Can constraint energy-saving policy facilitate industrial green production performance in China?

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Abstract: The role of constraint energy-saving policy (ESP) playing in the coordinated development of energy conservation, emission reduction, and economic growth is of great significance to the country's sustainable progress. Applying a non-radial and non-oriented DEA model incorporating innovation output and multiple undesirable outputs, this paper measures the green production performance (GPP) of China's industrial sectors from 2002 to 2015. And then the effect of implementing energy-saving policy on GPP is investigated through Quasi-difference-in-differences (Quasi-DID) method. The results show that China's industrial GPP rises during 2002-2004 and then declines with fluctuations. Technology change (TC) is the dominant driver. Energy-saving policy positively affects industrial GPP in general yet further dynamic analysis reveals that such a positive effect remains unstable and finally manifests a reverse impact at the end of every five-year-plan period. Therefore, China should properly introduce market mechanisms, formulate comprehensive policy mix strategies to balance sustainable improvement of industrial economy and ecological environment.

1 Introduction

China has made remarkable achievements over the last 40 years and emerged as the world's second-largest economy. Characterizing with high investment and excessive consumption of materials, China's economic growth brings about various environmental problems and thereby impedes its sustainable development. It is reported that China's energy consumption reaches 4.3 billion tons of standard coal in 2016, of which coal consumption accounts for 61.9% [1]. Aiming at achieving the transition shifting from an extensive pattern to an intensive pattern, the Chinese government seeks for green production and more balanced development and targets energy saving and emissions reduction as a strategic deployment. Accordingly, measuring the bygone green production levels and assessing the effects of actualizing energy-saving policies are indispensable and significant for industrial green transformation and upgrading. So far compulsory policies and targets are generally oriented to industry. The constraint indicators were first explicitly proposed in China's 11th Five-Year Plan (FYP) in 2006 instead of the expected ones in previous plans to control energy consumption. Yet the question that whether implementing these policies can accelerate the green production level in China's industry deserves more profound researches.

The studies regarding production performance are always focusing on economics and fruitful results have been made, however, ignoring the undesirable byproducts. Green production performance (GPP) are applied in many existing literatures by means of Malmquist-Luenberger (ML) index which illustrates the changes in green total factor productivity considering undesirable outputs to reflect the level of green development [2]. There exist many researches focusing on the effects of policies on GPP and some reveal that constraint policies affect industrial GPP significantly [1,2]. In summary, rich conclusions have been made in terms of the impacts of mandatory policies on regional GPP while the research conducting across industrial sectors is lacking. Moreover, most scholars only focus on the overall influences of policies or the effects of the same one policy with different enforcement strengths on GPP. In addition, little attention is paid to time-varying effect of the policy's implementation.

The contributions of this paper include three aspects: (1) Enriching the evaluation index system by introducing patents, sulfur dioxide (SO_2), and chemical oxygen demand (COD) into outputs and thereby improving the measurement of GPP; (2) Investigating` the comprehensive effect of implementing of energy-saving policy on industrial GPP; (3) Tracing the time-varying effect of energy-saving policy on industrial GPP.

The remainder of this paper is organized as follows: Section 2 presents the DEA model for measuring industrial GPP and the Quasi-DID model for evaluating

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the impact of ESP on GPP. Section 3 reports the empirical results and discussions. Section 4 gives the main conclusions and policy implications.

2 Methodology

2.1 DEA model for measuring GPP

We regard each industrial sector as a decision making unit (DMU), supposing that each DMU $k=1,2,\ldots K$ uses N inputs (Capital stock (K), Labor force (L) and Energy consumption (E)), $x=(x_1,\ldots,x_n)\in R_N^+$ to produce M desirable outputs (Output value (O) and Patent application (P)), $y=(y_1,\ldots,y_m)\in R_M^+$ and I undesirable outputs (CO_2, SO_2 and COD), $b=(b_1,\ldots,b_i)\in R_I^+$. According to Zhou et al. [3] and Li et al. [4], we establish a global non-radial and non-oriented directional distance function (NNDDF) in the global environmental production technology $P^G(x)=(P^1(x)\cup P^2(x)\ldots P^t(x))$ as follows:

$$\begin{aligned}&\vec{D}_C^G=(x^t,y^t,b^t;g^t)=\max w_n^x\beta_{nx}^{G,t}+w_m^y\beta_{my}^{G,t}+w_i^b\beta_{ib}^{G,t}\\&s.t\sum_{t=1}^{T}\sum_{k=1}^{K}\lambda_k^t x_{kn}^t\le x_n^t-\beta_{nx}^{G,t}g_{nx}^t,\forall n;\\&\sum_{t=1}^{T}\sum_{k=1}^{K}\lambda_k^t y_{km}^t\le y_n^t+\beta_{my}^{G,t}g_{my}^t,\forall m;\\&\sum_{t=1}^{T}\sum_{k=1}^{K}\lambda_k^t b_{ki}^t\le b_i^t-\beta_{nx}^{G,t}g_{ib}^t,\forall i;\lambda_k^t\ge 0,\forall k\end{aligned}\tag{1}$$

where $w=(w_n^x,w_m^y,w_i^b)^T$ denotes a normalized weight vector, which is related to the numbers of inputs and outputs. $g=(-g_x,g_y,-g_b)$ is a directional vector that indicates the change in direction of each index. $g=(-x,y,-b)$ is a directional vector, $\beta=(\beta_{nx},\beta_{my},\beta_{ib})^T$ is a vector of scaling factors, representing inefficiency for inputs and outputs. Similarly, we can construct the t+1[th] global NNDDF and t[th], t+1[th] contemporaneous NNDDF (D_c^t and D_c^{t+1}). Therefore, according to the definition of the Luenberger index, this paper defines the green production performance (GPP) as follows:

$$GPP=\vec{D}_c^G(x^t,y^t,b^t;g^t)-\vec{D}_c^G(x^{t+1},y^{t+1},b^{t+1};g^{t+1})\tag{2}$$

$GPP>0(GPP<0)$ means the improvement (deterioration) of green total factor productivity, according to Grosskopf [5], GPP can be decomposed into the sum of efficiency change (EC) and technology change (TC), as follows:

$$\begin{aligned}TC=&\vec{D}_c^G(x^t,y^t,b^t;g^t)-\vec{D}_c^t(x^t,y^t,b^t;g^t)+\\&\vec{D}_c^{t+1}(x^{t+1},y^{t+1},b^{t+1};g^{t+1})-\vec{D}_c^G(x^{t+1},y^{t+1},b^{t+1};g^{t+1})\end{aligned}\tag{3}$$

$$EC=\vec{D}_c^t(x^t,y^t,b^t;g^t)-\vec{D}_c^{t+1}(x^{t+1},y^{t+1},b^{t+1};g^{t+1})=GPP-TC\tag{4}$$

Furthermore, Fujii et al. [6] proposes that inputs and outputs are the sources of GPP. Based on the additive nature of NNDDF and Luenberger index, GPP can also be rewritten as follows

$$\begin{aligned}GPP&=\frac{1}{3}\beta_x^{G,t}+\frac{1}{3}\beta_y^{G,t}+\frac{1}{3}\beta_b^{G,t}-(\frac{1}{3}\beta_x^{G,t+1}+\frac{1}{3}\beta_y^{G,t+1}+\frac{1}{3}\beta_b^{G,t+1})\\&=\frac{1}{3}(\beta_x^{G,t}-\beta_x^{G,t+1})+\frac{1}{3}(\beta_y^{G,t}-\beta_y^{G,t+1})+\frac{1}{3}(\beta_b^{G,t}-\beta_b^{G,t+1})\\&=GPP_x+GPP_y+GPP_b\end{aligned}\tag{5}$$

where GPP_x, GPP_y and GPP_b denote the contributions of inputs, desirable outputs and undesirable outputs to GPP, meaning input-saving effect, desirable-output-growth effect and emission-reduction effect, respectively.

2.2 Regression model for quantifying the effect of ESP

(1) Average effect of ESP. China's "11th FYP" first stipulated the target of energy intensity reduction. Quasi-DID method [2] is employed to investigate the effect of the ESP on GPP. In addition, considering that GPP may have the path dependence, we add the first-order lag of GPP (GPP_{it-1}) as the explanatory variable on the right side of the equation to capture the path dependence of GPP. The model is as follows:

$$\begin{aligned}&GPP_{it}=\alpha_0+\alpha_1 GPP_{it-1}+\alpha_2 EI_{it}\times I_t+\alpha_3 lnpe_{it}\\&+\alpha_3 X_{it}+f_i+f_t+\varepsilon_{it}\end{aligned}\tag{6}$$

where i and t imply the industrial sector and the time. EI_{it} represents continuous data on energy intensity, $EI_{it}\times I_t$ means the implementation of ESP. I_t is the dummy variable, that equals to 1 in the period after policy implementation and equals to 0 in the period before policy implementation. pe_{it} is the energy price index, representing the effect of external energy market [7]. X_{it} denotes other control variables; f_i and f_t reflect the fixed effects of sector and time, respectively. ε_{it} is the error term.

