Climate Change and Structural Transformation

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Overview

- Climate change resulting from the emissions of greenhouse gases is an example of global externality.

- The design of policies to take into account of externalities should be based on the nature of the damages caused by externalities.

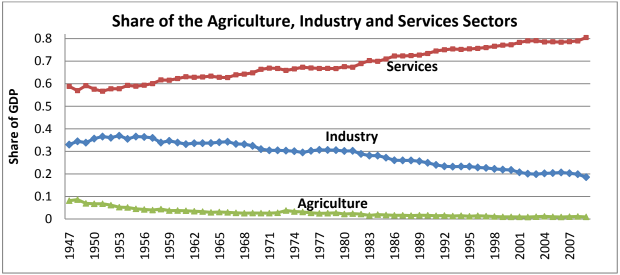
- Nordhaus' DICE/RICE models largely focus on physical damages, but ignore the feedback effect of damages in environmental amenities.

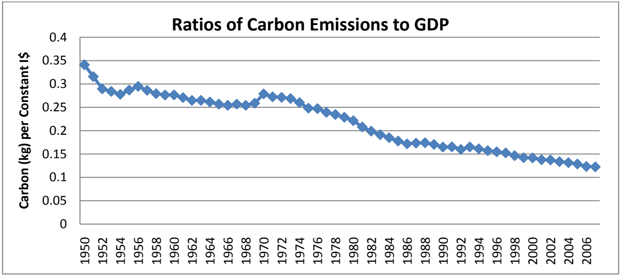
Overview

- Facts of both developed and developing countries cannot reconcile the CO2/Output path by abatement technologies and energy sources alone.

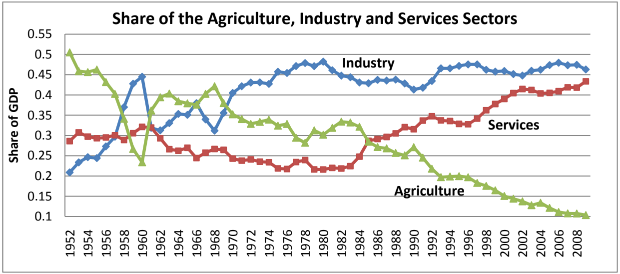
- We need consistent descriptions that integrate structural transformation with climate change models.

United States

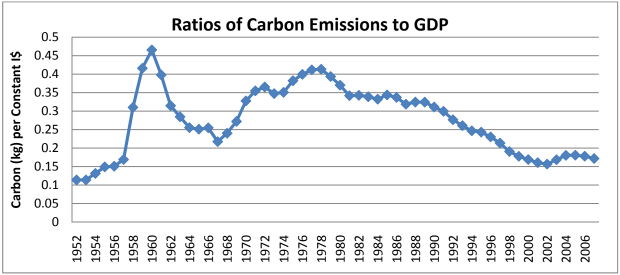




China

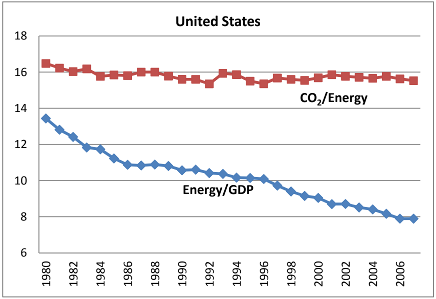


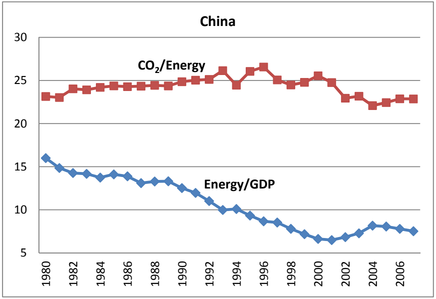
Share of the Agriculture, Industry and Services Sectors
Share of GDP
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
Industry
Services
Agriculture
1952 1954 1956 1958 1960 1962 1964 1966 1968 1970 1972 1974 1976 1978 1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008



Ratios of Carbon Emissions to GDP
Carbon (kg) per Constant I$
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1952 1954 1956 1958 1960 1962 1964 1966 1968 1970 1972 1974 1976 1978 1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006

