General Equilibrium Assessment of Environmental Policies: Reconciling Spatial Granularity With Economy Wide Scale

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* Joint research with Minqiang (Kent) Zhao of Wang Yanan Institute for Studies in Economics (WISE), Xiamen University; a paper will be available shortly. Contact me if you are interested at kerry.smith@asu.edu.

My Objectives

- Convince you a general equilibrium perspective for large scale environmental policy analysis is essential
- Admit I have been giving presentations on this topic for over 25 years and have to date *failed* to convince anyone (except perhaps my wife) –so it is incumbent on me to explain a few of the very good questions raised
- Propose a new strategy, illustrate it, and outline how it can be used; of course this raises some of the questions

Thank You!!

- Danish Environmental Economics Council and Thomas Bue Bjørner for inviting me and arranging activities so nicely
- My co-author for this research– Minqiang (Kent) Zhao of Wang Yanan Institute for Studies in Economics (WISE), Xiamen University
- Europe – Michael Holland, EMRC; Mayeres Inge, Vito; and Bert Saveyn, JRC.
- US – Mary Evans, Claremont Mc Kenna; Wayne Gray, Clark Univ.; David Mintz U.S. EPA; Dan Phaneuf, Univ. of Wisconsin; and John Reilly, MIT.

Why is a GE Perspective Important? - I

PE Examples

Example 1: In April 2015, the WHO reported the findings of an OECD study estimating air pollution costs Europeans $1.6 trillion U.S. dollars a year (estimated for 2010). For the EU it was $1.48 trillion – **about 8% of GDP**.

Example 2: In 2011 the U.S. EPA estimated the 1990 Clean Air Act saved the U.S. population $1.3 trillion dollars (in 2010) – **about 8.7% of GDP.**

What are the Changes in Pollution Underlying These Measures?

WHO / OECD (2005)

	Theoretical Minimum	2005	% Change
PM 2.5	5.8 – 8.8 ug/m³	16	54.4

EPA Prospective (2011)

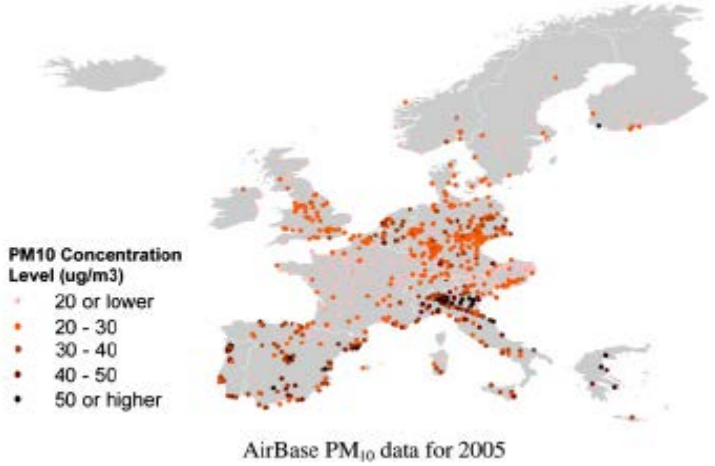
	Estimate With	Without	
PM10 (ug/m³)	25.73	55.02	53.20

Why is a GE Perspective Important? - II

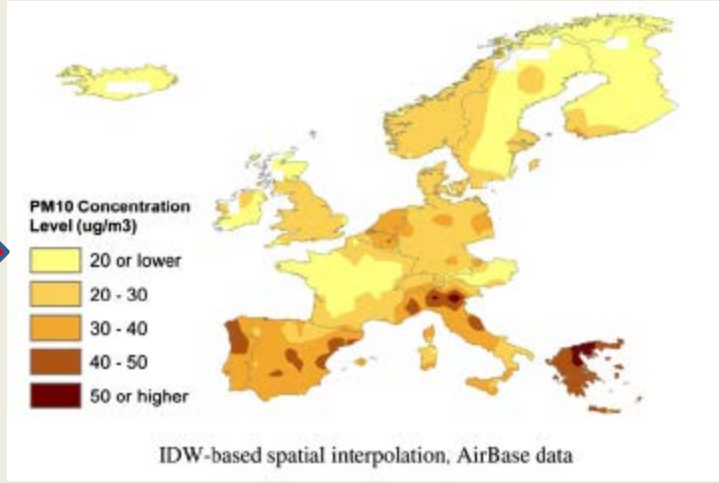
GE Examples

Example 1: In 2010 Nam, Sein, Reilly and Paltev (Energy Policy) estimated the burden of air pollution for the EU between 1970 and 2005 was between $336 and $429 billion U.S. dollars per year. About 3% GDP in 2005.

Some Details of MIT EPPA-HE GE Analysis



AirBase PM_{10} data for 2005



IDW-based spatial interpolation, AirBase data

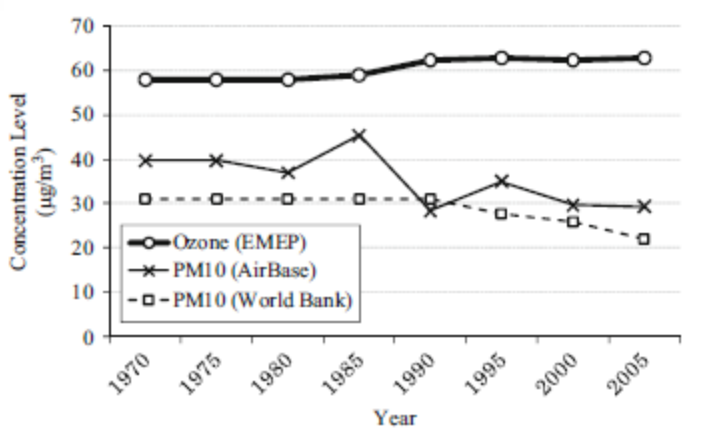
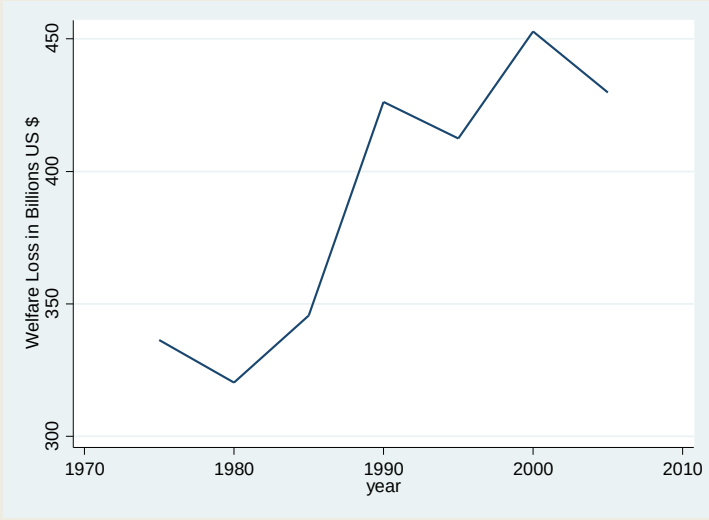


