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A grey neural network and input-output combined forecasting model and its application in primary energy related CO_2 emissions estimation by sector in China

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Abstract

In this paper, a Grey Neural Network and Input-Output Combined Forecasting Model (GNF-IO) was built to forecast by sector primary energy related CO_2 emissions. Applied the GNF-IO model, the coal, crude oil and natural gas consumption volume and the related CO_2 emissions volume by China's 42 sectors in 2010 were estimated. The total energy-related CO_2 emissions volume in China in 2010 was forecasted as 7508.56 million tons, in which 80.2 percent was from coal consumption, 17.6 percent was from oil consumption. By sector CO_2 emissions results showed that the energy efficiency work of coal can be focused on electricity, heat production and supply, ferrous metal smelting and rolling processing industry, petroleum processing, coking and nuclear fuel processing industry. The energy efficiency work of crude oil can be emphasized on petroleum processing, coking and nuclear fuel processing industry, raw chemical materials and chemical products.

Keywords: CO_2 emissions estimation; Kinds of primary energy; Combined Forecasting Model; By sector

1. Introduction

As one of the two largest emitters of CO_2 in the world today, China has and will continue to receive more and more pressures to reduce GHG emissions [1]. On the Copenhagen Climate Summit in 2009, China proposed a carbon emission reduction of 40%-45% by 2020 based on the 2005 carbon emission level. China's coal-based energy consumption structure determines more than 75% greenhouse gas emissions of China comes from the energy consumption. According to the statistics of CDIAC (2002),

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approximately 77.9% of total energy-related CO_2 emissions of China were from coal combustion, 19.8% from petroleum and 2.3% from natural gas.

The authorities commented that the heavy task of carbon emissions reduction in China will be broken down to specific industries in 12th Five-Year-Plan. However, there is no solid index which could be applied to determine by sector carbon emission reduction tasks†.

To estimate three types of fossil fuels coal, crude oil and gas consumption and resulting CO_2 emissions by each industry could be an effective factor to determine by sector carbon emission reduction tasks.

Hitherto, there have been many studies which focused on the future energy requirements and related CO_2 emissions in China. At the national level, van Vuuren et al. (2003) employed the model IMAGE/TIMER to develop a set of energy and emission scenarios for China between 1995 and 2100[2]. Chen (2005) used the model MARKAL-MACRO to generate China's reference scenario for future energy development and carbon emission through the year 2050[3]. Crompton and Wu (2005) applied Bayesian vector autoregressive methodology to forecast China's energy consumption through the year 2010[4]. Other similar works include Lu and Ma (2004), Zheng et al. (2005), Shi and Zhao (1999) projected China's total energy consumption in 2005 and 2015. They considered transportation and residential sectors would likely be the sectors contributing to China's increased energy consumption in the future [5-7]. Several earlier studies have estimated the historical trends of energy demand and/or the associated GHG emissions in China's road transport sector and the future trends under different policy scenarios [8-11].

However, there was little studies forecasted energy related CO_2 emission by sector systematically. It is a complex system with incomplete information. Combined forecasting method is fit for it much more, which can integrate many single forecasting models and get a new model that includes kinds of forecasting news from different forecasting model.

This paper established a Grey Neural Network and Input-Output Combined Forecasting Model (GNF-IO) and applied it to forecast CO_2 emission from coal, oil and gas consumption by sector. In the following parts of this paper, section 2 analyses 3 kinds of primary energy consumption structure by 42 sectors. Section 3 provides GNF-IO model. Section 4 applies GNF-IO model. Section 5 concludes and provides suggestions.

Nomenclature

C_{ij}	the CO_2 emission from sector j for it consumed energy i
E_i	the total consumed volume of energy i
b_{ij}	the proportion of consumed energy i by sector j to the total amount of energy i
f_i	the emission factor of energy i
(p, q)	BP neural network structure
P	the number of the first hidden layer
q	the number of the second hidden layer

† http://www.zjjjxww.com/html/news_62/201001165511.html

r	nodes number of input layer
s	nodes number of output layer

2. Consumption structure: 3 kinds of primary energy among 42 industries

With the 2007 energy consumption statistics data in China Energy Statistics Yearbook 2008 and the China 2007 input-output table, the China energy input-occupancy-output table with 42 sectors was compiled. Sector classification sees Appendix A. With this table, the consumption structure of 3 kinds of primary energy among 42 sectors in China in 2007 can be calculated. Sectors which have top 3 proportions see Table1.

