.3	3	122	-0.3	3	122	-0.3	3	141
CA	-0.3	2	105	-0.3	1	122	-0.3	1	122	-0.3	1	122	-0.3	1	141
LA	-0.3	16	105	-0.3	19	122	-0.3	19	122	-0.3	19	122	-0.3	21	141
scenario	lh	lh	lh	ml	ml	ml	mh	mh	mh	hl	hl	hl	hh	hh	hh
demand region	e	D_{ref}	p_{ref}	e	D_{ref}	p_{ref}	e	D_{ref}	p_{ref}	e	D_{ref}	p_{ref}	elasticity	D_{ref}	p_{ref}
Shandong	-0.3	406	166	-0.3	437	166	-0.3	504	166	-0.2	498	166	-0.3	571	166
Jiangsu	-0.3	307	171	-0.3	330	171	-0.3	381	171	-0.2	376	171	-0.3	432	171
Zhejiang	-0.3	154	171	-0.3	166	171	-0.3	191	171	-0.2	189	171	-0.3	217	171
Guangdong	-0.3	54	180	-0.3	58	180	-0.3	67	180	-0.2	67	180	-0.3	76	180
Fujian	-0.3	77	180	-0.3	83	180	-0.3	95	180	-0.2	94	180	-0.3	108	180
JA	-0.3	130	162	-0.3	130	162	-0.3	130	162	-0.3	130	162	-0.3	130	162
KR	-0.3	84	171	-0.3	84	171	-0.3	84	171	-0.3	84	171	-0.3	84	171
TW	-0.3	53	174	-0.3	53	174	-0.3	53	174	-0.3	53	174	-0.3	53	174
OA	-0.3	51	180	-0.3	51	180	-0.3	51	180	-0.3	51	180	-0.3	51	180
IN-West	-0.3	85	160	-0.3	85	160	-0.3	85	160	-0.3	85	160	-0.3	85	160
IN-East	-0.3	85	160	-0.3	85	160	-0.3	85	160	-0.3	85	160	-0.3	85	160
EU-MED	-0.3	33	144	-0.3	33	144	-0.3	33	144	-0.3	33	144	-0.3	33	144
EU-ARA	-0.3	74	144	-0.3	74	144	-0.3	74	144	-0.3	74	144	-0.3	74	144
EU-East	-0.3	53	144	-0.3	53	144	-0.3	53	144	-0.3	53	144	-0.3	53	144
US	-0.3	3	141	-0.3	3	141	-0.3	3	141	-0.3	3	141	-0.3	3	141
CA	-0.3	1	141	-0.3	1	141	-0.3	1	141	-0.3	1	141	-0.3	1	141
LA	-0.3	21	141	-0.3	21	141	-0.3	21	141	-0.3	21	141	-0.3	21	141

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EWI is a so called An-Institute annexed to the University of Cologne. The character of such an institute is determined by a complete freedom of research and teaching and it is solely bound to scientific principles. The EWI is supported by the University of Cologne as well as by a benefactors society whose members are of more than forty organizations, federations and companies. The EWI receives financial means and material support on the part of various sides, among others from the German Federal State North Rhine-Westphalia, from the University of Cologne as well as – with less than half of the budget – from the energy companies E.ON and RWE. These funds are granted to the institute EWI for the period from 2009 to 2013 without any further stipulations. Additional funds are generated through research projects and expert reports. The support by E.ON, RWE and the state of North Rhine-Westphalia, which for a start has been fixed for the period of five years, amounts to twelve Million Euros and was arranged on 11th September, 2008 in a framework agreement with the University of Cologne and the benefactors society. In this agreement, the secured independence and the scientific autonomy of the institute plays a crucial part. The agreement guarantees the primacy of the public authorities and in particular of the scientists active at the EWI, regarding the disposition of funds. This special promotion serves the purpose of increasing scientific quality as well as enhancing internationalization of the institute. The funding by the state of North Rhine-Westphalia, E.ON and RWE is being conducted in an entirely transparent manner.