Fig. 5. Concentration levels of ozone and PM_{10}, EUR, 1970–2005. *Notes*: Here, the measurement standard for ozone is annual means of 8 h daily maximum, and that for PM_{10} is annual means of 24 h average.

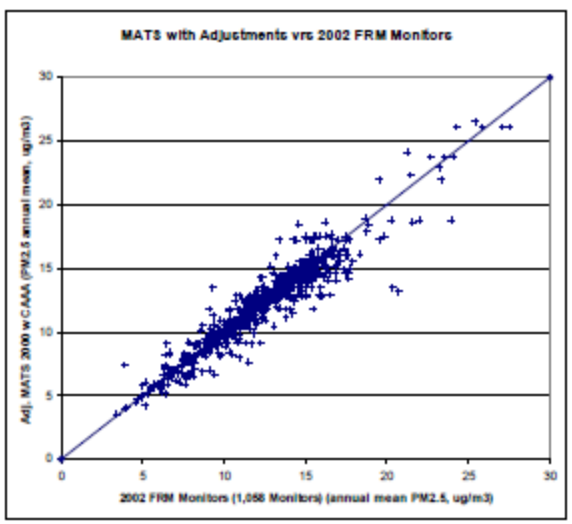


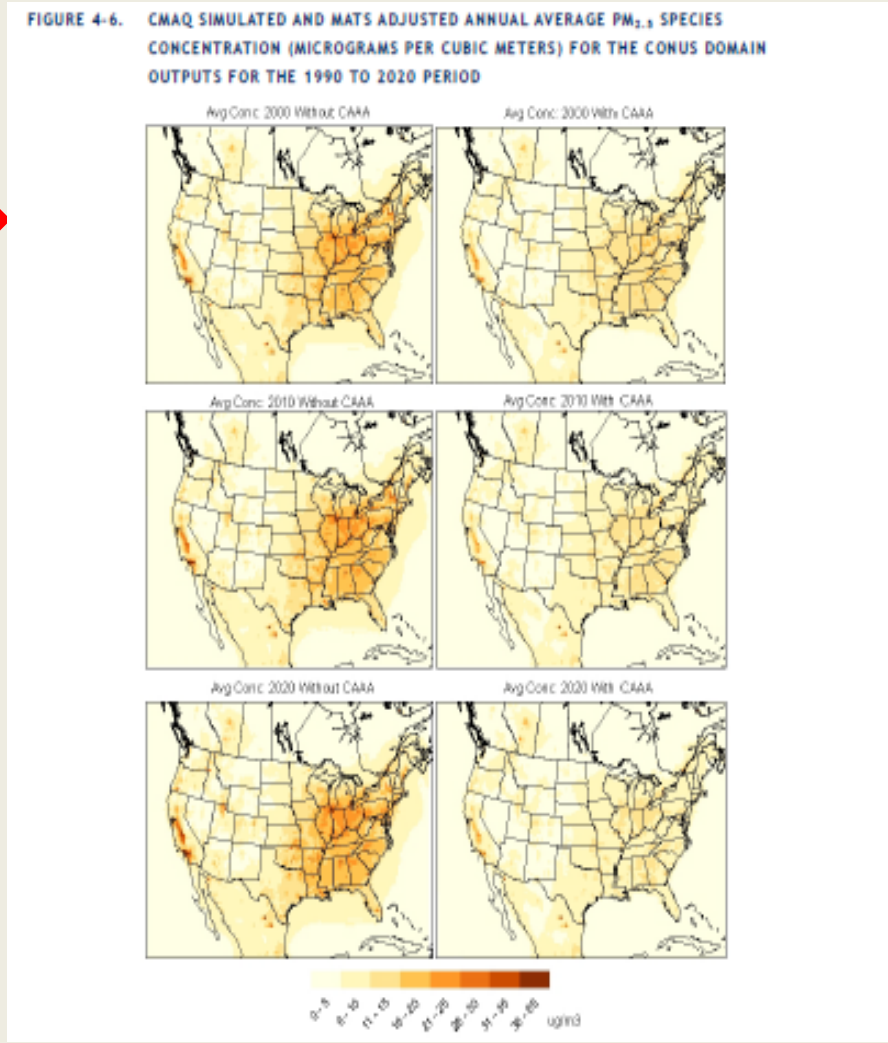
Why is a GE Perspective Important? - III

