Advances in Environmental Research, Vol. 1, No. 4 (2012) 237-255

DOI: http://dx.doi.org/10.12989/aer.2012.1.4.237

Inverted-U curve for material consumption of China industrial system: a new implication from environmental regulation

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(Received September 12, 2012, Revised November 1, 2012, Accepted November 16, 2012)

Abstract. We review the research literature on relationship between environmental regulation and industrial development in three aspects of environmental regulation and investment, environmental regulation and efficiency, environmental regulation and trade. Indeed, the linkage between environmental regulation and material consumption of industrial system is absent. Environmental regulation is measured as the expenditure share for industrial pollutants abatement, and effluent charge intensity. Using panel-level data from 31 provinces, municipalities and autonomous regions in China, we build correlation models between material consumption and environmental regulation, results show that: (1) there are significant quadratic function relationship between material consumption and environmental regulation. And there is the fact that inflection point exists. (2) On basis of inflection points, we make two remarkable reflections. Firstly, the inflection points are the most important scale to judge reasonability and performance of regulations. Secondly, a Pareto improvement may occur when the regulations achieve a certain target. (3) Both intensities of industrial pollutants abatement expenditure and effluent charge have not yet achieved the expected target in most regions of mainland China at present. And most of regions of material consumption decreasing are distributed in western China. Main reasons lie in the impacts of industrial features as well as the regulations.

Keywords: material consumption of industrial system; environmental regulation; inflection point of curve; China

1. Introduction

Environmental regulations are the environmental means concerned with the protection of the natural resource, the contamination control and the environmental management (Zhao *et al.* 2009, Xue *et al.* 2010). The industrial sector is usually considered to generate more pollution than the service sector (Gassebner *et al.* 2011). And it is becoming apparent that industrial activity plays an essential role in a sustainable society (Fang and Zhou 2008). Following the goal of industrial sustainable development, the research conducted in causal relationship between industrial development and environmental regulation has been continuously expanding since 1980s, as a whole, the three particular focus of attention has been on: environmental regulation and industrial investment, environmental regulation and efficiency, environmental regulation and trade.

With respect to environmental regulation and industrial investment dimension, as early as in

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1980, Kopp and Smith (1980) conducted empirical study of the relationship between environmental regulation and investment behavior. Garofalo and Malhotra (1995) quantified the effect of environmental regulations on regional manufacturing capital formation. They found that more stringent environmental regulations raise the firm's cost of production both directly and indirectly, thus lowering the rate of capital formation. Greenstone (2002) also found a similar result in his empirical study. Gray and Shadbegian (1998), List and Co (2000) test whether environmental regulation affects investment decisions, they suggest that firms shift investment towards plants facing less stringent abatement requirement. Globerman and Shapiro (2002) point out that environmental regulation is an important determinant of foreign direct investments (FDI). Similar studies also include the effects of environmental regulation on FDI of high and low pollution-intensive industries (Xing and Kolstad 2002) on investment decision-making of domestic and foreign enterprises (List *et al.* 2003, List *et al.* 2004), on industrial SO_2 emission (He 2006), on investment of manufacturing sectors (Leiter *et al.* 2011). The second aspect closely to industrial investment is the location choice of firms. In early 1970s, Stafford (1977) investigated the impact environmental regulation on the location of U.S. manufacturing industries. Hereafter, Levinson (1996) concluded that the differences in environmental regulations do not systematically affect the site allocation of manufacturing plants. In 1997, Ulph and Valentini (1997) extended the linkage analysis of strategic environmental policy and firm allocation. According to a survey by Dean *et al.* (2000) they noted that environmental regulation is no effects on the formation of large establishments. And the study conducted by Jeppesen *et al.* (2002) is distinctive different with previous research, they extended the analysis method for location choice of firms, and provided a new insight of meta-analysis for decision-maker by using empirical specification, data, environmental regulatory measure, and other control variables categories. More recent empirical research typically finds that environmental regulations affect the allocation of new firms (Brunnermeier and Levinson 2004, Spatarean 2007, Dam and Scholtens 2008).

With respect to environmental regulation and industrial efficiency dimension, whether and to what extent environmental regulations influence the competitiveness of industrial firms remains a hotly debated issue, the 1990s marked an unprecedented increase in this field. From the existing literature, more empirical studies focus on the linkages between environmental regulation and productivity, competitiveness, and efficiency. There are three viewpoints being debate: favorable impact (Porter), adverse impact (Neo-classical) and no significant impact. Indeed, concern about the trade off between environmental regulation and competitiveness was triggered in earlier 1970s. But, it was in 1991 that Porter made the clearest and highest profile break with the neo-classical economic framework in which the debate had been largely conducted (Poter 1991). Subsequently, Michael Porter (1995), Lanjouw and Mody (1996), Berman and Bui (2001), Arocena and Price (2002), Brunnermeier and Cohen (2003), Murty and Kumar (2003, 2006), Chakrabarti and Mitra (2005), Telle and Larsson (2007), Hamamota (2008), Lanoie *et al. (*2008), López-Gamero *et al. (*2009), Wang *et al. (*2011), Testa *et al. (*2011), Lin and Yang (2011) all proposed and elaborated that stringent environmental regulation can lead to increase situation of industrial competitiveness and efficiency. On the contrary, Corad and Wastl (1995), Ayerbe and Górriz (2001), Shadbegian and Gray (2005), Chintrakarn (2008), Xie *et al. (*2008) point out that environmental regulations barrier the promotion of industrial efficiency. In addition, there is the different conclusion or viewpoint about the impact of environmental regulation on efficiency presented at the existing literature (Jaffe *et al.* 1995, Honkasalo *et al.* 2005, Triebswetter and Hitchens 2005, López-Gamero *et al.* 2010).

With respect to the impact of environmental regulation on trade, isolating the scale, composition, and technique effects of international trade on industrial pollution is one of the most interesting fields, with the emergence of trade liberalization as an environmental issue (Copeland and Taylor 1994, Cole and Rayner 2000). A number of authors have empirically tested the impact of environmental regulations on trade patterns, although results have been inconclusive. Larson *et al.* (2002) estimate the impact of potential changes in environmental regulations on exports from six case countries. Cole and Elliott (2003) estimate the sensitivity of pollution output to trade openness. Similarly, other authors (e.g., Cole *et al.* 2010, van Beers and van den Bergh 1997, Ederington and Minier 2003, Levinson and Taylor 2008) also found that regulations are influencing trade patterns. In contract, Harris *et al.* (2002), Tobey (1990), Janicke *et al.* (1997), Xu and Song (2000) find that environmental regulations do not appear to influence trade.

