Estimating China's Energy and Environmental Productivity Efficiency: A Parametric Hyperbolic Distance Function Approach

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Introduction

- Throughout this decade, China's GDP growth has exceeded 9% annually. This growth is fueled by large increases in energy consumption, led by a coal-dominated energy structure with associated high sulfur dioxide and dust emissions.
- To address these energy and environmental challenges, the government set energy conservation and emission reduction targets in the 11th Five Year Plan (2006-2010):
  - Relative to 2005, a 20% reduction in energy use per unit of GDP by 2010.
  - A 10% reduction in primary emission pollutant s by 2010.
- These targets were then disaggregated into energy conservation targets for each province. Consistent with the country target, provinces were generally arbitrarily assigned a 20% energy target.
- Not guided by technical and economic efficiency principles, this disaggregation may not be optimal from the perspectives of social equity and efficiency.

Objectives and Procedures

- Estimate each province's energy and environmental technology efficiency.
- Based on these technology efficiencies, estimate how each province can reduce its undesirable output, while simultaneously saving energy inputs.
- Test whether these technology efficiencies change over time and whether there are significant differences across different regions
- Procedure: Model China's production technology with the desirable output (GDP) and undesirable output (SO_2 emissions) through an enhanced hyperbolic translog distance function.

Data

A panel dataset including 29 provinces in China from 2000 to 2007:

- Inputs: capital stock (K), labor (L), energy consumption (E)
- Outputs: real GDP (RGDP), SO_2 emissions (SO_2)
- Using the methodology of Zhang et al. and their 2000 base year data, provincial stock capital is estimated
- All data are from the *China Statistical Yearbook* (various years)

Data

Based on their economic development level and geographic location, the provincial-level regions in China are divided into three regions: eastern, central and western (figure 1).

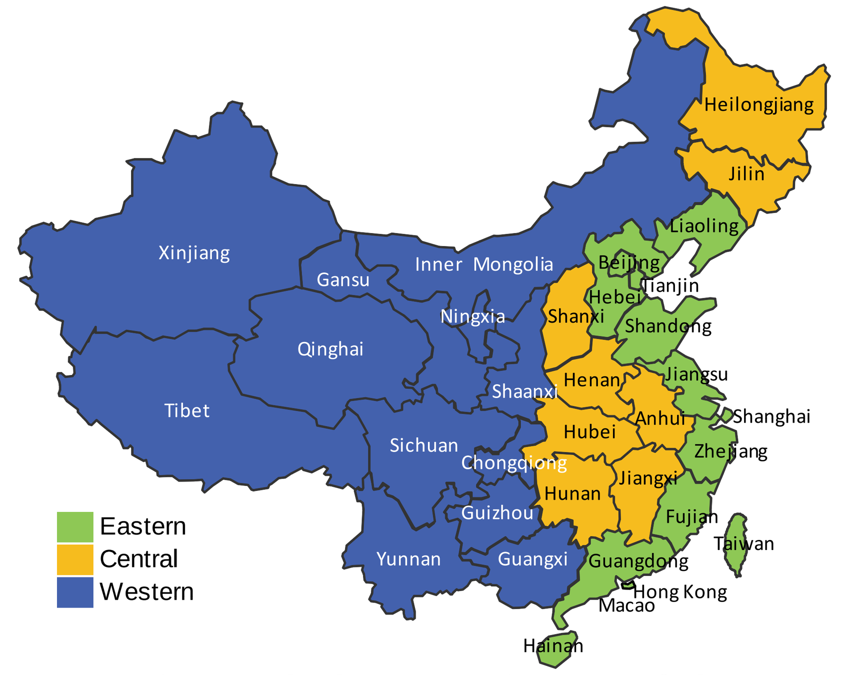

Figure 1. The three economic regions of China

These three regions have different average real GDP (figure 2) and SO_2 emissions (figure 3), as well as significantly different inputs in capital stock, labor, and energy (figures 4, 5, and 6).