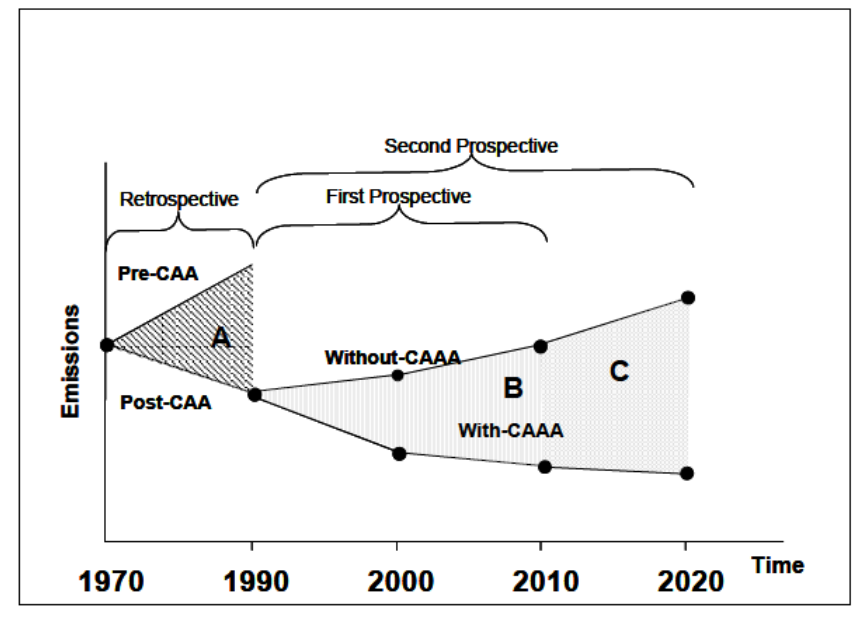
GE Examples

Example 2: Is also the EPA Second Prospective Study; this analysis estimates *both* PE and GE measures for the “same” air quality scenario; in the GE analysis, the1990 Clean Air Act was estimated to have saved the U.S. population $11 billion dollars (in 2010) – **about 0.07% of GDP.**

Some Details of the EMPAX GE Analysis







Summary of EMPAX – CGE Analysis for CAAA (billions of 2006 dollars)

	Year	
Cost Only Analysis	**2010**	**2020**

Benefits and Costs – "Together" Analysis		
GDP with CAAA	15,027	20,202
GDP without CAAA	15,059	20,197
% change	-0.21%	0.02%
Hicksian EV	11	29
PE measure (Health 95%)	1,300	2,000
	(118.2)	(69.0)

Summary of EMPAX – CGE Analysis for CAAA (billions of 2006 dollars)

	Year	
Cost Only Analysis	**2010**	**2020**
GDP with CAAA	15,027	20,202
GDP without CAAA	15,106	20,312
% change	-0.52%	-0.54%
Hicksian EV (social cost negative)	54	75
PE cost measure	53	65
	(1.02)	(1.15)
Benefits and Costs – "Together" Analysis		
GDP with CAAA	15,027	20,202
GDP without CAAA	15,059	20,197
% change	-0.21%	0.02%
Hicksian EV	11	29
PE measure (Health 95%)	1,300	2,000
	(118.2)	(69.0)

CGE Models Share a Common Feature

Models

U.S.	EMPAX – CGE
World	MIT – EPPA – HE
Europe	GEM – E3

Common Feature:

NONE OF THE MODELS ACTUALLY INCLUDE CONVENTIONAL AIR POLLUTANTS

EFFECTS ARE INTRODUCED BASED ON EXTERNAL MEASURES OF ECONOMIC ACTIVITY(with what are referred to as “soft links”)

How Did We (Environmental Economists) Get In This Spot?

We are Victims of the Curse of the Circular Flow

Environmental Services are not treated as an integral part of economic processes with recognition of feedbacks

Knight and Samuelson's Legacy

Samuelson's text

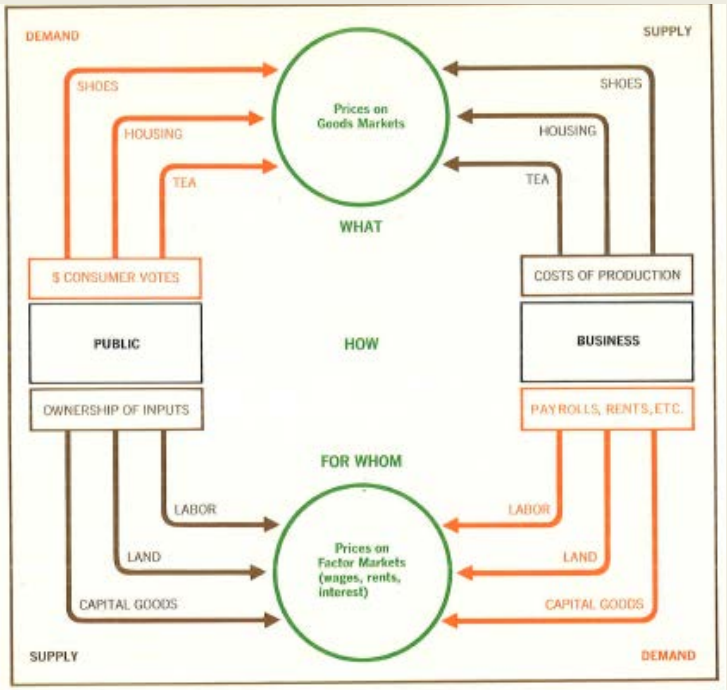
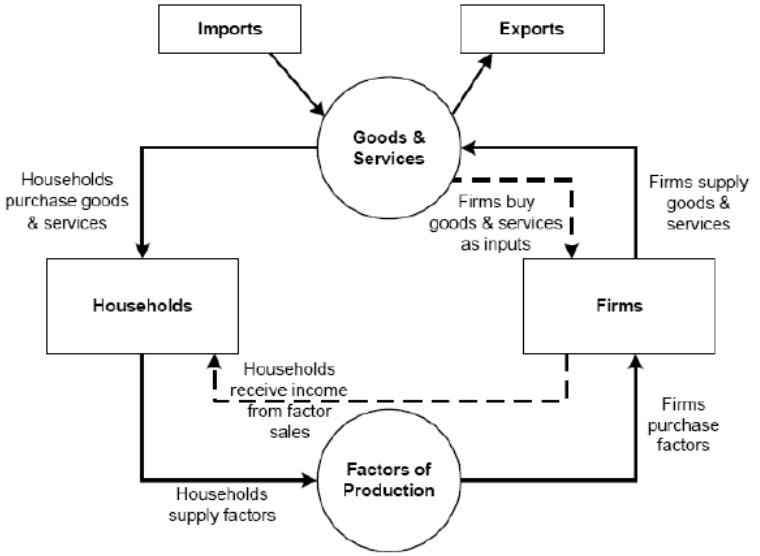