(2) Dynamic effect of ESP. We further decompose average effect in equation (6) to explore the dynamic impact. According to Yang et al. [2], the regression model is established as follows:

$$\begin{aligned}&GPP_{it}=\phi_0+\phi_1 GPP_{it-1}+\sum_{t}^{2015}\phi_t CCP_{it}\times I_t+\phi_2 lnpe_{it}\\&+\phi_3 X_{it}+f_i+f_t+\varepsilon_{it}\end{aligned}\tag{7}$$

Based on the relevant literature [2, 8] and the development status of China, we select the following control variables: 1) Industrial structure (IS): is estimated by the ratio of sector's output in total industrial output; 2) R&D investment (rd): is measured by the ratio of internal R&D expenditures in sector's output; 3) Learning by export (exp) is estimated by the share of total export value to the total sales value; 4) Energy structure (ecs): is measured by the proportion of coal consumption to the total energy consumption; 5) The technology spillover of foreign direct investment (fdi): is measured by the ratio of sales of foreign businesses to total sales value.

3 Results and discussions

3.1 Estimation results of GPP

GPP is greater than 0 during 2002-2015, which means China's industrial green total factor productivity continues to grow, the GPP tends to fluctuating declining after a transient ascending. From the view of its decomposition factors, TC dominates the basic trend of the GPP, with a contribution of 99.08%, on average, while the devotion of EC is relatively minor, only 0.09%. From the inputs and outputs perspective, GPPy is the biggest driver, devoting 95.22%. The contribution of GPPb is the second highest at 4.60%. However, the impact of GPPx is the weakest, only 0.18%. From its development trend view, industrial GPP is satisfied and grows faster in 2002-2004 because China's join to the World Trade Organization (WTO), industrial production capacity continues to expand with economy and technology developing rapidly. GPP boosts with the increase of GPPy. However, after 2004, GPP declines, for China forces to accelerate the exit of tens of thousands of high-energy-consuming enterprises to eliminate backward production capacity [9], GPPy decreasing significantly. In particular, the financial crisis breaks out in 2008 and economy slows down as well as technological progress. Moreover, the influence of GPPb begins to be obvious in 2006 and the greatest reduction effect is achieved at 0.0438 in 2011, accounting for 21.33% of GPP. In addition, input-saving effect (GPPx) also appears to grow since 2004.

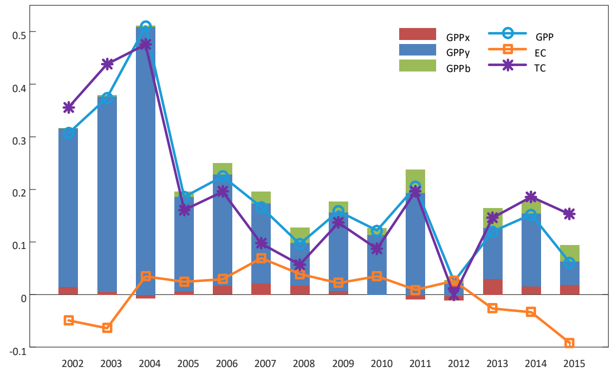

Figure 1. Average values of GPP and its components in China industry during 2002-2015

3.2 Average effect of ESP

It can be seen that coefficient of the lag_GPP is significantly positive, confirming the evident path dependence of industrial GPP, consistent with the study by Chen and Golley [10]. Energy price index produces a positive impact on GPP, because energy market contributes to the prosperity of the industrial economy and the increase in energy-saving effect to some extent [11]. The influencing coefficient of ESP on industrial GPP is significantly positive, which suggests that the restrictive ESP since 2006 exerts a positive effect on industrial GPP.

Table 2. Average effect of ESP on GPP, GPPx, GPPy, and GPPb

Variable	GPP	GPPx	GPPy	GPPb
lag_GPP	1.0597***	-0.4199**	0.5264***	0.3762**
CESP(EI*T)	0.3296**	-0.5982*	0.2757***	0.6244
lnpe	0.6094***	-0.0679	0.1906**	0.2832***
IS	1.2827**	0.4485**	2.4087**	2.1436***
fdi	-0.0759	-0.3260	-1.2609	-0.1512
exp	-0.0418	-0.0337	-0.2503	-0.1221
rd	0.1483***	0.0300	0.1533*	0.0823***
ecs	-0.9181**	-0.2492**	-0.2711***	-0.3123*
sector fixed	Yes	Yes	Yes	Yes
time fixed	Yes	Yes	Yes	Yes
F-statistics (P)	2111.82(0.0000)	9.73(0.0000)	164.27(0.0000)	17.04(0.0000)
AR(1)test(P)	-9.14(0.0000)	-3.26(0.0001)	-8.81(0.0000)	0.236(0.0019)
AR(2)test(P)	1.83(0.0670)	0.83（0.4080）	0.44(0.6620)	-1.16(0.2450)
Sargan test(P)	13.80(0.1820)	7.87(0.6420)	8.20(0.2240)	6.44(0.2660)