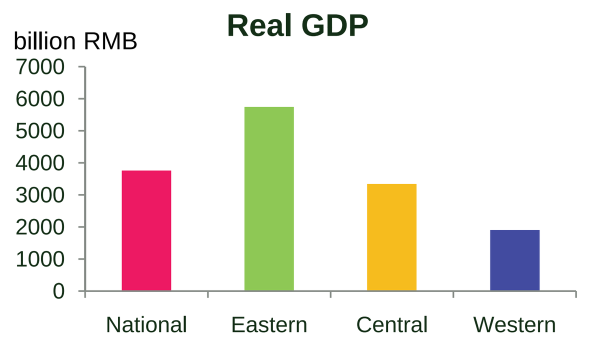

Figure 2. Average real GDP (2000-2007)

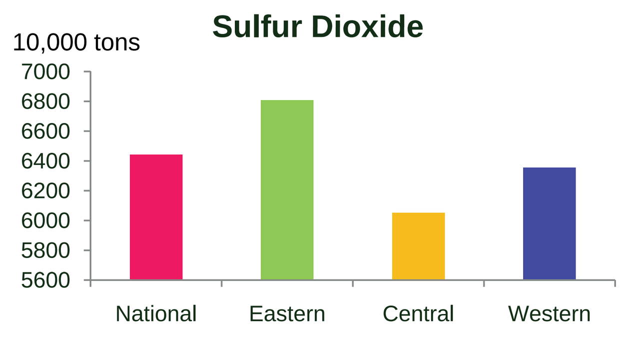

Figure 3. Average SO_2 emissions (2000-2007)

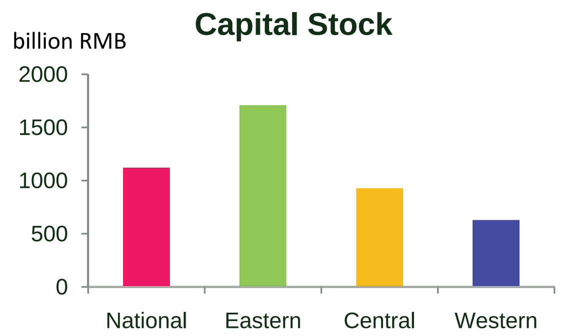

Figure 4. Average capital stock (2000-2007)

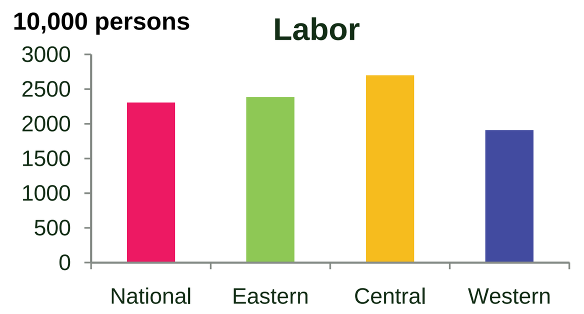

Figure 5. Average labor input (2000-2007)

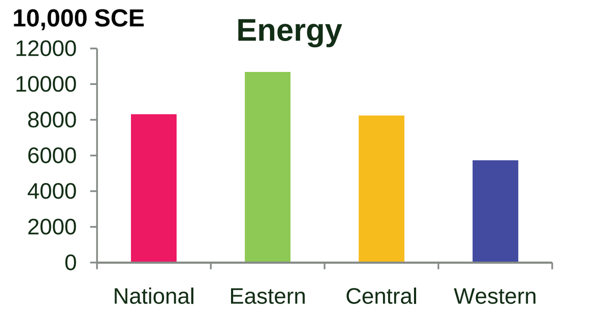

Figure 6. Average energy input (2000-2007)

Enhanced Hyperbolic Distance Function

Let input vector is x = (K, L, E) and T denotes the technology set

$$T = \{(x, RGDP, SO_2): x \text{ can produce } (RGDP, SO_2)\},$$

Following Cuesta et al. , the enhanced hyperbolic distance function D_E is defined as

$$D_E(x, RGDP, SO_2) = \inf\{\phi > 0: (x\phi, RGDP/\phi, SO_2\phi) \in T\}.$$

The properties of the enhanced hyperbolic distance function are

- $0 < D_E \leq 1$
- almost homogenous of degrees -1, 1, -1, 1, i.e.