The Environmental Kuznets Curve (EKC) hypothesis states that economic growth degrades the environment at low-income levels, but as incomes rise, harmful environmental impacts decrease (Kuznets 1955). Typically, in EKC research a quadratic or cubic function is analyzed in reduced form in order to test the inverted-U shape of the EKC. However, so far EKC relationship has only been observed for certain substances, which could also be due to substitution processes among different natural resources (Seppälä *et al.* 2001). If the ecosystem is to be sustained, some reduction of material flows may be necessary. That is way the EKC hypothesis has to be tested with aggregated direct material flow data (Seppälä *et al.* 2001). Therefore, the relationship issues between material flows and economic growth has received increasing attention based on EKC hypothesis in recent years (Seppälä *et al.* 2001, Vehmas *et al.* 2007). Seppälä *et al.* (2001) analyzed the EKC with direct material flow data. Results indicated that the EKC hypothesis does not hold in the case of aggregated direct material flows among industrialized countries like Germany, Japan, the USA, the Netherlands and Finland. Similarly, Vehmas *et al.* (2007) carried out the linking and EKC analysis using direct material input (DMI) against GDP and DMI/GDP, as well as Domestic Material Consumption (DMC) against Public and Private Consumption (PPC) and DMC/PPC. They concluded that the trend in the European Union is a weak de-linking of material flows from economic growth during the years 1980-2000. On the contrary, Ghertner and Fripp (2007) highlighted the perspective of consumption, their study extended this line of research from production-based approach to consumption-based approach using life-cycle tool. They quantified the extent to which the US has shifted the environmental impact associated with the goods it consumes to other countries through trade. In addition, Muñoz and Hubacek (2008) explained the change in DMI by using Structural Decomposition Analysis (SDA), they mainly stress the effects of international trade and economic growth on environmental pressures in their study.

To summarize, if we look at the previous works which study the effects of environmental regulation on industrial economy at different levels, we find that they focus on impact measure and quantitative estimate of environmental regulation on industrial investment, efficiency and trade. At the same time, they also typically refer to the linkage between material flows and economic growth. But no direct and single measures of “material consumption” elements of industrial system are taken into account. In other words, this has been little studied in quantification the relationship between industrial material consumption and environmental regulation to date, but has important implications for further understanding material consumption change and regulation efficiency. Moreover, China’s industrial growth has been extremely rapid during the period of economic reform (Wang and Wheeler 2005). Industry is China’s largest productive sector

(National Bureau of Statistics of China 2009, Fang 2012). As Chinese income rise, the use of food, energy and raw materials will also continue to climb. In 2005, China consumed 26% of the world's crude steel, 32% of its rice, 37% of cotton and 47% of cement (Worldwatch Institute 2006).

In this paper, we take material consumption of industrial system as independent variable to build the linkage between material consumption and environmental regulation, and to identify possible inflection point of material consumption dynamic. We will address the implication of potential turning point of environmental regulation, regional difference of industrial material consumption and its cause analysis. The purpose of this paper is: (1) to build the correlation model between material consumption and environmental regulation; (2) to identify possible inflection point of material consumption curve of industrial system; (3) to reveal the implication of possible inflection point; (4) to present the regional difference of material consumption. The chapter is structured as follows: Section 1 describes research method and background in this study. Section 2 presents the empirical results and discussion. Section 3 depicts a summary and concluding remark.

2. Study methods

2.1 Study area

Considering the availability of reliable data, the research area in this paper is mainland China. It consists of 31 provinces, municipalities, and autonomous regions. They are: Beijing, Tianjin, Shanghai, Guangdong, Jiangsu, Zhejiang, Shandong, Liaoning, Hebei, Fujian, Hainan, etc. (Eastern China); Hubei, Hunan, Heilongjiang, Henan, Jilin, Anhui, Shanxi, Jiangxi, etc. (Central China); Inner Mongolia, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, Guangxi, Tibet, etc. (Western China), respectively.

2.2 Selecting evaluation variables

2.2.1 Total material consumption variable

Dematerialization emphasizes on the decrease of material input and reduction of waste discharge from the original sources (Cleveland and Ruth 1998). Material Flow Analysis (MFA) is a quantitative procedure for determining the flow of materials and energy through the economy based on the laws of Thermodynamics. MFA was developed in Europe in 1990s, largely at the Wuppertal Institute in Germany, and has been adopted as a methodology by the European Union with respect to its sustainable development program (European Communities 2001). To date, a variety of MFA studies have been conducted for both developed countries and economies in transition (European Communities 2001). However, the process of MFA is not only complicated (including data availability, the calculation process, etc.), and, there are still many unresolved issues using MFA, such as its units, aggregation techniques, and omitted energy flows (Huang *et al.* 2006). Indeed, recent studies have attempted to advance consumption-based approaches to environmental indicators (Ghertner and Fripp 2007). This paper, we will use "intermediate input of industry" as a proxy to measure material consumption level of industrial system. According to the definition of National Bureau of Statistics of China, "intermediate input of industry" refers to the value of all non-fixed-asset goods (production-based) and services consumed and used (consumption-based) in the same period by an industry. Intermediate input is given by following accounting identity.

$$\begin{aligned}&\text{Industrial intermediate input} = \\&(\text{gross industrial output}) - (\text{value-added of industry}) + (\text{value-added tax payable})\end{aligned} \tag{1}$$

where, gross industrial output value is the total volume of final industrial products produced and industrial services provided during a given period. Value-added of industry is the final results of industrial production of industrial enterprises in monetary terms during the reference period. And value-added tax payable refers to the amount of the value-added tax which should be paid by the enterprises during the reference period. Based on Eq. (1), these indices on gross industrial output, value-added of industry, and value-added tax payable are very easy to collect through China Statistical Yearbook. And, material consumption of industrial system could be presented in monetary terms. Therefore, one of the advantages of the proposed indicator of intermediate input is the clear compatibility of different indicators and regions.

