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Analysis of the Competition Network of Industrial Waste Emissions in Beijing, China

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ABSTRACT

Beijing is facing an increasing threat from environmental problems. Since the environment is a public resource, waste emissions from industries are non-competitive and non-exclusive, which indicates that there are competition relationships among industries in Beijing. In order to investigate these relationships in quantity, this paper employs a 2-mode network method to construct a competition network of Beijing's industries using data for 2011 and then analyses the competition network using network indices. Five kinds of wastes are considered: wastewater, waste gas, common solid waste, waste dust and hazardous emissions. Our main findings include: the manufacture of raw chemical materials and chemical products and the manufacture of non-metallic mineral products are under intense emission competition in Beijing. Industries are divided into three groups by waste emission. Two industries mainly discharge hazardous waste; six industries mainly discharge wastewater; and the remaining 12 industries discharge waste dust, common solid waste and waste gas. These relationships should be considered in industrial planning, and industries that discharge similar waste types should not be located close together.

INTRODUCTION

Beijing is facing an increasing threat from environmental issues, with waste emissions by industries contributing a great deal to these problems. Analysing industrial waste emissions helps ascertain the source of environmental problems, and is also useful in industrial planning.

There are some researchers that focus on industrial emissions (Vermeer 1998, Fillaudeau et al. 2006, Birdsall et al. 1993, Hettige et al. 2000, Boznar et al. 1993, Porter et al. 2002, Kudo & Miyahara 1991). Most of these papers focus on one industry or some industries without considering the relationship of emission among different industries. Since the environment is usually treated as a public resource, waste emissions from industries are non-competitive and non-exclusive. In the field of environmental economy, researchers often introduce the notion of externality when discussing the waste emissions of industries or companies. There are two kinds of externality: positive externality and negative externality. Waste emissions from industries are negative externalities, which result in detrimental effects and harm to the general public. Therefore, there are competition relationships among industries. A quantitative investigation into these competition relationships assists with the formulation of prudent environmental management policies.

In order to research the competition relationships among industrial waste emissions in quantity, this paper builds a waste emission competition network among Beijing's industries. In this model, the following emissions are considered: waste water (WW), waste gas (WG), waste dust (WD), common solid waste (CSW) and hazardous waste (HW). Based on the emission data for Beijing's industries for the year of 2011, a 2-mode network and a 1-mode network are built based on 2-mode network theory.

The 2-mode network is a method of complex network theory. There are two kinds of nodes in 2-mode networks: actors and groups. The possible application of a 2-mode network analysis is wide, including cooperation networks and competition networks. Cooperation networks and competition networks are the two most common networks in human society. The most famous application of a 2-mode network is the study of class and race by Davis et al. (2009). Other examples of use include studies into the interrelationships of competencies within specialities in a large multi-disciplinary national laboratory (Mote et al. 2005), the development of sexually transmitted infection prevention strategies (Niekamp et al. 2013), 2-mode networks of software bugs and contributors (Conaldi & Lomi 2013), self-assembly mechanisms of ad hoc project teams (Zhu et al. 2013), and interlocking world city network (Liu 2012). In articles based on 2-mode networks, researchers often transfer 2-mode networks to 1-mode networks as it is of considerable use to work on cooperation or competition networks among the same type of nodes.

This paper attempts to analyse the waste emission competition network among industries in Beijing using a 2-mode network. Through this study, we aim to find the answers to the following questions: which industries have a close relationship because of similar emissions, and how many industry groups does Beijing have? Based on these results, we can identify which industries should no longer be supported in Beijing, and which industries are reasonably similar in their emissions, and hence should not be located close together.

METHODOLOGY

This paper utilizes a 2-mode network as its basic methodology. In typical networks, the nodes in them are of same type. However, in a 2-mode network the nodes are different entities, as 2-mode data refer to data recording ties between two sets of entities. A 2-mode case arises when researchers collect relations between classes of actors, such as persons and organizations, or persons and events. In this paper, the two types of nodes in the 2-mode network are industries and emissions. We use industries as one node type and five kinds of emission as the other. The emission relationship among industries and emissions are edges.

