Measurement to regulatory preference for electric power industry based on social welfare maximization model

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Abstract. Regulator’s preference to electricity generation or environmental remediation will affect policy option in electric power industry. This paper is to measure regulatory preference for this industry based on welfare economics and nonlinear programming approach. Previously, it builds a social welfare maximization model, thereafter inserts social welfare elasticity of input factor into model’s K-T condition and gets the measurable formula of regulatory preference. Employing this formula to measure regulator’s preference for Chongqing electric power industry during 2008-2018, the results reveal that there is a high and stationary preference to electricity generation rather than environmental remediation. However, production elasticity of total input factors in environment subsystem is higher than that of in electricity subsystem, which implies that investment in environment remediation will bring about more social welfare. The empirical research suggests that clean energy generation and environmental remediation should be addressed to maximize social welfare brought by electric power industry.

1. Introduction

With energy and environment problems being more and more serious to modern economy, electric power industry requires policy maker to coordinately govern both energy production and environmental remediation[1-2]. When implementing coordinated regulation[3], regulator needs to concern production factor input among electricity generation and environmental remediation to pursue social welfare maximization. In reality, however, there exists regulatory preference to electricity generation subsystem or environmental remediation subsystem for policy maker and this phenomenon will affect resources allocation when governing electric power industry development. Therefore, it is necessary to measure regulator’s preference before scheduling resources allocation.

In literature, Stigler[4] and Peltzman[5] previously study how to measure regulator’s preference for regulatory activities. They find that government pricing on public goods and services may reflect its preference to enterprise or consumer. Latter, Nelson[6], Roberts et al.[7] and Snowberger[8] report that regulatory preference can be revealed by calculating the Ramsey number. Christopher et al.[9] propose an addition-type social welfare function which is composed of weighted sectoral utility and consumer surplus, and regulator may realize social welfare maximization by adjusting price variable. The common point of the above studies is that regulatory preference is strongly affected by the elasticity of decision variable. Article [10] builds an addition-type social welfare function through adding up producer surplus and public utility of pollutants mitigation together, hence proposes a conceptual model of regulatory preference for electric power industry. Benefited from this idea, article [11] employs Cobb-Douglas multiple-type social welfare function to derive an output elasticity, then
quantifies regulator’s preference for this industry. However, it is unlikely accurate to catch the economic meaning of social welfare maximization in a way of coordinating resources allocation among electricity production and environmental remediation, furthermore it still depends on concrete math form choice.

This paper explores measurement to regulatory preference for electric power industry, which is not restricted by concrete function form option. Based on welfare economics, section 2 does a qualitative analysis of regulator’s preference. Section 3 derives a partial social welfare elasticity and builds a social welfare optimization model, thereafter inserts the former into the latter’s K-T condition and gets measurable formula of regulatory preference. Meanwhile, section 4 carries out an empirical research on regulatory preference for Chongqing electric power industry. Finally, a brief conclusion is summarized in section 5.

2. Qualitative analysis

2.1. Economic meaning
From welfare economics perspective, social welfare brought by electric power industry can be explained as an input-output process\[12\]. Electric power industry coordinated regulation makes the two opposing subsystems, electricity generation and environmental remediation, harmonious development[2]. In electricity industry development progress, concerning social welfare contributed by both energy generation and pollutants mitigation, regulatory preference reflects policy maker’s resources investment inclination when making optimal development strategy. Based on regulatory preference, regulator coordinates resources allocation among the two subsystems to realize social welfare at Pareto optimization state.

2.2. Concept of regulator preference
This section employs ordinal utility theory to qualitatively analyze regulatory preference for governing electric power industry. Suppose \(x, y\) are two production factors and respective price is \(p_1, p_2\). When regulator’s input budget is \(G = xp_1 + yp_2\), maximum social welfare is \(U(x, y)\) and corresponding optimal factor portfolio is \((x, y)\). Given input budget gets a marginal change \(\Delta G = \Delta x p_1 + \Delta y p_2\), then maximum social welfare is \(U(x + \Delta x, y + \Delta y)\) and corresponding optimal factor portfolio is \((x + \Delta x, y + \Delta y)\). If there exists \(\Delta x \mid x^{-1} < \Delta y \mid y^{-1}\), meaning that growth rate of social welfare is more sensitive to growth rate of \(x\), thus regulator’s preference between the two production factors is \(x > y\). In summary, regulatory preference is the sensitivity of social welfare growth rate to the growth rate of input production factor under restriction that social welfare expanding lies on its optimal pathway.

Simply extending the above analysis, substitute \(x\) by electricity production utility \(U_1(Q_1)\) causing by production factors and \(y\) by environmental treatment utility \(U_2(Q_2)\) coming from pollutants reduction, according to social welfare function \(W = W(U_1, U_2)\), one subsystem’s regulatory preference is the sensitivity of social welfare growth rate to the growth rate of total production factors under restrictions that both production function and social welfare expanding lie on their optimal pathway.

