# Energy Saving Technological Change in U.S. Manufacturing
(Preliminary)

Tiefeng Qian

SITE@CUFE

October 12, 2017

# Part I

# Introduction

# Facts

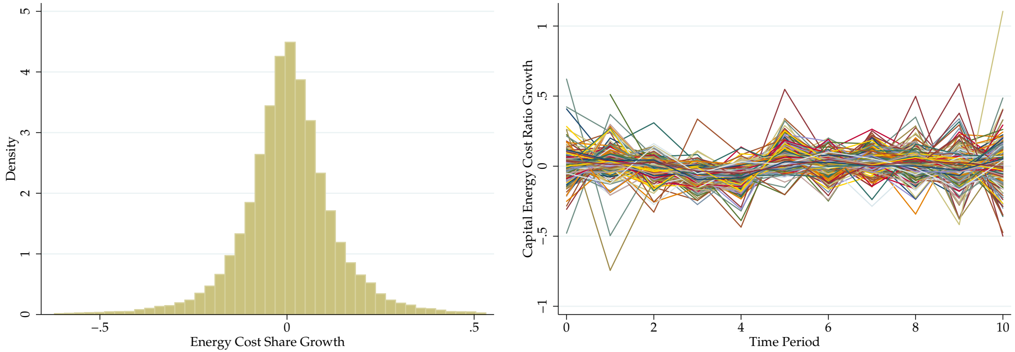


Figure 1: Distribution of Energy Cost Share Growth Rate

# Research Question

**Research Question:**

1. Given the significant heterogeneity across industries, how biased is the estimate of ESTC for the U.S. manufacturing?
2. How does heterogeneity evolve over time?
3. In what way(s), does heterogeneity affect the reduction of energy intensity? Which component makes greater contribution?

# Literature

1. Estimation of aggregate CES production nesting energy, Polgreen and Silos [2009], following Krusell *et al* [2000]. Identifying BTC from elasticity (Diamond *et.al* [1978], ).
2. Debate on technical change versus structural change (Composition Effect), Trade, Preference, Regulation. Levinson [2009, 2015], Stefani [2013], Shaprio and Walker [Forthcoming].
3. Relationship between heterogeneity (within between industry) and the aggregate technology (Oberfield and Raval [2014])

# Part II

# Model

# Production

1. Inner level of the production

$$g_i(K_i, E_i) = A^k_{i,t}\left[(1-\delta_i)\cdot(K_{it})^{\rho_E} + \delta_{it}\cdot(\varphi_{Eit}E_{it})^{\rho_E}\right]^{\frac{1}{\rho_E}}$$

2. Middle level

$$f^g_i(K_{it}, E_{it}, L_{it}) = A^v_{i,t}\left[(1-\mu_i)\left(g_i(K_{it}, E_{it})\right)^{\rho_l} + \mu\cdot(\varphi_{Lit}L_{it})^{\rho_l}\right]^{\frac{1}{\rho_l}}$$

3. Outter level

$$Y^g_{it} = A^g_{i,t}\left[(1-\lambda_i)\left(f^g_i(K_t, L_t, E_t)\right)^{\rho_m} + \lambda_i\cdot(\varphi_{imt}M_{it})^{\rho_m}\right]^{\frac{1}{\rho_m}}$$

# Demand I

Demand structure features nested ACES utility function.

1. At the top level

$$Q_t = \left( \sum_{g=1}^{J} \omega_g \cdot Q_{gt}^{\beta} \right)^{\frac{1}{\beta}} \tag{1}$$

   where $1/(1-\beta)$ is the elasticity of substitution between industries, and quantity of industry $g$, $Q_{gt}$ can be further specified:

2. At the bottom level

$$Q_{gt} = \left( \sum_{i=1}^{I} \left( \exp\left[ \lambda_{ig}(E_t) \right] \cdot q_{igt} \right)^{\alpha_g} \right)^{\frac{1}{\alpha_g}}$$