Decomposition of CO_2/GDP

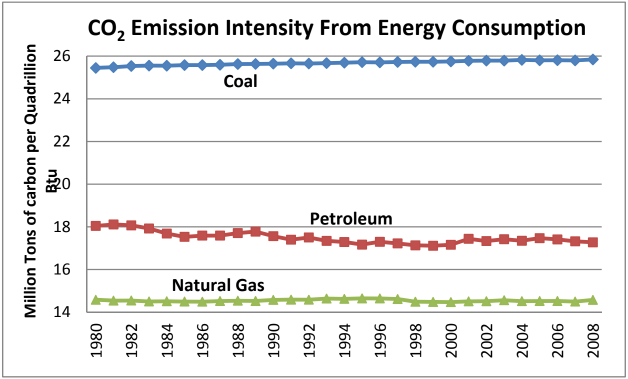




CO_2/Energy: metric ton of carbon per quadrillion Btu
Energy/GDP: quadrillion Btu per million of international dollar

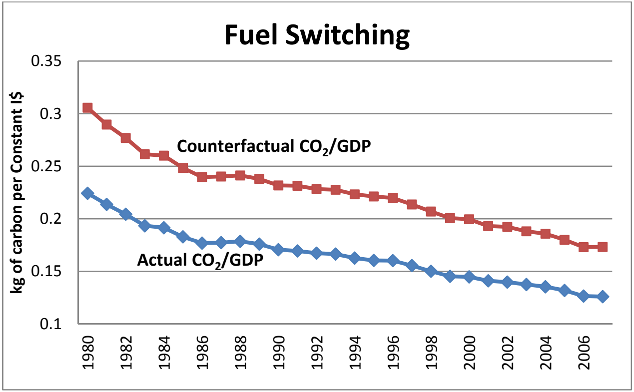
Counterfactual Experiment

Replace natural gas and petroleum levels during 1980-2007 with coal under the constraint of generating the same amount of energy.



Counterfactual Experiment

Replace natural gas and petroleum levels during 1980-2007 with coal under the constraint of generating the same amount of energy.



Simple Regression Analysis

$$Y_{ct} = \beta_1 A_{ct} + \beta_2 S_{ct} + D_c + D_t + e_{et}$$

Time period: 1960-2007

Y_{ct}: CO2/GDP ratio of country c at time t (1Kg carbon per constant international dollar)

A_{ct}: a dummy indicator for an agriculture-based economy

S_{ct}: a dummy indicator for a services-based economy

	Coef.	SE	P>|t|
A_{ct}	-0.0193	0.0029	0.000
S_{ct}	-0.0124	0.0022	0.000

This Paper

- Non-separable environmental amenities impacted by climate change are introduced into the preference functions to generate dynamic, non-market feedback effects

- Global warming is described in a framework that recognizes the role of the structural transformation of economic activities

- The analysis builds on Nordhaus' (2008) DICE/RICE structures so that it includes consistent treatment of the geophysical relationships linking the stock of greenhouse gases to the inter-temporal externalities associated with climate changes

Basic Model with Non-Separable Environmental Quality

Channels that Drive Structural Transformation

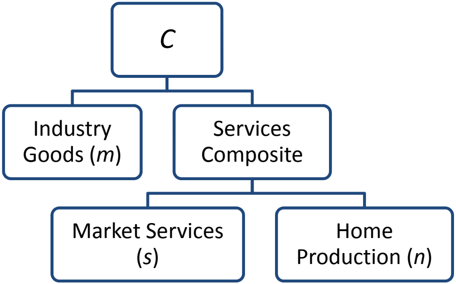
- Non-homothetic preference (e.g. Echevarria 1997, Laitner 2000, Caselli and Coleman II 2001, Kongsamut et al. 2001, Gollin et al. 2002, Gollin et al. 2007): requires some income elasticities $\neq 1$.

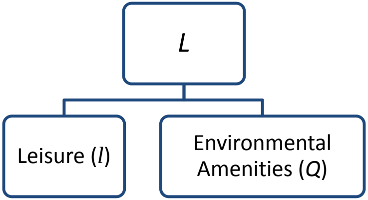
- Uneven productivity progress across sectors (e.g. Baumol 1967, Ngai and Pissarides 2007): requires substitution elasticities across goods $\neq 1$

Basic Model with Non-Separable Environmental Quality

Preferences

$$U(C,L) = \frac{\{C^{1-\nu}L^{\nu}\}^{1-\eta}}{1-\eta}$$





$$C = [\alpha_m (m - \boxed{\bar{m}})^{\chi} + (1-\alpha_m) F(s,n)^{\chi}]^{\frac{1}{\chi}}$$

$$F(s,n) = [\alpha_s s^{\varpi} + (1-\alpha_s) n^{\varpi}]^{\frac{1}{\varpi}}$$

$$L = [\alpha_l l^{\varphi} + (1-\alpha_l) Q^{\varphi}]^{\frac{1}{\varphi}}$$

Basic Model with Non-Separable Environmental Quality

Production Technology

- Industry Sector: $m = A_m h_m$
- Service Sector: $s = A_s h_s$
- Home Production: $n = A_n h_n$