Table 1. Coal, crude oil and gas consumption by main sectors in 2007 in China

Coal		Crude oil		Gas	
Sector Code	Proportion (%)	Sector Code	Proportion (%)	Sector Code	Proportion (%)
35	48.7	17	86.5	18	33
24	8.8	18	8.4	3	17.8
17	8.7	3	4.6	42	17
The others	33.8	The others	0.5	The others	32.2

As shown in Table 1, the distribution of coal consumption among China's various industries was very different in 2007: electricity, heat production and supply consumed most coal, accounted for 48.7% of the total coal consumption; ferrous metal smelting and rolling processing industry consumed 8.8% of the total coal consumption; petroleum processing, coking and nuclear fuel processing industry consumed 8.7%, the other 39 sectors consumed 33.8% of the total coal consumption. 86.5% of China's crude oil was consumed by oil processing; coking and nuclear fuel processing industry and 8.4% of crude oil was consumed by Raw Chemical Materials and Chemical Products industry. 33% of natural gas was consumed in raw chemical materials and chemical products industry, 17.8% of natural gas was consumed by oil and natural gas mining industry, and 17.0% was consumed by living.

3. GNF-IO Model Structure

Based on the above analysis, by combining the advantages of GM(1, 1)[12], WPGM(1, 1) [13], pGM(1, 1)[14] and BP neural network [15], GNF-IO model was proposed, in which the predicting results of three gray prediction models were used as the neural network's inputs, and the original sequence was used as the output of the neural network. The neural network was trained to get the optimal structure, weights and thresholds (Figure1 shows the model structure). The combined model integrates the advantages of three models in the grey system theory, combining the predict results to the grey neural network. Using the function approximation properties of neural network, achieve the best fit between the predicted and observed values.

Set m as the original data sequence, set n as the forecasting sequence. Two hidden layer structure of the four layer neural network is (p, q), where p represents the number of the first hidden layer, q denotes the number of the second hidden layer. The steps of the GNF-IO model are as follows.

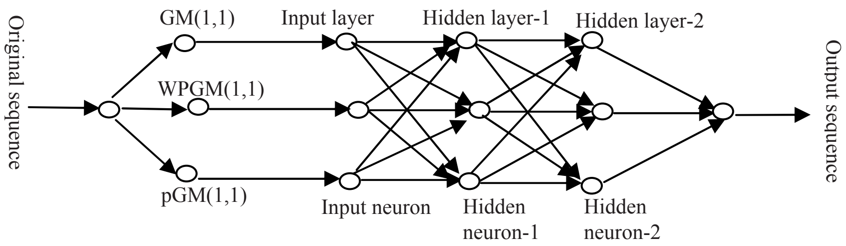

Fig.1. Topology structure of GNF-IO Model

Step 1: To one data sequence, applied GM (1, 1), WPGM (1, 1), pGM (1, 1) to get m simulation values and n forecasting values.

Step 2: Use the simulation value of the three grey models as the input vector of BP neural network, use initial data sequence as the output vector of the BP neural network, set the network structure (p, q) as (1,1), begin network training, and record total error E of the sample set of the corresponding network structure.

Step 3: Increased p and q by 1 respectively, until p=q=8 (Use the nodes number calculated from empirical formula [p, q]= $\sqrt{0.43r^2+0.12s^2+2.54r+0.77s+0.35}+0.51$ as the median number), where p, q are nodes of hidden layer, r, s are nodes number of input layer and output layer[16].

Step 4: Selected the corresponding (p, q) of the minimum values among 7 values of E above, set it as (p^0, q^0).

Step 5: In accordance with the structure of (p^0, 1), (p^0, 2)…… (p^0, 7), (q^0, 1), (q^0, 2)…… (q^0, 7), obtained 14 E by Step 2, selected the corresponding (p, q) of the minimum values among 14 values of E above, set it as (p^1, q^1).

Step 6: Use three groups of n predicted values in the Step 1 as input values, simulate the original sequence according to (p^1, q^1) network structure, and get n outputs.