3. The representative consumer maximize the utility $U_t$ subject to the constraint:

$$\sum_g \sum_i q_{igt} \cdot p_{igt} = E_{mt}$$

## Demand II

4. Based on the CES aggregation structure, we can define the price index in industry $g$ as

$$P_{gt} = \left( \sum_{i=1}^{I} \exp[\lambda_{ig}(E_t)]^{\frac{1}{1-\alpha_g}} \left(p_{igt}\right)^{\frac{\alpha_g}{\alpha_g - 1}} \right)^{\frac{\alpha_g - 1}{\alpha_g}} .$$

   and the price index for the whole manufacturing sector as:

$$P_t = \left( \sum_g \omega_g \left( \frac{P_{gt}}{\omega_g} \right)^{\frac{\beta}{\beta - 1}} \right)^{\frac{\beta - 1}{\beta}}$$

5. Demand for product group $g$,

$$Q_{gt} = Q_t \omega_g^{\frac{1}{1-\beta}} \left( \frac{P_t}{P_{gt}} \right)^{\frac{1}{1-\beta}}$$

   and of $q_{igt}$ for industry $i$ in group $g$,

$$q_{igt} = Q_{gt} \exp[\lambda_{ig}(E_t)]^{\frac{1}{1-\alpha_g}} \left( \frac{P_{gt}}{P_{igt}} \right)^{\frac{1}{1-\alpha_g}}$$

# Demand III

6. The share of expenditure on $q_{igt}$ out of that on group $g$ can be calculated:

$$\chi_{igt} = \frac{p_{igt} \cdot q_{igt}}{P_{gt} \cdot Q_{gt}} = \exp[\lambda_{ig}(E_t)]^{\frac{1}{1-\alpha_g}} \left(\frac{P_{gt}}{p_{igt}}\right)^{\frac{\alpha_g}{1-\alpha_g}}$$

and the expenditure share of group $g$ out of the entire manufacturing sector is:

$$\chi_{gt} = \frac{P_{gt} \cdot Q_{gt}}{P_t \cdot Q_t} = \omega_g^{\frac{1}{1-\beta}} \left(\frac{P_t}{P_{gt}}\right)^{\frac{\beta}{1-\beta}} .$$

7. Loglinearizing the first equation gives:

$$\log \chi_{igt} = \underbrace{\frac{1}{1-\alpha_g} \lambda_{ig}(E_t)}_{\text{Income Effect}} + \underbrace{\frac{\alpha_g}{1-\alpha_g} \log(P_{gt}/P_{igt})}_{\text{Price Effect}},$$

which separate the income effect and price effect and can be easily estimated by OLS. The same method cam be applied to $\chi_{gt}$.

# Part III

## Aggregation

# Aggregating $\psi_{E,i}$ I

1. Consider a scenario with no changes in the relative price, i.e. $\Delta\log(p_E/r) = 0$, and see how factor cost share (factor use) responds to the changes in the $\psi_e$,

$$\psi_e = \Delta\log\left(\frac{E}{K}\right) = \Delta\log\frac{s_E}{1-s_E}$$

and for each industry $i$,

$$\psi_{e,i} = \Delta\log\left(\frac{E_i}{K_i}\right) = \Delta\log\frac{s_{E,i}}{1-s_{E,i}}$$

2. With $s_E = \sum_i \theta_i s_{E,i}$, we have:

$$\psi_e = \sum_i \frac{(1-s_{E,i})s_{E,i}}{(1-s_E)s_E}\theta_i\psi_{e,i} + \sum_i \frac{s_{E,i}-s_E}{(1-s_E)s_E}\frac{d\theta_i}{dt}.$$

Define

$$\overline{\psi}_e = \sum_i \frac{(1-s_{E,i})\times s_{E,i}\times\theta_i}{\sum_j(1-s_{E,j})\times s_{E,j}\times\theta_j}\psi_{e,i},$$

# Aggregating $\psi_{E,i}$ II

and

$$\Xi \equiv \sum_i \frac{(s_{E,i} - s_E)^2}{s_E \times (1 - s_E)} \theta_i$$

we have

$$\psi_e = (1 - \Xi) \cdot \overline{\psi}_e + \sum_i \frac{s_{E,i} - s_E}{(1 - s_E) \times s_E} \frac{d\theta_i}{dt},$$