FIG. 3-1
The competitive price system uses supply-demand markets to solve the basic economic problems—WHAT, HOW, and FOR WHOM
All demand relations are shown in orange; all the supply relations, in brown. See how consumer-dollar votes of demand interact in the upper goods markets with business cost-supply decisions, thus helping determine WHAT is produced. And how business demand for inputs or productive factors meets the public's supply of labor and other inputs in the lower factor markets to help determine wage, rent, and interest income—i.e., FOR WHOM goods are produced. Business competition to buy factor inputs and sell goods most cheaply determines HOW goods are to be produced. (WARNING: All parts of the diagram interact together. WHAT depends on the lower part, just as FOR WHOM depends on the upper part—carpenter wages depend on housing demand, and demand for yachts depends on oil-land royalties.)

Outline of EPA's EMPAX CGE Model

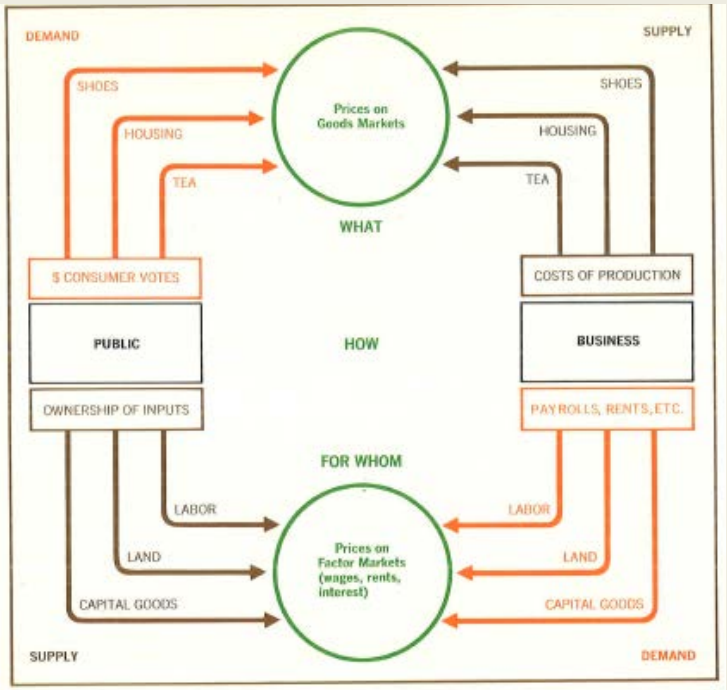
FIGURE 8-1. CGE MODEL SCHEMATIC



Source: RTI International, EMPAX-CGE Model Documentation, prepared for U.S. EPA Office of Air Quality Planning and Standards, March 2008.

Is it a Curse for Environmental Economists?

Samuelson's text



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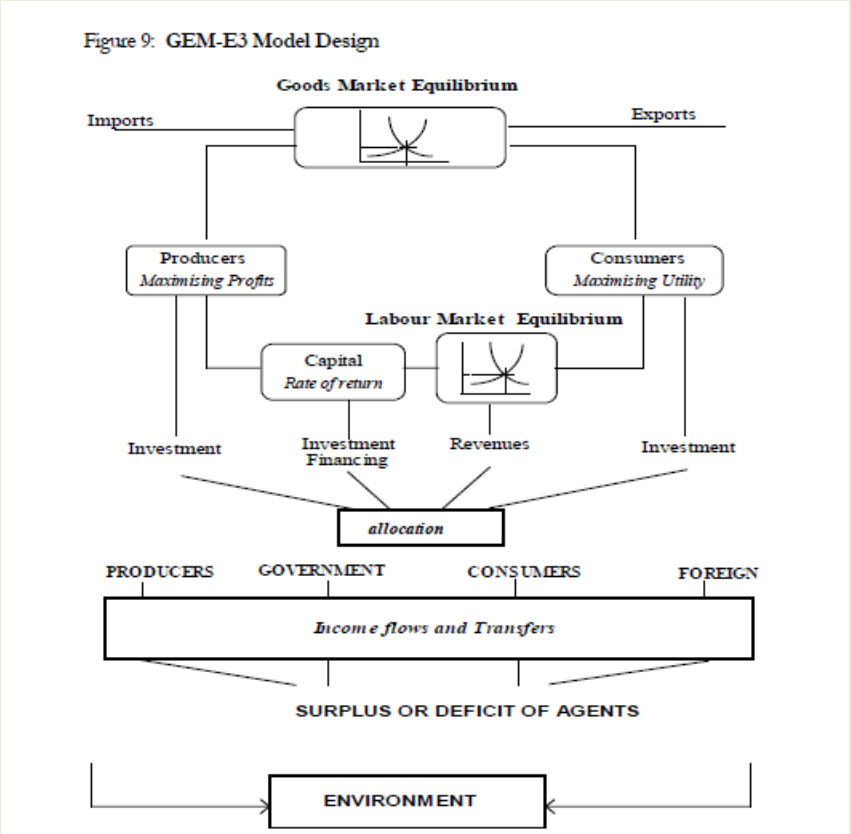
Outline of GEM-E3 CGE Model



Circular Flow is not going away anytime soon!

Charles Hulten, leading economist in design and evaluation of national income accounting systems, noted in an NBER volume on future challenges that:

> *“Moving current accounting practices forward, the CFM (circular flow model) structure should be a central goal of the field of national income and wealth accounting.”(Hulten (2006)* P. 213)

What Have My Students, Post-docs, and I tried to do?