Source data: Data used in this paper can be found in the China Statistical Yearbook on Environment 2012 (National Bureau of Statistics of China 2012), where main waste emissions of 40 industries are provided. Five kinds of emissions and discharges are analysed in this paper: industrial waste water (WW), industrial waste gas (WG), industrial waste dust (WD), common industrial solid wastes (CSW), and hazardous wastes (HW).

Table 1 shows the waste emissions of 40 industries in Beijing for the year 2011. From Table 1 we can see that the manufacture of paper and paper products discharges 3.82 billion tons of wastewater, which is the top contributor to Beijing's wastewater discharge. Besides this industry, the manufacture of raw chemical materials and chemical products and manufacture of textiles are the other main contributors to wastewater. As for waste gas, the production and supply of electric power and heat power and the smelting and pressing of ferrous metals are the main emission sources of waste gas. The manufacture of non-metallic mineral products, the production and supply of electric power and heat power, and the smelting and pressing of ferrous metals are the three main emission sources of waste dust. The mining and processing of ferrous metal ores and the production and supply of electric power and heat power are the main emission sources of common solid waste. Lastly, the manufacture of paper and paper products, the mining and processing of non-metal ores, and the manufacture of raw chemical materials and chemical products are the main emission sources of hazardous waste.

Data processing: 2-mode networks consist of two types of nodes. This is also called a membership network or competition network. In this paper, a waste emission network is built to show the emission competition among industries in Beijing. In this 2-mode network, industries are listed as rows and the different waste types are listed as columns (as in Table 1). If industry *i* discharges waste *k*, then there is an edge between this industry and the waste.

According to the source data, every industry discharges waste. However, the amounts are different. Therefore, a threshold is used before building the network to focus on the main emission relationships. The threshold used in this paper is 90% of total emissions. Firstly, we ranked industries by their emission of waste *k* in reverse order. Then we calculated the fraction of each industry using eq. (1), where fr_{ik} is the fraction of industry *i* (*i*=1, 2, …, 40) in the emission of waste *k* (k=1, 2, …, 5), and a_{ik} is the amount of waste *k* that is discharged by industry *i*.

$$fr_{i,k} = \frac{a_{ik}}{\sum_{i=1}^{40} a_{ik}} \quad ...(1)$$

It is noteworthy that industries are ranked by their emission of waste *k*, so that:

$$a_{ik} > a_{i+1,k} \geq 0 \quad ...(2)$$

$$fr_{i,k} \leq fr_{i+1,k} \quad ...(3)$$

Then we calculate the cumulative fraction ($Fr_{i,k}$) of waste *k* discharged by industries :

$$Fr_{i,k} = \sum_{i=1}^{i} fr_{i,k} = \sum_{i=1}^{i} \frac{a_{ik}}{\sum_{i=1}^{40} a_{ik}} \quad ...(4)$$

Furthermore, we have the following relationship since industries are ranked by the amount of waste *k* emitted:

$$Fr_{i,k} \leq Fr_{i+1,k} \quad ...(5)$$

We use 90% as our threshold, which means the former *i* industries are considered the main contributor of emission *k* while other industries are not. In other words, only these *i* industries have a connection with waste *k*. We repeat this process for the five kinds of wastes and the relationship matrix of waste emission can then be obtained.

The 2-mode network build in this paper is shown in Fig. 1. The red node indicates different kinds of emission while

Table 1: Waste emissions from 40 industries in Beijing, 2011.