3. How the composition $\theta_i$ respond to technology changes $\psi_{e,i}$ over time. For simplicity, assume capital and energy are the only two inputs in each industry, resulting in that $\theta_{i,t} = \chi_{i,t}$.

$$\psi_e = (1 - \Xi) \cdot \overline{\psi}_e + \underbrace{\sum_i \frac{s_{E,i} - s_E}{(1 - s_E) \times s_E} \frac{1}{1 - \beta} \Delta \lambda_i(E_t)}_{\text{Income Effect}} + \underbrace{\sum_i \frac{s_{E,i} - s_E}{(1 - s_E) \times s_E} \frac{\beta}{1 - \beta} \Delta \log(P_t / P_{it})}_{\text{Price Effect}}$$

# Aggregate Elasticity $\sigma^{ke}$ I

Analogously, we can define $\sigma^{ke}$ for the entire manufacturing sector relying the equation

$$\Delta \log \left( \frac{s_E}{s_K} \right) = (1 - \sigma_a^{ke}) \Delta \log \left( \frac{r}{p_E} \right) + \psi_e.$$

To define the aggregate elasticity, we look at the response of cost ratio to relative price changes absent (aggregate) biased technical change.

1. we define $\sigma_{agg}$ through the equation:

$$\Delta \log \left( \frac{s_E}{s_K} \right) = (1 - \sigma_i^{ke}) \Delta \log \left( \frac{r}{p_E} \right)$$

Analogously for each industry by keeping industrial energy saving technology $\phi_{e,i} = 0$:

$$\Delta \log \left( \frac{s_{E,i}}{s_{K,i}} \right) = (1 - \sigma_i) \Delta \log \left( \frac{r}{p_E} \right).$$

# Aggregate Elasticity $\sigma^{ke}$ II

2. we then have

$$\sigma_a^{ke} = (1-\Xi)\bar{\sigma}^{ke} + \frac{\sum_i (s_{E,i} - s_E)\frac{\partial \theta_i}{\partial \log(r/p_E)}}{s_E(1-s_E)} + \Xi$$

   with

$$\bar{\sigma}^{ke} \equiv \sum_i \frac{s_{E,i} \times (1-s_{E,i}) \times \theta_i}{\sum_j s_{E,j} \times (1-s_{E,j}) \times \theta_j} \sigma_i^{ke}$$

   $\bar{\sigma}^{ke}$ is a weighted average of $\sigma_i^{ke}$, while $\Xi$ stands for a heterogeneity index, the result is similar to Oberfield and Ravel [2014].

3. A special case

$$\sigma_a^{ke} \approx (1-\Xi)\bar{\sigma}^{ke} + \Xi$$

   hence $\sigma_a^{ke} \geq \Xi$, $\sigma_a^{ke} \geq \bar{\sigma}^{ke}$, and $\sigma_a^{ke} \leq \Xi + \bar{\sigma}^{ke}$

# Part IV

## Empirical Strategy

# Method

- To estimate **long-run** elasticities, annual data is not perfect. **5-year-window-average** of growth rate is employed, which is similar to the spirit of Chirinko and Mallick [2017], favoring low-frequency variation.
- Low-frequency data reduce the effect of short-run shocks, frictions (e.g. adjustment cost).
- NBER-CES U.S. Manufacturing data set is employed, covering 400+ industries, from 1958 through 2011.

## Estimating $\sigma^{ke}$ and $\psi_e$

1. Equalizing marginal product of inputs to its prices gives:

$$\Delta log\left(\frac{s_K}{s_E}\right)_{it} = (1-\sigma^{ke})\phi_{e\sim k,i} + (1-\sigma^{ke})\Delta log\left(\frac{r}{p_e}\right)_{it} + \epsilon_{it}$$

   where $\sigma^{ke} = 1/(1-\rho_E)$ is the long-run ES between capital and energy and $\psi_{s\sim k,i}$ is the ESTC in $i$.