3. Measurement to regulatory preference

3.1. Partial social welfare elasticity of production factor
In line with economics theory[2], input production factors of electricity generation include capital, labour, land, entrepreneurship, technology and coal, output is dispatched electricity. Negative externality caused by electricity generation contains greenhouse gases (GHGs), sulfur dioxide (SO\(_2\)), nitrogen oxides (NO\(_x\)), mercury, soot, solid pollutants as well as water contamination. Suppose (i) electric power industry’s two subsystems have the same kinds of resources input, (ii) production factor
has non-negative marginal returns and, (iii) social welfare function, utility function and production function are first-order differential. Based on Bergson-Samuelson function form, social welfare function of electric power industry can be written as,

$$W = W(U_i(Q_i), U_j(Q_j))$$

(1)

Where $U_i$ indicates regulator’s utility function in the $i^{th}$ ($i=1,2$) subsystem.

Production function of the two subsystems can be written as,

$$Q_i = Q_i(A, x_{i1}, \ldots, x_{in}); i = 1,2$$

(2)

Where $x_{ij}$ signs quantity of the $j^{th}$ ($j=1,\ldots,n$) production factor in the $i^{th}$ subsystem. $A_i$ represents subsystem’s technology advancement.

Equation (3) is regulator’s input budget. Where $p_j$ is price of the $j^{th}$ production factor.

$$\sum_{i=1}^{2} \sum_{j=1}^{n} p_j x_{ij} = G; \forall x_{ij} \geq 0$$

(3)

In line with section 2.2, regulator’s preference to electricity generation or environmental remediation can be measured by equations (4), (5) and (6).

$$\lambda_i = \sum_{j=1}^{n} \lambda_{ij}; i = 1,2$$

(4)

Where, $\sum_{i=1}^{2} \lambda_{ij} = 1; 0 < \lambda_{ij} < 1; i = 1,2$

$$\lambda_{ij} = \frac{\partial W}{\partial U_i} \cdot \frac{\partial U_i}{\partial Q_i} \cdot \frac{\partial Q_i}{\partial x_{ij}} \cdot \frac{x_{ij}}{W}; i = 1,2; j = 1,\ldots,n$$

(5)

Equation (6) is social welfare elasticity of production factor. Equation (4) means that regulatory preference is the sum of all social welfare elasticities of the subsystem. Considering normal constraint in equation (5), regulatory preference can differentiate policy inclination among electricity generation and environmental remediation in electric power industry. Mathematically, social welfare function and sectoral utility function have a characteristics of convex to coordinates center. Concerning assumption (ii) and normal constraint, social welfare elasticity of production factor also has a non-negative feature. In line with equation (2), equation (6) may be rewritten as

$$\lambda_{ij} = \frac{\partial W}{\partial U_i} \cdot \frac{\partial U_i}{\partial Q_i} \cdot \frac{Q_i}{W} \alpha_{ij}; i = 1,2; j = 1,\ldots,n$$

(7)

Where production elasticity of input factor $\alpha_{ij} = (\partial Q_i/\partial x_{ij} / Q_i); i = 1,2; j = 1,\ldots,n$.

Equation (7) implies that under constraint of production function, there exists a positive mapping among the $n$ social welfare elasticities of each subsystem. Moreover, its economic meaning is that given subsystem’s output increases by 1%, if contributed by a single production factor, then the proportion among those $n$ growth rates is equal to the proportion among respective production elasticity. Choosing a production factor $j_0$ as basis, equation (7) can be transformed into partial social welfare elasticity, i.e.,

$$\lambda_{ij} = \alpha_{ij} \lambda_{j0}; i = 1,2; j = 1,\ldots,n$$

(8)

By employing partial social welfare elasticity, equation (4) is rewritten as,

$$\lambda_i = \alpha_{j0}^{-1} \sum_{j=1}^{n} \alpha_{ij} \lambda_{j0}; i = 1,2$$

(9)

Equation (9) reveals that output growth rate of the $i^{th}$ subsystem may be attributed to corresponding growth rate of each production factor. Note that, to accurately measure regulatory preference for electric power industry, equation (9) still needs to meet the condition of “setting social welfare expanding trajectory on its optimal pathway”. Section 3.2 builds a nonlinear programming to solve this problem.
3.2. Measurable formula of regulatory preference