2.2.2 Environmental regulation variable

Recognition is now widespread that the abatement of industrial pollution and material consumption is one of the top priorities of the environmental management. This is primarily achieved through the enforcement of environmental laws and regulations. Many empirical findings suggest that environmental regulation can be descripted actively by environmental expenditures and revenues from environmental taxation (Leiter *et al.* 2011). The expenditure of industrial pollution control and dematerialization includes a measure of “end of line” (e.g., wastes abatement) and “production process enhancements” (e.g., resource cycling). At present, almost all of China’s counties and cities have implemented the pollution levy system (Wang and Wheeler 2005). Based on previous studies and data availability, this paper, we use the expenditure share of industrial pollutants abatement (e.g., percentage of the industrial pollutants abatement investment in total

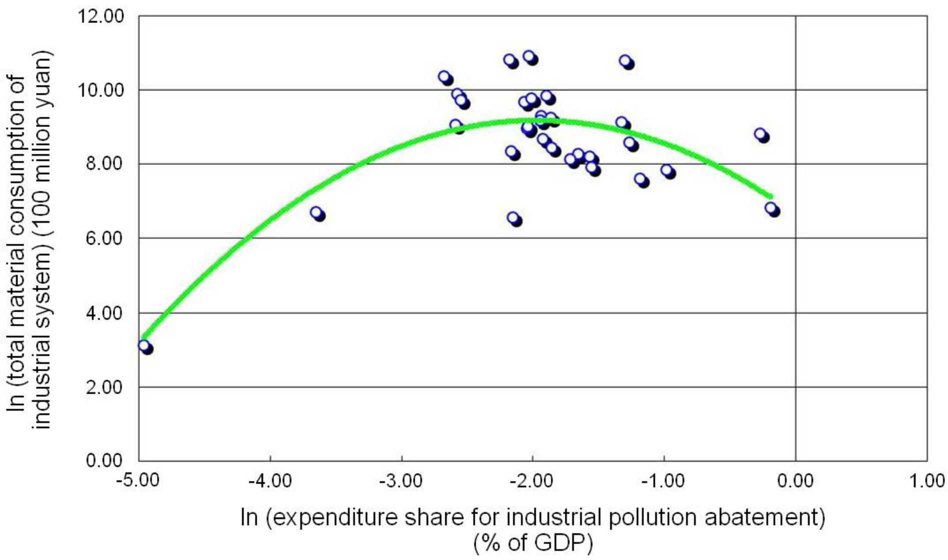

Fig. 1 Material consumption vs. expenditure share for industrial pollution abatement

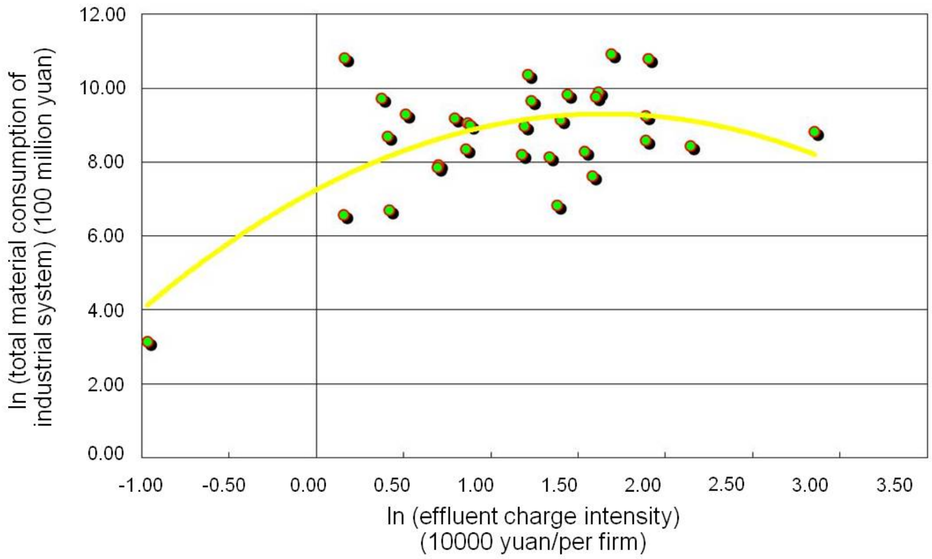

Fig. 2 Material consumption vs. effluent charge intensity per firm

GDP per year) and industrial effluent charge intensity (e.g., effluent charge intensity per industrial firm) at province-level (provincial specific) to measure the governing capacity as well as level of environmental regulation in China industrial system.

2.2.3 Material consumption intensity variable

The intensity of material consumption implies that can be measured by total material consumption per unit GDP.

2.3 Data collection and description

In this study, we use provincial-level (e.g., mainland China excluding Hong Kong Special Administrative Region, Macao Special Administrative Region and Taiwan Province. It consists of 31 provinces, municipalities, and autonomous regions) statistical data on GDP, gross industrial output value, value-added of industry, value added tax payable, expenditure share of industrial pollutants abatement in GDP, total value of effluent charge, number of units charges levied, etc. These data are taken from China Statistical Yearbook for the year 2009 and 2006. The time scale of mentioned above all index is 2008 and 2005. And GDP, gross industrial output value are calculated at current prices.