2. And

$$\Delta log\left(\frac{s_K}{s_L}\right)_{it} = (1-\sigma^{kl})\phi_{l\sim k,i} + (1-\sigma^{kl})\Delta log\left(\frac{r}{w}\right)_{it} + \frac{\sigma^{kl}-\sigma^{ke}}{\sigma^{ke}-1}\Delta log\left(1+\frac{s_E}{s_K}\right)_{it} + \varepsilon_{it}$$

   where $\sigma^{kl} = 1/(1-\rho_l)$ is the long-run ES between capital and labor, $\psi_{l\sim k,i}$ is the LBTC.

# Estimating $\beta_g$ and $\lambda_{ig}$

3. Taking the first difference of log expenditure gives us estimating equation

$$\Delta \log \chi_{igt} = \frac{1}{1-\alpha_g} \Delta \lambda_{ig}(E_t) + \frac{\alpha_g}{1-\alpha_g} \Delta \log(P_{gt}/P_{igt}) + \nu_{igt}$$

   Income effect is estimated as the fixed effect, price effect is identified by the variation in relative price changes across industries over time.

# Part V

## Empirical Results

# Results

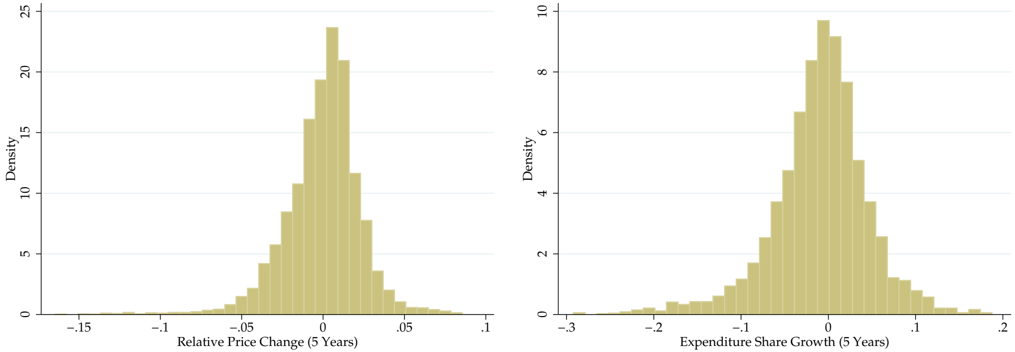


Figure 2: Variations in Relative Price and Expenditure Growth

# Results I

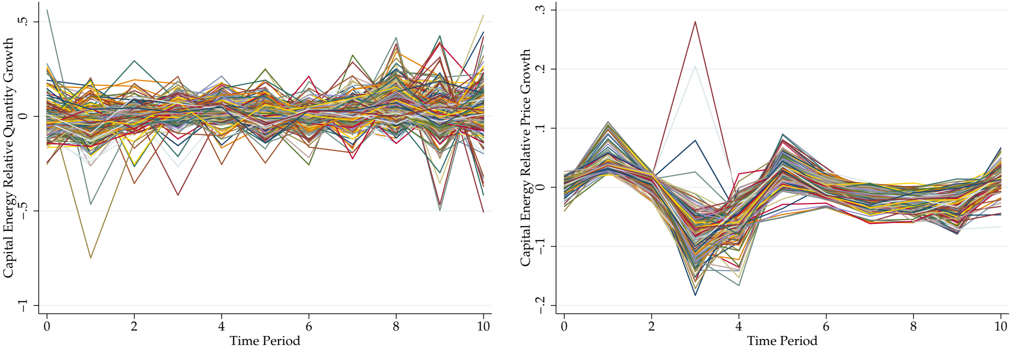


Figure 3: Variations in Capital-Energy Relative Price and Relative Quantity.

