香港城市大學
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能源及環境學院
SCHOOL OF ENERGY
AND ENVIRONMENT

Workshop

Estimation of energy efficiency and the evaluation of policy impacts

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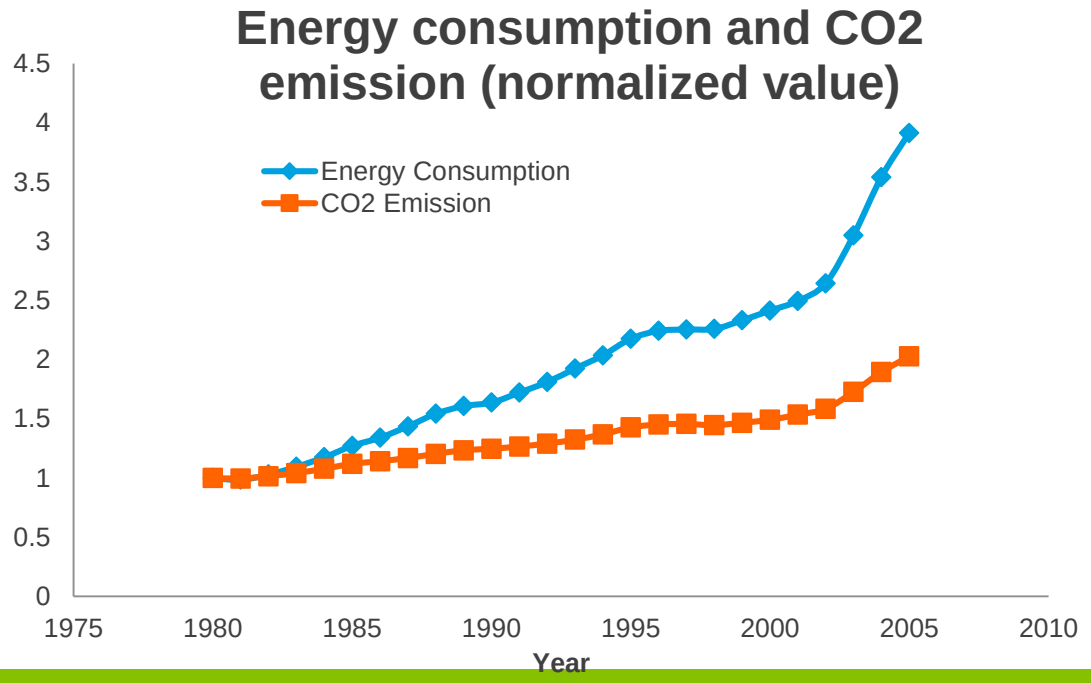
Motivation and goals

- To achieve sustainability and for the energy sector:
  - Transition to renewable energy
  - Improvement of energy efficiency
- **Improving energy efficiency** is one of the most cost-effective ways of reducing CO2 emissions and increasing security of energy supply



Data source: Energy consumption (unit: Mtce) data from China Statistical Yearbook, CO2 emission (unit: Mt) data from IEA.

- We need to know the **current level of energy efficiency** first.

