Trade in virtual carbon: Evidence from spatial econometric models

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Shanghai, May 25,2015

* Ferdi, Fudan University, and Paris 1 University joint workshop
"China and Globalization"

Outline

- Pollution Havens & Virtual Trade in Carbon: stylized facts
  - Pollution havens effects: small
  - Virtual Trade in Carbon: large discrepancy in results
- Framework
- Data and estimation
- (Preliminary) Results

Pollution Havens and Virtual Trade in Carbon: Stylized facts

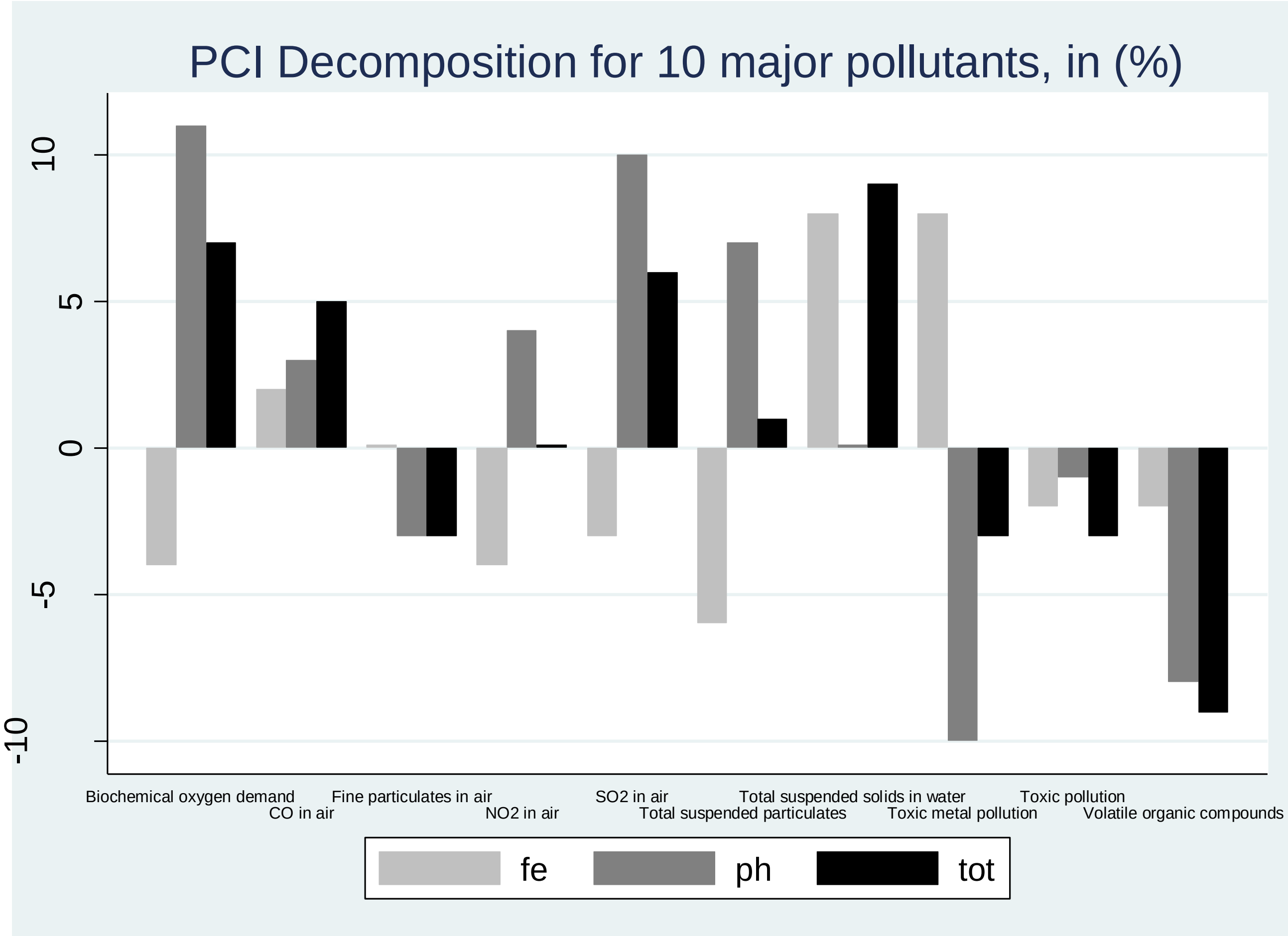
Pollution Havens: Stylized Facts

Evidence mostly from SO2—a local pollutant

- Energy-intensive sectors are weight-reducing = Not footlose (not much world-wide displacement of production for SO2-intensive sectors over period 1990-2000--see extra slides) Relevant for CO2?

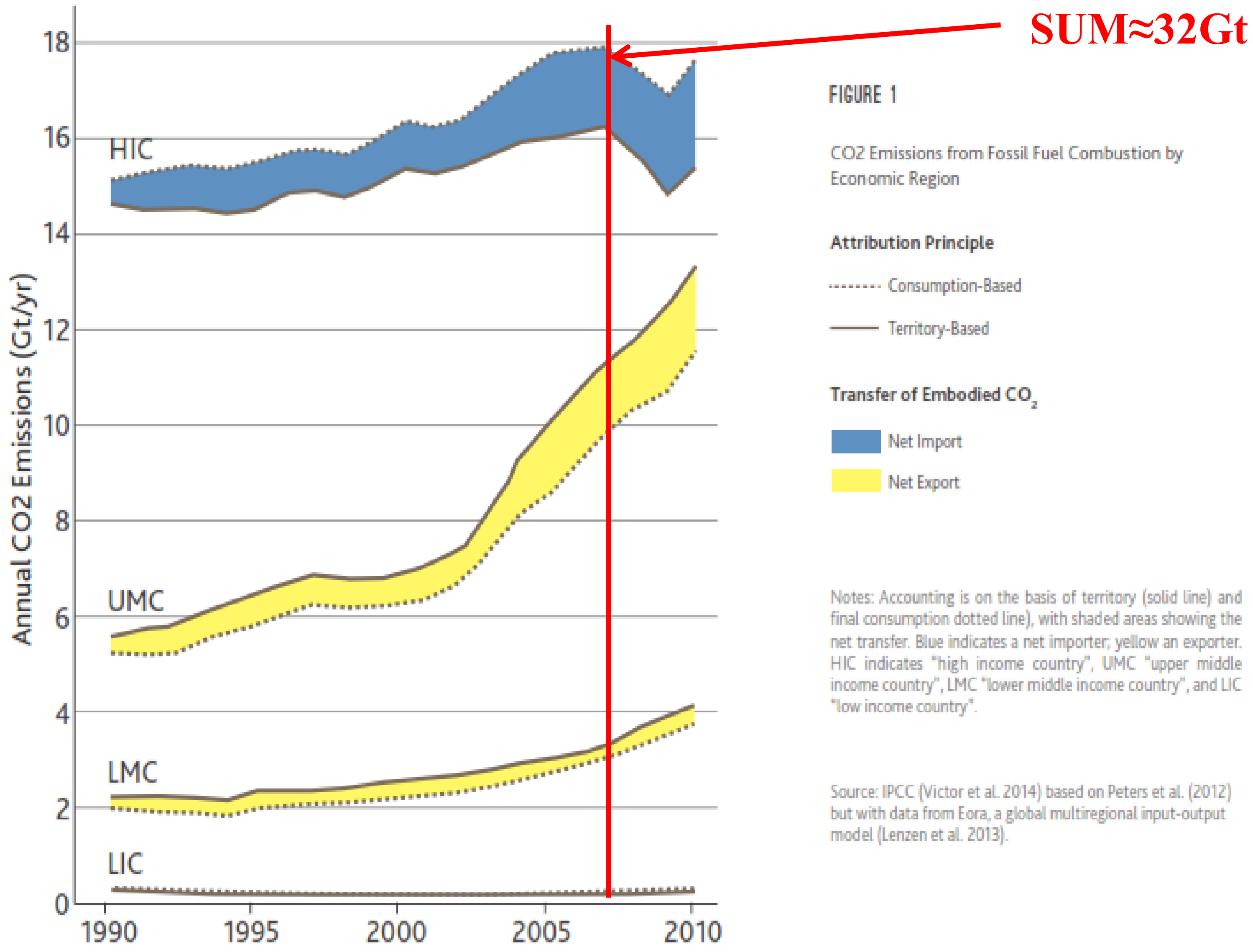
- Global studies: Small PH effects in bilateral trade (but strong composition effects as NN dominates NS trade ver 1990-00 so Pollution Content of Imports (PCI) is not much affected by environment policies-next slide)