3. Empirical results

3.1 Modeling of total material consumption

On basis of the 2008 provincial level data and selected indicators of above mentioned, we choose natural logarithm(total material consumption, *MC*)as dependent variable, natural logarithm

Table 1 Statistical test of material consumption for China industrial system

	Independence variables	In (total material consumption) (dependence variable)					
		R^2	*F*	*P(F<C)*	*β*	*λ*	*ε*
2008	In (expenditure share for Industrial pollution abatement)	0.558	17.692***	0.000	-0.653*** (0.122)	-2.574*** (0.628)	6.652*** (0.752)
	In (effluent charge intensity per firm)	0.422	10.229***	0.000	-0.755*** (0.247)	2.490*** (0.572)	7.252*** (0.414)
2005	In (expenditure share for industrial pollution abatement)	0.517	14.997***	0.000	-0.694*** (0.206)	-1.930** (0.933)	7.110*** (0.943)
	In (effluent charge intensity per firm)	0.492	13.579***	0.000	-0.607*** (0.184)	1.360*** (0.279)	7.828*** (0.251)

Note: Asterisks indicate: significance levels: *** 1% level, ** 5% level and * 10% level
The data in parenthesis present standards error
β, λ, ε are the parameters of quadratic, one-time and constant items to be estimated respectively

(the expenditure share for industrial pollutants abatement, *EI*; effluent charge intensity, *ER*) as independent variables. Figs. 1 and 2 clearly reveal that there is significant non-liner relationship between total material consumption and the expenditure for industrial pollutants abatement, between total material consumption and effluent charge intensity. Therefore, we use a static framework as proposed by Fang (2012), basic regression models are respectively

$$\ln(MC) = -0.653\ln(EI)^2 - 2.574\ln(EI) + 6.652 \tag{2}$$

$$\ln(MC) = -0.755\ln(ER)^2 + 2.490\ln(ER) + 7.252 \tag{3}$$

where, *MC* is total material consumption of industrial system, *EI* is the expenditure share for industrial pollutants abatement, *ER* is effluent charge intensity per firm.

Table 1 lists the statistical results for the material consumption based on both 2005 and 2008 data from the samples of 31 provinces, municipalities, and autonomous regions. From Table 1, all coefficients are significant at the 1% level by *F* and *t*-test even though the determination coefficients (R^2) for the regression models are only 0.422~0.558. This result shows that 99% of composed error variance of material consumption intensity can be explained by the variance of environmental regulation. At the same time, from Table 1, it is also observed that the coefficient of quadratic term is negative sign. It implies that total material consumption of industrial system is decreasing along with the enhancing of expenditure share for industrial pollutants abatement and effluent charge intensity.

3.2 Modeling of material consumption intensity

It is well known that the scale of industrial development (economic growth) is the main driving force for high level of materials consumption (Vehmas *et al.* 2007, Muñoz and Hubacek 2008). And Fig. 3 also shows that the correlation coefficient (0.962) is near linear relationship between

Table 2 Statistical test of material consumption intensity for China industrial system

	Independence variables	In (material consumption intensity) (dependence variable)					
		R^2	F	$P(F<C)$	β	λ	ε
2008	In (expenditure share for industrial pollution abatement)	0.493	13.635***	0.000	-0.194*** (0.043)	-0.726*** (0.223)	0.003 (0.268)
	In (effluent charge intensity per firm)	0.496	13.750***	0.000	-0.332*** (0.077)	0.931*** (0.178)	0.081 (0.129)
2005	In (expenditure share for industrial pollution abatement)	0.411	9.438***	0.001	-0.253** (0.120)	-1.698*** (0.543)	-2.556*** (0.291)
	In (effluent charge intensity per firm)	0.392	8.695***	0.001	0.033 (0.041)	-0.260*** (0.063)	-0.509*** (0.058)

Note: Asterisks indicate: significance levels: *** 1% level, ** 5% level and * 10% level
The data in parenthesis present standards error
β, λ, ε are the parameters of quadratic, one-time and constant items to be estimated respectively

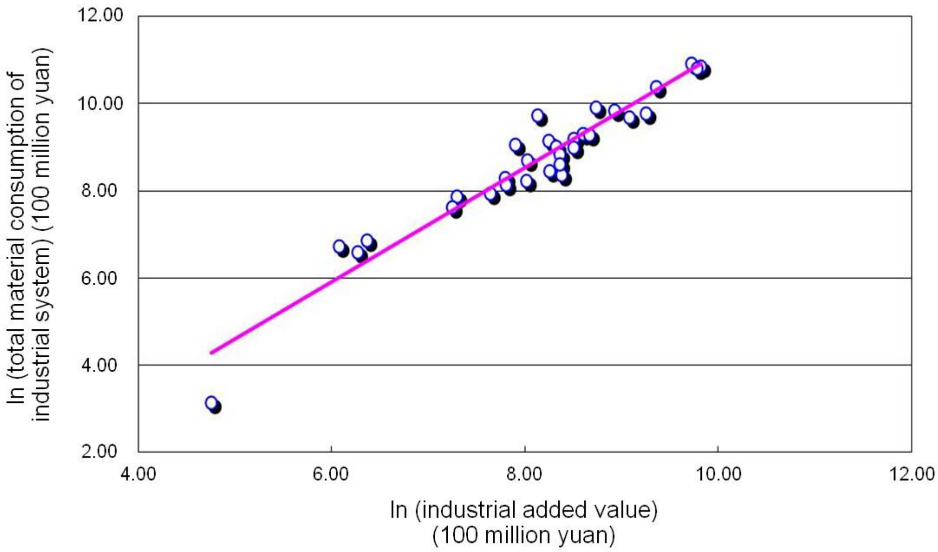

Fig. 3 Material consumption of industrial system vs. industrial added value

two variables. Therefore, besides the total material consumption, material consumption intensity (total material consumption per unit GDP) is also an important variable to further understanding the effect of environmental regulation or EKC analysis (Vehmas *et al.* 2007). Similarly, according to the 2008 provincial level data, Figs. 4 and 5 clearly reveal that there is also significant non-liner relationship between material consumption intensity and the expenditure share for industrial pollutants abatement, between material consumption intensity and effluent charge intensity. In similar way, we obtained following two fitting equations respectively