- Use existing CGE models and include non-market environmental services into the household's preferences *in a non-separable way*
- *Results* –incorporating them **definitely** affects outcomes in important ways – **BUT** our conclusions depend on what we assume about substitution or complementarity between environmental services and market goods (or services) and leisure

To Understand Why We Need to go Back to Construction of a Typical CGE

Figure 1. Social Accounting Matrix

		INTERMEDIATE USE by Production Sectors				FINAL USE				OUT-PUT
		1	2	...j...	n	Private Consump.	Government Consumption	Investment	Export	
Domestic Production	1 2 : i : n	A				B				C
Imports	1 2 : i : n	D				E				F
Value added:	-labor -capital - natural resources	G				H				I
INPUT		J								

Figure 2. Expanded SAM for health effects.

		INTERMEDIATE USE by Production Sectors				*Household Services*		FINAL USE				OUT-PUT
		1	2	...j...	n	*Mitigation of Pollution Health Effects*	*Labor-Leisure Choice*	Private consum.	Gov't consum.	Invest.	Export	
Domestic Production	1 2 : i : ***Medical Services for Health Pollution*** n	A				***Medical Services***		***Health Services***	B			C
Imports	1 2 : i : n	D						E				F
Leisure							***Leisure***	***Leisure***				
Value added:	-labor -capital - natural resources	G				***Labor***	***Labor***	***Labor***	H			I
INPUT		J										

Added components are in bold italic.

Source: Sergey Paltsev and John Reilly “Incorporating Climate Change Feedbacks into a General Economic Equilibrium Model Joint Program on the Science and Policy of Global Change Massachusetts Institute of Technology, Cambridge, MA 02139, USA

What's Wrong with This Strategy?

- Seeks to reproduce the flows as levels of expenditures in the calibration
- Operate on unit simplex (normalize prices to unity) so expenditures in SAM are quantities.
- **Must assume substitution elasticities**
- Use Rutherford's algebraic "magic" with CES functions to link share parameters to baseline composition of expenditures in SAM.

Take a Page from Prescott's Playbook

- Isolate the key research questions
- Structure a parsimonious, economically consistent, model capable of addressing them
- Assure the model "matches" the data
- Assess what factors influence what we learn from stylized model

What is Different About this Approach?

- Simplify model so it is possible to use a few variables that can be defined in normalized form.
- Focus on conditions describing optimal choices, rather than levels.
- Use these conditions as moments – then we can ask what are *the changes in the model's parameters that are needed* in order to match these first order conditions?

Rogerson Model – Introduction - I

Step 1 – Modeling Assumptions for Basic Rogerson (JPE 2008) Model

(1) $U(C, 1-H) = \alpha_c \ln(C) + (1-\alpha_c)\ln(1-H)$

C = composite consumption

$1-H$ = leisure

(2) $C = (\alpha_G(G-\bar{G})^{\epsilon} + (1-\alpha_G)F(S,N)^{\epsilon})^{1/\epsilon}$

G = market goods

S = market services

N = non-market services or home production

$\sigma_{GF} = \frac{1}{1-\epsilon}$

Rogerson Model – Introduction - 2

(3) $$\mathrm{F}(S,N) = (\alpha_S S^{\eta} + (1-\alpha_S)N^{\eta})^{\frac{1}{\eta}}$$

$$\sigma_{SN} = \frac{1}{1-\eta}$$

Rogerson Model – Introduction - 3

Production Technologies

$G = A_G \cdot H_G$ (manufactured goods) $A_{Gt} = (1 + \gamma_G)^t$

$S = A_S H_S$ (services) $A_{St} = (1 + \gamma_S)^t$

$N = A_N H_N$ (home production, not traded) $A_{Nt} = (1 + \gamma_N)^t$

(A's are normalized to unity in base year,1950)

These assumptions determine relative prices. Normalize wage rates at unity in base year, then competitive prices for $G\ and\ S$ will be:

$$P_G = \frac{1}{A_G}$$

$$P_S = \frac{1}{A_S}$$

Rogerson Model – Introduction - 4

Budget Constraint

$$P_G \cdot G + P_S \cdot S = (1 - \tau)(H_G + H_S) + T$$

τ = income tax rate

T = transfer of taxes to household

($T = \tau \cdot (H_G + H_S)$, not recognized by consumer)

Rogerson Model – Introduction - 4

Time Constraint

$$H_G + H_S + H_N + H_L = 1$$

$$H = H_G + H_S + H_N$$

So

$$1 - H = H_L \text{ (leisure)}$$

Allow for labor productivity

Calibrate the Model Using Three Moments Describe Time Allocation Consistent with Market and Non-Market Incentives

- Household Services vs. Market Services
- Goods vs. Services
- Market Goods or Leisure
- Add Moment based on model's estimate of
  - economic tradeoff for reducing PM10 relative to aggregate wage compensation with and without feedbacks

Summary of the Modifications to Rogerson's Model

- Allocation condition between household services and markets yields link between H_N and H_S he uses to derive $A_N$from calibration; we use Duernecker and Herrendorf [2015] estimates for productivity of A_N (i.e. the estimate for γ_N).
- Update to 2005 so use 1950 and 2005.
- Add environmental services to non-market services.

$$F = \left[\alpha_S S^{\eta} + (1-\alpha_S)\left(\alpha_N N^{\varphi} + (1-\alpha_N)Q^{\varphi}\right)^{\frac{\eta}{\varphi}}\right]^{\frac{1}{\eta}}$$

- Add new moment

What are My Research Questions?

- Does the share we assign to the new moment matter for the “primitives” in describing the economy?
- Does Incorporation of Feedbacks (versus the “soft links”) affect the model’s description of the economy?
- Can Model Calibration “help” in gauging the plausibility of counterfactuals used to motivate policy?