- Factoring in FDI--mostly directed to EPZs likely to lead to cleaner exports (Dean and Lovely (2009) for China).



$$\text{TOT PCI}^{k}_{ij} = 1(\text{‘fundamental’}) + \text{TOT} = (1 + \text{PH})(1 + \text{FE})$$

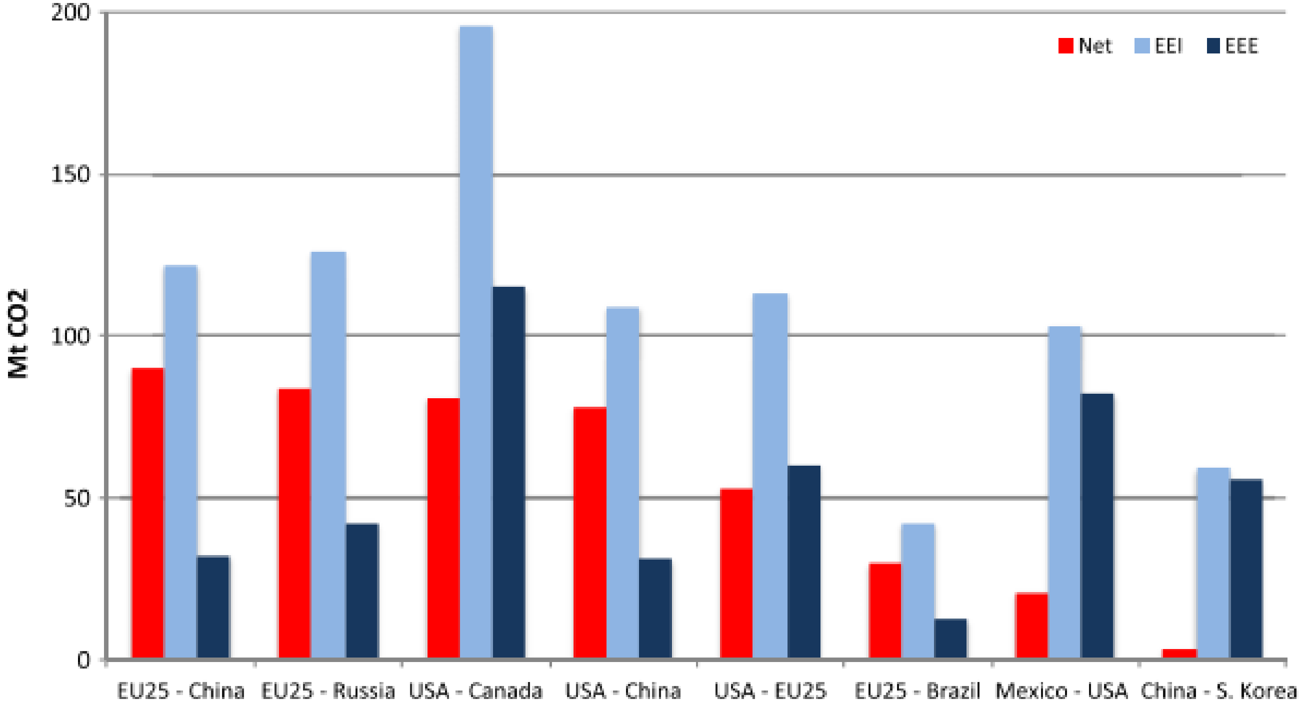
CO2 emissions from fuel Combustion by region (1)



Source: Victor (2015, figure 1 from IPPCC (SPM) WGIII)

Bilateral Product-level embodied emissions in Trade

(estimates for 2006 using average world emission factors)



Absolute volumes
EEI: Emissions Embodied in Imports
EEE: Emissions Embodied in Exports

5/1080 products account for 15% of emissions.; 10% account for 50% of emissions

- ❑ Aggregating gives 2006 patterns : ‘Production centers’ (Indonesia, Australia); ‘Consumption centers’ (Singapore, UK);
- ❑ ‘production and consumption centres’: (US, FR) import ‘downstream’ products while Italy and Germany export ‘downstream’ products.
- ⇨ Annex B- non-annex B groupings makes little sense.
- ⇨ Do patterns evolve over time?

Embodied carbon in China's trade in 2004

Large differences across studies for the SAME year

4.4Gt <EET (2004)< 6.2Gt

Problems:
(1) Estimates typically for 1 year
(2) lack of mechanisms to account for the emissions produced in one country and consumed in another

