Two-Sided Matching in Coal Mining and Power Generation

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Contributor: Di Wang

Under the current marketized coal and planned electricity price systems, barriers to price shifting between coal and electricity are created and conflicts between the two sectors are aggravated. The stable trading matching between coal mining and power generation companies is not only an effective means to resolve the conflict in the coal trading market, but also a ballast stone for price stabilization and supply guarantees in coal trading.

Keywords: coal mining and power generation companies ; two-sided matching ; stable trading ; mechanism and algorithm ; stability and sensitivity

1. Introduction

Coal is the most important energy source in China, a country with a prominent coal-dominated energy structure. Power generation companies are the largest customers of the coal industry; there is a high degree of interdependence between coal and electrical power [1]. However, there are double price regulations in the coal and electricity markets: market-based coal pricing and regulated electricity pricing. The different degrees of the marketization of coal and electricity have created barriers to price shifting between coal and electricity and have aggravated the conflict between the two sectors [2]. In recent years, both the coal mining and power generation industries have seen over-production capacity and unstable markets. Trading conflicts between the two sectors continue to grow. In January 2018, four large power generation conglomerates in China bemoaned their predicament by submitting an urgent report to the National Development and Reform Commission on the grave situation of coal supply for power generation companies. In November 2019, 11 giant coal mining companies in China, including the China Energy Investment Corporation, issued a joint statement to advocate for stabilizing the coal supply and price. The statement called for smoothing the abnormal price fluctuations and introducing a credit rating system for firms in order to ensure that coal prices remained within the green zone. In April 2020, the Fuel Branch of China Electricity Council held a meeting to coordinate the signing of the 2020 medium- and long-term contracts for coal to be shipped through marine transport. The meeting aimed to address the coal supply issues that occurred during the early days of the COVID-19 pandemic, including the supply shortages, price increases, and certain coal mining companies ceasing to supply coal under their long-term contracts.

Given the unstable coal and electricity markets and the conflicts between coal mining and power generation companies, the government frequently identifies policies to help to smooth the operations of the two sectors [3]. However, there are significant barriers for central government-owned power generation companies and coal mining companies to execute the “long-term contract price”, which is set mainly through governmental interference [4]. Market fluctuations lead to conflicts between the two prices that are in play at the same time: the market-based price and the long-term contract price. Due to the “wait-and-see” attitude of both of the sides of the negotiations, agreements are difficult to reach and the outcomes of the execution are less ideal. In 2016, the State-owned Assets Supervision and Administration Commission of the State Council in China issued an arrangement for ensuring the long-term and stable collaboration between central government-owned coal mining and power generation companies in an effort to improve the long-term collaboration mechanism between the two sectors. From 2017 to 2021, the General Office of the National Development and Reform Commission issued a notice on improving the signing and execution of medium- and long-term coal trading contracts; this was aimed at enforcing certain regulations in order to ensure the smooth operation of the medium- and long-term contracts between coal mining and power generation companies. However, under the government-dominated trading mechanism, coal price fluctuations always increase uncertainty in the negotiations; it is impossible to reach agreements that satisfy both sides of the trade and the execution of the contracts is difficult. As a result, the long-term, stable growth of coal mining and power generation companies is undermined.

Since the coal mining and power generation companies—the two important sectors in the supply chain—are always clashing with each other, the government encourages the firms in the two sectors to develop joint ventures [5]. In May 2019, China's National Development and Reform Commission, the Ministry of Industry and Information Technology, and the National Energy Administration issued a joint policy, *Strategies for Absorbing Surplus Coal Production Capacity*. This policy continues to encourage coal mining and power generation companies to jointly invest in projects that integrate coal mining and power generation; it also encourages the coal mining and power generation companies to hold each other's stocks and to exchange stocks in order to formulate joint coal–electricity operations. These joint operations are intended to internalize the external conflicts, thereby easing the clashes between the two sectors. The government supervisory authorities have placed high expectations on this approach.

Despite the governments' continuous pushing through of policy statements for joint coal–electricity operations in recent years, the results have fallen short of expectations. The most important reason behind this failure is that the two sectors operate in two incompatible systems with different degrees of marketization. The initiative of joint coal–electricity operations is more of a government requirement than a business decision that was formed voluntarily by coal mining and power generation companies to secure long-term coal supply and stable sales [6]. Due to lack of a shared interest, the bond within the joint operation is weak.

2. Proposition of Two-Sided Matching Theory

The two-sided matching issue was first raised in the paper *College Admissions and the Stability of Marriage* by Gale and Shapley (the latter author being a joint winner of the 2012 Nobel Memorial Prize in Economic Sciences). This paper discussed the decision-making issues in marriage matching and matching between colleges and applicants. It marked the beginning of the research on two-sided matching theory. The deferred acceptance algorithm that was proposed by Gale and Shapley was the pilot of the two-sided matching theory. In their paper, Gale and Shapley examined matching for marriages, supposing that a certain community consists of m women and n men. Each person ranks those of the opposite sex in accordance with his or her preferences for a marriage partner. How to achieve a set of stable marriages and optimal satisfaction for both sides was the emphasis of the research on marriage matching. Based on cooperative game theory, Shapley proposed the stable assignment theory and the deferred acceptance algorithm. The focus of the theory is on how not to upset the current matching arrangement and how to maintain the stability of the matches [7]. Building on the analysis of marriage matching that was performed by Gale and Shapley, Roth, a Harvard professor, first proposed the "two-sided matching" concept and identified the practical applications of stable matching theory and its algorithm. Following this, more scholars have turned their research interests to the study of two-sided matching theory. Based on the study of marriage matching, researchers have made theoretical improvements to the Gale–Shapley (G–S) algorithm for two-sided matching and expanded it in light of real situations [8].