Step 7: $C_{ij} = E_i * b_{ij} * f_i$ (1)

where E_i is the output in Step 6.

4. Model Application

4.1. Assumptions

China has announced a development plan for renewable energy, which determined the target that renewable energy accounted for 10% and 15% of the total primal energy consumption by 2010and 2020. By the end of 2006, the proportion of the total renewable energy consumption (not including the traditional use of biomass) was about 8%, rose 0.5% from 2005, which has taken a solid step to the 2010 renewable energy target. In the paper, the renewable energy was assumed to account for 10% of the total primal energy consumption in China in 2010.

Based on the consumption data during 2003-2007 years of the primal energy coal, crude oil and natural gas in China Energy Statistical Yearbook 2004-2008, divided and re-combined their sector classifications into the same as that in Attachment 1. Calculated the correlation coefficient between any two years of three kinds of primal energy consumption structure among 42 sectors in 2003, 2005, 2006 and 2007, all the correlation coefficients between any two years of coal, crude oil and gas consumption structure among 42 sectors in 2003, 2005, 2006 and 2007 were bigger than 0.96, especially to coal, the correlation coefficients were all bigger than 0.99. This showed that from 2003 to 2007, consumption structure of coal, crude oil and gas among 42 sectors is stable. It is assumed that the consumption structure of primal energy among 42 sectors in 2010 is similar with that of 2007.

4.2. Model Test and Application

We have annual energy consumption data in China but no CO_2 emission data every year, so we made model test by comparing annual energy consumption real data with their forecasted results. With the primary energy coal, oil and natural gas consumption data during 1990-2004 in China, applied GM(1,1), WPGM(1,1), pGM(1,1) model to simulate energy consumption volume in China, then applied GNF-IO model to simulate the same data sequence, four kinds of simulation results from four models can be obtained. The relative error of the four models (Fig. 2) and model checking (Table 2) showed that the error of the Grey prediction models was much greater than that of GNF-IO model, at some point, the accuracy of Grey prediction models were instability. The simulation accuracy of GNF-IO model was significantly better than the single grey model.

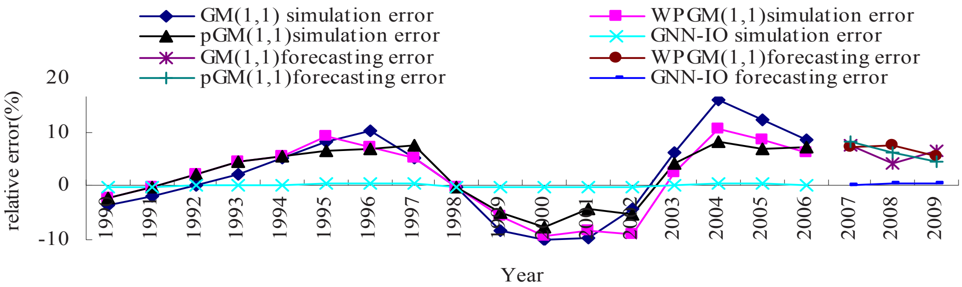

Fig.2. Errors of different models (%)

Table 2. Model testing and assessing

Model	Small Error Probability (p)	Assess criteria of p	Mean Square Error Ratio (c)	Assess criteria of c	Accuracy level
GM(1,1)	0.94	0.80-0.95	0.3712	0.35-0.5	Qualified
WPGM(1,1)	1.00	>0.95	0.0571	<0.35	Good
pGM(1,1)	1.00	>0.95	0.0552	<0.35	Good
GNF-IO	1.00	>0.95	0.0029	<0.35	Good

Next, applied four models to forecast energy consumption volume in year 2005, 2006 and 2007 and checked the forecasted error (see Figure 2). Also applied other combined forecasting methods and compared their forecasted errors (See Table 3). Figure 2 and Table 3 showed that the forecast error of the GNF-IO model was the smallest; the average forecast error was only 0.27%. To sum up, the GNF-IO model was much better in simulation and prediction performance than other models. As a result, GNF-IO model was chosen. Based on coal, oil and natural gas consumption data during 1990-2007 in China, applied the model, three kinds of primary energy consumption volume in 2010 in China was forecasted (See Table 4).