Our approach:
'Augmented' EKC estimated using spatial econometric methods

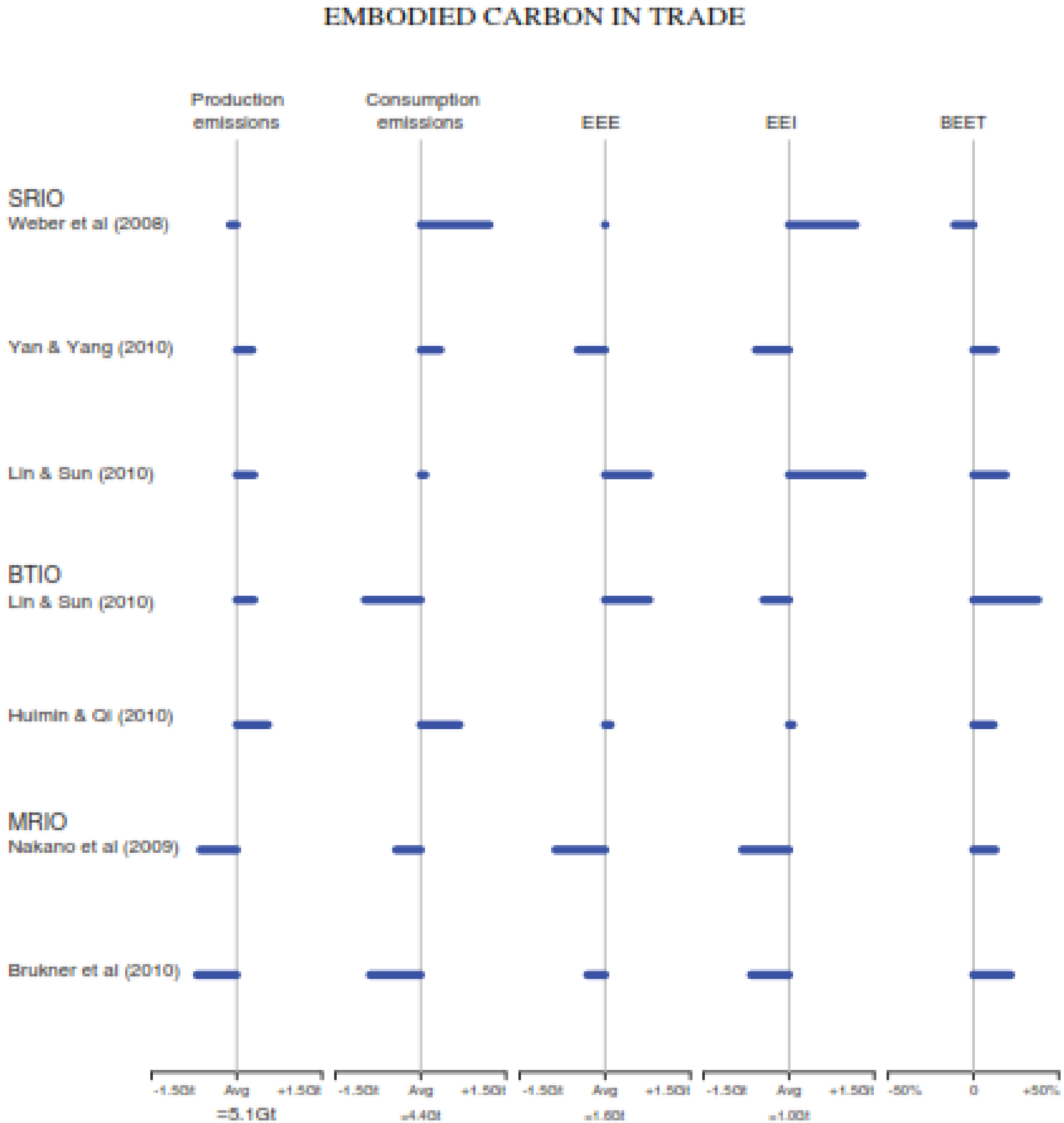


Figure 3. Comparison of EET Estimates from the Literature for China in 2005.

Framework

Reduced form representation of CO_2 emission

Omitting country and time subscripts, the standard EKC model in panel relates CO_2 emissions, E, to a vector, X, of country-specific variables

$$E = X\beta + \mu + \gamma + \epsilon \qquad (1)$$

Where:
E: CO_2 emissions from fossil fuels in production (territorial)
X : a vector of country-specific variables (income, environmental policy stringency, population density)
γ : a dummy variable that controls for country-specific time-invariant omitted variables
μ: a dummy variable that captures common time-specific shocks

This specification has been estimated many times under the strong identification assumption that the condition for pooling countries is satisfied (See Ordas (2008))

Augmented representation

Trade between countries lead to trade in virtual carbon (like trade in virtual water)

➔ Emissions in country i measured at the consumption (rather than production) level also depend on the emissions of its trade partners j≠i

$$E_{it} = X\beta + \lambda E_{j\neq i,j} + \mu + \gamma + \epsilon \qquad (2)$$

Where:

λ: captures the interdependency in emissions or «connectivity» between i and other countries (after controlling for differences in environmental policies)

Larger volume of bilateral trade signifies stronger economic interdependence

Here trade between countries is not modelled. It depends on

- Trade costs
- Environmental policies
- Political regimes
- Common language
- Common culture/religions, etc.

Case I: Symmetric countries, 1 sector

- Emissions in production for countries i and j is given by

$$E_i^P = Y_i \Omega_i a(\theta_i) \text{ and } E_j^P = Y_j \Omega_j a(\theta_j) \quad (3)$$

- Where $\Omega_k a(\theta_k)$, k = i, j is emission intensity depending on strigency of environtmental policy (Brock and Taylor, 2008)
- From national accounts:

Y≡C+X-M

Y : GDP, C : Domestic consumption, X : exports, M : imports

- Virtual carbon in bilateral trade can be written as:

$$E_i^C = Y_i \Omega_i a(\theta_i) - (M_i - X_i) \Omega_i a(\theta_i) \quad (4)$$

$$E_j^C = Y_j \Omega_j a(\theta_j) - (X_j - M_j) \Omega_j a(\theta_j) \quad (5)$$

- Since $(X_i - M_i) = (M_j - X_j)$, manipulations relate emissions in consumption to intensities in production and to patterns of trade :

$$E_i^P = -\underbrace{\left\{ \frac{\overbrace{\frac{\Omega_i a(\theta_i)}{\Omega_j a(\theta_j)}}^{\substack{relative\ emission \\ intensity}} \quad \overbrace{\frac{(M_i - X_i)}{Y_j}}^{elements\ of\ trade\ matrix}}{\left[1 + \left(\frac{X_i - M_i}{Y_i}\right)\right]} \right\}}_{spatial\ matrix} E_j^P + \underbrace{\frac{1}{\left[1 + \left(\frac{X_i - M_i}{Y_i}\right)\right]} E_i^P}_{EKC\ rescaled\ by\ trade\ ratio} \quad (6)$$

Case I: Symmetric countries, 1 sector (end)

Estimation function can be written as:

$$E = \lambda WE + X\beta + \mu + \gamma + \epsilon \quad (7)$$

Where W is a N ×N square weight matrix, whose elements measure the share of the net import by country i from country j (illustration for the case of three countries)

$$W= \begin{bmatrix} 0 & Trade_t^{1\leftarrow 2} & Trade_t^{1\leftarrow 3} \\ Trade_t^{2\leftarrow 1} & 0 & Trade_t^{2\leftarrow 3} \\ Trade_t^{3\leftarrow 1} & Trade_t^{3\leftarrow 2} & 0 \end{bmatrix} \quad (8)$$

$$Trade_t{}^{i\leftarrow j} = \frac{\Omega_{it}}{\Omega_{jt}} \frac{import_t{}^{i\leftarrow j} - export_t{}^{i\rightarrow j}}{Y_{jt}} \quad (9)$$

(the arrows show the direction of the merchandise movements between countries)

Case II: Symmetric countries, 2 sectors (H and L-carbon)

H carbon trade

L carbon trade

Emission transfer of i via net imports from j is reflected by negative coefficient

…e differences in the impacts on virtual carbon between :

…products (h)

…)

$$E_i^P = \underbrace{-\frac{\Omega_i a(\theta_i)}{\Omega_j a(\theta_j)} \times \frac{\overbrace{\left[\frac{(M_i^h - X_i^h)\Omega_j^h a(\theta_j^h)}{Y_j \Omega_j a(\theta_j)} + \frac{(M_i^l - X_i^l)\Omega_j^l a(\theta_j^l)}{Y_j \Omega_j a(\theta_j)}\right]}^{\ldots trade\ matrix}}{\left[1 + \frac{(X_i^h - M_i^h)}{Y_i} \times \frac{\Omega_i^h a(\theta_i^h)}{\Omega_i a(\theta_i)} + \frac{(X_i^l - M_i^l)}{Y_i} \times \frac{\Omega_i^l a(\theta_i^l)}{\Omega_i a(\theta_i)}\right]}}_{Bilateral\ trade\ matrix} \times E_j^P + \underbrace{\frac{E_i^P}{\left[1 + \frac{(X_i^h - M_i^h)}{Y_i} \times \frac{\Omega_i^h a(\theta_i^h)}{\Omega_i a(\theta_i)} + \frac{(X_i^l - M_i^l)}{Y_i} \times \frac{\Omega_i^l a(\theta_i^l)}{\Omega_i a(\theta_i)}\right]}}_{Scaled\ EKC}$$

So the bilateral trade matrix W is now written as:

$$\lambda W = \underbrace{\lambda^h W^h}_{Heavy\ polluting\ products'\ trade\ matrix} + \underbrace{\lambda^l W^l}_{other\ products'\ trade\ matrix}$$

Where the element of W^h is $\frac{(M_i^h - X_i^h)}{Y_j}$ and the element of W^h is $\frac{(M_i^l - X_i^l)}{Y_j}$

λ^h captures $\frac{\Omega_j^h a(\theta_j^h)}{\Omega_j a(\theta_j)}$ and λ^l captures $\frac{\Omega_j^l a(\theta_j^l)}{\Omega_j a(\theta_j)}$

Case III: 2-country groups, 2 sectors (H and L-carbon)

- To distinguish trade between countries according to their environmental policies
  - with similar environtmental policies (North←North, South←South)
  - with different environmental policies (North←South, South←North)