3. Development of Two-Sided Matching Theory

Over the 50-plus years from the proposition of the two-sided matching theory in 1962, a large body of literature on this subject has been developed. The evolution of the theory and the new developments in its application can be summarized as representing three themes: first, the traditional research on two-sided theory that was presented by Gale and Shapley (1962), in which money is not involved; second, the research that was presented by Shapley and Shubik (1972) and Kelso and Crawford (1982), wherein money was introduced into the theory; and third, the research on the theory of matching with contracts, as presented by Hatfield and Milgrom (2005), which incorporated the two-sided matching theories with and without money into one framework [9][10][11]. In a two-sided matching market where no money exists, stability is the most important element. Orders of preferences or orders of priority are the basis for the matching between the two sides and the deferred acceptance—the key feature of the G–S algorithm—ensures matching stability in the market. Shapley and Shubik (1972) creatively identified another research perspective and developed a new theoretical matching model that is referred to as the "assignment game model". Under this model, the two-sided matching market that contains money is defined and money is used to measure the utility in the market. The introduction of money connects two-sided matching theory with auction theory and competitive equilibrium theory. As one of the most important developments in matching theory over the past two decades, the theory of matching with contracts is at the forefront of the research on two-sided matching theory. This theory integrates the two-sided matching problem into markets with and without money [12].

The continuous introduction of money and contracts into traditional two-sided matching models makes the theory more applicable to reality. The progress in the research on two-sided matching is not only demonstrated by the continuous evolution of the matching model, this research has also advanced market design and expansion. Examples include the matching between colleges and applicants, job matching in the labor market, matching kidney transplant donors and recipients, auctions of vehicle licenses, ratio spectrums, and internet advertisements. The stable matching concept

originated first from practice and then its theoretical development followed. The earliest example of its practice was the National Resident Matching Program (NRMP), which was adopted in 1952 in the United States. Stable matching theory has now been applied to a range of academic subjects and markets. It has also been successfully adopted in a wide array of places, such as Canada, Britain, South Korea, the Netherlands, and Hong Kong.

4. Research on the Stable Matching Mechanism

The major research focus of the international academic community on stable matching mechanisms has been to develop economic theories that are based on matching stability and the deferred acceptance procedure. Stability is critical for the participants to make their choices while considering the choices of the others in the two-sided market. Roth (2008) pointed out that, although the algorithms that are used by the centralized clearinghouse had been improved multiple times so as to meet the evolving needs of hospitals and medical students, stability remained the key to the success of the matching mechanism; the deferred acceptance procedure, in turn, is critical to matching stability and many matching mechanisms have been designed based on this procedure [13]. Lee (2017) found that incentive compatibility extends to many-to-one matching when the agents employ truncation strategies and capacity manipulations in a Gale–Shapley mechanism [14]. Alimudin and Ishida (2022) proposed a matching–updating mechanism which is a solution for the stable marriage problem with dynamic preferences [15]. Research on stable matching mechanisms can be sorted into three categories: one-to-one matching, many-to-one matching, and many-to-many matching.

A one-to-one matching mechanism is also referred to as the marriage matching mechanism because it resembles the matching that is required for monogamous heterosexual marriages: each participant on one side can only match with one participant on the other side. The one-to-one matching mechanism is the most classical matching model in two-sided matching theories and scholars have conducted considerable research on this topic.

The many-to-one matching mechanism is also referred to as the college admission matching mechanism, another subject on which many scholars have performed in-depth studies. Roth and Sotomayor (1989) compared the marriage matching mechanism with the college admission matching mechanism and pointed out that the two cannot be viewed as equivalent, as the college admission mechanism only retains the main features of the marriage matching mechanism [16].

The many-to-many matching mechanism is also referred to as the worker–firm matching mechanism. As the depth of the research has been extended, scholars have generalized the marriage matching mechanism and the college admission matching mechanism, expanding the research to the many-to-many problem [17]. Worker–firm matching is a typical many-to-many matching model. In comparison to many-to-one and one-to-one matching, there is less research devoted to many-to-many matching, but this is mainly due to the sequence of theoretical development, not because the many-to-many market is unimportant.

5. Applications of Two-Sided Matching Theory

In recent years, two-sided matching theory has been extended to a few applications. Jiang et al. (2016) proposed an optimal matching approach for one-shot multiattribute exchanges with simultaneous fuzzy information and indivisible demand considerations [18]. Wang et al. (2017) presented mathematical programming approaches to quickly find good stable or nearly stable matchings for single-rider, single-driver dynamic ridesharing [19]. Gao et al. (2017) formulated the cooperative spectrum sharing between multiple PUs and multiple SUs as a two-sided market and studied the market equilibrium under both complete and incomplete information [20]. Wang et al. (2020) applied the lexicographical method in order to solve the multi-objective linear programming model so as to obtain the optimal bilateral transaction matching pair [21]. Lee et al. (2020) proposed an app-matching system and generalized deferred acceptance algorithms so as to match mobile applications with users [22]. Yang et al. (2021) presented a two-sided matching framework in order to model the resource allocation among customers and manufacturers and leveraged the stable matching algorithm to optimize the matches between customers and AM providers [23]. Shurrab et al. (2021) showed a realistic modelling of the V2V energy sharing problem and proposed a two-layer matching approach that can efficiently match the EVs [24].

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