Table 3. Errors of different combination models

Year	GNF-IO	GM-PLS	ARMA
2004	0.29%	8.9%	2.7%
2005	0.31%	15.8%	10.3%
2006	0.26%	10.7%	15.6%
2007	0.21%	15.5%	18.9%

Table 4. Primary energy consumption forecasted results in China in 2010 (Unit: million tons coal equivalent (MtCE))

Year	Coal	Crude Oil	Gas	Renewable Energy
2010	2137.6	704	86.43	272
Proportion	66.8%	22.0%	2.7%	8.5%

Table 4 showed that the proportion of coal in the total primal energy consumption fell from 68.7% in 2008 to 66.8% in 2010. According to Keii's projection [17], the share of coal as a primary energy over total energy consumption would decline over time, it would account for about 65% of China's primary energy by 2010. Our result has the same direction with Keii’s and is 1.8% higher. Table 5 showed that in 2009, 51.3% of crude oil consumed in China was imported. In 2010, crude oil consumption would be increased. Compare Table 4 and Table 5, there may be 360MtCE crude oil need to be imported to China in 2010. This would be challenging for both China and the rest of the world.

Table 5. Primal energy production in 2009 in China (Unit: MtCE)

Year	Coal	Crude Oil	Gas
2009	2960	270	110
The year-on-year growth rate	12.7%	-0.4%	7.7%
Import proportion	-	51.3%	-

With primary energy consumption forecasted results in China in 2010, calculated b_{ij} from energy input-occupancy-output table of China in 2010, got f_i was from IPCC, applied equation (1), CO_2 emissions of 42 industrial sectors in 2010 came from coal, oil and natural gas consumption in China were estimated (See Table 6) .

Table 6 showed that the total energy-related CO2 emissions volume in China in 2010 was 7508.56 million tons, which is 37.44 million tons smaller than that estimated by EIA (7546 million tons). The main reason was that the primal energy consumption data the paper applied was from the China Statistics Book and the total energy consumption forecasted results had -0.62% error, and their assumptions were different.

The industries which have top 5 CO_2 emissions volume from natural gas consumption were: raw chemical materials and chemical products; oil and natural gas mining; living consumption; non-metallic mineral products industry; petroleum processing, coking and nuclear fuel processing industry.

Table 6. CO_2 emission volume from 3 kinds of primary energy consumption by 42 sectors in China in 2010 (Unit: a hundred million ton)

Sector Code	FCC	PR	FOC	PR	FNGC	PR	FTEC	PR
1	64.32	1.1%	53.20	4.0%	0.00	0.0%	117.52	1.5%
2	363.86	6.0%	2.37	0.2%	1.61	1.0%	367.84	5.0%
3	9.40	0.2%	42.32	3.2%	30.22	17.8%	81.94	1.1%
4	3.11	0.1%	1.09	0.1%	0.01	0.0%	4.21	0.1%
5	2.53	0.0%	0.49	0.0%	0.01	0.0%	3.03	0.0%
6	16.00	0.3%	1.83	0.1%	0.01	0.0%	17.84	0.2%
7	54.66	0.9%	3.44	0.3%	0.61	0.4%	58.72	0.8%
8	18.95	0.3%	0.94	0.1%	0.20	0.1%	20.09	0.3%
9	3.00	0.0%	0.22	0.0%	0.10	0.1%	3.31	0.0%
10	59.48	1.0%	2.82	0.2%	0.22	0.1%	62.52	0.8%
11	5.33	0.1%	1.26	0.1%	0.04	0.0%	6.62	0.1%
12	2.33	0.0%	0.84	0.1%	0.01	0.0%	3.18	0.0%
13	10.41	0.2%	0.84	0.1%	0.06	0.0%	11.31	0.2%
14	84.12	1.4%	1.68	0.1%	0.20	0.1%	86.00	1.2%
15	1.00	0.0%	0.43	0.0%	0.08	0.0%	1.51	0.0%
16	0.46	0.0%	0.51	0.0%	0.00	0.0%	0.97	0.0%
17	525.63	8.7%	681.58	51.7%	7.07	4.2%	1214.28	15.7%
18	311.41	5.2%	77.95	5.9%	55.93	33.0%	445.29	6.0%
19	15.94	0.3%	0.60	0.0%	0.38	0.2%	16.92	0.2%
20	21.11	0.4%	1.38	0.1%	0.12	0.1%	22.62	0.3%
21	10.09	0.2%	1.00	0.1%	0.14	0.1%	11.23	0.2%
22	6.21	0.1%	1.87	0.1%	0.22	0.1%	8.30	0.1%
23	465.75	7.7%	21.57	1.6%	9.43	5.6%	496.75	6.7%
24	533.05	8.9%	7.96	0.6%	3.87	2.3%	544.88	7.3%
25	62.18	1.0%	3.99	0.3%	1.53	0.9%	67.70	0.9%
26	7.59	0.1%	2.41	0.2%	0.27	0.2%	10.28	0.1%