## Estimates of $\sigma^{ke}$ I

Table 1: Capital-Energy Elasticity of Substitution

| Dependent Variable: $\Delta_\tau log\left(\frac{s_K}{s_E}\right)_{it}$ | | | | |
|---|---|---|---|---|
| $\Delta_\tau log(P_K/P_E)_{it}$ | 0.7600 | **0.7939** | 0.2768 | 0.3862 |
| | (0.0308) | **(0.0321)** | (0.0657) | (0.0722) |
| Industry | | ✓ | | ✓ |
| $\tau$ | | | ✓ | ✓ |
| Obs | 4971 | 4971 | 4971 | 4971 |

# Estimates of $\sigma^{ke}$ II

Table 2: Capital-Energy Elasticity of Substitution (78-83 onward)

| | Dependent Variable: $\Delta_\tau log\left(\frac{s_K}{s_E}\right)_{it}$ | | | |
|---|---|---|---|---|
| $\Delta_\tau log(P_K/P_E)_{it}$ | 0.9580 | **1.0429** | 0.3011 | 0.4847 |
| | (0.0516) | **(0.0557)** | (0.0927) | (0.1096) |
| Industry | | $\checkmark$ | | $\checkmark$ |
| $\tau$ | | | $\checkmark$ | $\checkmark$ |
| Obs | 3191 | 3191 | 3191 | 3191 |

# Estimates of $\psi_{e,i}$

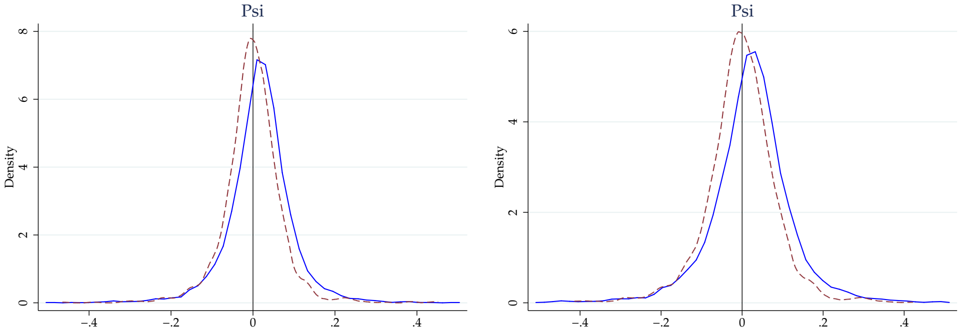


Figure 4: Distribution of $\psi_{ei}$ before and after the crises.

# Estimates of $\sigma^{kl}$

Table 3: Capital-Labor Elasticity of Substitution

| Dependent Variable: $\Delta_\tau log\left(\frac{s_K}{s_L}\right)_{it}$ | | | | |
|---|---|---|---|---|
| $\Delta_\tau log(P_K/P_L)_{it}$ | 0.3156 | **0.3908** | 0.2357 | **0.3539** |
| | (0.0376) | **(0.0408)** | (0.0466) | **(0.0527)** |
| $\Delta_\tau log[1+(s_E/s_K)]_{it}$ | -1.3301 | **-1.3200** | -1.2830 | **-1.2609** |
| | (0.0397) | **(0.0408)** | (0.0402) | **(0.0414)** |
| Industry | | ✓ | | ✓ |
| $\tau$ | | | ✓ | ✓ |
| Obs | 4971 | 4971 | 4971 | 4971 |

## Estimates of $\sigma_\beta$ and $\lambda_i$ I

Table 4: Elasticity of Substitution Between Industries

| Dependent Variable: $\Delta_\tau log \chi_{it}$ | | | | |
|---|---|---|---|---|
| $\Delta_\tau log(P_{it}/P_t)$ | 0.4200 | **0.5731** | 0.4011 | **0.5625** |
| | (0.0291) | **(0.0331)** | (0.0296) | **(0.0342)** |
| Industry | | ✓ | | ✓ |
| $\tau$ | | | ✓ | ✓ |
| Obs | 4971 | 4971 | 4971 | 4971 |

## Estimates of $\sigma_\beta$ and $\lambda_i$ II

Table 5: Elasticity of Substitution Between Industries

| | Dependent Variable: $\Delta_\tau log \chi_{it}$ | | | |
|---|---|---|---|---|
| $\Delta_\tau log(P_{it}/P_t)$ | 0.4200 | **0.4860** | 0.4011 | **0.5170** |
| | (0.0291) | **(0.0344)** | (0.0296) | **(0.0354)** |
| Industry | | ✓ | | ✓ |
| $\lambda_i \times$ Industry | | ✓ | | ✓ |
| $\tau$ | | | ✓ | ✓ |
| Obs | 4971 | 4971 | 4971 | 4971 |