	WW	WG	WD	CSW	HW
Mining and washing of coal	143493	2039	208876	34988	0.30
Extraction of petroleum and natural gas	8172	1342	16507	124	35.89
Mining and processing of ferrous metal ores	22643	2865	121655	69085	6.85
Mining and processing of non-ferrous metal ores	51181	243	14640	37419	109.90
Mining and processing of non-metal ores	6191	613	56466	3737	723.12
Ancillary activities for exploitation	1054	75	2758	267	0.68
Mining of other ores	247	10	215	9	
Processing of food from agricultural products	138116	5473	202114	1987	0.43
Manufacture of foods	51950	2351	69643	610	2.34
Manufacture of wine, drinks and refined tea	71664	2218	74457	1006	0.12
Manufacture of tobacco	2090	542	5904	58	0.02
Manufacture of textile	240802	4342	101440	673	3.68
Manufacture of textile, wearing and apparel	19878	643	8792	47	0.07
Manufacture of leather, fur, feather and related products and footwear	25785	409	12977	64	2.86
Processing of timber, manufacture of wood, bamboo, palm, and straw products	3522	3258	204574	344	0.10
Manufacture of furniture	735	285	2864	13	0.24
Manufacture of paper and paper products	382265	17094	207497	2483	745.67
Printing, reproduction of recording media	1303	251	1793	22	1.09
Manufacture of articles for culture, education and sport activity	1937	217	2151	6	0.99
Processing of petroleum, coking, processing of nuclear fuel	79587	21762	458741	3951	192.13
Manufacture of raw chemical materials and chemical products	288331	31205	657009	26548	642.58
Manufacture of medicines	48586	3604	48427	309	55.50
Manufacture of chemical fibres	41428	2069	33127	365	30.84
Manufacture of rubber	12155	4129	30168	208	6.84
Manufacture of non-metallic mineral products	26075	129851	2790786	5950	27.76
Smelting and pressing of ferrous metals	121037	173215	2061538	42344	153.55
Smelting and pressing of non-ferrous metals	33545	31892	348479	10304	373.33
Manufacture of metal products	29912	8871	87576	472	41.07
Manufacture of general purpose machinery	11973	1631	49025	211	9.73
Manufacture of special purpose machinery	6454	3071	22229	151	3.10
Manufacture of automobile	15069	3780	100381	330	22.33
Manufacture of railway, shipbuilding, aerospace and other transportation equipment	13326	2166	59058	244	12.21
Manufacture of electrical machinery and equipment	9631	1523	5762	67	18.43
Manufacture of computers, communication, and other electronic equipment	44961	6153	5369	97	138.65
Manufacture of measuring instrument	2242	101	1016	5	9.99
Other manufactures	3997	668	21749	114	2.86
Utilization of waste resources	2069	227	4740	355	6.48
Metal products, machinery and equipment repair	1310	1135	10047	29	0.67
Production and supply of electric power and heat power	158928	202906	2155978	61061	46.81
Production and supply of gas	989	261	11965	68	1.91
Production and supply of water	3559	7	262	10	0.09
Other sectors	840	9	1406	2	

the blue node indicates industries. There are only 20 industries in Fig. 1, which means that the other 19 industries are not main contributors of any waste emission, and hence are not featured in the waste competition network.

Fig. 1 shows that many industries only connect with the emission of one or two kinds of waste. For example, the mining and processing of non-metal ores only connects with hazardous waste; manufacture of chemical fibres only connects with waste water; and mining and processing of ferrous metal ores only connect with common solid waste. In other words, many industries are the single main producer of one specific type of waste. However, there are certain other industries that connect with many kinds of wastes. For example, the processing of petroleum, coking and processing of nuclear fuel connect with four waste kinds: wastewater, hazardous waste, waste gas and waste dust, which means that this industry is the main contributor of many types of wastes.

Table 2 shows the number of connections of each kind of waste. A low number of connections indicates that most of this waste is discharged by only a few industries. Conversely, a high number of connections indicates that there