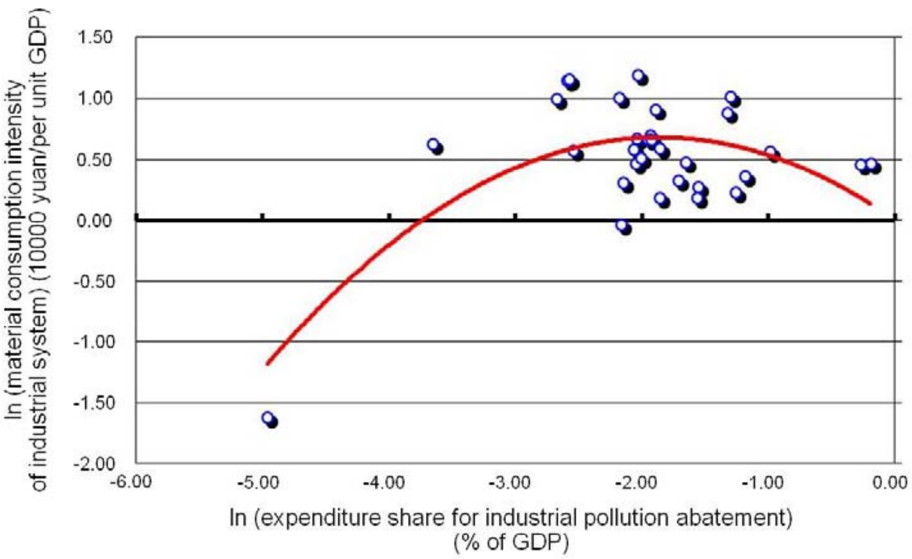

Fig. 4 Material consumption intensity vs. expenditure share for industrial pollution abatement

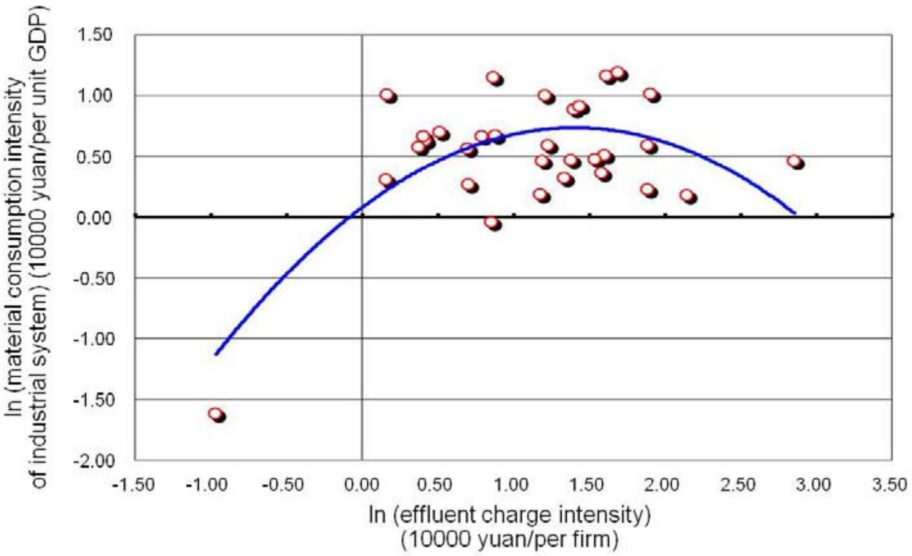

Fig. 5 Material consumption intensity vs. effluent charge intensity per firm

$$\ln(MI) = -0.194\ln(EI)^2 - 0.726\ln(EI) + 0.003 \tag{4}$$

$$\ln(MI) = -0.332\ln(ER)^2 + 0.931\ln(ER) + 0.081 \tag{5}$$

where, *MI* representing the material consumption intensity of industrial system, *EI* is the expenditure share for industrial pollutants abatement, *ER* is effluent charge intensity per firm.

Table 2 summarizes our empirical findings for two different fitting models based on both 2005 and 2008 data from the samples of 31 provinces, municipalities, and autonomous regions respectively. From Table 2, the models seem to fit generally well both 2005 and 2008. All F-test are significant at the 1% level ($p = 0.000 < 0.001$). And most of coefficients ($\beta, \lambda, \varepsilon$) are significant at the 5% level by t-test with the exception of coefficients ε in 2008 and β in 2005 although the determination coefficients (R^2) for the regression models are lower. This result indicates that 95% of composed error variance of material consumption intensity can be explained by the variance of environmental regulation. In general tendency, the coefficients presented in Tables 1 and 2 are consistent with the favorable impact of environmental regulation on dematerialization of industrial system. That is, the coefficient of quadratic term in Eqs. (2) - (5) is negative for all observations. The result is consistent with our basic hypothesis that more stringent environmental regulations tend to reduce material consumption of industrial system. However, caution is also required in interpreting favorable or adverse impact of environmental regulation on material consumption. Namely, there is a mix of adverse and favorable impacts of environmental regulation on material consumption with environmental regulation change. In other words, the causal relationship between environmental regulation and material consumption is that, before reaching the maximum peak value, material consumption increases with environmental regulation rise, presenting a adverse correlation; after reaching the maximum peak value, material consumption decreases with environmental regulation rise, presenting a positive correlation, it implies that the efficiency of environmental regulation is enhancing in following period. Therefore, the positive impact of environmental regulation on material consumption reduction depends on if environmental regulation or not has achieved a certain level (i.e., minimum value).

3.3 Inflection point of material consumption and implication

According to the Tables 1 and 2, the statistical results both 2005 and 2008 are very similar, and the statistical correlation is higher in 2008 than that in 2005. Therefore, in the following paragraphs, we focus on the threshold analysis based on 2008 data. As Eq. (2), there is the fact that extreme value $(\ln EI_m) = (4\beta * \varepsilon - \lambda * \lambda)/4\beta$ exists (see Fig. 1). Then, the corresponding value of variable EI (e.g., expenditure share for industrial pollutants abatement) is 0.14% of GDP. Result indicates that there is a mix of adverse and favorable impacts of EI on MC (e.g., total material consumption) with EI change. The adverse impact of EI on MC indicates that EI level has not met the demand of lowering material consumption for industrial system. On the contrary, the positive impact of EI on MC indicates that EI level has met the demand of lowering material consumption for industrial system.

As Eq. (3), there also is the fact that extreme value $(\ln ER_m) = (4\beta * \varepsilon - \lambda * \lambda)/4\beta$ exists (see Fig. 2). Then, the corresponding value of variable ER (e.g., effluent charge intensity per firm) is 52 thousand RMB Yuan per firm. Result also shows that there is a mix of adverse and favorable impacts of ER on MC with ER change. The adverse impact of ER on MC also shows that ER has not met the demand of lowering material consumption for industrial system. In contrast, the positive impact of ER on MC indicates that ER has met the demand of lowering material consumption.