Trade matrix now divided into four parts

$$\lambda W = \lambda \begin{bmatrix} W^{N\leftarrow N} & W^{N\leftarrow S} \\ W^{S\leftarrow N} & W^{S\leftarrow S} \end{bmatrix} = \lambda_{NN} \begin{bmatrix} W^{N\leftarrow N} & 0 \\ 0 & 0 \end{bmatrix} + \lambda_{NS} \begin{bmatrix} 0 & W^{N\leftarrow S} \\ 0 & 0 \end{bmatrix} + \lambda_{SN} \begin{bmatrix} 0 & 0 \\ W^{S\leftarrow N} & 0 \end{bmatrix} + \lambda_{SS} \begin{bmatrix} 0 & 0 \\ 0 & W^{S\leftarrow S} \end{bmatrix}$$

- Further distinction of trade according to carbon-intensity category:
  - Trade in carbon intensive products (h)
  - Trade in other products (l)

$$\lambda W = \underbrace{\lambda^h_{NN} W^h_{NN} + \lambda^h_{NS} W^h_{NS} + \lambda^h_{SN} W^h_{SN} + \lambda^h_{SS} W^h_{SS}}_{Heavy\ polluting\ products'\ trade\ matrix} + \underbrace{\lambda^l_{NN} W^l_{NN} + \lambda^l_{NS} W^l_{NS} + \lambda^l_{SN} W^l_{SN} + \lambda^l_{SS} W^l_{SS}}_{other\ products'\ trade\ matrix}$$

Data and estimation

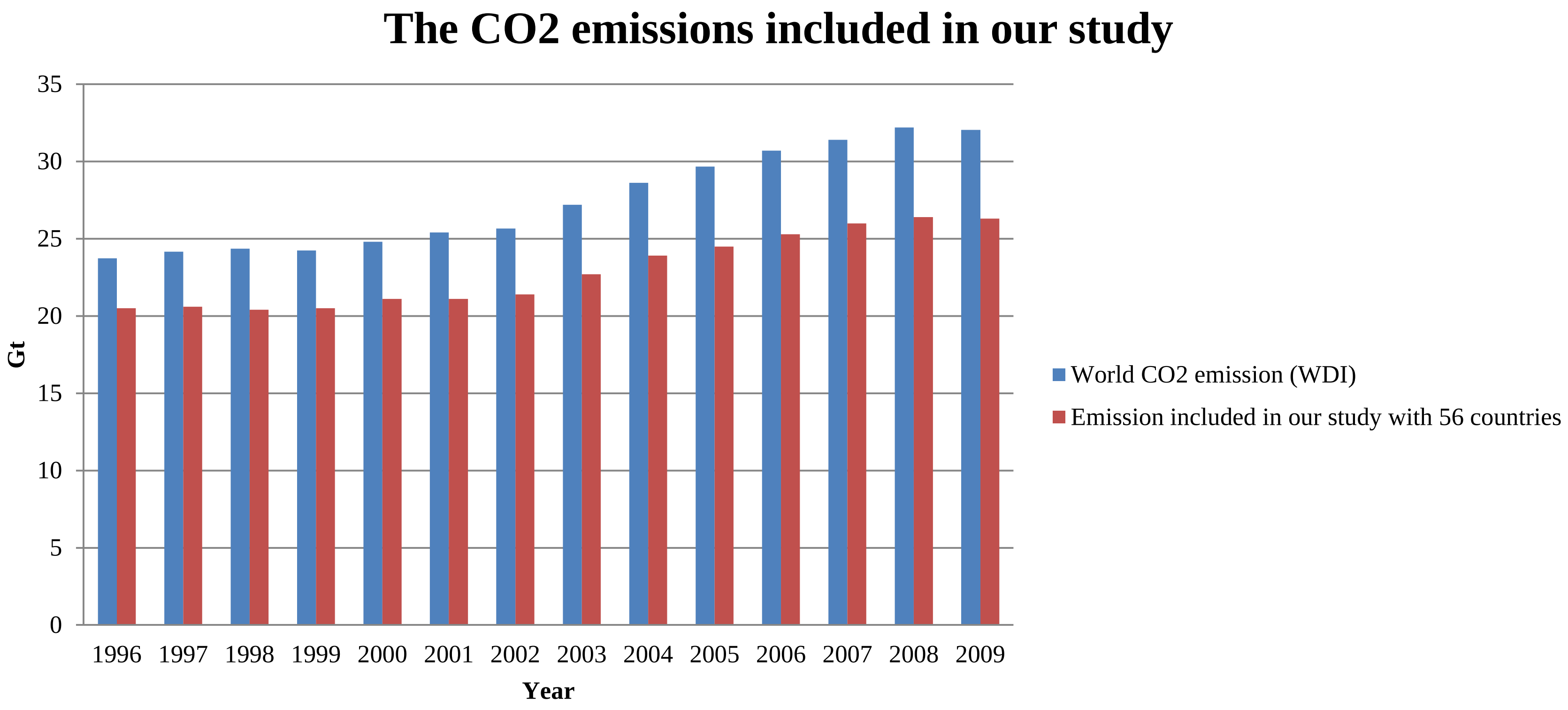
Data and estimation

Data: 1996-2009 (14 years), 56 countries (see coverage in next slide)

1. Bilateral trade data from UNcomtrade database (mirro data of export used)
2. CO_2 emission from fossil fuel combustion (WDI)
3. Other macroeconomic data from WDI and other sources

Econometric Strategy:

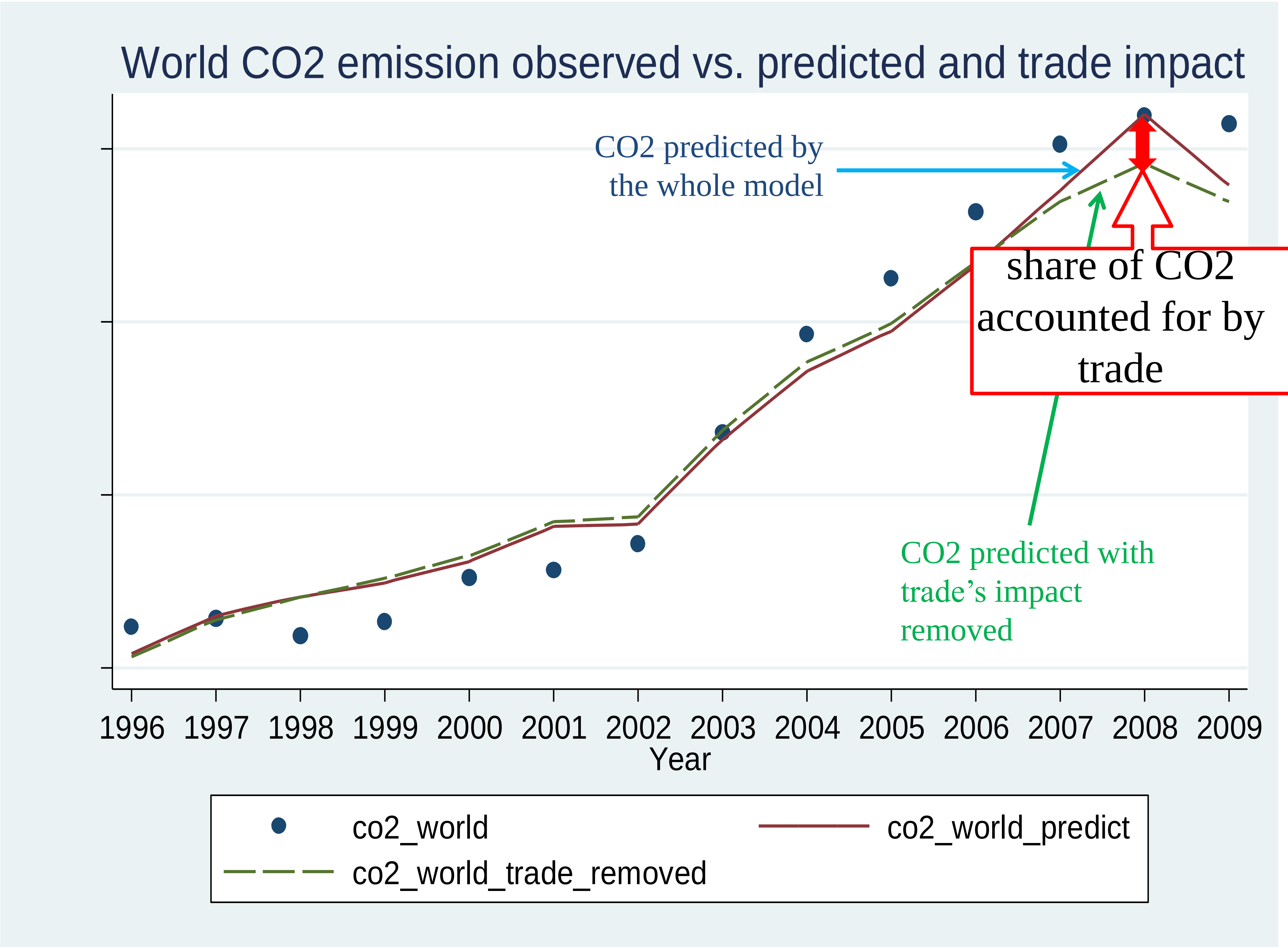
1. 2SLS proposed by Kelejian and Prucha (1998) to take care of the endogeneity of Ej
2. GMM to take care of the heteroskedasticity of panel data (Lee, 2003)