27	9.46	0.2%	2.65	0.2%	0.72	0.4%	12.83	0.2%
28	12.69	0.2%	1.39	0.1%	1.07	0.6%	15.15	0.2%
29	20.29	0.3%	3.40	0.3%	1.94	1.1%	25.63	0.3%
30	3.83	0.1%	2.30	0.2%	0.49	0.3%	6.62	0.1%
31	3.67	0.1%	2.37	0.2%	1.89	1.1%	7.93	0.1%
32	0.55	0.0%	0.37	0.0%	0.03	0.0%	0.95	0.0%
33	13.85	0.2%	0.59	0.0%	0.02	0.0%	14.46	0.2%
34	0.17	0.0%	0.07	0.0%	0.00	0.0%	0.24	0.0%
35	2934.01	48.7%	40.44	3.1%	6.81	4.0%	2981.26	40.1%
36	36.01	0.6%	0.72	0.1%	2.80	1.7%	39.53	0.5%
37	0.85	0.0%	0.15	0.0%	0.02	0.0%	1.02	0.0%
38	16.77	0.3%	14.74	1.1%	0.54	0.3%	32.05	0.4%
39	22.65	0.4%	248.53	18.9%	4.71	2.8%	275.90	3.5%
40	24.29	0.4%	21.01	1.6%	3.91	2.3%	49.20	0.6%
41	21.28	0.4%	52.82	4.0%	3.31	2.0%	77.41	1.0%
42	242.80	4.0%	11.98	0.9%	28.77	17.0%	283.55	3.8%
Sum up	6021.12	100%	1318.09	100%	169.35	100%	7508.56	100%

Note: In Table 6, FCC means From Coal Consumption; FOC means From Oil Consumption; FNGC means From Natural Gas Consumption; FTEC means From Three Kinds of Energy Consumption. PR means proportion.

The industries which have top 5 CO_2 emissions volume from the primal energy consumption were: electricity, heat production and supply; petroleum processing, coking and nuclear fuel processing industry; ferrous metal smelting and rolling processing industry; non-metallic mineral products industry; raw chemical materials and chemical products. They were similar to industries which have the top 5 CO_2 emissions generated from coal consumption.

5. Conclusions and suggestions

GNF-IO model combined the advantages of GM(1, 1), WPGM(1, 1), pGM(1, 1), BP neural network and input-output analysis. Model test showed that the model had high simulation and forecasting accuracy on energy consumption. Applied the model, this paper provided a more reliable estimation by employing a plausible approach to estimate the CO_2 emission that comes from three kinds of primal energy consumed by each industry.

To the total energy related CO_2 emission, 80.2 percent was from coal consumption, 17.6 percent was from oil consumption. The energy efficiency work of coal can be focused on electricity, heat production and supply, ferrous metal smelting and rolling processing industry, petroleum processing, coking and nuclear fuel processing industry. The energy efficiency work of crude oil can be focused on petroleum processing, coking and nuclear fuel processing industry, raw chemical materials and chemical products.

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References

[1] He J.K., Liu B. and Wang, Y. Addressing global climate change: challenges and countermeasures in China, Journal of Tsinghua University (Philosophy and Social Sciences Ed) 2007;5:75-83 (in Chinese).

[2] Van Vuuren D., Zhou F., Vries B., Jiang K., Graveland C. and Li, Y. Energy and emission scenarios for China in the 21st century—exploration of baseline development and mitigation options , Energy Policy, 2003;31:369-387.