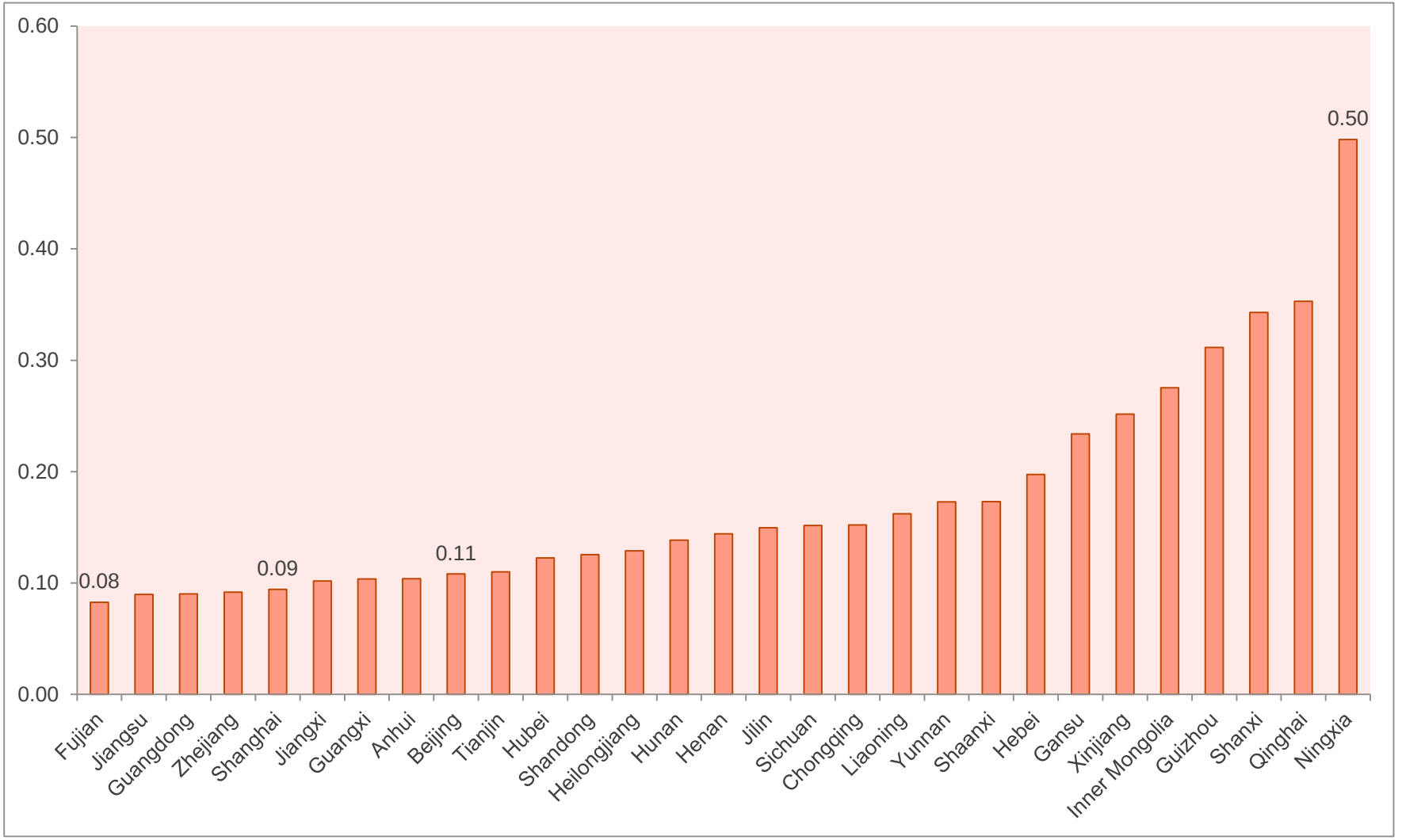
- How to measure?
  - For an air-conditioner, it is easy.
  - For an economic entity, it can be complex

- This leads us to think:
  - **How to measure the level of "underlying energy efficiency"** (country, province, city, district, sector, firm…) **in a precise way**

- **How to measure the level of energy efficiency?**

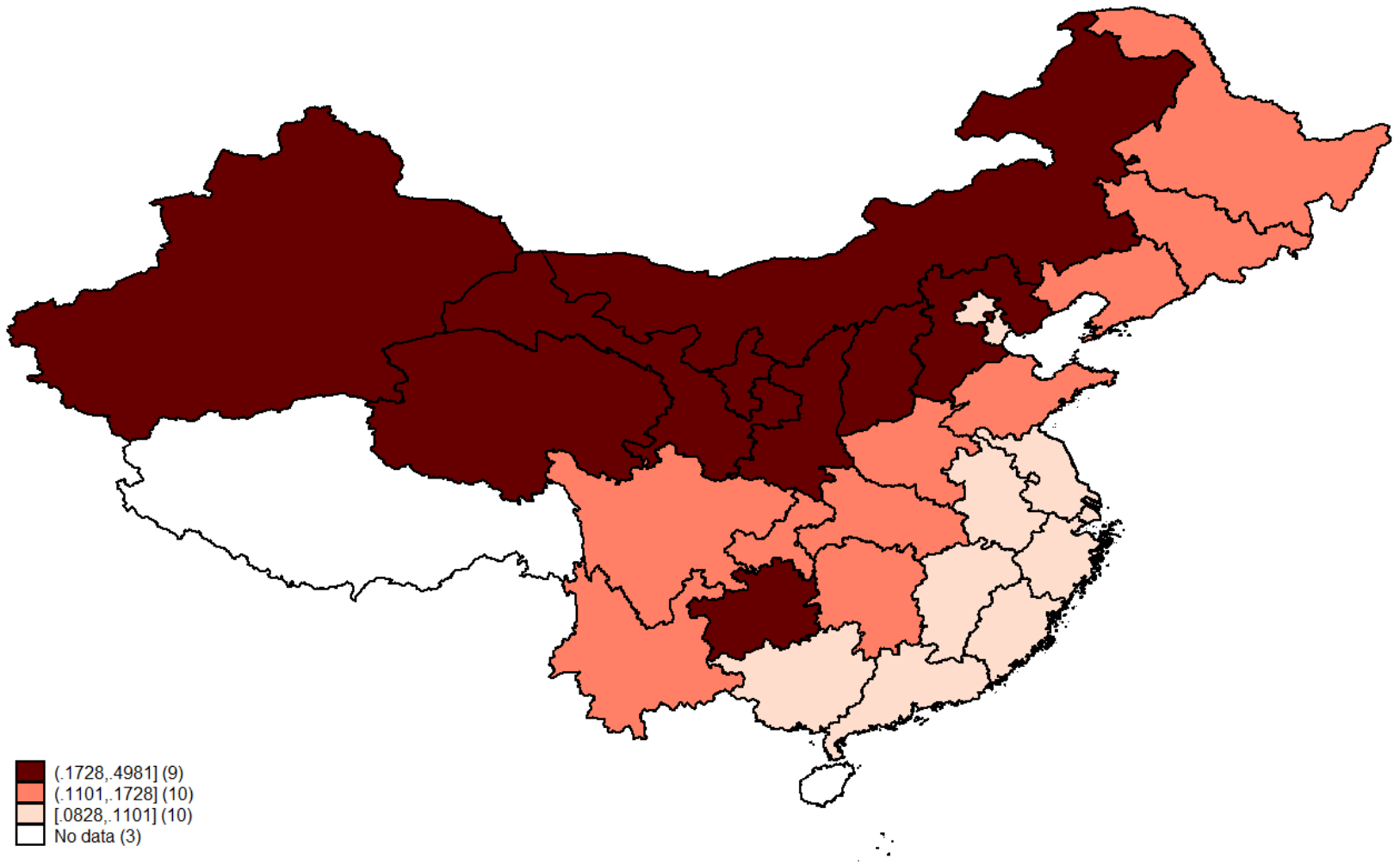
- Often use of proxy indicators
  - **Energy intensity (Energy consumption/GDP)**
  - Energy productivity (inverse of energy intensity)