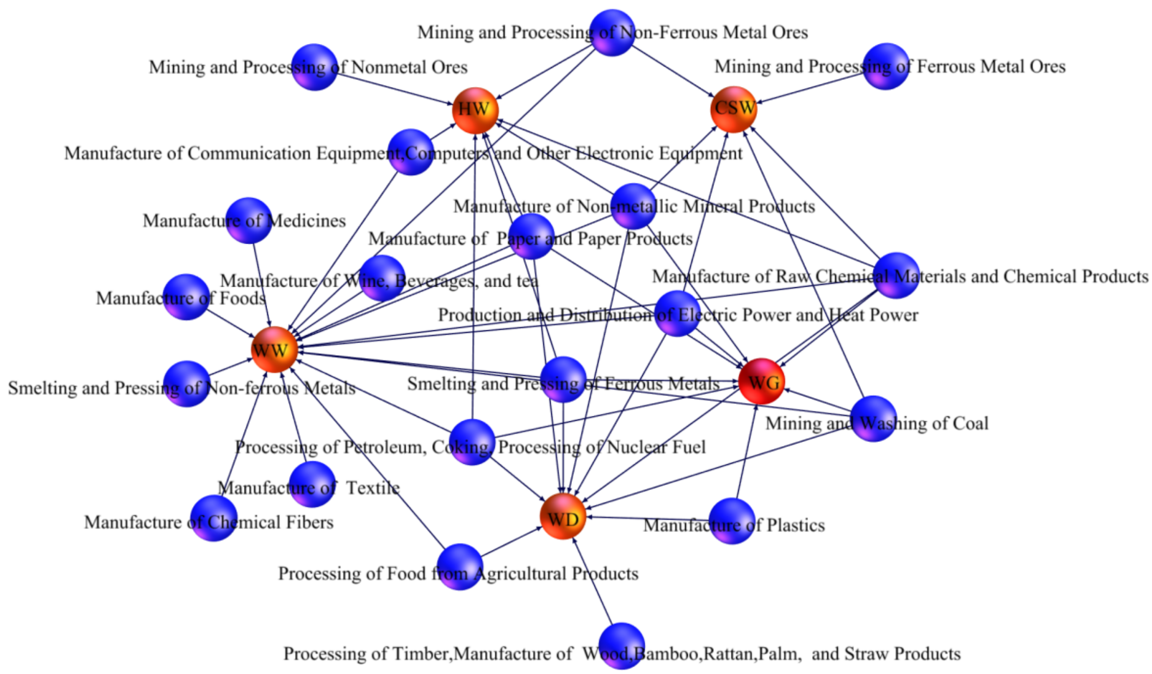

Fig. 1: Visualization of the 2-mode waste emission competition network.

Table 2: Connection number of each emission.

	Number of Connections
Hazardous Waste	8
Wastewater	16
Waste Gas	8
Common Solid Waste	6
Waste Dust	10

are many industries which discharge this kind of emission. In Table 2, wastewater has the most connections. This means that 16 industries contribute 90% of total wastewater emission. On the other hand, common solid waste only has six connections, which means only six industries discharge 90% of common solid waste.

THE INTENSITY OF COMPETITION

In order to deeply analyse the 2-mode network using network theory, it should first be changed into a corresponding 1-mode network. The nodes of the 1-mode network are industries and the edges among nodes are competition relationships. In other words, if two industries discharge the same waste, then they have an edge among them. In our network, the edges have weight. If two industries discharge two kinds of the same waste, the weight of their connection would be two. Fig. 2 shows an example of how to translate a 2-mode network into a 1-mode network. The example in Fig. 2 shows industry *i* and industry *j* both discharge waste *m* and waste *n* in a 2-mode network. This means there is an edge between industry *i* and industry *j* in a 1-mode network. The weight of the edge among them is 2. The 1-mode network is shown in Fig. 3.

According to sociologists, it is the relationship between one person and others that makes him or her powerful, as it is in indicator of his or her ability to exert influence over others. Similarly, nodes that have a larger degree have more power in the particular network under examination. Therefore, we use the degree of each industry to show its importance in the waste emission competition network. Industries that have a higher degree have relationships with more industries and thus can have larger scale impacts on the network. The degrees of each industry are listed in Table 3.

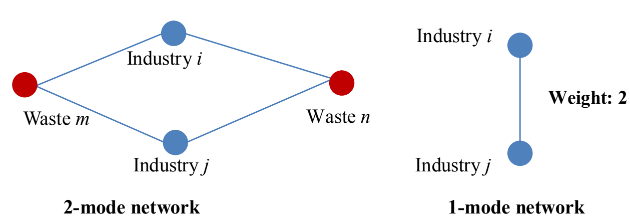

Fig. 2: Example of a method to build a 1-mode network based on a 2-mode network.