Basic Model with Non-Separable Environmental Quality

Case One: Non-homothetic preference ($\overline{m} > 0$) and even productivity progress across sectors ($A = A_m = A_s = A_n$)

As A increases,

- h_n, h_s, $l \nearrow$; $h_m \searrow$
- $\frac{h_s}{h_m}$, $\frac{Q_s}{Q_m} \nearrow$; $\frac{P_s}{P_m} = 1$

As Q decreases,

- $0 < \varphi < 1$: (1) $l \nearrow$; (2) h_n, h_s, h_m, $\frac{h_s}{h_m} \searrow$
- $\varphi < 0$: (1) $l \searrow$; (2) h_n, h_s, h_m, $\frac{h_s}{h_m} \nearrow$
- $\varphi = 0$: no impacts

Basic Model with Non-Separable Environmental Quality

Case Two: Homothetic preference ($\overline{m} = 0$) and uneven productivity progress across sectors

As A_s and $\frac{A_m}{A_s}$ increase ($A_s = A_n$)

- $\frac{Q_s}{Q_m} \searrow$; $\frac{P_s}{P_m} \nearrow$
- $0 < \chi < 1$: h_s, $\frac{h_s}{h_m} \searrow$; $h_m \nearrow$
- $\chi < 0$: h_s, $\frac{h_s}{h_m} \nearrow$; $h_m \searrow$
- $\chi = 0$: no impacts

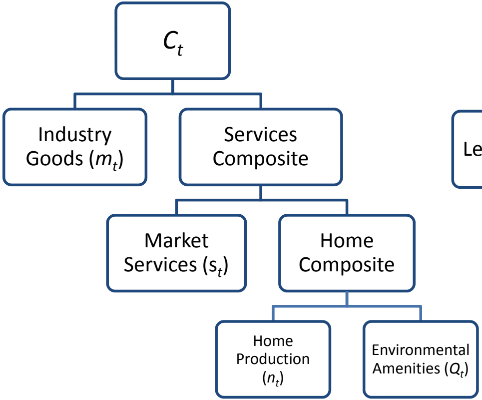
As Q decreases,

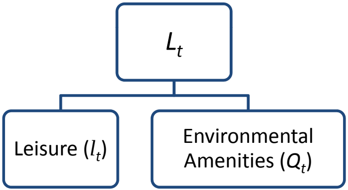
- $0 < \varphi < 1$: (1) $l \nearrow$; (2) h_n, h_s, $h_m \searrow$; (3) $\frac{h_s}{h_m}$, $\frac{Q_s}{Q_m}$ unchanged
- $\varphi < 0$: (1) $l \searrow$; (2) h_n, h_s, $h_m \nearrow$; (3) $\frac{h_s}{h_m}$, $\frac{Q_s}{Q_m}$ unchanged
- $\varphi = 0$: no impacts

Dynamic Model with Non-Separable Environmental Quality

Preferences

$$U(C_t, L_t, g_t) = \frac{\{C_t^{1-\nu} L_t^{\nu}\}^{1-\eta}}{1-\eta} + B(g_t)$$





$$C_t = [\alpha_m (m_t - \overline{m})^{\chi} + (1-\alpha_m) F(s_t, N_t)^{\chi}]^{\frac{1}{\chi}}$$

$$F(s_t, N_t) = [\alpha_s s_t^{\varpi} + (1-\alpha_s) N_t^{\varpi}]^{\frac{1}{\varpi}}$$

$$N_t = \left(\alpha_n n_t^{\mu} + (1-\alpha_n) Q_t^{\mu}\right)^{\frac{1}{\mu}}$$

$$L_t = [\alpha_l l_t^{\varphi} + (1-\alpha_l) Q_t^{\varphi}]^{\frac{1}{\varphi}}$$

$$B(g_t) = \begin{cases} \min\{g_t, \overline{g}\} & \text{if } g_t \geq \overline{g} \\ -\infty & \text{if } g_t < \overline{g} \end{cases}$$