Energy intensity in 2008 (unit: tce/1000RMB)



Data source: calculated based on the data from China Statistical Yearbook

Geographic illustration of energy intensity (mainland China only)



PROGRESS WITH IMPLEMENTING ENERGY EFFICIENCY POLICIES IN THE G8

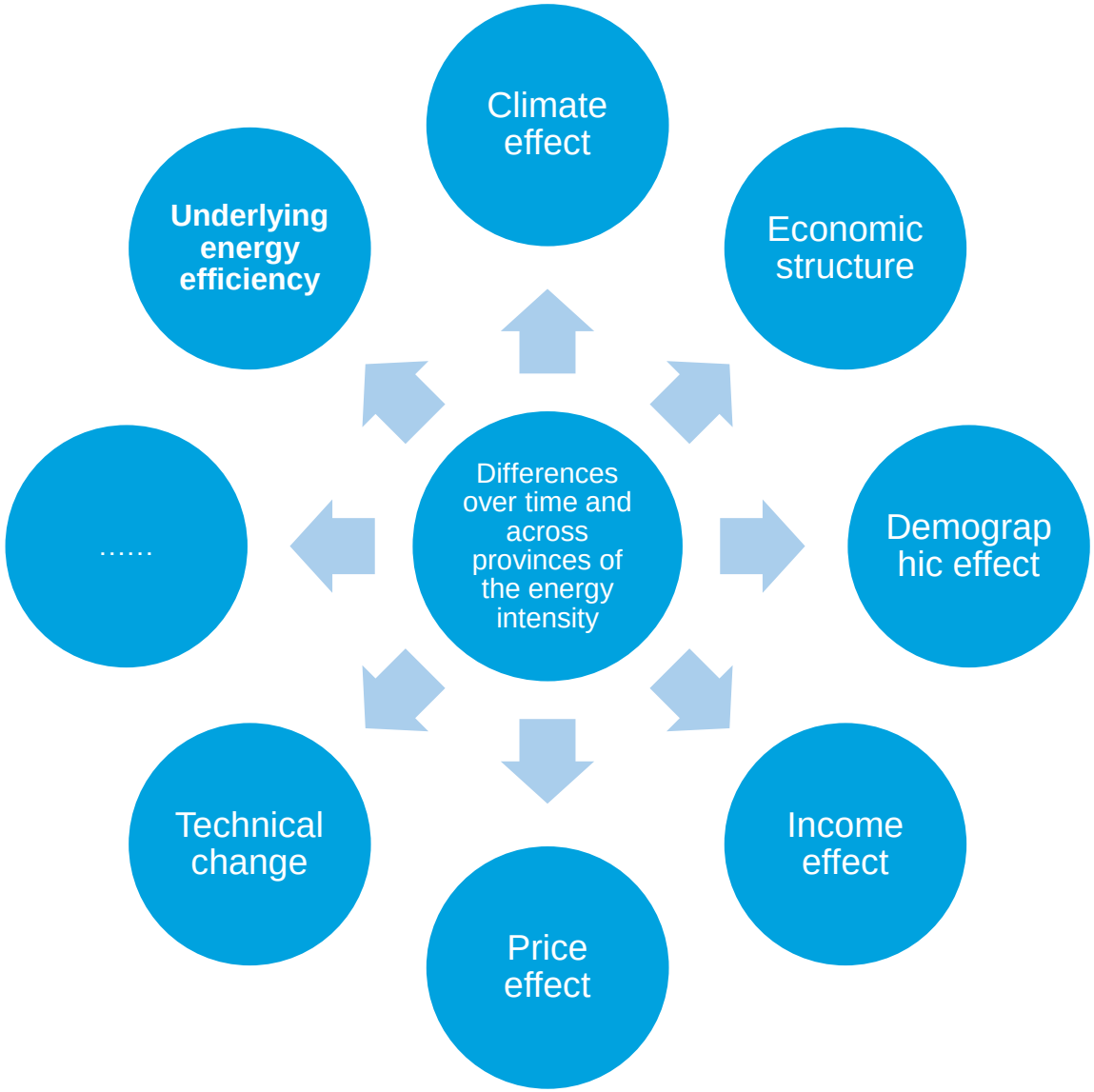
- "Energy intensity is commonly calculated as the ratio of energy use to GDP. Energy intensity is often taken as a proxy for energy efficiency, although this is **not entirely accurate** since changes in **energy intensity are a function of changes in several factors** including the structure of the economy, climate,… and energy efficiency"