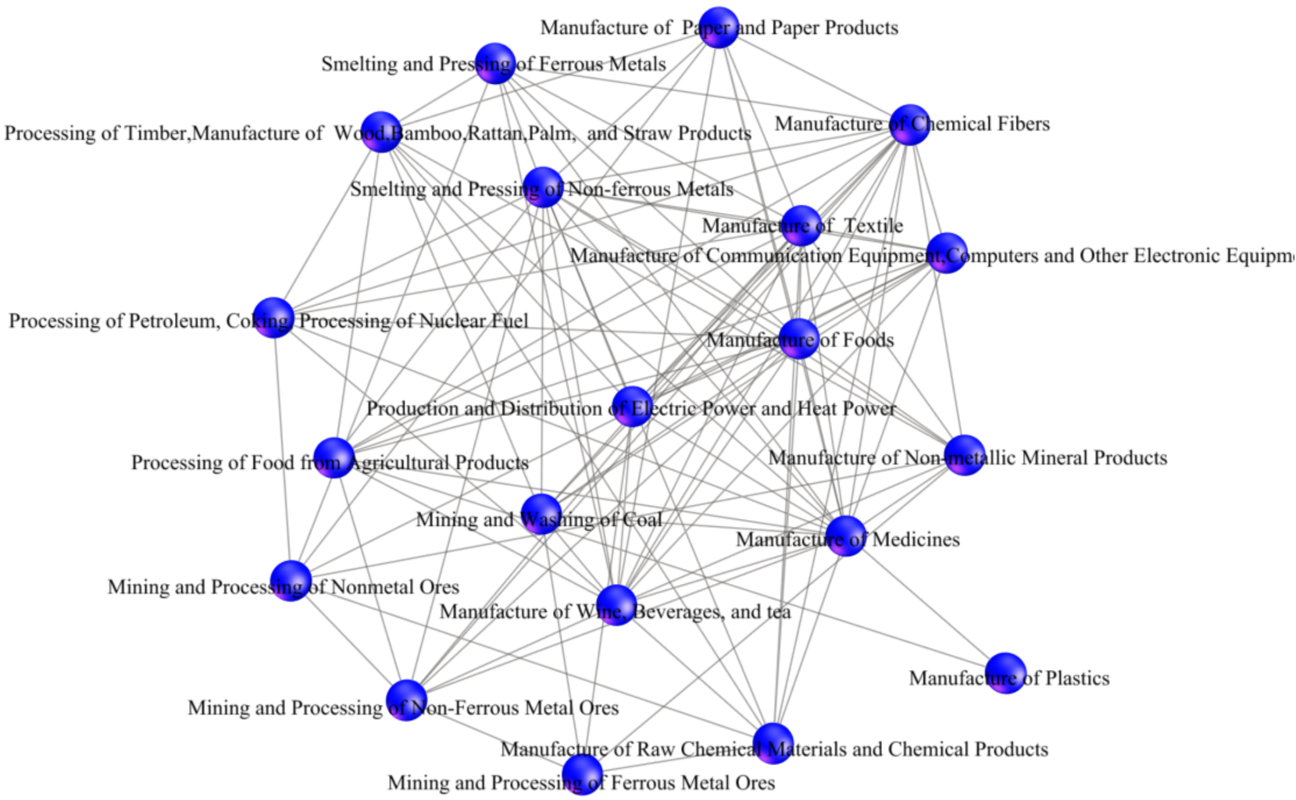

Fig. 3: Visualization of the competition network among industries.

In the waste emission competition network, industries with higher degrees have competition relationships with many industries. From Table 3, the degree of the manufacture of raw chemical materials and chemical products and the manufacture of non-metallic mineral products is 20, which means that they emit the same waste alongside as many as 20 industries. Furthermore, there are five industries whose degree is 19: The manufacture of paper and paper products, the processing of petroleum, coking and processing of nuclear fuel, the smelting and pressing of ferrous metals, the production and supply of electric power and heat power, and the mining and washing of coal. At the other end of the scale, the degree of mining and processing of ferrous metal ores is only six, which is the least among all 20 industries. Similarly, the degree of mining and processing of non-metal ores is only 8. This indicator should be considered in industrial planning. Those industries with high degrees discharge the same emission types, and hence are under high emission competition in Beijing.