Calibration Results

Results of Amended Rogerson Model			
Parameters	Base Model	Our Replication	2005 & include γ_N
Share of goods (α_G)	0.07	0.074	0.1
(market vs. services)			
Share of services (α_S)	0.46	0.46	0.47
(markets vs. home production)			
Share of consumption (α_C)	0.5	0.5	0.5
Share of home (α_N)	—	—	—
home vs. nature			
Elasticity of substitution markets vs. services	0.44	0.48	0.5
$\sigma_{GF} = {}^{1}/_{(1-\epsilon)}$			
Elasticity of substitution	1.82	1.82	1.82
$\sigma_{SN} = {}^{1}/_{(1-\eta)}$			
Elasticity of nature	—	—	—
$\sigma_{NQ} = {}^{1}/_{(1-\varphi)}$			
Subsistence market goods $\bar{G}$	0.035	0.039	0.032
Productivity			
Goods (γ_G)	2.48	2.48	2.48
Services (γ_S)	1.44	1.44	1.44
Household (γ_N)	—	—	0.07
			tau =.30

Introducing Environmental Quality: Do Feedbacks Matter?

Results of Amended Rogerson Model

	Feedback Included in Model			No Feedback in Model	
			Prospective		Prospective
Parameters	2005 & include γ_N	Q Share = .0295	Q share = .1747	Q Share = .0295	Q share = .1747
Share of goods (α_G)	0.1	0.25	0.47	0.99	0.98
(market vs. services)					
Share of services (α_S)	0.47	0.48	0.31	0.08	0.49
(markets vs. home production)					
Share of consumption (α_C)	0.5	0.57	0.62	0.72	0.58
Share of home (α_N)	—	0.99	0.64	0.3	0.99
home vs. nature					
Elasticity of substitution markets vs. services	0.5	0.17	0.28	0.23	0.01
$\sigma_{GF} = {}^{1}/_{(1-\epsilon)}$					
Elasticity of substitution	1.82	2.00	2.00	2.00	2.00
$\sigma_{SN} = {}^{1}/_{(1-\eta)}$					
Elasticity of nature	—	0.27	0.89	0.96	1.13
$\sigma_{NQ} = {}^{1}/_{(1-\varphi)}$					
Subsistence market goods $\bar{G}$	0.032	-0.07	-0.09	-0.13	-0.09
H_S Model/Data-1950		1.10	1.00	1.12	1.15
H_G Model/Data-1950		1.00	1.00	1.00	0.99
H_N Model/Data-1950		1.00	1.00	1.00	0.94
H_S Model/Data-2005		0.95	1.00	0.40	0.94
H_G Model/Data-2005		1.05	1.00	2.06	1.02
H_N Model/Data-2005		1.00	1.00	1.29	1.08
Q share 2005_Model/Data		1.22	1.00	50.23	0.001

My Research Questions - Some Preliminary Answers

1. Does Environmental Share Matter?
   - Only when increase by 5 to 6 times
   - Calibrate share, substitution and performance about same (except Q value share)
2. Do Feedbacks Matter?
   - **Definitely** – largest consideration
3. Can the Results of Model Calibration Help in Gauging Plausibility?
   - *Maybe* – process raises significant research questions about what we do in non-market valuation

Next Steps

1. Use the Model as Rogerson did for Europe.

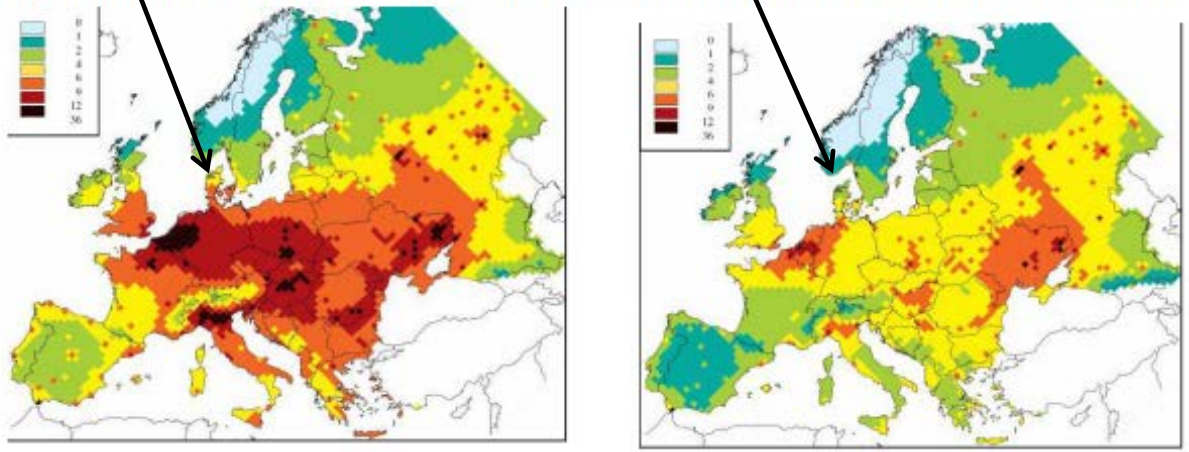
   As part of closing my discussion I selected Denmark.

   – Use Rogerson's assumptions for Denmark plus PM10 records and ask how does it compare to in terms of predicted air quality?
   – Does this offer an approximate bound for plausibility assessment of PE aggregate benefit measures?