- Energy intensity does not measure the level of "**underlying energy efficiency**" that characterizes an economy

- According to EIA (1995; p.vii) without a clear definition, the term energy efficiency is "a **vague, subjective** concept that engenders directionless speculation and confusion rather than insightful analysis"

- Therefore
  - Cross province comparison of EI could give a misleading picture
  - Furthermore, it is difficult to make conclusions for energy policy based upon this simple measure

Factors that influences the level of energy intensity



Decomposition of the change in energy intensity

Index Decomposition Analysis (IDA)

- Use of several type of index numbers
- Decomposition of the changes into the change in fuel mix, the change in the structure of the economy, energy efficiency…

Econometric Decomposition of the energy intensity

- Measurement of the level of productive efficiency **(Microeconomics Production Theory)**
- Decomposition of the changes into the change in climate, population, prices, output, technical change, …., and **level of energy efficiency**

Previous studies (analysis for China)

- Fisher-Vanden et al. (2004): investigate driving force for energy intensity decline, panel data for 2500 industrial enterprises during 1997-1999, multiplicative form of Divisia decomposition method
- Ma and Stern (2008): logarithmic mean Divisia index (LMDI) techniques to decompose changes in energy intensity, aggregate data (1980-2003), structural change effect
- Wei et al. (2009): estimate energy efficiency in China by DEA method, panel data for 29 provinces
- Hu and Wang (2006): estimate total-factor energy efficiency by DEA model, panel data for 29 provinces