Significance: *P<0.1, **P<0.05, ***P<0.01

ESP stimulates industrial companies to adopt technical and management measures to achieve the decline in energy input, followed by a fall in CO_2 and pollutants, which is exactly in favor of advancing GPP. Meanwhile, several high energy-consuming enterprises are forced to withdraw from the market so that the market concentration would further be enhanced under ESP. However, to accomplish the energy intensity reduction target, industrial enterprises will urgently cut back energy input in a short run. The substitution among input factors will severely be strengthened through increasing input of other production factors, resulting in lower input efficiency. ESP's implementation causes a significant inhibitory effect on GPPx. On the contrary, it plays an important role in promoting GPPy. On the one hand, the large amount of investment in alternatives ensure and maintain industrial output growth at a relatively high level, according to the statistical data, we find that the average annual growth rate of industrial output is still as high as 15.77% after 2006. On the other hand, ESP prompts companies to vigorously develop energy technologies, with China's industrial patent applications measuring up to 8.50 times that of 2006 in 2015. Table 2 demonstrates that ESP promotes emission-reduction effect (GPPb), however, it is not evident. The majority of carbon and pollutants emissions originate from the combustion and utilization of fossil fuels in industrial production. ESP's implementation will bring in lower energy input, which is beneficial to a drop in the emissions of CO_2 and pollutants.

3.3 Dynamic effect of ESP

The ESP is promulgated in 2006. Within the three years of its enactment, its effect is not significant, however, showing a positive effect with an intensifying trend. ESP begins to be significant positive in 2009 but turns negative in 2010. During the "11th FYP" period (2006-2010), the effect of ESP shifts from insignificant positive to significant promotion, then turns to suppression. It can be seen the restrictive nature of ESP undergoes from weak to strong, then weakening. In the initial stage of the execution of energy intensity decline target, various industrial enterprises will energetically carry out energy-conservation activities to achieve reduction goals. However, with the realization of energy-saving objectives, such a binding force gradually weakens. Statistics show that in 2009, China's industrial energy intensity decreases by 23.80% compared to 2006 levels, with the 20% reduction target accomplished ahead of schedule. As a result, the restraint effect of ESP becomes waning in 2010. During the 12th FYP period, the government redefines the energy intensity reduction target based on 2010 levels. Similar to effect of ESP in the "11th FYP" period, the restraint force of ESP experiences a process of from weak to strong then weakening. In 2013, industrial energy intensity falls by 23.00% compared to 2010 levels, the goal of reduction by 16% is fulfilled in advance. With respect to inputs and outputs, generally speaking, ESP has a significant inhibitory effect on GPPx, what's worse, such an inhibitory effect becomes strengthened during the 11th FYP and 12th FYP period. ESP plays a significant positive role in promoting GPPy. However, it undergoes from weak to strong then to weak. In addition, ESP produces an insignificant positive impact on GPPb, the coefficient of ESP in most years is positive, yet not significant. Decline of energy intensity can abate carbon and pollutants indirectly, otherwise, its direct constraint effect on emissions reduction is weaker.