Clean Air Policy Package: Example of Focus on Granularity

Denmark

Figure 3: Loss in life expectancy attributable to anthropogenic $PM_{2.5}$ in 2000 and 2020



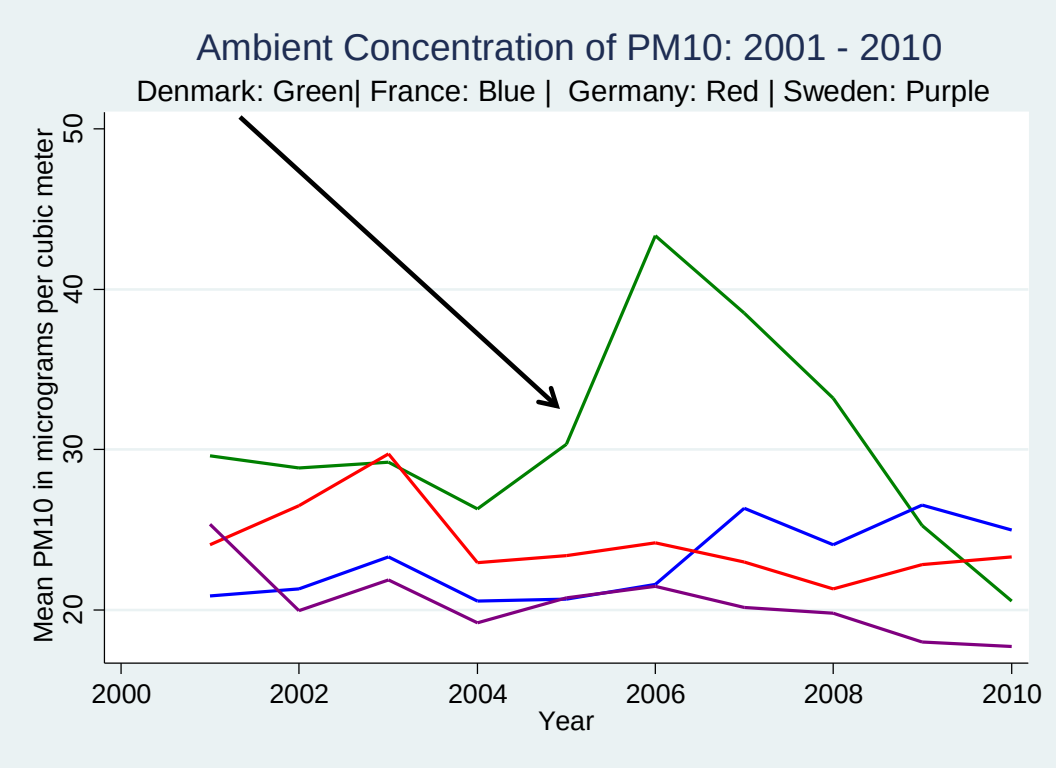
2000 **Baseline 2020**

Source: RAINS. Note: Calculation based on meteorological conditions of 1997.

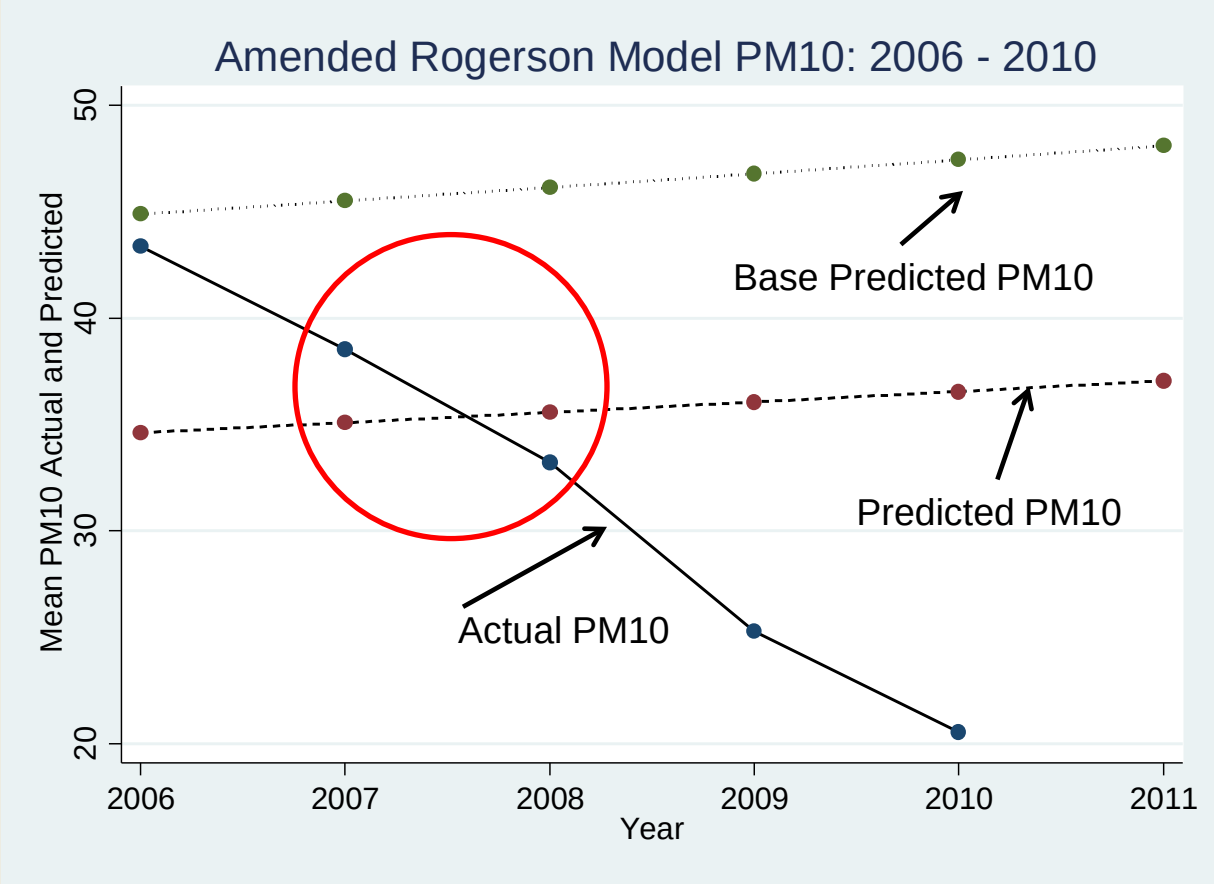
Assumptions

- Denmark's population is about 2%of US so scaling of benefits in Q share needs adjustment
- Air Quality policy is "Clean Air Policy Package" –scenario B1(25% improvement) and 0.2% increase in annual costs due to abatement
- Use Model calibrated for two value shares—low value and US Prospective with μ (the transfer coefficient) corresponding to conditions in Denmark