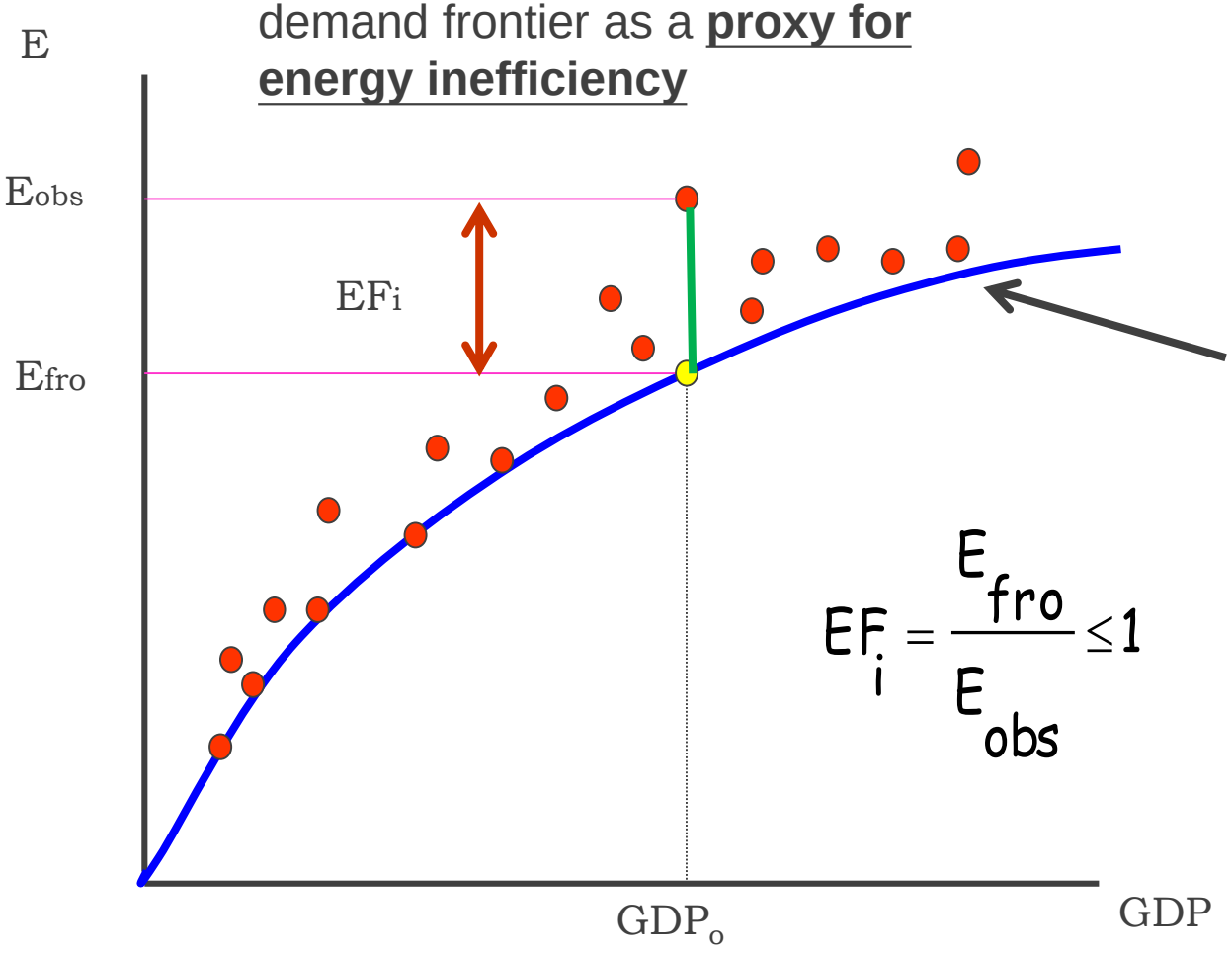
Econometric approach

- To estimate the level of energy efficiency for Chinese provinces by combining:
  - **Energy demand modelling**
  - **Stochastic frontier approach**
- An aggregate **energy demand frontier** function is estimated

- Behind any **energy service** we have a **production process** and an associated **production function**.
- From the microeconomics point of view the term energy efficiency **measures the ability of an economic entity to minimize the use of energy, given a level of GDP**

An aggregate energy demand frontier model

Interpret the distance from the demand frontier as a **proxy for energy inefficiency**



$$EF_i = \frac{E_{fro}}{E_{obs}} \leq 1$$

Energy demand frontier

Energy efficiency measures the ability of a country to minimize the energy consumption, given a level of GDP

The model to estimate the energy efficiency

- Energy demand frontier model (Filippini and Hunt 2012; Greene 2005)

$$lnE_{it} = \alpha_i + X_{it}\delta + \alpha_{dT} dT_t + u_{it} + v_{it}$$

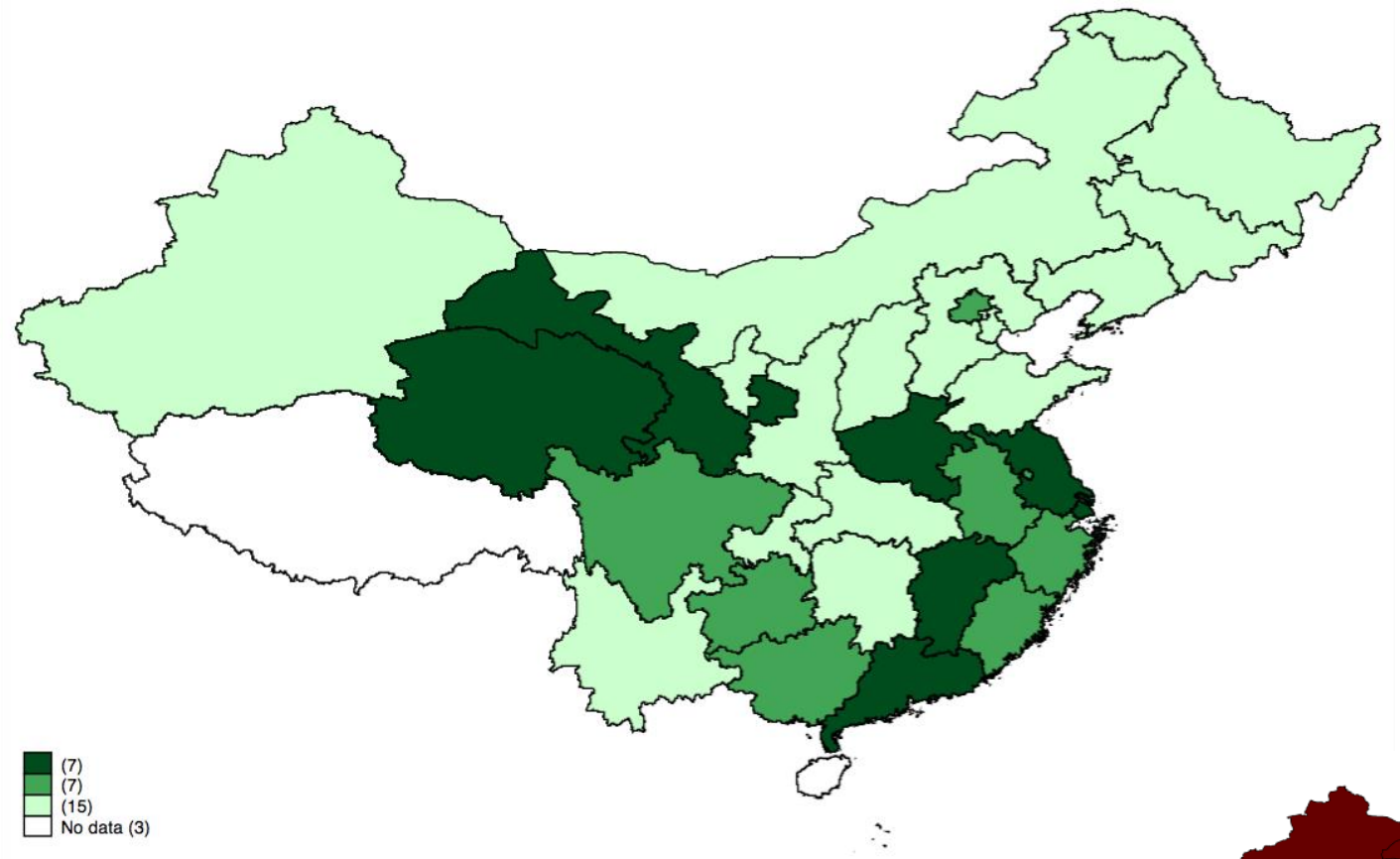
- Econometric specifications of efficiency term