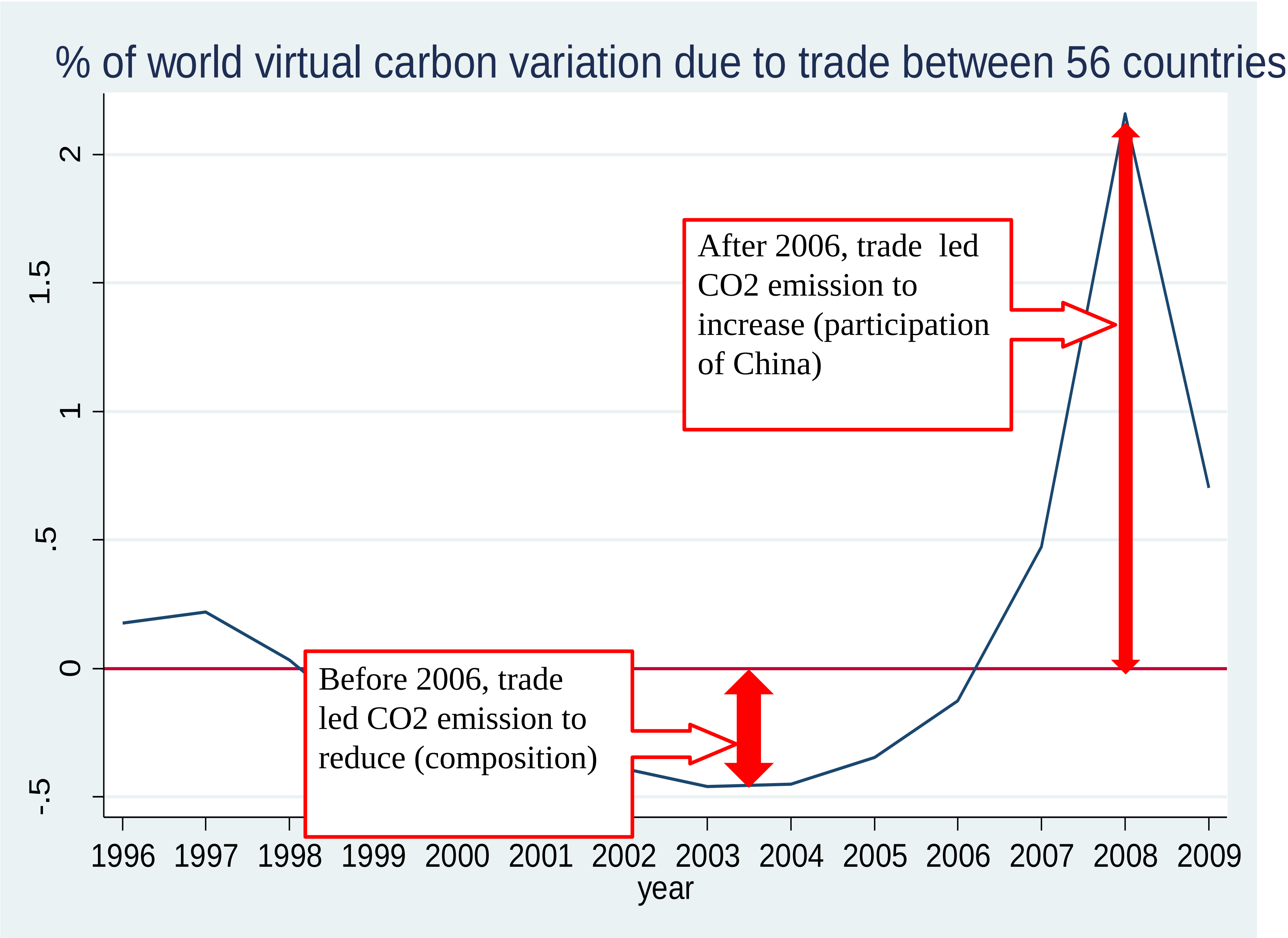

The CO2 emissions included in our study
35
30
25
20
15
10
5
0
Gt
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Year
World CO2 emission (WDI)
Emission included in our study with 56 countries

Preliminary Results:
Symmetric countries, one product category

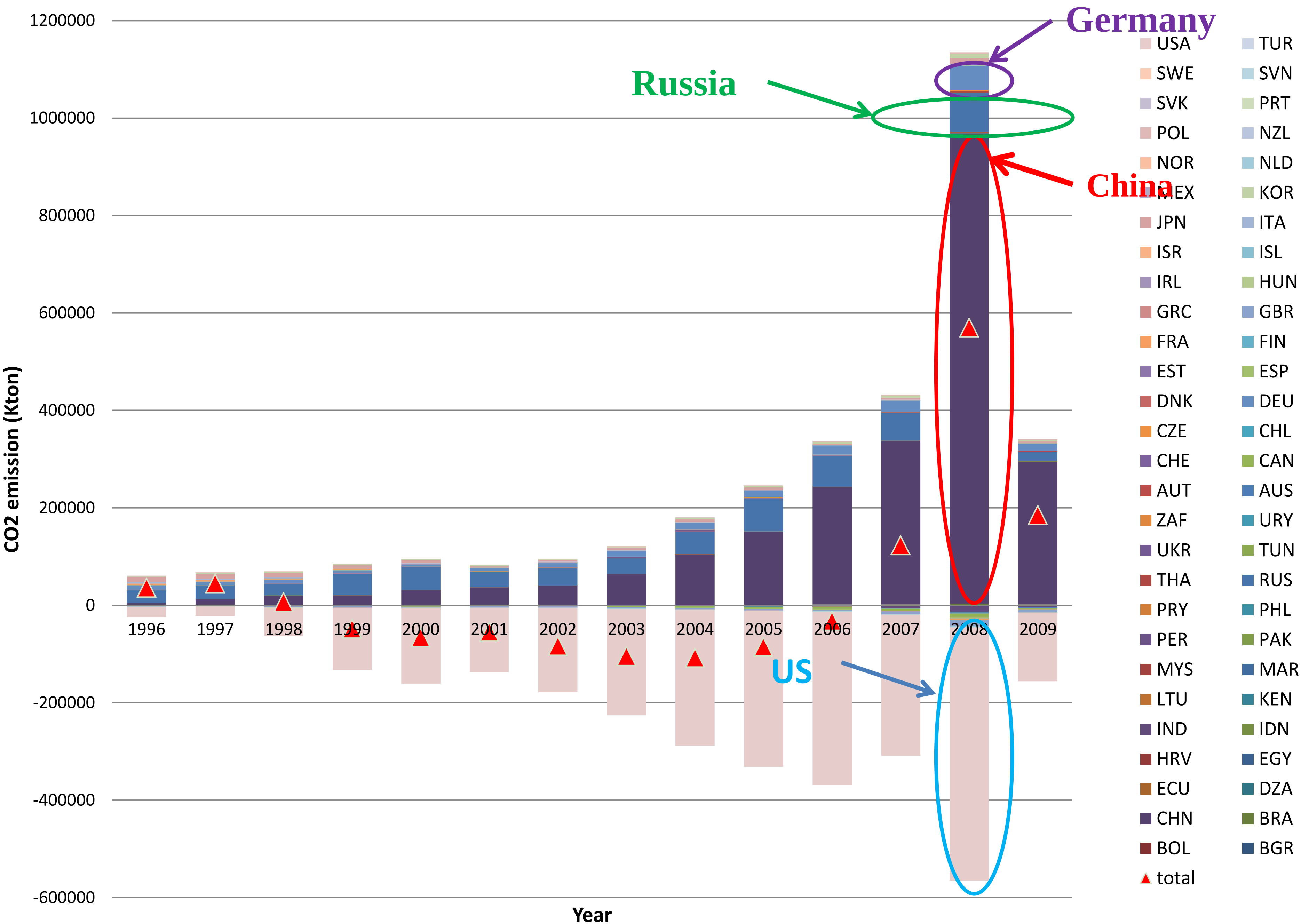
Table 1. total trade spatial weight matrix

