

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

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# 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 pollutants 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<sub>2</sub> 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<sub>2</sub> emissions (SO<sub>2</sub>)
- 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).

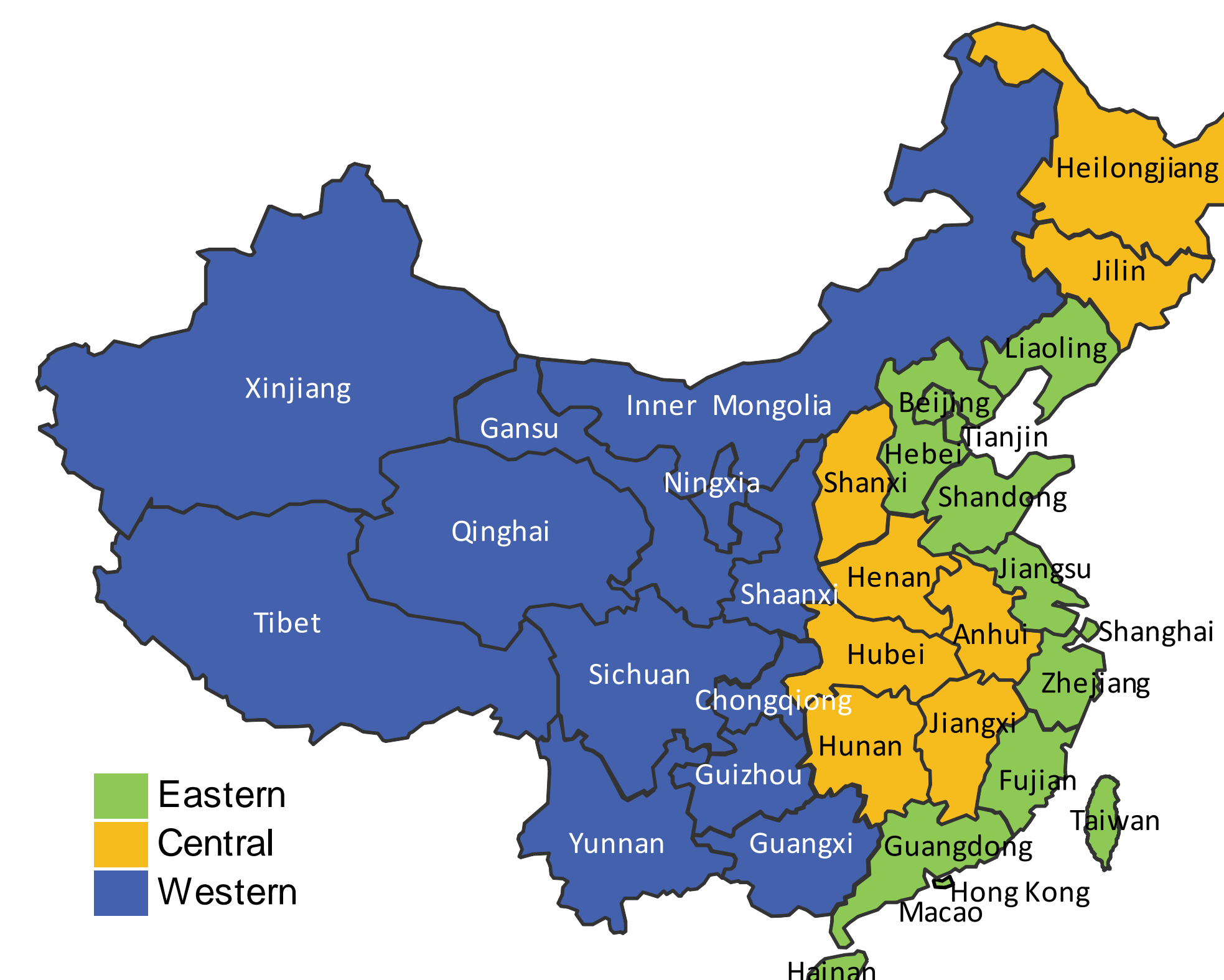


Figure 1. The three economic regions of China

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

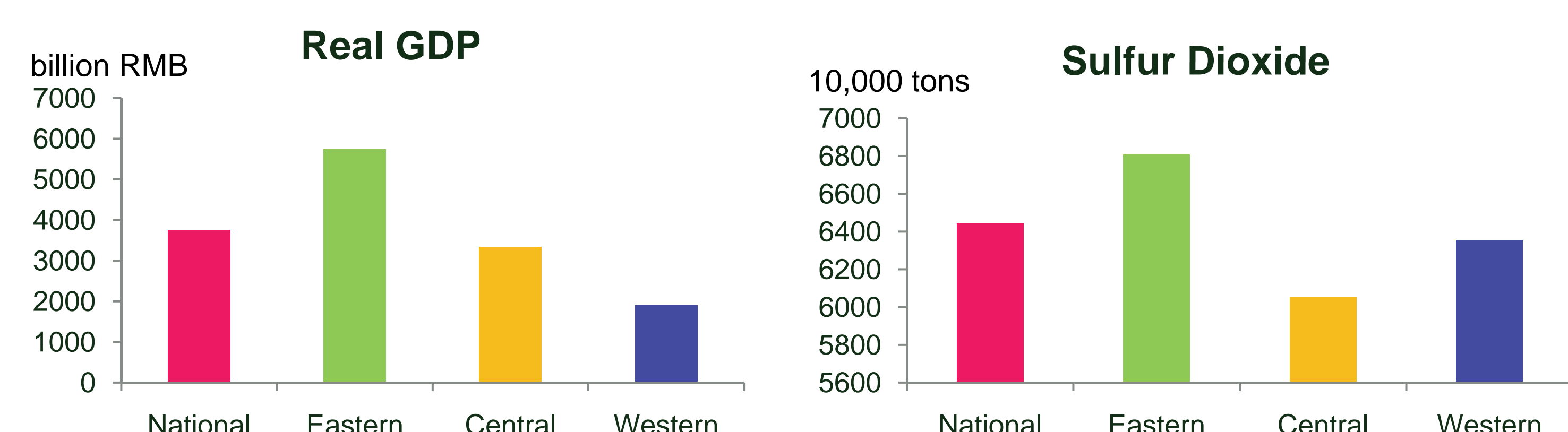


Figure 2. Average real GDP (2000-2007)

Figure 3. Average SO<sub>2</sub> emissions (2000-2007)

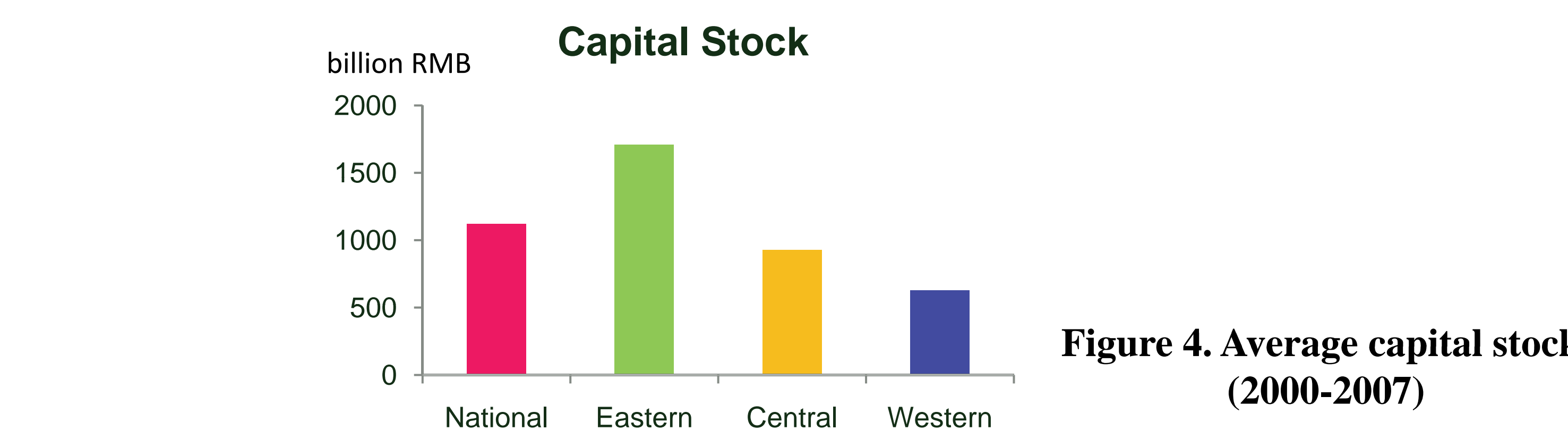


Figure 4. Average capital stock (2000-2007)