Let’s put equation (2) into equation (1) and take resources input into consideration, the social welfare maximization model for electric power industry can be described as,

$$\max \ W = W(U_1(Q_1(A_1,x_{11},x_{12},...,x_{1n})),U_2(Q_2(A_2,x_{21},x_{22},...,x_{2n})))$$

subject to

$$\sum_{i=1}^{n} \sum_{j=1}^{n} p_{ij}x_{ij} \leq G$$

$$\forall x_{ij} \geq 0; i=1,2; j=1,\ldots,n$$

Obviously, gradient vector of model’s inequality constraints is linearly independent with gradient vector of objective function; moreover, in reality quantity of production factor is above zero. Therefore, the model’s K-T condition is,

$$\frac{\partial W}{\partial U_i} \frac{\partial Q_i}{\partial x_{ij}} - \gamma p_j = 0; i=1,2; j=1,\ldots,n$$

$$\sum_{i=1}^{n} \sum_{j=1}^{n} p_{ij}x_{ij} = G$$

Equation (10) includes regulatory preference’s condition of “setting social welfare on its optimal expanding pathway”. Let’s put equation (6) into equation (10), there is,

$$\lambda_iW.x_{ij} - \gamma p_j = 0; i=1,2; j=1,\ldots,n$$

To take equation (9) and (11) together, regulatory preference can be written as,

$$\lambda_i = [\gamma.(\sum_{q=1}^{n} \alpha_{iq}x_{iq}) - \sum_{j=1}^{n} p_j]W^{-1}; i=1,2; j=1,\ldots,n$$

Equation (12) reveals that subsystem’s regulatory preference is conjointly determined by $n$ equations of production elasticity, which meets the requirement that factor portfolio lies on the social welfare optimal expanding pathway. Therefore, equation (12) together with normal constraint in equation (5) forms the definition formula of regulatory preference for electric power industry.

Let’s add up subsystem’s $n$ equations, there is,

$$\lambda_i = [\sum_{q=1}^{n} \alpha_{iq}x_{iq}] - \sum_{j=1}^{n} p_j = 0; i=1,2$$

Equation (13) shows that production factor input is strong optimality because it also meets the equal marginal return law at subsystem level. Generally, $W \neq 0$ and shadow price in equation (10) $\gamma \neq 0$.

Let’s put equation (13) and (5) together, the measurable formula of regulatory preference is solved by equation (14).

$$\lambda_i = \frac{[\sum_{q=1}^{n} \alpha_{iq}x_{iq}] - \sum_{j=1}^{n} p_j}{\sum_{q=1}^{n} \alpha_{iq}x_{iq}^{-1} + \sum_{j=1}^{n} \alpha_{ij}^{-1}}; i=1,2$$

Where $\tilde{i}$ signs if $i=1$, then $\tilde{i}=2$, and vice versa.

4. Empirical research

4.1. Data collection and process

To evaluate regulatory preference for Chongqing electric power industry during 2008-2018, this section designates dispatched energy as output of electricity subsystem, SO2 mitigation as output of environment subsystem, capital and coal as two input production factors. Through investigating local government departments and companies, such as Chongqing Eco-Environment Bureau, Chongqing Development and Reform Commission, State Grid Chongqing Electric Power Company, as well as databases of China environment yearbook and China electric power yearbook, this research gets data
on dispatched electricity, coal consumption, new generation facilities investment; removed SO$_2$, desulfur equipment investment and coal consumption by SO$_2$ removal from 2008 to 2018. Of which electricity consumption by SO$_2$ removal is equivalently transformed into capital and coal inputs. Data process is fulfilled in Matlab R2014 environment.

4.2. Results and discussion

Figure 1 shows production elasticity of total factors of electricity subsystem and environment subsystem for Chongqing electric industry. During 2009-2018, production elasticity of environment subsystem has 7 years higher than that of electricity subsystem. It indicates that production efficiency of the former is superior over the latter subsystem.

Figure 1. Production elasticity of total factors of each subsystem during 2009-2018.

Figure 2 provides regulatory preference and its tendency for each subsystem. During 2009-2018, regulatory preference of electricity subsystem is around 0.95-0.99, featured as relative stability. In the past ten years electricity demand grew quickly in Chongqing municipality, many aged coal-fired power plants were retrofitted and expanded, as a consequence of that, policy maker kept high preference to electricity production.

Figure 2. Regulatory preference for Chongqing electric power industry during 2009-2018.

From welfare economics perspective, concerning environment subsystem has a feature of low regulatory preference and high production elasticity, Chongqing electric industry may further develop clean energy and renewable energy, such as hydro power, wind power, photovoltaic power, biomass power as well as clean energy technologies, to increase regulatory preference to environmental remediation.

5. Conclusions

Based on welfare economics, this article employs production elasticity of total input factors to measure regulatory preference for electric power industry. Previously, it analyzed the economic meaning and qualitative concept of regulatory preference. Then it built a social welfare maximization model by applying social welfare function, sectoral utility function and production function where all of them are independent of concrete math form choice. Through inserting elasticity of production
factor into model’s K-T condition, the measurable formula of regulatory preference was solved. This article further carried out an empirical research on regulatory preference for Chongqing electric power industry from 2008 to 2018. The results reveals that regulator has a high and stationary preference to electricity production rather than environmental remediation. Concerning production elasticity of total factors of respective subsystem, this study suggests that clean energy and environmental remediation should be addressed in Chongqing electric power industry to make economy, energy and environment systems harmonious development.

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