$$D_E(\rho^{-1}x, \rho RGDP, \rho^{-1}SO2) = \rho D_E(x, RGDP, SO2), \forall \rho > 0$$

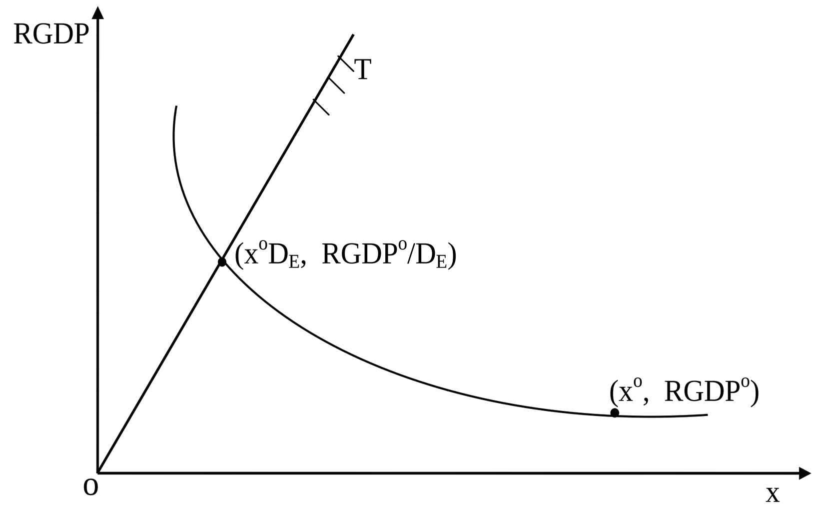

Figure 7 illustrates that D_E projects the input output vector (x^o, $RGDP^o$) onto the boundary of T by proportionally reducing inputs and proportionally expanding the desirable output.

Figure 7. The enhanced hyperbolic distance function

The translog specification of the distance function is

$$\begin{aligned} ln(D_E) = {} & \alpha_0 + \alpha_1 lnK + \alpha_2 lnL + \alpha_3 lnE + 0.5\alpha_{11}(lnK)^2 + 0.5\alpha_{22}(lnL)^2 \\ & + 0.5\alpha_{33}(lnE)^2 + \alpha_{12} lnKLnL + \alpha_{13} lnKlnE + \alpha_{23} lnLlnE \\ & + \beta_1 \ln GDP + 0.5\beta_{11}(lnGDP)^2 + \gamma_1 lnSO_2 \\ & + 0.5\gamma_{11}(lnSO_2)^2 + \delta_{11} lnKlnGDP + \delta_{21} lnLlnGDP + \delta_{31} lnElnGDP \\ & + \zeta_{11} lnKlnSO_2 + \zeta_{21} lnLlnSO_2 + \zeta_{31} lnElnSO_2 + \upsilon_{11} lnGDPlnSO_2 + \psi t \\ & + \varepsilon \end{aligned}$$

where t is the time trend that captures the presence of neutral technical change from 2000 to 2007 , and ε is the error term representing random noise.

Using RGDP for normalizing purpose, ρ = 1/RGDP, we obtain

$$D_E(RGDP \times x, RGDP \times SO_2) = D_E(x, RGDP, SO_2) / RGDP$$

Therefore, we have

$$\begin{aligned} ln(D_E/RGDP) = {} & \alpha_0 + \alpha_1 lnK^* + \alpha_2 lnL^* + \alpha_3 lnE^* + 0.5\alpha_{11}(lnK^*)^2 + 0.5\alpha_{22}(lnL^*)^2 \\ & + 0.5\alpha_{33}(lnE^*)^2 + \alpha_{12} lnK^*LnL^* + \alpha_{13} lnK^*lnE^* + \alpha_{23} lnL^*lnE^* \\ & + \gamma_1 lnSO_2{}^* + 0.5\gamma_{11}(lnSO_2{}^*)^2 + \zeta_{11} lnK^*lnSO_2{}^* + \zeta_{21} lnL^*lnSO_2{}^* \\ & + \zeta_{31} lnE^*lnSO_2{}^* + \psi t + \varepsilon \end{aligned}$$

where $K^* = K \times RGDP$, $L^* = L \times RGDP$, $E^* = E \times RGDP$, and $SO_2{}^* = SO_2 \times RGDP$. All terms involving RGDP are null.