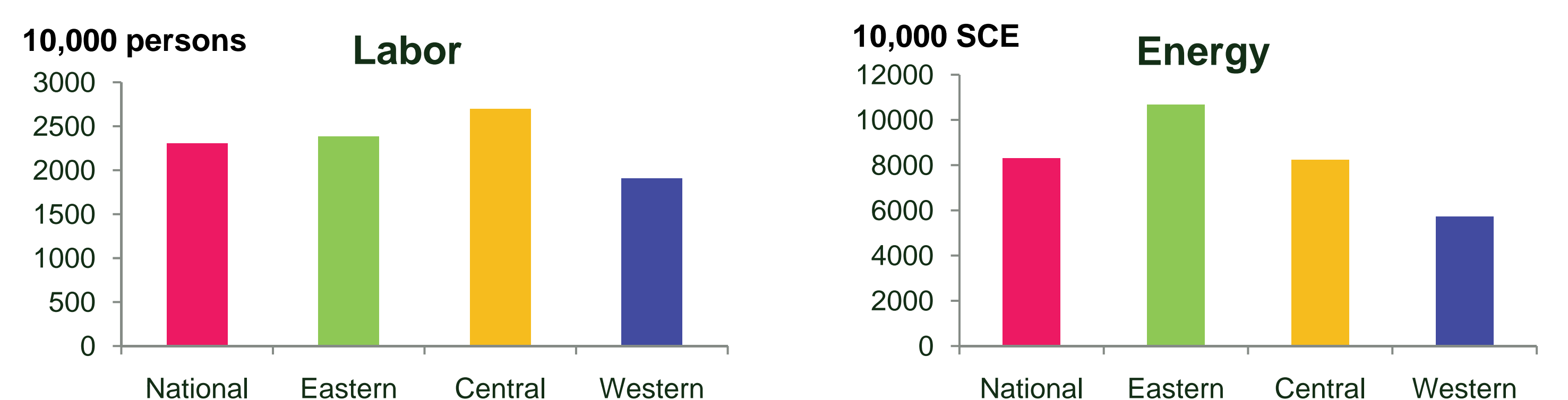


Figure 5. Average labor input (2000-2007)

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.  
 $D_E(\rho^{-1}x, \rho RGDP, \rho^{-1}SO_2) = \rho D_E(x, RGDP, SO_2), \forall \rho > 0$