Dynamic Model with Non-Separable Environmental Quality

A representative household maximizes

$$\sum_{t=0}^{\infty} \beta^t U(C_t, L_t, g_t)$$

$$s.t.$$

$$p_{mt} I_t + p_{mt} m_t + p_{st} s_t + p_{gt} g_t = w_t(1 - l_t - h_{nt}) + r_t(K_t - K_{nt})$$

$$K_{t+1} = (1-\delta) K_t + I_t$$

$$n_t = \Omega_n(T_{At}) A_{nt} K_{nt}^{\theta} h_{nt}^{1-\theta}$$

Dynamic Model with Non-Separable Environmental Quality

Producers

- A representative firm in the industry sector maximizes

$$p_{mt}\Omega_m(T_{At})A_{mt}K_{mt}^{\theta_m}h_{mt}^{1-\theta_m}-r_tK_{mt}-w_th_{mt}$$

- A representative firm in the service sector maximizes

$$p_{st}\Omega_s(T_{At})A_{st}K_{st}^{\theta_s}h_{st}^{1-\theta_s}-r_tK_{st}-w_th_{st}$$

- A representative firm in the agriculture sector maximizes

$$P_{gt}\Omega_g(T_{At})A_{gt}h_{gt}-w_th_{st}$$

Dynamic Model with Non-Separable Environmental Quality

Geophysical Equations

- $$\begin{bmatrix} M_{At} \\ M_{Ut} \\ M_{Lt} \end{bmatrix} = \begin{bmatrix} \phi_{11} & \phi_{21} & 0 \\ 1-\phi_{11} & \phi_{22} & \phi_{32} \\ 0 & 1-\phi_{21}-\phi_{22} & 1-\phi_{32} \end{bmatrix} \begin{bmatrix} M_{A,t-1} \\ M_{U,t-1} \\ M_{L,t-1} \end{bmatrix} + \begin{bmatrix} E_{t-1} \\ 0 \\ 0 \end{bmatrix}$$
- $F_t = a_1 log_2(M_{At}/M_{A,1750}) + F_{EX,t}$
- $T_{At} = T_{A,t-1} + b_1 [(F_t - b_2 T_{A,t-1}) - b_3(T_{A,t-1} - T_{L,t-1})]$
- $T_{Lt} = T_{L,t-1} + b_4(T_{A,t-1} - T_{L,t-1})$

Climate Damage Functions

- $\Omega_i(T_t) = \frac{1}{1+\pi_i(T_{At})}$, where $i \in \{g, m, s, n\}$

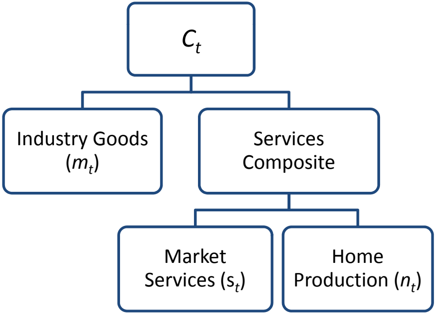
Calibration

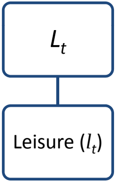
We calibrate each of the following models separately to match the features of the US economy during the period of 1951-2000:

- Model without Q: without non-separable environmental amenities in preferences.
- Model with LQ: allow leisure to interact with environmental amenities.
- Model with CQ: allow home services to interact with environmental amenities.

Calibration

Model without Q





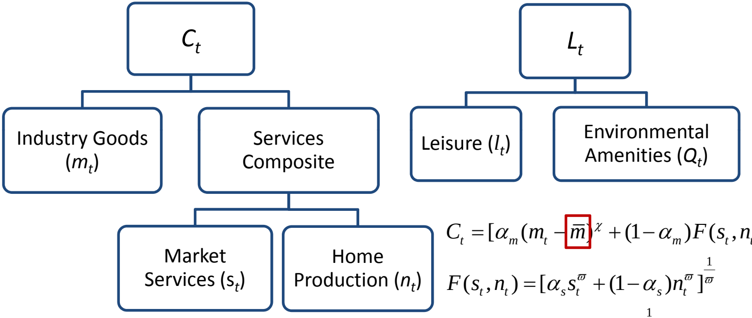
$$C_t = [\alpha_m (m_t - \boxed{\bar{m}})^{\chi} + (1-\alpha_m) F(s_t, n_t)^{\chi}]^{\frac{1}{\chi}}$$

$$F(s_t, n_t) = [\alpha_s s_t^{\varpi} + (1-\alpha_s) n_t^{\varpi}]^{\frac{1}{\varpi}}$$

$$L_t = l_t$$

$$B(g_t) = \begin{cases} \min\{g_t, \bar{g}\} & \text{if } g_t \geq \bar{g} \\ -\infty & \text{if } g_t < \bar{g} \end{cases}$$