Ei=Ln(CO2)	Simple EKC		Spatial weight matrix adjusted by carbon efficiency	
	FE	RE	FE	RE
W*Ej			-0.0027	-0.0029**
			(2.19)**	(2.32)
LGDPPC	1.64***	1.80***	1.56***	1.71***
	(10.13)	(11.21)***	(9.35)	(10.35)
LGDPPC2	-0.06***	-0.07***	-0.05***	0.07***
	(5.43)	(6.96)	(5.03)	(6.45)
LPOPDEN	1.69***	1.36***	1.69***	1.36***
	(16.58)	(15.48)	(16.63)	(15.54)
LER	-0.17***	-0.19***	-0.16***	-0.19***
	(5.70)	(6.66)	(5.69)	(6.65)
C	-4.32***	-3.06***	-3.88***	-2.60***
	(5.92)	(4.34)	(5.15)	(3.57)
R^2	0.9980	0.5662	0.9979	0.5589
Country Effect	Yes	Yes	Yes	Yes
Year effect	Yes	Yes	Yes	Yes
Hausman		44.25	45.58	


World CO2 emission observed vs. predicted and trade impact
CO2 predicted by the whole model
share of CO2 accounted for by trade
CO2 predicted with trade's impact removed
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Year
co2_world
co2_world_predict
co2_world_trade_removed


% of world virtual carbon variation due to trade between 56 countries
After 2006, trade led CO2 emission to increase (participation of China)
Before 2006, trade led CO2 emission to reduce (composition)
-.5
0
.5
1
1.5
2
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
year