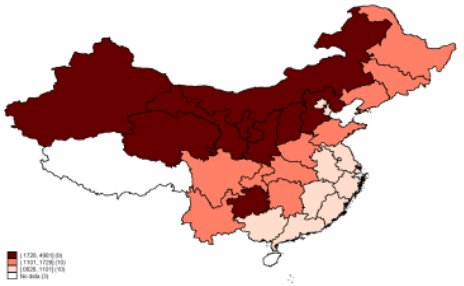
  (Greene 2005; Jondrow et al. 1982)

Model	Full random error ε_{it}	Inefficiency estimator	Efficiency score computation
TRE	$\varepsilon_{it} = \alpha_i + u_{it} + v_{it}$ $u_{it} \sim N^{+}(0, \sigma_u^2)$ $\quad v_{it} \sim N(0, \sigma_v^2)$ $\alpha_i \sim N(0, \sigma_r^2)$	$E(u_{it} \mid \varepsilon_{it})$	$EF_{it} = \frac{E_{it}^F}{E_{it}} = \exp(-\hat{u}_{it})$

Note: E_{it} is the observed energy consumption and E_{it}^F is the frontier or minimum demand of the i^{th} province in time t.

Geographic illustration of transient energy efficiency across provinces (average value)





Overall correlation coefficients between efficiency scores and energy intensity： -0.27

Source: Filippini and Zhang (2016)

Policy background

- Chinese government decided to reduce its energy intensity by 20% in the 11th Five-Year-Plan (FYP) period.
- In 2011, the residential energy consumption consumed 414.54 Mtce of energy, which accounted for **11%** of total energy consumption in China (LBNL 2012).
- In north China the level of energy efficiency of a very high proportion of the urban residential buildings is **low**.
- heating energy consumption in terms of per square meter of building space in China is about **1-1.5** times more than that in Northern Europe.
  - mainly due to the poor insulation, inefficient heating system and lack of heat metering facilities

- In 2007 the central government introduced a policy in the northern areas of China to **promote heat metering and energy efficiency retrofitting** (HMEER).

- The program is directed and supervised by the joint efforts of Ministry of Housing and Urban-Rural Development (MOHURD) and Ministry of Finance (MOF).

- The main tasks of HMEER were:
  - to promote the installation and retrofit of heat meters
  - and to promote temperature regulation of heating system and
  - to promote energy efficiency retrofit of building envelop (MOHURD and MOF 2008).

- Although there are papers:
  - discussing the organizational issues, challenges and difficulties (Zhao et al. 2009a,b)
  - and calculating the implementation effects based on technical numbers (Ding et al. 2011; Bao et al. 2012)

- Lacks of an **economic approach** to investigate the impacts of the HMEER policy.

- The goal of this paper is
  - to perform an **empirical analysis** to evaluate the impacts of the introduction of HMEER on residential energy consumption and on the level of energy efficiency in Chinese provinces.