Table 3. Dynamic effect of ESP on GPP, GPPx, GPPy, and GPPb

Variable	GPP	GPPx	GPPy	GPPb
lag_GPP	1.1448***	-0.2693***	1.1213***	0.9548***
lnpe	1.2301***	0.0614*	1.0870***	0.0531*
Y06	0.1148	-0.6664	0.1345	-0.2442
Y07	0.2045	-0.7923	0.2332	0.0546
Y08	0.1623	-2.0431*	0.1547	-0.1263
Y09	1.0297***	-2.9845**	1.0001***	0.9306*
Y10	-0.5183*	-3.0945*	-0.4389*	0.1375
Y11	0.9489***	-2.6330	0.9101***	0.2413
Y12	0.9723***	-3.1071**	0.9396***	0.2498
Y13	0.3618	-4.0909**	0.3326	0.1691
Y14	-0.1285	-4.4482***	0.1715	0.2321
Y15	2.9308*	-3.8178**	-0.8182*	0.0693
IS	2.9308*	15.4082***	2.0710**	1.0931*
fdi	-0.7452	-1.1067	-0.7102	-0.1261
exp	-0.0732	-0.8228	-0.0117	-0.0257
rd	0.2822**	0.1900**	0.2739***	0.0819*
ecs	-1.8039***	-2.8030*	-1.5915	-0.0733**
sector fixed	Yes	Yes	Yes	Yes
time fixed	Yes	Yes	Yes	Yes
F-statistics (P)	838.69(0.0000)	1.90(0.0170)	924.22(0.0000)	11.48(0.0000)
AR(1)test(P)	-6.85(0.0000)	-9.32(0.0000)	-7.06(0.0000)	-6.34(0.0000)
AR(2)test(P)	2.04(0.0560)	-0.97(0.3300)	-0.15(0.8820)	0.84(0.3990)
Sargan test(P)	5.13(0.0770)	4.58(0.1010)	4.60(0.1000)	7.02(0.7230)

Significance: *P<0.1, **P<0.05, ***P<0.01

4 Conclusions and policy implications

Main findings are concluded as follows:(1) China's industrial GPP shows the trend of circuitous downward after an ephemeral ascending. Technology change is the dominant driver for GPP's fluctuation. (2) Energy-saving policy produces a positive effect on industrial GPP, however further dynamic analysis suggests that such a positive effect performs unstable and finally manifests a reverse impact in each five-year-plan period.

Based on the results, we propose the following policy implications: (1) The Chinese government should focus on the overall goal of green development and formulate a systematic policy mix. The results show that energy-saving policy promotes the improvement of the industrial GPP, however, with problem of insufficient stamina. The corresponding policy mix is indispensable for the green development of industrial sectors. Therefore, China needs to construct a more synthesized and systematic green development policy system and establish balanced policy portfolios to achieve more all-around promotion of green development. (2) Combining constraint energy-saving policy with market-based policies tightly to facilitate the flexibility of companies in saving energy. China's policies rely heavily on coercive measures and neglect the importance of market mechanisms. Hence, China should embrace industrial enterprises to optimize allocation efficiency by issuing market-oriented measures.

Acknowledgements

This work was supported by the National Natural Science Foundation of China (No. 71573069).

References

1. C, Chen, Q, Lan, M, Gao, Y, Sun. Green Total Factor Productivity Growth and Its Determinants in China's Industrial Economy. Sustainability. **10** (2018).
2. Z, Yang M, Fan, S, Shao, L, Yang. Does Carbon Intensity Constraint Policy Improve Industrial Green Production Performance in China? A Quasi-DID Analysis. Energy Econ. **68**, 271-282 (2017).
3. P, Zhou, H, Wang. Energy and CO_2 emission performance in electricity generation: A non-radial directional distance function approach. Eur. J. Oper. Res. **221**, 625-635 (2012).
4. A, Li, A, Zhang, H, Huang, X, Yao. Measuring unified efficiency of fossil fuel power plants across provinces in China: An analysis based on non-radial directional distance functions. Energy. **152**, 549-561 (2018).
5. Grosskopf, S., Some Remarks on Productivity and its Decompositions. J. Prod. Anal. **20**, 459-474(2003).
6. H, Fujii, J, Cao, S, Managi. Decomposition of Productivity Considering Multi-environmental Pollutants in Chinese Industrial Sector. Rev. Dev. Econ. **19**, 75-84(2015).
7. J.A., Cullen, E.T., Mansur. Inferring Carbon Abatement Costs in Electricity Markets: A Revealed Preference Approach Using the Shale Revolution. Nber Working Papers. **9**, 106-133(2014).
8. Z, Cheng, L, Li, J, Liu. emissions reduction effect and technical progress effect of environmental regulation policy tools. J. Clean. Prod. **149**, 191-205 (2017).
9. N, Liu, Z, Ma, J Kang. Changes in carbon intensity in China's industrial sector: Decomposition and attribution analysis. Energy Policy. **87**, 28-38(2015).
10. S.Y, Chen, J, Golley. 'Green' productivity growth in China's industrial economy. Enery Econ. **44**, 89-98(2014).
11. H, Ma, L, Oxley, J, Gibson. China's energy economy: Technical change, factor demand and interfactor/interfuel substitution. Enery Econ. **30**, 2167-2183 (2008).