PM10 in Denmark versus Neighbors –Using AIRS Data Base

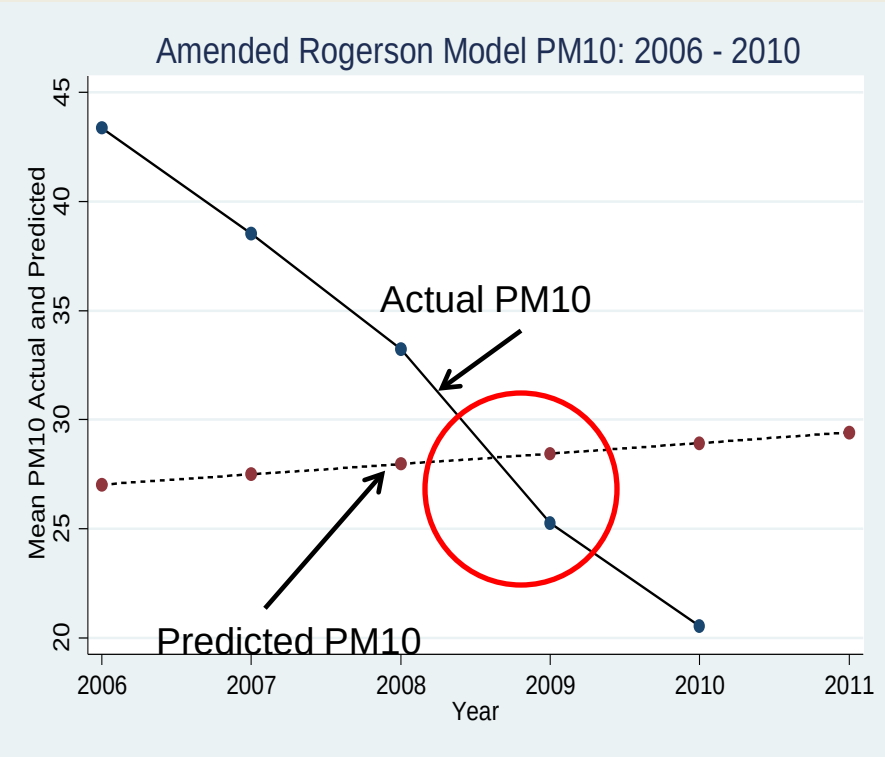


Model Results Using Q share =.175

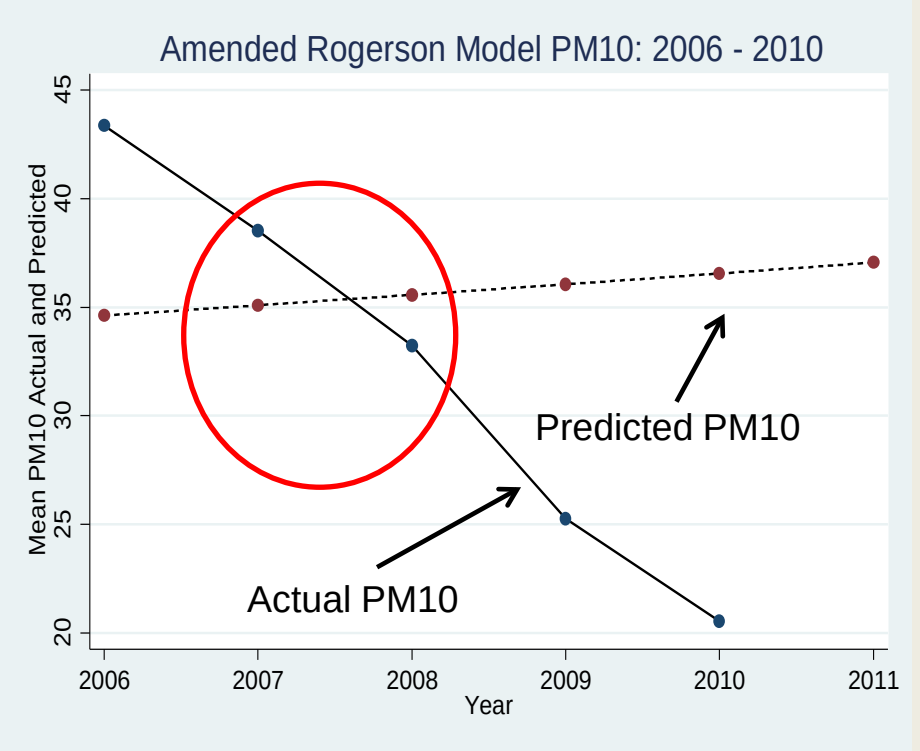


The Model with Different Q -Shares

Q share =.029



Q share = .175



Comparing the Model With EU Policy Evaluation – A "Quick and Dirty" Comparison

Variable	Q Share =.029	Q share=.175
PM10 - Policy Goal	25% reduction in PM10 Equivalents –(other pollutants-PM2.5,SO2)	25% reduction in PM10 Equivalents –(other pollutants-PM2.5,SO2)
Realized GE PM10 Reduction	23.4% reduction in PM10	22.9% reduction in PM10
Predicted Q - Share	0.050 of wage compensation	0.055 of wage compensation
Implicit Annual Aggregate Benefit Bound	145 million US dollars (2007 dollars)	167 million US dollars (2007 dollars)
Estimate of Denmark's Health Related Benefits in 2025 –B1 scenario	78 million US dollars (2007dollars)	

Next Steps

2. Can we use this strategy to gauge plausibility of “new” micro-oriented, highly granular policy evaluations?

- Q-Shares are put together as a patchwork of estimates; need to refocus non-market valuation
- Structure of Economy – for large rules, keeping it simple seems to make sense; for smaller or very focused, may make sense to target components differently – Clean Power Rule in US and the role of electricity.
- Measurement of Q – how should we convey the details introduced thru granularity and how should they be reflected in the valuation share