Decomposition of the emission transferred via trade between 56 countries

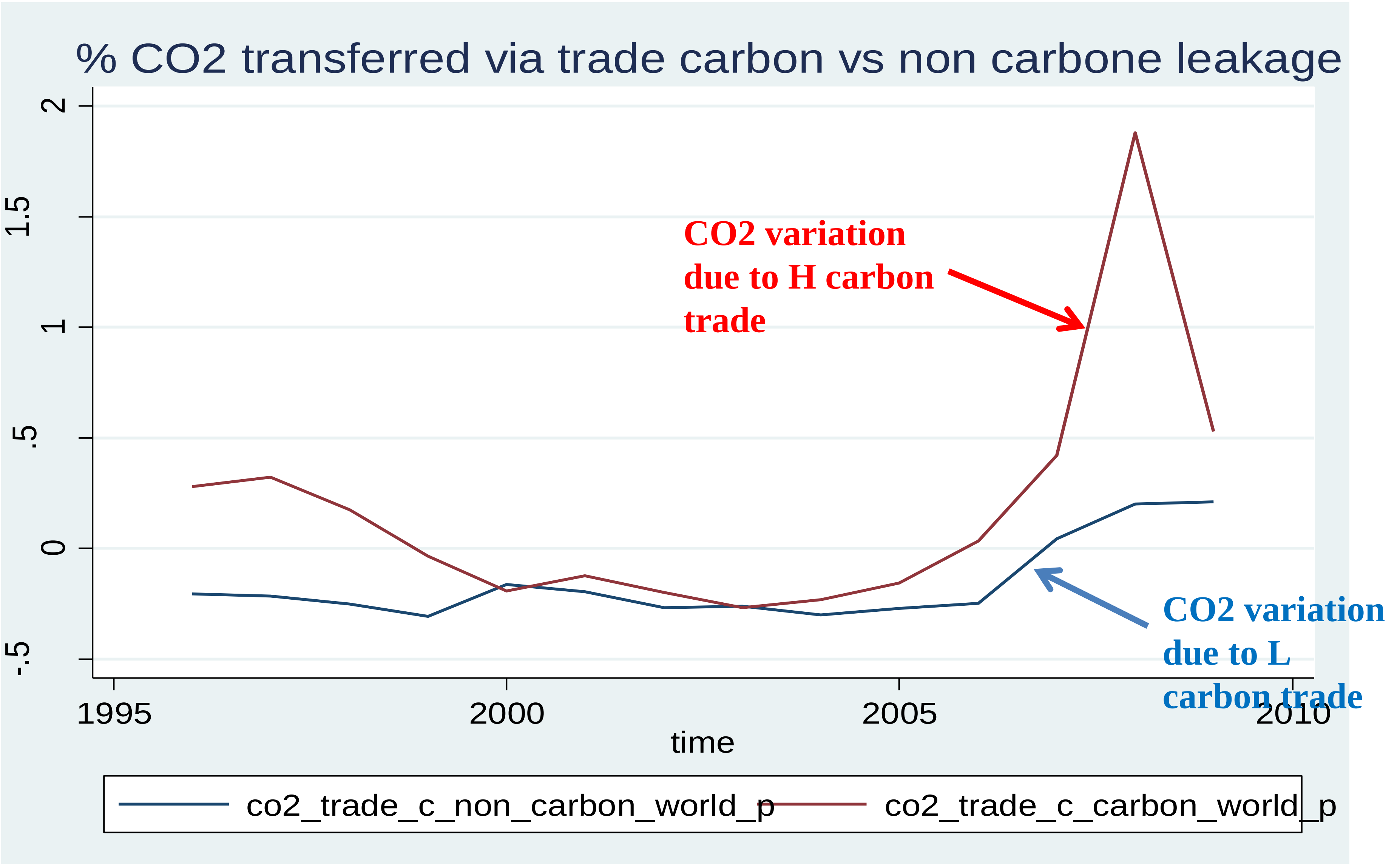


Preliminary Results

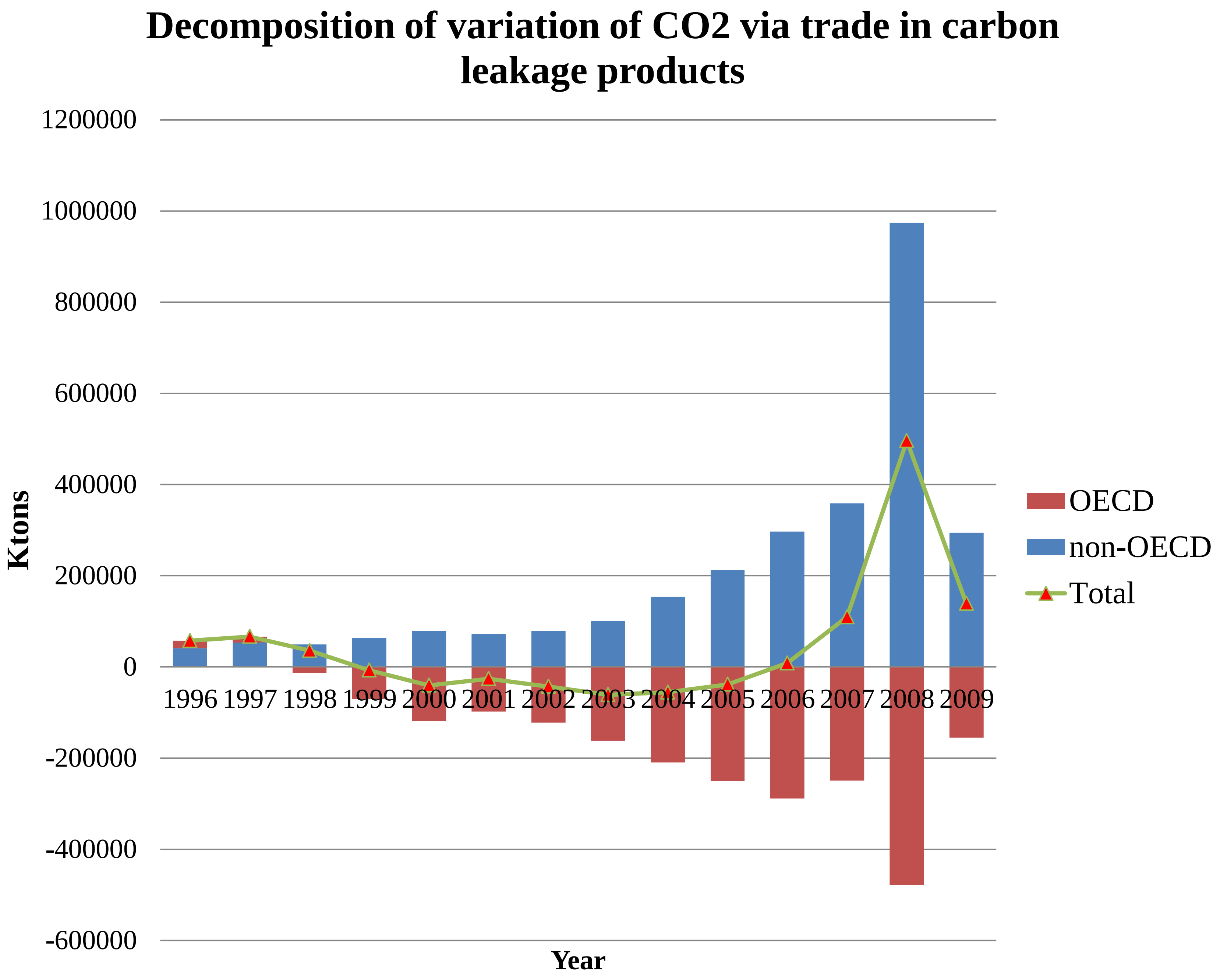
Symmetric countries, 2 sectors (H and L-carbon)

Table 3. Results with H- carbon and L-carbon sectors distinguished

	Spatial weight matrix adjusted by carbon efficiency	
	FE	RE
H Carbon trade	-0.0025***	-0.0028**
	-2.9252	-2.6025
L Carbon trade	-0.0043	-0.0033
	-1.2277	-0.8998
Ln(GDP per capital)	1.5720***	1.7098***
	7.6587	7.5625
Ln(GDP per capital)^2	-0.0549***	-0.0683***
	-4.2676	-5.0561
Ln(People density)	1.6900***	1.3545***
	12.1460	11.3636
Ln(environmental regulatory intensity)	-0.1654***	-0.1902***
	-4.1361	-4.6971
Constant	-3.9507***	-2.6106***
	-4.5901	-2.7473
R2	0.9978	0.5580



% CO2 transferred via trade carbon vs non carbone leakage
2
1.5
1
.5
0
-.5
1995
2000
2005
2010
time
CO2 variation
due to H carbon
trade
CO2 variation
due to L
carbon trade
co2_trade_c_non_carbon_world_p
co2_trade_c_carbon_world_p



Decomposition of variation of CO2 via trade in carbon leakage products
1200000
1000000
800000
600000
400000
200000
0
-200000
-400000
-600000
Ktons
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Year
OECD
non-OECD
Total