# Part VI

## Quantitative Assessment

## Heterogeneity Index

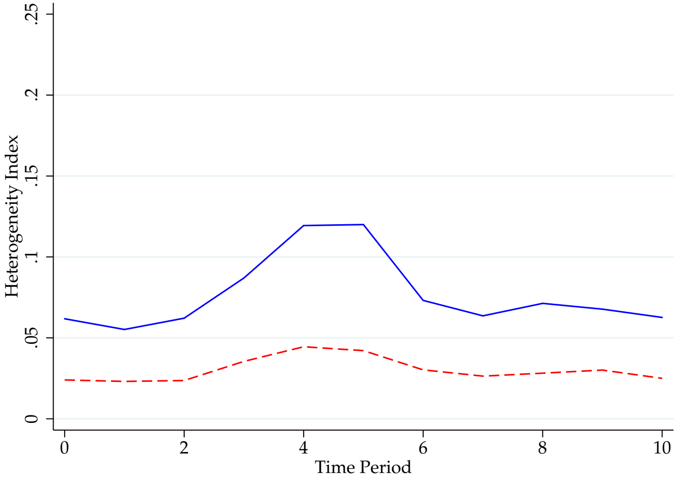


Figure 5: Heterogeneity Index: Blue solid capital-energy for $\theta_i$; Red dashed for gross $\theta_i$

## $\overline{\psi}_e$

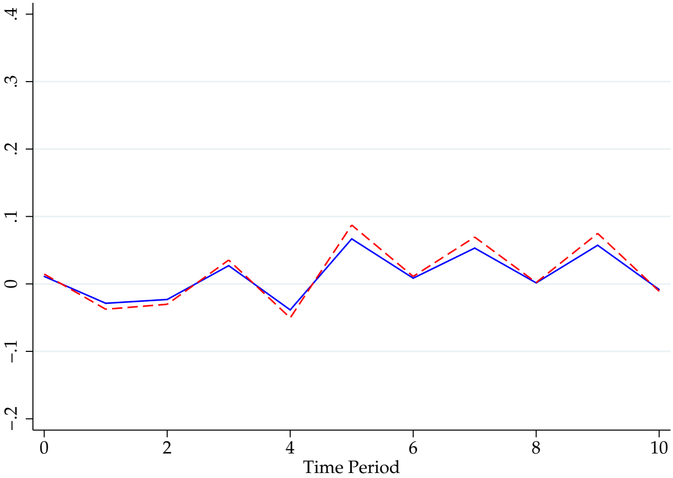


Figure 6: Heterogeneity Index: Blue solid for capital-energy $\theta_i$; Red dashed for gross $\theta_i$

# Price Effect vs. Income Effect

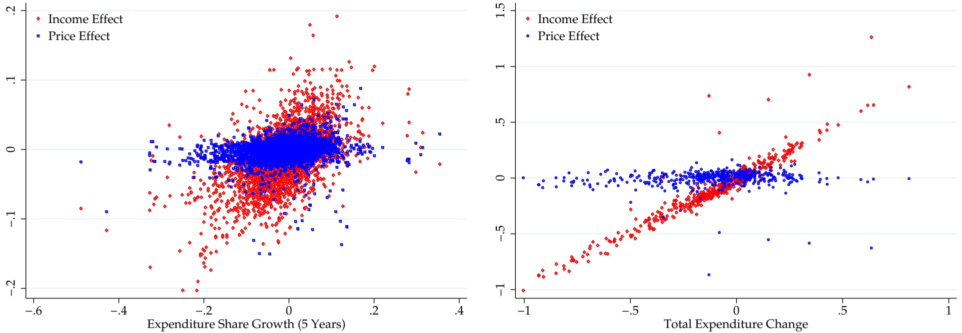


Figure 7: Expenditure: Income Effect versus Price Effect

# Conclusion