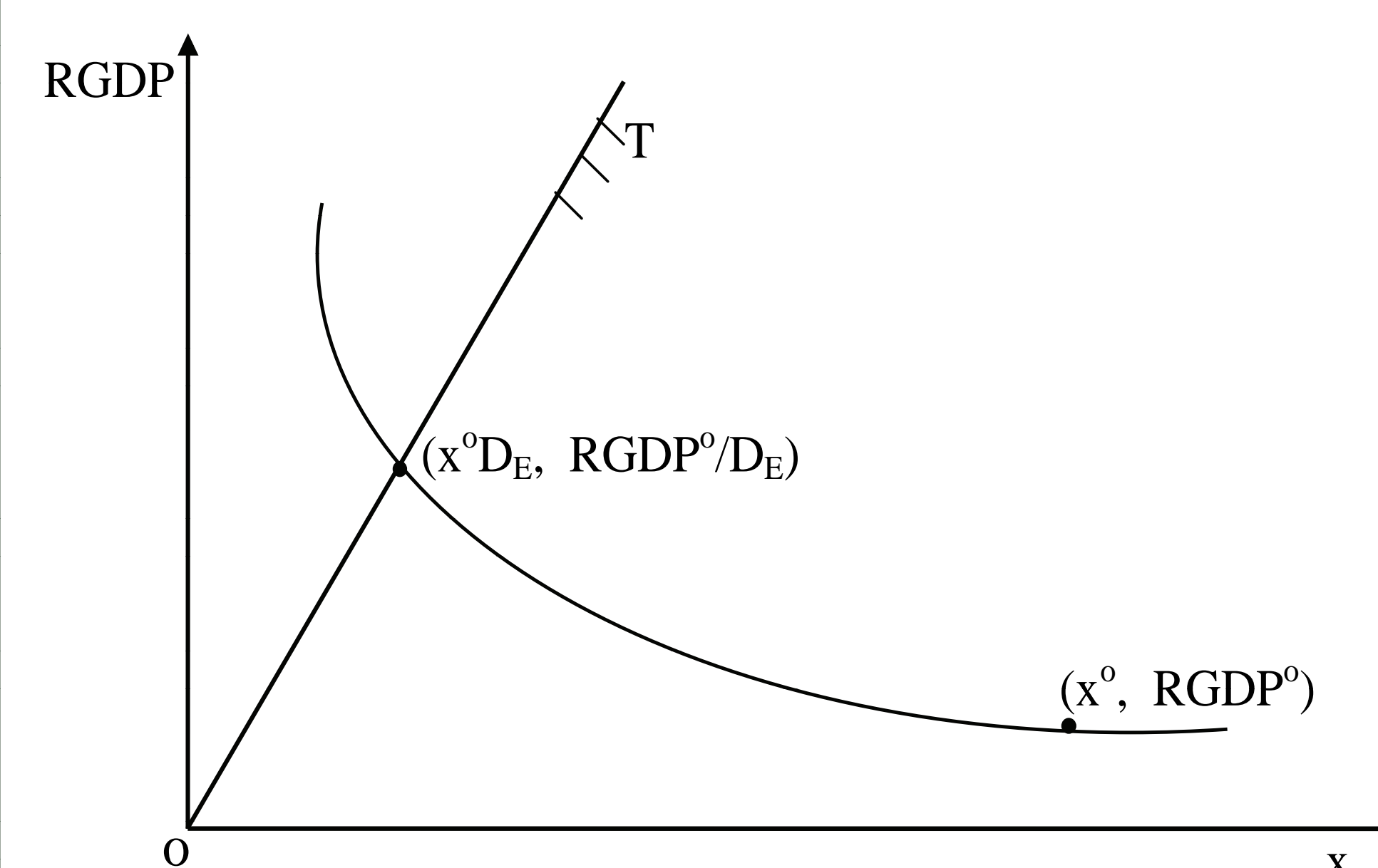


Figure 7. The enhanced hyperbolic distance function

Figure 7 illustrates that  $D_E$  projects the input output vector  $(x^0, RGDP^0)$  onto the boundary of  $T$  by proportionally reducing inputs and proportionally expanding the desirable output.

The translog specification of the distance function is

$$\ln(D_E) = \alpha_0 + \alpha_1 \ln K + \alpha_2 \ln L + \alpha_3 \ln E + 0.5\alpha_{11}(\ln K)^2 + 0.5\alpha_{22}(\ln L)^2 + 0.5\alpha_{33}(\ln E)^2 + \alpha_{12} \ln K \ln L + \alpha_{13} \ln K \ln E + \alpha_{23} \ln L \ln E + \beta_1 \ln GDP + 0.5\beta_{11}(\ln GDP)^2 + \gamma_1 \ln SO_2 + 0.5\gamma_{11}(\ln SO_2)^2 + \delta_{11} \ln K \ln GDP + \delta_{21} \ln L \ln GDP + \delta_{31} \ln E \ln GDP + \zeta_{11} \ln K \ln SO_2 + \zeta_{21} \ln L \ln SO_2 + \zeta_{31} \ln E \ln SO_2 + \nu_{11} \ln GDP \ln SO_2 + \psi t + \varepsilon$$

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

Using RGDP for normalizing purpose,  $\rho = 1/RGDP$ , we obtain

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

Therefore, we have

$$\ln(D_E/RGDP) = \alpha_0 + \alpha_1 \ln K^* + \alpha_2 \ln L^* + \alpha_3 \ln E^* + 0.5\alpha_{11}(\ln K^*)^2 + 0.5\alpha_{22}(\ln L^*)^2 + 0.5\alpha_{33}(\ln E^*)^2 + \alpha_{12} \ln K^* \ln L^* + \alpha_{13} \ln K^* \ln E^* + \alpha_{23} \ln L^* \ln E^* + \gamma_1 \ln SO_2^* + 0.5\gamma_{11}(\ln SO_2^*)^2 + \zeta_{11} \ln K^* \ln SO_2^* + \zeta_{21} \ln L^* \ln SO_2^* + \zeta_{31} \ln E^* \ln SO_2^* + \psi t + \varepsilon$$