Literature review

- Existing studies on the ex-post impact of energy policy measures on residential energy consumption using rigorous methodological approaches are limited.
  - randomized control trial or
  - quasi experiment with DID
- Fowlie et. al. (2015) evaluated the impact of a large energy saving program, the Weatherization Assistance Program.
- Allcott and Kessler (2016) presented a social welfare evaluation of home energy reports through a randomized control trial and suggested larger energy savings from survey respondents in residential sector.
- Boomhover and Davis (2015) estimated the change in electricity consumption due to the residential air conditioner program
- Houde et al. (2013) conducted a field experiment to estimate the impacts of real-time feedback technologies.

- based on quasi experiments data and investigate the impacts of policy instruments on the residential energy consumption using DID approach
  - Horowitz (2007), Datta and Filippini (2016), Sheer et al. (2013), Adan and Fuerst (2015)

- Studies analyzing China's residential energy consumption in the literature using other methods
  - Chen et al. (2008): data aggregation method
  - Zhao et al. (2012): decomposition analysis
  - Zheng et al. (2014): comprehensive survey of 1450 houseolds
  - Xu et al. (2016): a set of six criteria through scorecard method

Our contribution

- complements to the literature on investigating the effect of a specific policy measure – HMEER policy – on the residential energy consumption in China by using a rigorous evaluation method.
  - based on **DID** approach
  - possibility to remove unobservable individual effects and common macro effects
  - take into account approximation errors and random behaviour through the statistical noise.

- estimation of an energy demand frontier model to obtain the second outcome variables used in the DID approach
  - i.e. an indicator of **the level of energy efficiency** in the residential sector

Econometric specifications

- Policy was implemented in northern heating areas from 2007
- We evaluate the impacts of policy on
  - Energy consumption in the residential sector
  - Energy efficiency in the residential sector

- Difference-in-difference (DID) approach

$$E_{it} = \alpha_i + \alpha_{dT} dT_t + \alpha_{pol} dPOL_{it} + X_{it}\delta + \mu_{it}$$

- Two assumptions for DID are verified
  - √ Parallel trends
  - √ Exogenous assignment on treated group

Descriptive statistics

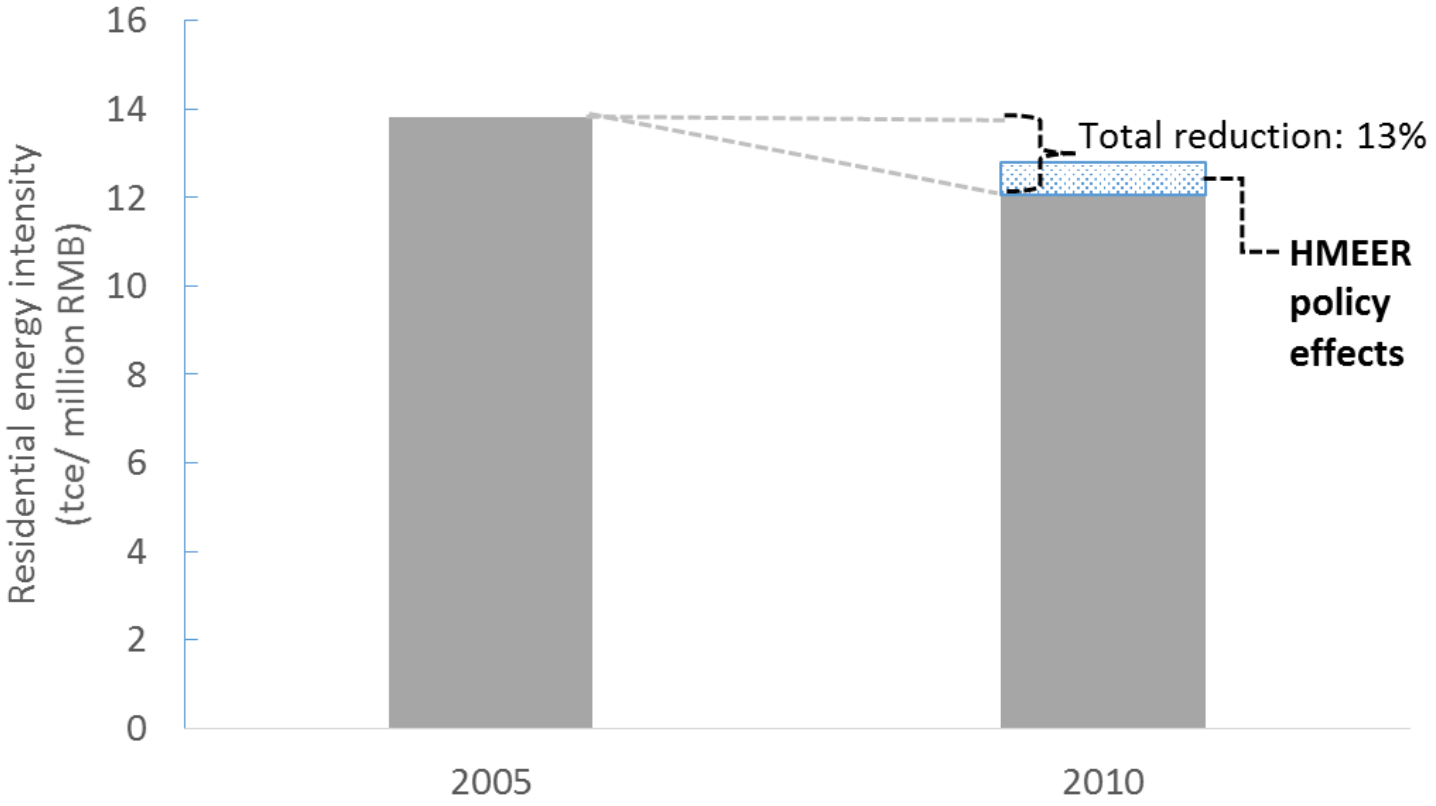
Variable	Obs	Mean	Std. Dev.	Min	Max
Residential energy consumption (Mtec)	261	11.11	6.70	1.40	40.49
Energy price index (Year 2003=100)	261	150.42	33.27	100	251.83
Real income (100 Million yuan)	261	8043.03	6871.79	385.34	35261.60
Population (10000)	261	4470.66	2587.82	534	10505
Average household size (persons)	261	3.20	0.31	2.39	4.4815
Heating degree days	261	547.97	678.11	0	2585.6
Cool degree days	261	97.55	112.43	0	401.70
Urbanization rate	261	0.48	0.15	0.25	0.89

