Dynamic Interaction between Economic Indicators and SO_2 Emission in U.S.

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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_2 emission (*EMS*): function of energy use (*ENG*) and government policy (*G*), e.g., **acid rain program (ARP)** and exogenous factors (technology), Z_1.

$$EMS = f^E(ENG, G, Z_1),\ \partial EMS/\partial ENG > 0,\ \partial EMS/\partial G < 0$$

- 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_2.

$$ENG = f^N(INC, Z_2),\ \partial ENG/\partial INC > 0$$

- Income (*INC*): function of energy use (*INC* and *ENG* nexus), trade openness(*OPN*) (*INC* and *OPN* nexus), and other factors, Z_3.

$$INC = f^I(ENG, OPN, Z_3),\ \partial INC/\partial ENG > 0,\ \partial INC/\partial OPN > 0$$

- 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

$$\mathbf{y}_t = \mathbf{c} + \sum_{i=1}^{k} \mathbf{A}_i \mathbf{y}_{t-i} + \mathbf{d}\mathbf{Z}_t + \boldsymbol{\varepsilon}_t \ (t = 1, \ldots, T)$$

- Moving average (MA) representation from the VAR and the impulse response functions to investigate relationships

$$\mathbf{y}_t = \sum_{i=0}^{\infty} \boldsymbol{\Theta}_i \boldsymbol{\varepsilon}_{t-i}, \qquad \frac{\partial \mathbf{y}_{t+h}}{\partial \boldsymbol{\varepsilon}_t} = \boldsymbol{\Theta}_h$$

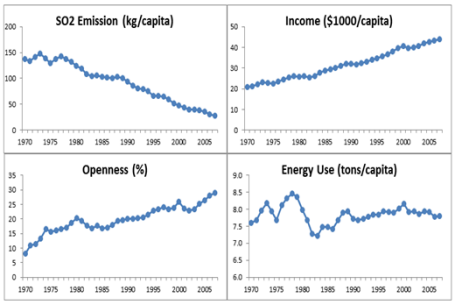
- **Historical decomposition** (HD) of the SO_2 emission

$$E_{t_0+k} = \sum_{s=k}^{\infty} \boldsymbol{\Theta}_s \boldsymbol{\varepsilon}_{t_0+k-s} + \sum_{s=0}^{k-1} \boldsymbol{\Theta}_s \boldsymbol{\varepsilon}_{t_0+k-s}$$

  - Left hand side: actual SO_2 emission
  - First term in right hand side: base projection of the SO_2 emission utilizing information up to t_0
  - Second term in RHS: partition of contributions of the individual series to deviation from t_0 to t_0+k

4. Data

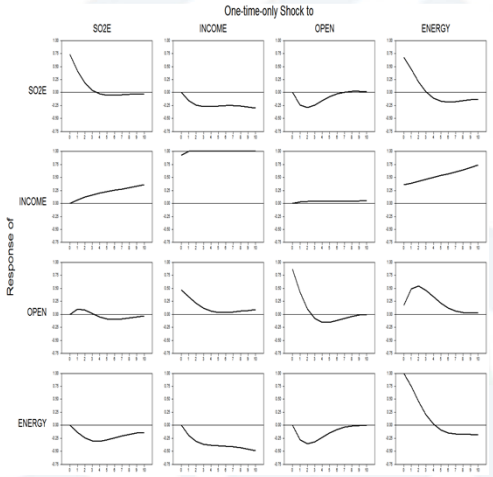
- SO2 emission per capita: Stern (2007)
  - http://www.sterndavidi.com/datasite.html
- Energy use per capita: Energy Information Agency
- Per capital income in U.S. dollar from World Bank
- Trade openness from World Bank (X+M)/Income



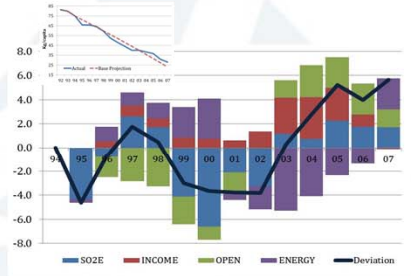
5. Contemporaneous Causal Structure

- The 4x1 vector $\boldsymbol{\Theta}_0$ in the MA representation contains the contemporaneous causal structure among orthogonal innovations ($\boldsymbol{\varepsilon}_t$), 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

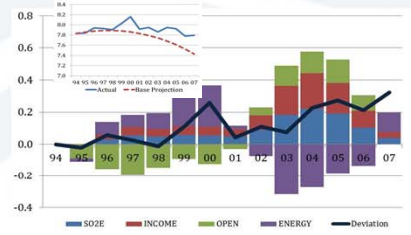
6. Impulse Response Functions (IRFs)



7. Historical Decomposition (HD)



Historical decomposition of SO2 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_2 emission and the income is negative (EKC hypothesis).
- HD shows that the actual SO_2 emission is lower than the baseline projection after implementing the ARP (phase 1, 1995 and phase 2, 2000) – **effectiveness of the ARP**
  - After 2003, the actual SO_2 emission is higher than the base projection. This is because of high SO_2 allowance prices linked with higher energy prices.
- Income has two effects on the SO_2 emission.
  - Indirect impact – lowering SO_2 emission through the policy instrument, e.g., ARP (EKC relationship).
  - Direct impact – increasing SO_2 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_2 emission even though its national income level is still low (Shaw et al, 2010).

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