[3] Chen C., Jing J. and Lyli et al., Transportation situation and traffic air pollution status in Shanghai (Part one report, draft) [M], Shanghai: Shanghai Academy of Environmental Sciences,2005.

[4] Crompton P. and Wu Y., Energy consumption in China: past trends and future directions. Energy Economics, 2005; 27: 195-208.

[5] Lu W. and Ma, Y. Image of energy consumption of well-off societies in China, Energy Conversion and Management, 2004; 45:1357-1367.

[6] Zheng B., Wang Y., Zhao J. and Deng H., Energy demand forecast in the process of modernization based on sustainable development in China, China Population Resources and Environment, 2005;15:47-51 (in Chinese).

[7] Q. Shi and J. Zhao, Editors, Development Report of Chinese Industries [M], China ZhiGong Publishing House, Beijing, 1999.

[8] He, K. Huo H., Zhang Q., He D., An, F. Wang M.and Walsh M.P., Oil consumption and CO_2 emissions in China's road transport: current status, future trends, and policy implications, Energy Policy, 2005; 33:1499-1507.

[9] Wang C., Cai, W. Lu X.and Chen J., CO_2 mitigation scenarios in China's road transport sector, Energy Conversion and Management, 2007; 48: 2110-2118.

[10] Yan, X., Crookes, R.J., A Study of energy use in China[C]. Proceedings of the 20th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems, 2007b, Vol. 2. Padova, Italy, June 25-28, 1661-1668.

[11] Zhang A.andLi J., Analysis on interregional input-output models, Journal of Systems Engineering, 2004; 19:615-619 (in Chinese).

[12] Dajun L., Xuhong S., Yongjun T., pGM(1,1) Grey prediction model and its application , Journal of East China Geological Institute, 2002; 25:223-227 (in Chinese)

[13] Peirong J., Weisong H., Xiangyong H., An unbiased grey forecasting model，System Engineering and Electronics, 2000; 22: 6-8 (in Chinese).

[14] Zhikun L., Xinzhou W., Xinyan Zh., pGM(1,1)Forecasting model and its parameter estimate , Bulletin of Surveying and Mapping, 2003; 11:14-19.

[15] Xin W, Lu Zh., Xiang L., MATLAB Neural Network Simulation and Application [M], Beijing, Science Publication, 2003.

[16] Lei W., Hengshen Y., The combined model based on the time series and neural network and its application． Statistics and Decision, 2005; 6: 17-18 (in Chinese).

[17] Keii C., China's energy supply and demand situations and coal industry's trends today, Research Reports, Vol. 162, Institute of Energy Economics, Japan (2000).

Appendix A. Sector classification of China energy input-holding-output table in 2007

Sector Code	Sector Name	Sector Code	Sector Name	Sector Code	Sector Name

1	Agriculture	15	Printing and Record Medium Reproduction Industry	29	Transport Equipment
2	Coal Mining and Dressing	16	Educational and Sports Goods	30	Electrical Machinery and Equipment
3	Oil and Natural Gas Mining	17	Petroleum processing, coking and nuclear fuel processing industry	31	Communications equipment, computers and other electronic equipment manufacturing
4	Ferrous mineral mining	18	Raw Chemical Materials and Chemical Products	32	Instruments, Cultural and Office Machinery
5	Non-ferrous mineral mining	19	Pharmaceutical Industry	33	Arts and crafts and other manufacturing
6	Non-metallic Minerals and Other Mining and Dressing	20	Chemical fiber manufacturing industry	34	Waste and scrap
7	Food processing and food manufacturing	21	Rubber Products	35	Electricity, heat Production and Supply
8	Beverage Manufacturing	22	Plastic Products	36	Gas Production and Supply
9	Tobacco industry	23	Non-metallic mineral products industry	37	Water Production and Supply
10	Textile	24	Ferrous metal smelting and rolling processing industry	38	Construction industry
11	Textile and Apparel, Footwear and Headgear	25	Non-ferrous metal smelting and rolling processing industry	39	Transport, storage and post
12	Leather, fur, feathers (down) and its products	26	Fabricated metal products	40	Wholesale, retail trade and accommodation, catering industry
13	Wood processing and furniture manufacturing	27	General Equipment	41	Other services
14	Paper and Paper Products	28	Special Equipment	42	Living consumption