The degree of nodes depicts the number of relationships the nodes have without considering the weight of the edges. In order to depict the strength of the competition status of industries, a weighted degree is used. The weighted degree of a node is the sum of all of the weighted values of its edges and can be calculated using eq. (6) (Liu 2009):

$$S_i = \sum_{j \in N_i} \omega_{ij} \qquad ...(6)$$

Where, S_i is the weighted degree of node i, N_i is the set of nodes adjacent to node i, and ω_{ij} is the weight of the edge between node i and node j. The weighted degree is a comprehensive reflection of the local information around the node. The weighted degrees of each industry are listed in Table 4.

In the waste emission network, weighted degree not only considers the number of waste emission competitors, but also considers the number of waste types that one industry discharges. Therefore, it is a comprehensive indicator showing the competition strength of industries. Table 4 shows that the manufacture of raw chemical materials and chemical products and the manufacture of non-metallic mineral products have the highest weighted degree, with both numbering 48. That is to say, these two industries are in the most intense waste emission competition. In addition to them, the manufacture of paper and paper products, the processing of petroleum, coking and processing of nuclear fuel, the

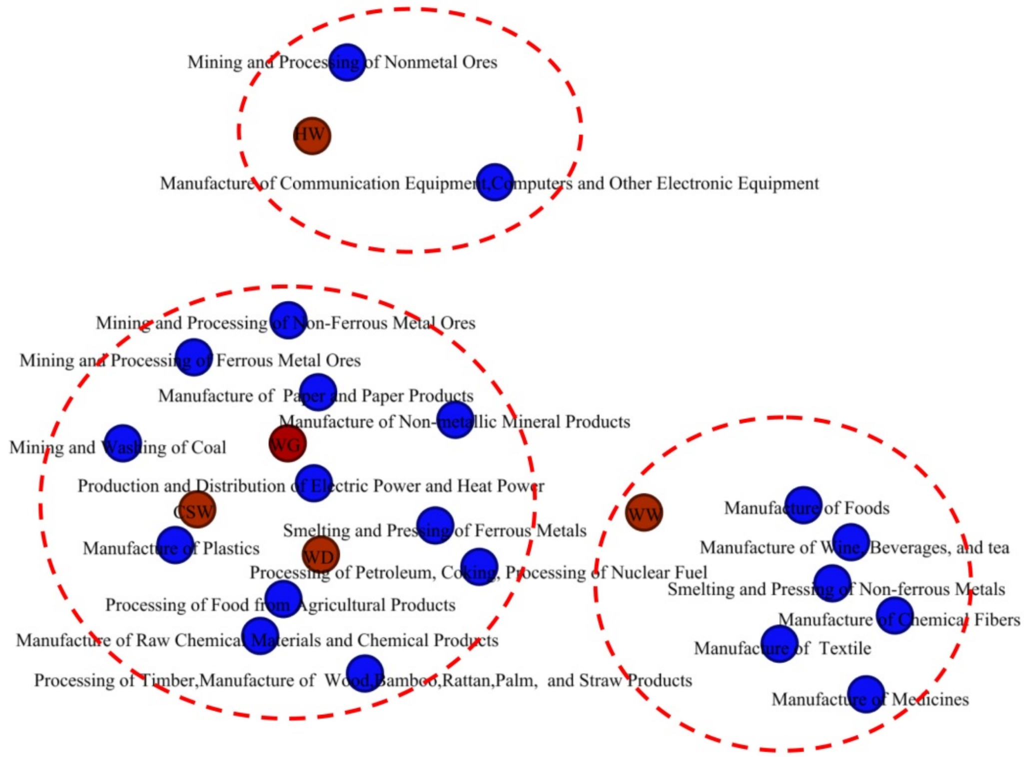

Fig. 4: Result of correspondence analysis.

smelting and pressing of ferrous metals, the production and supply of electric power and heat power, and the mining and washing of coal are also all participating in intense waste emission competition. The weighted degrees of the remaining industries are much smaller, which indicates that these industries are not in close waste emission competition.

THE STRUCTURE OF COMPETITION

In order to show the structure of competition in the waste emission competition network among Beijing's industries, the correspondence of the network is utilized. Correspondence analysis (CA) was first introduced by Hirschfeld (Hirschfeld 1935) and later developed by Jean-Paul Benzécri (Benzécri 1992). Correspondence analysis is a method that helps to show the group among entities, in a manner similar to principal analysis. The difference between correspondence analysis and principal analysis is that correspondence analysis allows categorical data rather than continuous data to be used.