Consistent with previous studies, based on Eqs. (4) and (5), the corresponding extreme values of variables EI and ER are 0.15% of GDP and 40.6 thousand RMB Yuan per firm respectively (Figs. 4 and 5).

In terms of the various equations are subject to environmental regulation. The equation change exhibits a boundary effect (turning point) that has a different impact on material consumption. This is because the boundary effect refers to the fact that environmental regulation exerts greater dematerialization efficiency after the level of environmental regulation exceeds a “threshold”. Therefore, we conclude that there is the inflection point of environmental regulation effect in assessment *MC* or *MI* change over time. For this reason, it is necessary to further identify the meaning of regulation inflection point.

Following the extreme value range of *EI* (e.g., 0.14%~0.15% of GDP) and *ER* (e.g., 40.6~52.0 thousand Yuan per firm), we define larger values (e.g., 0.15% and 52.0) as critical scale of environmental regulation effect change respectively. A particularly striking feature is that the lowering effects of *MC* and *MI* may occur when *EI* and *ER* are more than 0.15% of GDP and 52.0 thousand Yuan per firm respectively. According to this result, we can make some valuable reflections.

Firstly, the two extreme value points of environmental regulation are the most important scale to judge reasonability and performance of industrial pollutants abatement expenditure and effluent charge intensity in selected period.

Secondly, taking into account the context of sample data (31 province-level data) is panel data (static). Thus, the inflection points reveal clarifying result for minimum expenditure intensity of industrial pollutants abatement and effluent charge intensity just in a special selected period (for example in 2008). It will change with technological development and target of industrial system improvement. However, new inflection points still can be taken as the critical scale to assess the reasonability of pollutants abatement investment or effluent charge intensity in new period.

Thirdly, although more stringent but properly designed environmental regulations can trigger innovation and greater dematerialization efficiency for industrial system. However, the prerequisite of a Pareto improvement or win-win situation occurrence is that environmental regulation achieves a certain level (i.e., minimum value). After that result is consistent with Porter Hypothesis (Poter 1991, Poter and van der Linde 1995, Poter *et al.* 1995).

3.4 Regional difference of material consumption and reason

While the disparities between Eastern, Central and Western China are numerous, knowing these differences will help us better understand the situation of material consumption for industrial system and the mechanics behind the environmental regulation. From the inflection points of *EI* and *ER* described above, we can divide fitting curves of material consumption into both right and left flanks. And we define right flank of fitting curve as dynamic zone for material consumption dropping, left flank of fitting curve as dynamic zone for material consumption rising, then, some important lessons can be identified that are relevant to economic feature and environmental regulation direction in China.

In the expenditure scale sense, Beijing, Shanghai, Guangdong, Jiangsu, Zhejiang, Hebei, Fujiang, Hainan, Hubei, Hunan, Heilongjiang, Henan, Jilin, Anhui, Jiangxi, Qinghai, Tibet Anonymous Region, etc. are occupying in the dynamic zone for material consumption rising (see Fig. 6), implying that the expenditure share of industrial pollutants abatement in these regions have not yet achieved 0.15 percent of GDP, with expenditure enhancement of industrial pollution abatement, as a whole, the total amount and intensity of material consumption still display an increasing tendency within a certain time. And Tianjin, Shandong, Liaoning, Shanxi, Inner Mongolia Autonomous Region, Sichuan, Chongqing, Shaanxi, Yunnan, Xinjiang Uygur Autonomous Region, Guangxi Zhuang Autonomous Region, Gansu, Ningxia Hui Autonomous occupying in the dynamic zone for material consumption dropping (see Fig. 6), implying that the

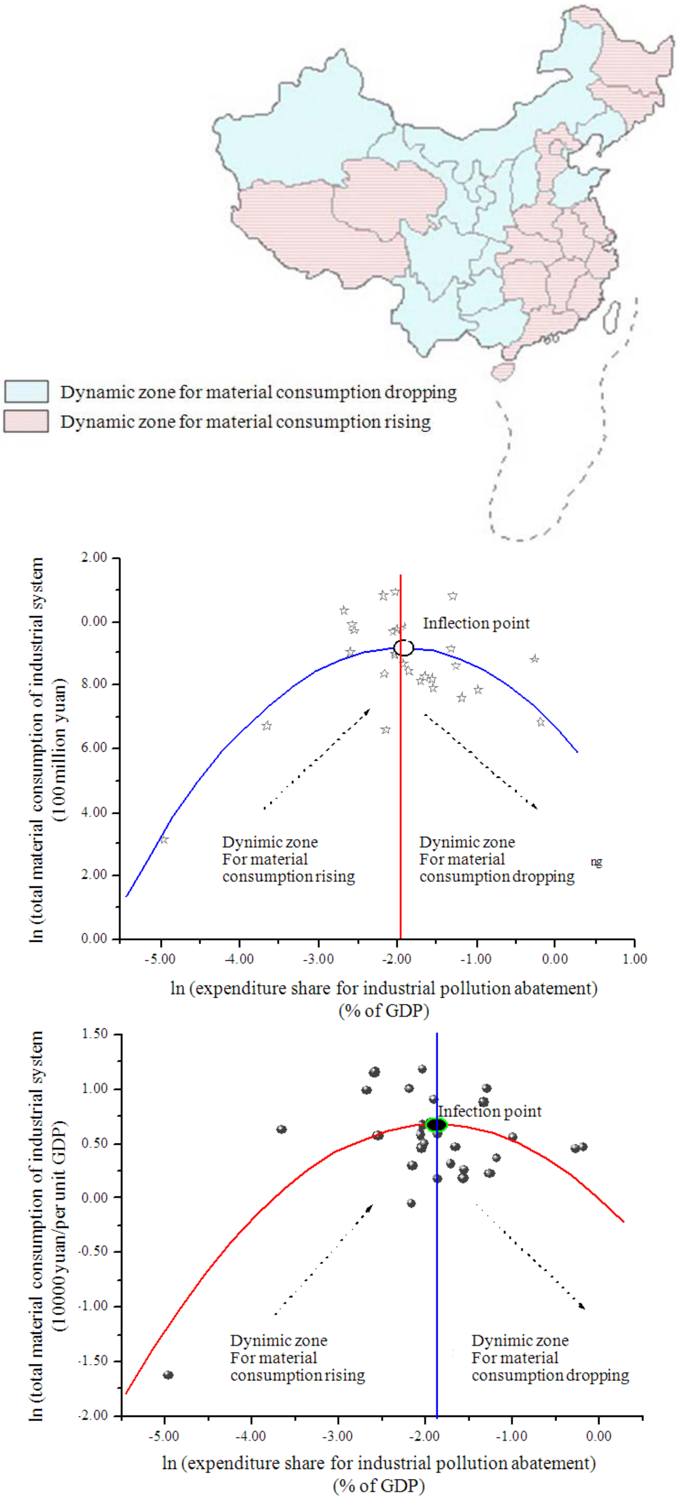

Fig. 6 Regional difference of material consumption based on expenditure share for industrial pollution abatement