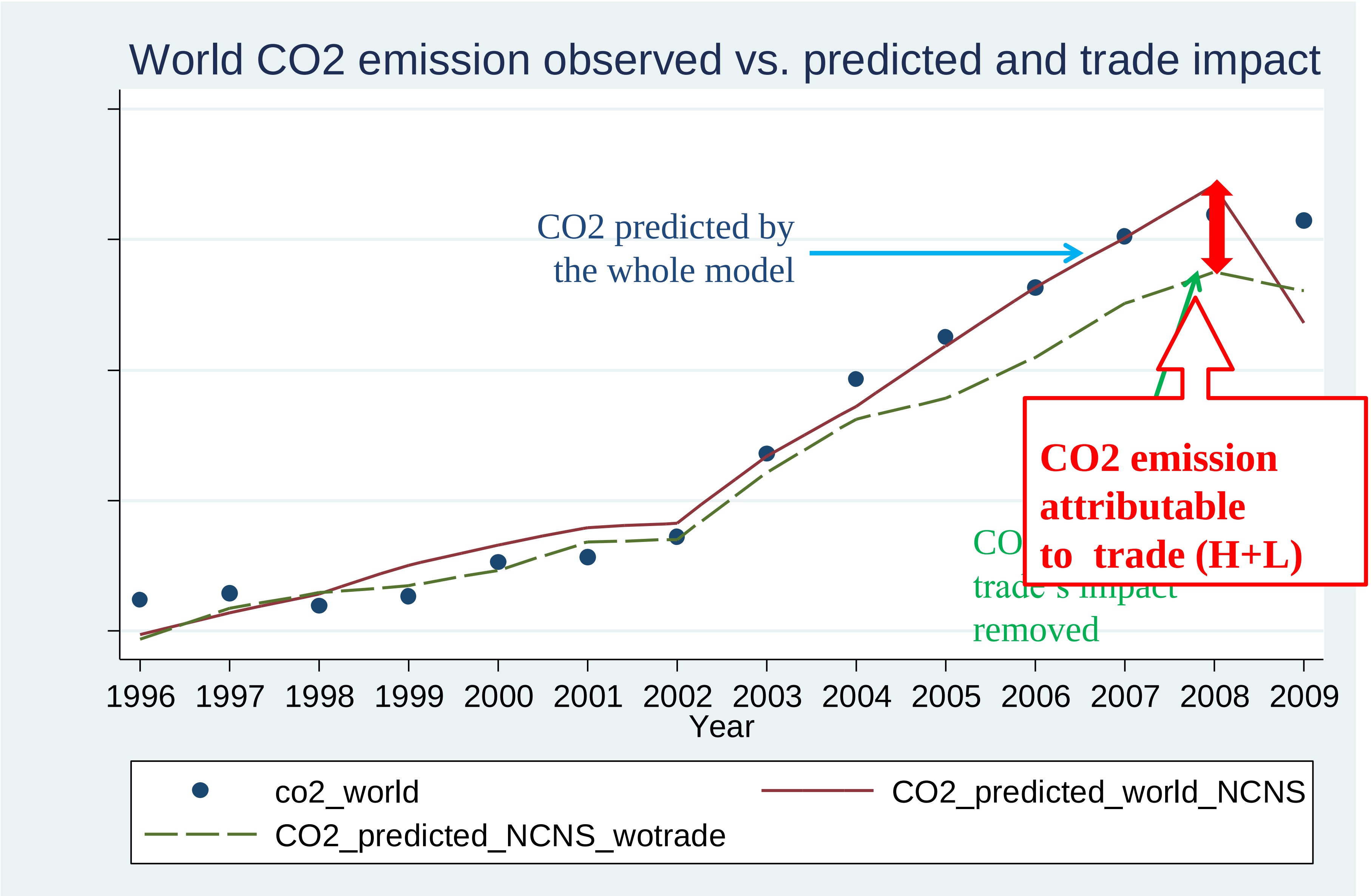
Preliminary Results

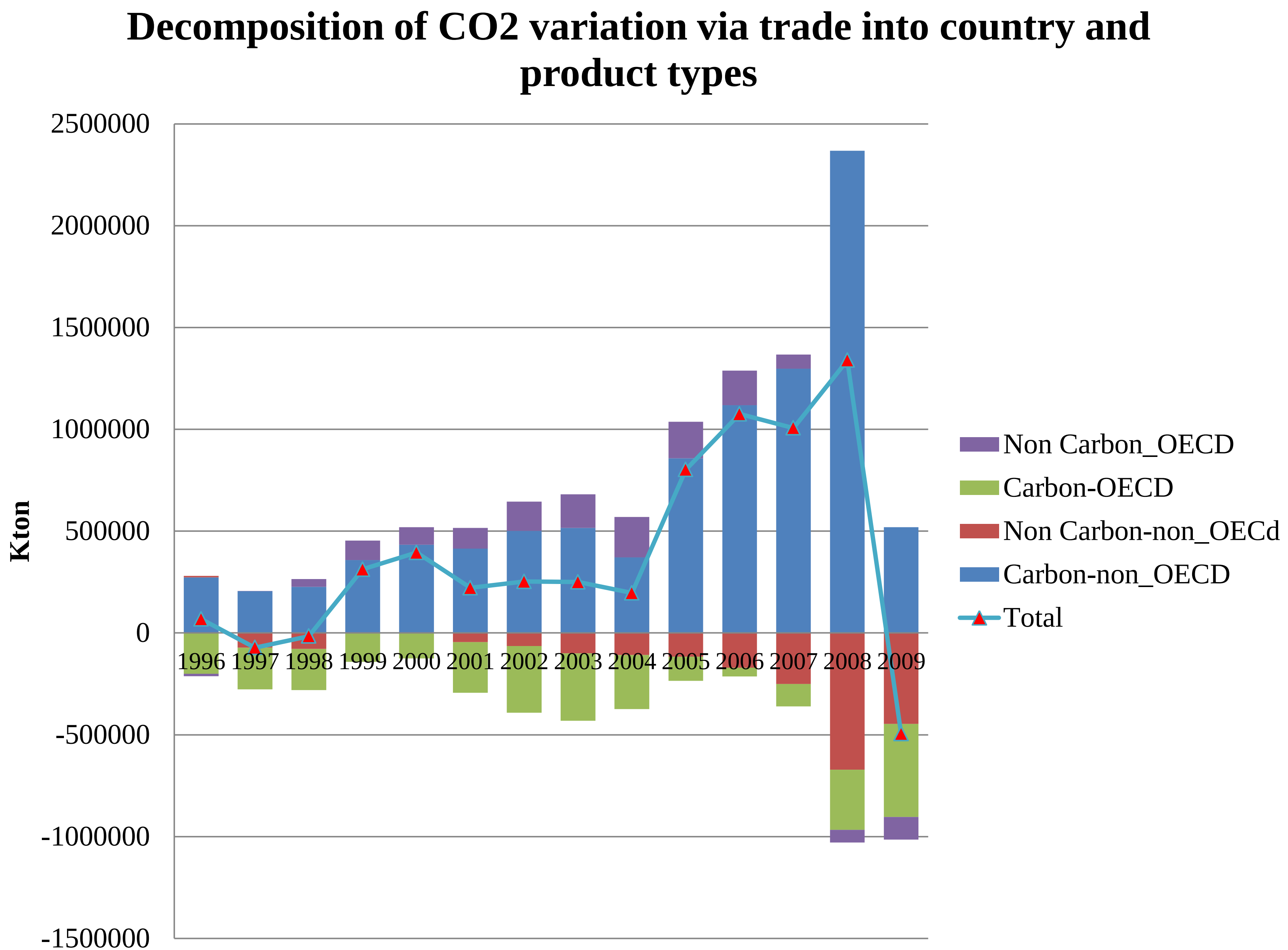
2- country groupings (N,S) and two product categories (H,L-carbon intensity)

Table 4. results with trade block and H-L carbon trade distinguished

	Spatial weight matrix adjusted by carbon efficiency	
	FE	RE
H Carbon Non OECD inside trade	0.0346	0.0353
	1.62	1.18
H Carbon Import by Non OECD from OECD	-0.0497**	-0.0680**
	-2.24	-2.27
H Carbon Import by OECD from Non OECD	0.0096**	-0.0156**
	2.26	-2.02
H Carbon OECD inside trade	-0.0171**	0.0435**
	-2.53	2.35
L Carbon Non OECD inside trade	0.0164	-0.0233
	0.39	-0.64
L Carbon Import from OECD to Non OECD	-0.0395	-0.0377
	-1.20	-0.91
L Carbon Import from Non OECD to OECD	0.0050	0.0242
	0.40	0.85
L Carbon OECD inside trade	0.0161	-0.0268
	1.54	-1.34
Ln(GDP per capital)	1.72***	1.69***
	7.53	13.22
Ln(GDP per capital)^2	-0.06***	-0.07***
	-4.81	-10.58

World CO2 emission observed vs predicted by model with 8 trade matrix (table 4, fixed effect)





Decomposition of CO2 variation via trade into country and product types
2500000
2000000
1500000
1000000
500000
0
-500000
-1000000
-1500000
Kton
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Non Carbon_OECD
Carbon-OECD
Non Carbon-non_OECd
Carbon-non_OECD
Total

Summary so far

- Carbon is exported by non OECD countries towards OECD countries
- Increases in virtual trade in carbon due to participation in trade of countries with lower carbon emission efficiency
- Role of trade on aggregate carbon emissions increases with time
- Some evidence of pollution havens especially in carbon leakage risk products' trade activities.
- Trade in carbon intensive products is responsible for most of the virtual carbon increase caused by trade.
- Incorporating product-level carbon intensity (Sato 2014) will give more accurate results than OECD (arbitrary) classification of 84 carbon intensive products.
- Simple OECD /Non OECD is misleading when discussing environmental trade policy for carbon intensive activities.

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Illustrative example of virtual trade in carbon

Evolution of carbon content of trade is an indirect (and partial) measure of carbon leakage as evolution is also dependent on other “fundamental” aspects comparative advantage that are independent of trade.

2-good 2-country example: North (N) & South (S) produce a clean and a dirty good with same endowments and same emissions per unit of output for dirty good.

- With stricter environmental stds in North: North trade will be embodied with emissions (i.e. $PCI_{NS} > 0$) while : ($PCI_{SN} = 0$) since it imports clean good.
- Globalization via reduction in transport costs or reduction in trade barriers will lead S to specialize in dirty products according to PH effect. Same results from environmental stds. tightening in N.
- Now assume that dirty industries are k-intensive. Then FE effect could determine comparative advantage even with stricter environmental stds. in N. Trade liberalization would then lead to relocation to dirty industry to N.
- In this framework, PHH holds if PH effect dominates FE effect in absolute value (see Grether et al. JITD 2012)