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

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

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

$$\hat{T}E_{it} = \exp(-\hat{u}_{it})$$

## Results

Table 1. Estimated parameters for the enhanced hyperbolic distance function

Parameter	Estimated Value	Std. Error	Parameter	Estimated Value	Std. Error
$\alpha_0$	2.1184***	1.1228	$\alpha_{13}$	0.0843	0.0515
$\alpha_1$	-0.6569*	0.1804	$\alpha_{23}$	0.0493***	0.0282
$\alpha_2$	-0.2241	0.1977	$\gamma_1$	-0.0615	0.0729
$\alpha_3$	0.2255	0.2089	$\gamma_{11}$	0.0608*	0.0204
$\alpha_{11}$	-0.1400*	0.0467	$\zeta_{11}$	0.0304	0.0235
$\alpha_{22}$	-0.0349	0.0311	$\zeta_{21}$	-0.0685*	0.0171
$\alpha_{33}$	-0.1006	0.0729	$\zeta_{31}$	-0.0402	0.0356
$\alpha_{12}$	0.0585**	0.0282	$\psi$	0.0301*	0.0029
$\mu$	0.3491*	0.0612	$\sigma_u^2$	0.0410*	0.0185
$\eta$	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<sub>2</sub> emissions by 32.58% ( $1 - 0.6742 = 0.3258$ )
  - saving energy inputs by 32.58%.

Since  $\eta$  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

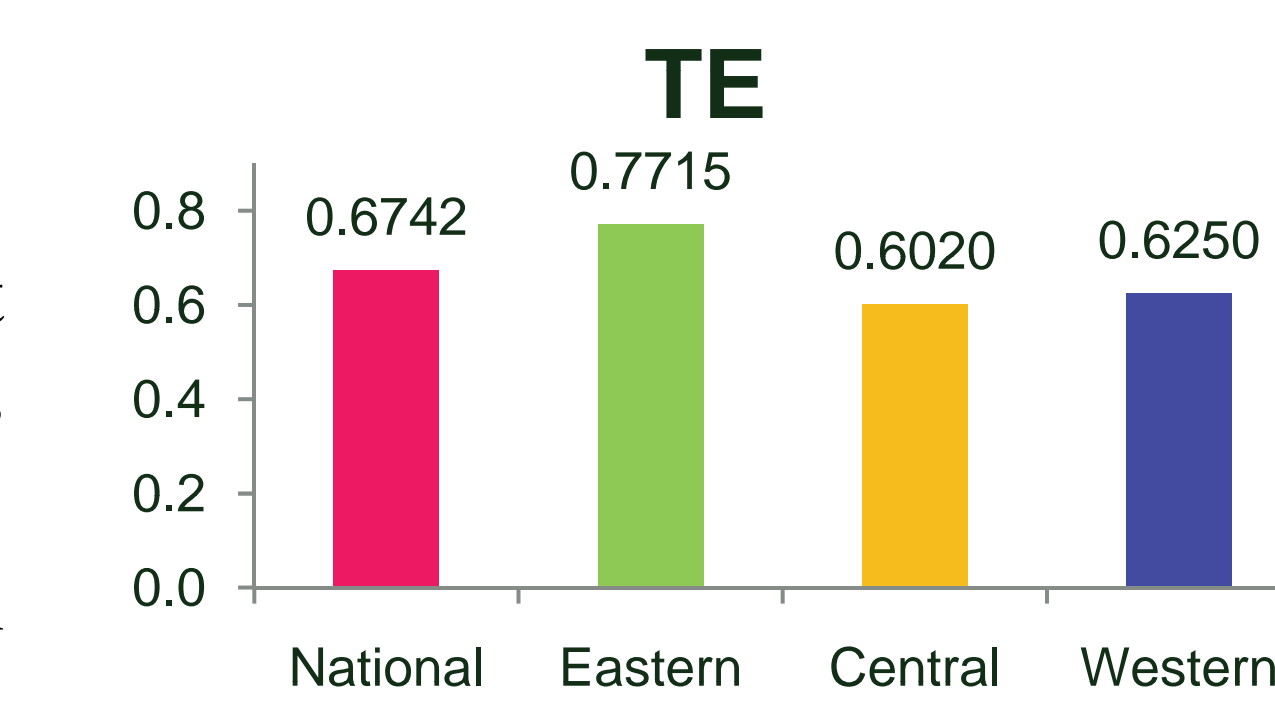


Figure 8. Average technical efficiency (2000-2007)

## Conclusions

- China has a great potential for reducing SO<sub>2</sub> emissions and energy consumption. During 2000 to 2007, on average, China could have
  - reduced SO<sub>2</sub> 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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