expenditure share of industrial pollutants abatement in these regions have achieved 0.15 percent of GDP (e.g., cross inflection point), as a whole, with expenditure enhancement of industrial pollution abatement, the both total amount and intensity of material consumption will display a decreasing tendency.

In the effluent charge scale sense, Beijing, Tianjin, Shanghai, Guangdong, Liaoning, Zhejiang, Hebei, Fujiang, Hainan, Hubei, Hunan, Heilongjiang, Henan, Jilin, Anhui, Jiangxi, Chongqing, Yunnan, Xinjiang Uygur Autonomous Region, Guangxi Zhuang Autonomous Region, Gansu, Ningxia Hui Autonomous Region, Qinghai, Guizhou, Tibet Autonomous Region, etc. are occupying in the dynamic zone for material consumption rising (see Fig. 7), implying that the effluent charge intensity of industrial system in these regions have not yet achieved 52.0 thousand RMB Yuan per firm. On the contrary, Jiangsu, Shandong, Shanxi, Inner Mongolia Autonomous Region, Sichuan, Shaanxi, etc. are occupying in the dynamic zone for material consumption dropping (see Fig. 7), implying that the effluent charge intensity in these regions have achieved 52.0 thousand RMB Yuan per firm, as a whole, with enhancement of effluent charge system, both the total amount and intensity of material consumption will display an decreasing tendency.

In both critical scales of pollutants abatement expenditure and effluent charge intensity sense, as can be seen from the Figs. 6 and 7, most of regions are located in the dynamic zone of material consumption rising (e.g., in left flank of curve). Therefore, our empirical findings clearly suggest that both intensities of industrial pollutants abatement expenditure and effluent charge have not yet achieved the expected target in most regions of mainland China at present, there is still a long road ahead in material consumption mitigation in China. In addition, from Figs. 6 and 7 we can draw the following conclusions: most of regions of material consumption decreasing are distributed in western China. In fact, there is similar conclusion with Ghertner and Fripp (2007)'s study. Evidence increasingly suggests that structural changes in the sectoral composition of domestic production are driving reductions in production-based environmental intensities in industrialized regions. These regions are characterized with high industrialization level (more than 52%), resource-based industries, and industrial structures of high material and energy consumption, and high pollution. Moreover, these regions not only are the cluster regions of heavy industries such as electric power, chemical, mining and metallurgy, machinery, etc. but also the key regions of industrial environmental management. Several possible causes of the regional differences in environmental regulation are as follows: (1) the enhancement of environmental regulation in key cluster regions of industry. In general, regulation is stricter in areas where industrialization rate is higher, and pollution is heavier. For example, the expenditure share of industrial pollutants abatement are 0.76%, 0.28%, 0.27%, 0.16% and 0.16% of GDP, and the effluent charge per firm are 173.4, 65.9, 66.9, 85.0 and 65.7 thousand RMB Yuan in Shanxi, Inner Mongolia Autonomous Region, Shandong, Shaanxi, and Sichuan, respectively. As a result, stricter regulation leads quantity control policy on material consumption of industrial system. The Chinese government has directly to the significant effect of material consumption reduction. (2) The actual effect of total implemented a system of total quantity control on key industrial pollutants discharge since 1995. And local governments of provinces, autonomous regions and municipalities shall reduce and control the total quantity of the discharge of key industrial pollutants in their respective administrative jurisdiction. Meanwhile, in recent year, Chinese Ministry of Environmental Protection (MEP, formerly SEPA), the National Development and Reform Commission (NDRC), announced the eight departments on the 14th green joint special operations, strict management of high energy consumption, high pollution, resource-based industries. Indeed, most of regions in Central and Western China such as Shanxi, Inner Mongolia Autonomous Region, Gansu, Shaanxi,

