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## **Dynamic Interaction between Economic Indicators and SO<sub>2</sub> Emission in U.S.**

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# DYNAMIC INTERACTION BETWEEN ECONOMIC INDICATORS AND SO<sub>2</sub> EMISSION IN U.S.

Man-Keun KIM and T. Edward YU

## 1. Motivation

- Economic growth (GDP or income) and environmental pollutants nexus – **EKC hypothesis**
  - A large number of studies using the reduced-form regression models.
- Energy consumption (energy use) and economic growth nexus
  - Does energy use cause economic growth? inconclusive evidences
- Trade (openness) is another key variable
  - Trade liberalization and economic growth nexus
  - Trade liberalization and pollution nexus – no clear consensus (pollution haven or race-to-the-bottom hypotheses)
- Somewhat surprisingly**, studies on economic growth, environmental pollutants, energy use and trade nexus are rare or few if any
  - Reveal the (causal) relationships between economic indicators

## 2. Theoretical Framework

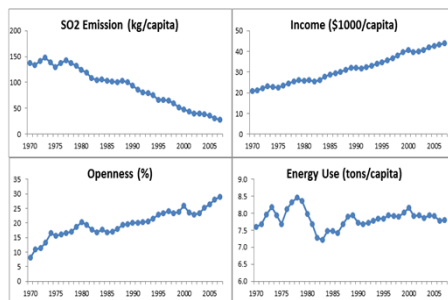
- SO<sub>2</sub> emission (*EMS*): function of energy use (*ENG*) and government policy (*G*), e.g., **acid rain program (ARP)** and exogenous factors (technology), *Z*<sub>1</sub>.
 
$$EMS = f^E(ENG, G, Z_1), \partial EMS / \partial ENG > 0, \partial EMS / \partial G < 0$$
- Government policy: function of income level (*INC*)
 
$$G = f^G(INC), \partial G / \partial INC > 0$$
- Energy use (*ENG*): function of income (*INC* and *ENG* nexus) and exogenous factors, *Z*<sub>2</sub>.
 
$$ENG = f^E(INC, Z_2), \partial ENG / \partial INC > 0$$
- Income (*INC*): function of energy use (*INC* and *ENG* nexus), trade openness (*OPN*) (*INC* and *OPN* nexus), and other factors, *Z*<sub>3</sub>.
 
$$INC = f^I(ENG, OPN, Z_3), \partial INC / \partial ENG > 0, \partial INC / \partial OPN > 0$$
- Trade openness (*OPN*): function of *INC* and other factors
 
$$OPN = f^O(INC, Z_4), \partial OPN / \partial INC > 0$$
- Inter-related variables over time**
  - Dynamic interactions
  - Vector Autoregression model (VAR)

## 3. Methods

- VAR with trend captures the evolutions and interdependencies among variables
 
$$y_t = c + \sum_{i=1}^k A_i y_{t-i} + dZ_t + \varepsilon_t \quad (t = 1, \dots, T)$$
- Moving average (MA) representation from the VAR and the impulse response functions to investigate relationships
 
$$y_t = \sum_{i=0}^{\infty} \Theta_i \varepsilon_{t-i}, \quad \frac{\partial y_{t+h}}{\partial \varepsilon_t} = \Theta_h$$
- Historical decomposition (HD)** of the SO<sub>2</sub> emission
 
$$E_{t_0+k} = \sum_{s=0}^{\infty} \Theta_s \varepsilon_{t_0+k-s} + \sum_{s=0}^{k-1} \Theta_s \varepsilon_{t_0+k-s}$$
  - Left hand side: actual SO<sub>2</sub> emission
  - First term in right hand side: base projection of the SO<sub>2</sub> emission utilizing information up to *t*<sub>0</sub>
  - Second term in RHS: partition of contributions of the individual series to deviation from *t*<sub>0</sub> to *t*<sub>0</sub>+*k*

## 4. Data

- SO<sub>2</sub> emission per capita: Stern (2007)
  - <http://www.sterndavidi.com/datasite.html>
- Energy use per capita: Energy Information Agency
- Per capital income in U.S. dollar from World Bank
- Trade openness from World Bank (X+M)/Income

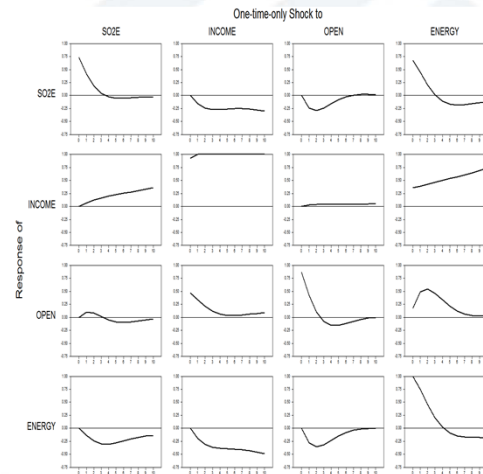


## 5. Contemporaneous Causal Structure

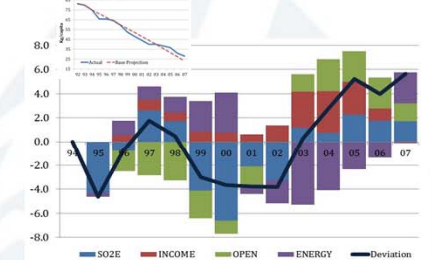
- The 4x1 vector  $\Theta_0$  in the MA representation contains the contemporaneous causal structure among orthogonal innovations ( $\varepsilon_t$ ), which is identified through direct acyclic graph (DAG)(Pearl 2000)
- DAG approach identifies the causal relationship among non-experimental data based on a **conditional independence**.
- Greedy Equivalence Search algorithm (GES)
  - It starts from a causal representation with no edge (all variables are independent), and it proceeds stepwise searching over causal flow using the Bayesian scoring criterion (Meek, 1997; Chickering, 2003).
- Causal structure using the GES algorithm



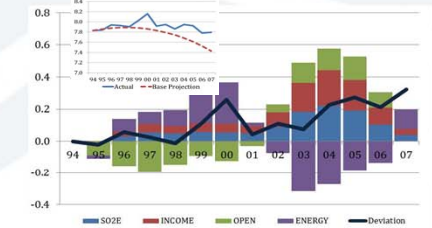
## 6. Impulse Response Functions (IRFs)



## 7. Historical Decomposition (HD)



Historical decomposition of SO<sub>2</sub> emission after ARP (1995) ↑



Historical decomposition of Energy Use after ARP (1995) ↑

## 8. Discussion

- From the causal structure, **contemporaneously, energy use → economic growth, and economic growth → openness.**
- IRFs show that the relationship between SO<sub>2</sub> emission and the income is negative (EKC hypothesis).
- HD shows that the actual SO<sub>2</sub> emission is higher than the baseline projection after implementing the ARP (phase 1, 1995 and phase 2, 2000) – **effectiveness of the ARP**
  - After 2003, the actual SO<sub>2</sub> emission is higher than the base projection. This is because of high SO<sub>2</sub> allowance prices linked with higher energy prices.
- Income has two effects on the SO<sub>2</sub> emission.
  - Indirect impact – lowering SO<sub>2</sub> emission through the policy instrument, e.g., ARP (EKC relationship).
  - Direct impact – increasing SO<sub>2</sub> emissions through higher energy use from the HD.
- The emerging economy may learn from the US experience for the emission control, i.e., China starts to reduce SO<sub>2</sub> emission even though its national income level is still low (Shaw et al, 2010).

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