Environmental Efficiency Measurement

Through the stochastic frontier analysis (SFA), the estimated enhanced hyperbolic distance function is

$$-\ln(RGDP_{it}) = \text{Translog}(K^*, L^*, E^*, SO_2{}^*; \text{parameters}) + \varepsilon_{it} + u_{it}.$$

Let u_i i.i.d. ~ $N^+(\mu, \sigma_u{}^2)$, then the one-side component u_{it} that captures time-varying decay inefficiency are modeled as

$$u_{it} = \exp\{-\eta(t-T_i)\}u_i$$

Finally, time-varying environmental (enhanced hyperbolic) efficiency estimates can be calculated for each province as

$$\widehat{TE}_{it} = \exp(-\hat{u}_{it})$$

Results

Table 1. Estimated parameters for the enhanced hyperbolic distance function

Parameter	Estimated Value	Std. Error	Parameter	Estimated Value	Std. Error
α_0	2.1184***	1.1228	α_{13}	0.0843	0.0515
α_1	-0.6569*	0.1804	α_{23}	0.0493***	0.0282
α_2	-0.2241	0.1977	γ_1	-0.0615	0.0729
α_3	0.2255	0.2089	γ_{11}	0.0608*	0.0204
α_{11}	-0.1400*	0.0467	ζ_{11}	0.0304	0.0235
α_{22}	--0.0349	0.0311	ζ_{21}	-0.0685*	0.0171
α_{33}	-0.1006	0.0729	ζ_{31}	-0.0402	0.0356
α_{12}	0.0585**	0.0282	ψ	0.0301*	0.0029
μ	0.3491*	0.0612	$\sigma_u{}^2$	0.0410*	0.0185
η	0.0344*	0.0070	$\sigma_\varepsilon{}^2$	0.0003*	0.0000
Mean TE	0.6742				

Note: *, *, and *** denote significant at 1%, 5%, and 10%, respectively.

From table 1, the average environmental technical efficiency is 0.6742, indicating how China can improve productive performance yielding

- increased RGDP by 48.32% (1/0.6742-1 = 0.4832)
- simultaneously reducing SO_2 emissions by 32.58% (1-0.6742=0.3518)
- saving energy inputs by 32.58%.

Since η is significantly greater than zero, the average environmental TE increases over time by 3.44% per year.

The most efficient province is Shanghai with an average TE of 0.9889, and the least efficient province is Guizhou with an average TE of 0.4365.

Figure 8 illustrates that the

- eastern region has the highest average TE
- average TEs are significantly different between eastern and central regions, as well as eastern and western regions
- there is no significant difference between central and western regions

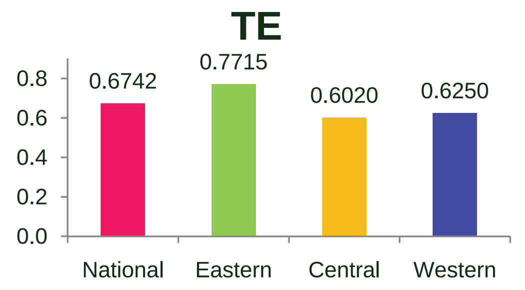

Figure 8. Average technical efficiency (2000-2007)

Conclusions

- China has a great potential for reducing SO_2 emissions and energy consumption. During 2000 to 2007 , on average, China could have
  - reduced SO_2 emissions by 32.58%, translating to reducing emissions from 64.43 to 43.44 million tons per year
  - equiproportionally saved energy inputs by 32.58%, translating to reducing energy consumption from 57.32 to 38.65 million tons of SCE per year
- The average environmental TE increase over time with 3.44% annual growth rate during the 2000 to 2007 period.
- The environmental TE varies across provinces
  - the provinces in the eastern region are the most efficient
  - while the provinces in the central region are the least efficient

Further Research

- Investigate how the industrial structure will affect environmental productivity efficiency.
- Identify potential different contributions of productivity growth for each province in China.
- Examine how the energy saving program will affect the environmental productivity growth for each province.

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