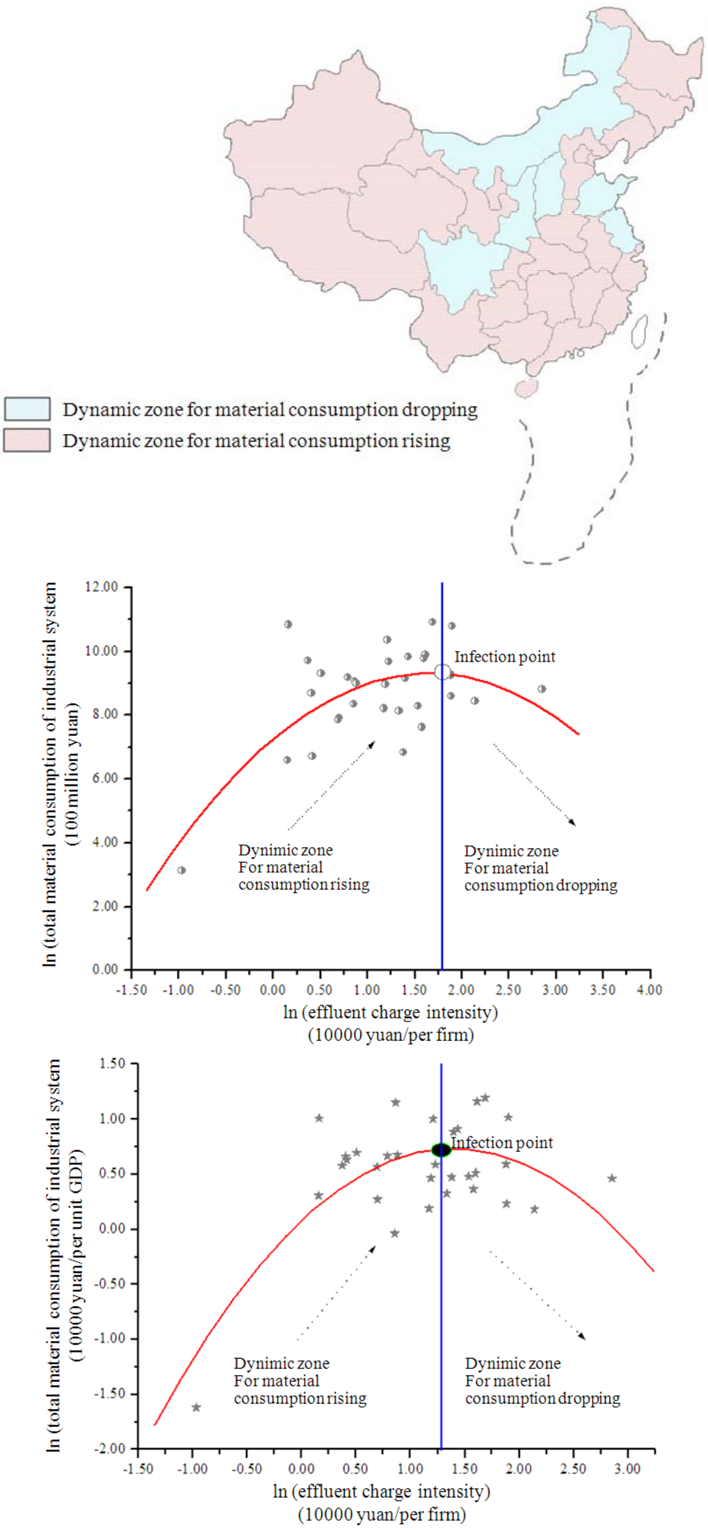

Fig. 7 Regional difference of material consumption based on effluent charge intensity

Xinjiang Uygur Autonomous Region, Sichuan, etc. become the key supervision areas of industrial environment. (3) China National Cleaner Production Strategy improves the performance of industrial dematerialization. The concept of Clean Production (CP) was introduced in China in the 1990s, and the Cleaner Production Promotion Law was adopted on June 29, 2002 and made effective on January 1, 2003. Guided by the CP strategy, China identifies the strategic priority industrial sectors involving in chemical, cement, distillery, brewery, iron and steel, pharmaceutical, food processing, metallurgy, paper making, non-ferrous metals, printing and dyeing sectors etc. (Ma *et al.* 2010). Meanwhile, we noted that strategic priority areas are basic consistent with priority industrial sectors due to the nature of industrial allocation in Western China, in recent years, as a strategy for realizing sustainable industrial development, China has made progress with CP demonstration projects, training and education in CP auditing, and CP policy studies. According to a description by Ma *et al.* (2010), the total input of fund for CP has reached to 41.1 billion RMB Yuan, a series of modification projects have cut 2.27 million tons of chemical oxygen demand and 49.32 million tons of standard coal usage, as well as reducing sulfur dioxide emissions by 712,000 tons from 2003 to 2009. (4) The circular economy enhancing the efficiency of resource utilization. The development process of policies related to the circular economy has entered the fast tract in China since the early of 2000s. *The Several Opinions on Accelerating Circular Economy Development (2005)*, *the Program for Experimental Units of Circular Economy (2005)*, *the Assessment Standards for National Experimental Eco-industrial Parks (2006)*, *and the Managerial Methods of Collection of Renewable Resources (2007)*, etc. were implemented successively (Ren 2007). The distinctly feature of these regulatory is the emphasis on key industrial sectors (i.e., iron and steel, metal, coal mining, power, petroleum, chemical engineering, building materials, paper making, dyeing and printing) and key provinces (i.e., Inner Mongolia Autonomous Region, Xinjiang Uygur Autonomous Region, Guangxi Zhuang Autonomous Region, Gansu, Guizhou, Henan, Hunan, Liaoning, and Shandong) in actively implemented process (Ren 2007). From the distribution of selected demonstration regions, most of them are located in western China. In 2008, it is worth mentioning that China passed the Circular Economy Promotion Law of the People's Republic of China, no doubt, it is a holistic milestone of circular economy development. In the course of implementing circular economy, and remarkable improvements have been achieved in efficiency of resource utilization and energy conservation (Ma *et al.* 2010).

4. Conclusions

There are significant quadratic function relationship between material consumption and the expenditure share for industrial pollutants abatement, between material consumption and effluent charge intensity. And there is the fact that inflection point exists, corresponding inflection points of two regulation variables are 0.14% of GDP, 0.15% of GDP, and 40.6 and 52.0 thousand RMB Yuan per firm respectively.

On basis of inflection points, we can make some valuable reflections on management of industrial environment. Firstly, the inflection points of regulations are the most important scale to judge reasonability and performance of industrial pollutants abatement expenditure and effluent charge intensity in selected period. Secondly, the inflection points reveal clarifying result for minimum expenditure share of industrial pollutants abatement and effluent charge intensity just in a special selected period. However, new inflection points still can be taken as the critical reference scale to assess the reasonability or performance of regulations in new period. Thirdly, a Pareto improvement or win-win situation may occur when the environmental regulation variables crosses a certain level (i.e., minimum value). After that result is completely consistent with Porter Hypothesis. In this sense, the inverted-U model of EKC can provide empirical information about the need for a more effective environmental policy.

Empirical findings suggest that both intensities of industrial pollutants abatement expenditure and effluent charge have not yet achieved the expected target in most regions of mainland China at present. And most of regions of material consumption decreasing are distributed in western China where are characterized with high industrialization rate, resource-based industries, and high material and energy consumption, and high pollution. Several possible causes of the regional differences in environmental regulations are the effects of the expenditure share for industrial pollutants abatement, effluent charge intensity in key cluster regions, as well as the effects of total quantity control, cleaner production, and the circular economy strategy.

Acknowledgements

This research was funded by the National Natural Science Foundation of China (Grant No. 40971304). The author thanks the anonymous referees which improved the paper.

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