Along with the development of the network method, correspondence is used to show the relationship structure among nodes in a network. It uses distance in a figure to show the distance of nodes in the network. As for the waste emission competition network, correspondence analysis helps draw a picture about different industries and wastes. The distance in the picture shows the distance of these industries and waste (Fig. 3). The emission competition network can be shown in Fig. 4. The result of correspondence (Fig. 4) shows that industries can be divided into three groups by waste emission.

Two industries mainly discharge hazardous waste: the mining and processing of non-metal ores, and the manufacture of communication equipment, computers and other electronic equipment. Six industries mainly discharge waste water: the manufacture of foods; the manufacture of wine, beverages and tea; the smelting and pressing of non-ferrous metals; the manufacture of medicines; the manufacture of chemical fibres; and the manufacture of textiles. The remaining 12 industries discharge waste dust, common solid waste and waste gas.

According to this result, the close industries in the picture discharge quite similar emissions. From this point of view, these relationships should be considered in industrial planning. Theoretically, these industries should not be physically located very close together. Although the location of industries is a result of many complex factors, emission should be considered as an indicator.

Table 3: Degree of each industry.

	Industry	K(i)
1	Manufacture of raw chemical materials and chemical products	20
2	Manufacture of non-metallic mineral products	20
3	Manufacture of paper and paper products	19
4	Processing of petroleum, coking, processing of Nuclear fuel	19
5	Smelting and pressing of ferrous metals	19
6	Production and supply of electric power and Heat power	19
7	Mining and washing of coal	19
8	Mining and processing of non-ferrous metal ores	18
9	Processing of food from agricultural products	18
10	Manufacture of computers, communication, and other electronic equipment	17
11	Smelting and pressing of non-ferrous metals	16
12	Manufacture of medicines	16
13	Manufacture of chemical fibres	16
14	Manufacture of textile	16
15	Manufacture of foods	16
16	Manufacture of wine, drinks and refined tea	16
17	Processing of timber, manufacture of wood bamboo, palm, and straw products	10
18	Manufacture of rubber	10
19	Mining and processing of non-metal ores	8
20	Mining and processing of ferrous metal ores	6

Table 4: Weighted degree of each industry.

	Industry	Sout(i)
1	Manufacture of raw chemical materials and Chemical products	48
2	Manufacture of non-metallic mineral products	48
3	Manufacture of paper and paper products	42
4	processing of petroleum, coking, processing of nuclear fuel	42
5	Smelting and pressing of ferrous metals	42
6	Production and supply of electric power and heat power	40
7	Mining and washing of coal	40
8	Mining and processing of non-ferrous metal ores	30
9	Processing of food from agricultural products	26
10	Manufacture of computers, communication, and other electronic equipment	24
11	Manufacture of rubber	18
12	Smelting and pressing of non-ferrous metals	16
13	Manufacture of medicines	16
14	Manufacture of chemical fibres	16
15	Manufacture of textiles	16
16	Manufacture of foods	16
17	Manufacture of wine, drinks and refined tea	16
18	Processing of timber, manufacture of wood bamboo, palm, and straw products	10
19	Mining and processing of non-metal ores	8
20	Mining and processing of ferrous metal ores	6

CONCLUSION

This paper focuses on the waste emission competition relationship among Beijing's industries. Using the emission data of 2011, this paper utilizes a 2-mode network method to investigate their competition relationships in quantity. Although there are many indicators available in network theory, this paper chooses three indices to answer the two most important questions pertaining to that topic: the intensity of competition of each industry and the whole structure of waste competition among industries. The main findings of this paper are as follows:

1. Hazardous waste, waste gas and common solid waste can be easily tracked as 6-8 industries contribute 90% of total waste.
2. The manufacture of raw chemical materials and chemical products and the manufacture of non-metallic mineral products have high degrees, indicating that they discharge the same emission with many industries. In other words, they are under intense emission competition in Beijing.
3. Correspondence analysis divided industries into three groups by waste emission. Two industries mainly discharge hazardous waste; six industries mainly discharge wastewater; and the remaining 12 industries discharge waste dust, common solid waste and waste gas. These relationships should be considered in industrial planning.

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