Provinces and the HMEER policy

Without policy (Control group)	With policy (Treated group)
Anhui, Chongqing, Fujian, Guangdong, Guangxi, Guizhou, Hubei, Hunan, Jiangsu, Shanghai, Sichuan, Yunnan, Zhejiang	Beijing, Gansu, Hebei, Heilongjiang, Henan, Inner Mongolia, Jilin, Liaoning, Ningxia, Qinghai, Shaanxi, Shandong, Shanxi, Tianjin, Xinjiang

	(A)	(B)
VARIABLES	Total Energy	Efficiency TRE
Policy	**-0.105****	**0.033****
	(0.041)	(0.015)
Log Price	-0.003***	
	(0.001)	
Log Income	1.335***	
	(0.262)	
Log Household size	-0.636**	
	(0.298)	
Log Population	0.556*	
	(0.305)	
Log Heating degree days	0.003	
	(0.012)	
Log Cooling degree days	0.032**	
	(0.014)	
Urbanization	1.164	
	(1.001)	
Constant	-28.913***	0.858***
	(9.304)	(0.011)
Observations	261	261
Provincial fixed effects	YES	YES
Time dummies	YES	YES

Comparison of the residential energy intensity between 2005 and 2010



Conclusion

- Econometric approach to estimate energy efficiency
- Rigorous ex-post evaluation of energy efficiency policies are vital to understand and hence to improve their contributions
  - Average impact of the policy is **10%** declining in energy demand for the treated provinces.
  - The direct impact of HMEER on energy saving for the policy period (2007-2010) is about **80 Mtce**, whereas the reduction of CO2 emissions is around **200 Mt CO2 equivalent.**
  - **43%** of the energy intensity reduction in the residential sector is attributed to the HMEER policy
- The energy saving potential can be very promising if HMEER could be implemented in a large scale, as HMEER considered only **4.6%** of the total building stock that need a retrofitting

Other issues

- By observing the progress of HMEER policy effect we find the **flip-flop** patterns:
  - local governments need to understand the heterogeneities among one another, and adopt appropriate instruments for an efficient resource allocation.
  - the estimated efficiency level could be used as a benchmarking indicators by the central government
  - President Xi: *supply-side structural reform* to improve the productivity

Thank you

- More information on the technical parts of this presentation could be found in following paper:
  - M. Filippini and L. Zhang (2017): Impacts of heat metering and efficiency retrofit policy on residential energy consumption: A Chinese perspective. *Under review*.

- Further information on the estimation of energy efficiency can be found in the following paper:
  - L. Zhang (2017): Correcting the uneven burden sharing of emission reduction across provinces in China. ***Energy Economics***, 64, 335-345.
  - M. Filippini and L. Zhang* (2016): Estimation of the energy efficiency in Chinese provinces. ***Energy Efficiency***, 9(6), 1315-1328.
  - V. C. Jaunky and L. Zhang* (2016): Convergence of operational efficiency in China's provincial power sector. ***The Energy Journal***, 37, SI1, 3-27.

THANK YOU!