Model with LQ



$$C_t = [\alpha_m (m_t - \bar{m})^{\chi} + (1-\alpha_m) F(s_t, n_t)^{\chi}]^{\frac{1}{\chi}}$$

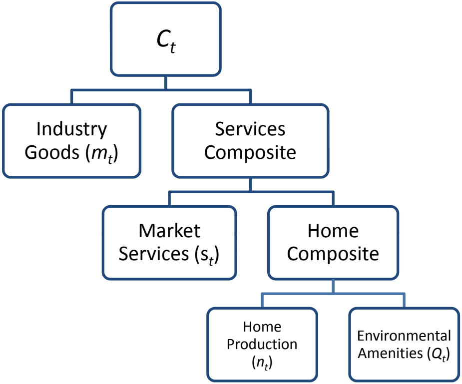
$$F(s_t, n_t) = [\alpha_s s_t^{\varpi} + (1-\alpha_s) n_t^{\varpi}]^{\frac{1}{\varpi}}$$

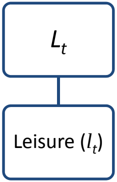
$$L_t = [\alpha_l l_t^{\varphi} + (1-\alpha_l) Q_t^{\varphi}]^{\frac{1}{\varphi}}$$

$$B(g_t) = \begin{cases} \min\{g_t, \bar{g}\} & \text{if } g_t \geq \bar{g} \\ -\infty & \text{if } g_t < \bar{g} \end{cases}$$

Calibration

Model with CQ





$$C_t = [\alpha_m (m_t - \boxed{\bar{m}})^{\chi} + (1-\alpha_m) F(s_t, N_t)^{\chi}]^{\frac{1}{\chi}}$$

$$F(s_t, N_t) = [\alpha_s s_t^{\varpi} + (1-\alpha_s) N_t^{\varpi}]^{\frac{1}{\varpi}}$$

$$N_t = \left(\alpha_n n_t^{\mu} + (1-\alpha_n) Q_t^{\mu}\right)^{\frac{1}{\mu}}$$

$$L_t = l_t$$

$$B(g_t) = \begin{cases} \min\{g_t, \bar{g}\} & \text{if } g_t \geq \bar{g} \\ -\infty & \text{if } g_t < \bar{g} \end{cases}$$

Calibration

- Climate Damage Functions
  - Schlenker and Roberts (2009): Under B1 (A1FI) warming scenario, average crop yields drop by about 30-46% (63-82%)
    $\Omega_g(T_{At}) = \frac{1}{1+0.1101 T_{At}+0.0174(T_{At})^2}$
  - 2010 DICE
    $\Omega_i(T_{At}) = \frac{1}{1+0.001414(T_{At})^2}, i \in \{m, s, n\}$

- Geophysical Equations
  - M_{A0}, M_{U0}, M_{L0}, T_{A0} and T_{L0}
  - $E_{US,t} = \vartheta \cdot \xi_t \cdot A_{mt} K_{mt}^{\theta_m} h_{mt}^{1-\theta_m}$
  - Carbon emissions from elsewhere: 2010 RICE model (baseline run)

Calibration

- Environmental Amenities
  $Q(T_{At}) = \frac{1}{1+T_{At}}$

- Production and Preference Functions
  - Employment Shares

	Agriculture	Industry	Services	Home Production
1951-1960	0.0198	0.101	0.188	0.301
1991-2000	0.0073	0.084	0.266	0.269

Calibration

- Production and Preference Functions
  - The elasticity of substitution between leisure and environmental quality ($\frac{1}{1-\varphi}$) and the elasticity of substitution between home produced goods and environmental quality ($\frac{1}{1-\mu}$)

Global Carbon Emssion Reduction (2010-2050)	85%	60%	30%
Temperature Increase	2^{o}F	3^{o}F	4^{o}F
WTP (share of income)	0.011	0.008	0.005

Source: Carlsson et al. (2010)

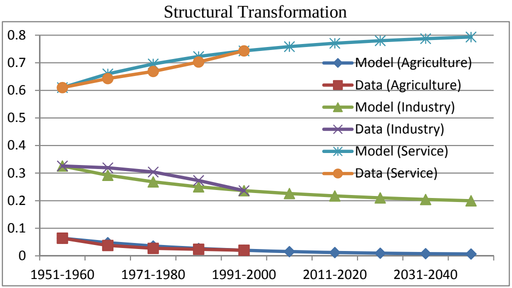
  - The model is also calibrated to match: average growth rates for real value added per hour in the industry and market service sectors, average capital-to-output ratio.

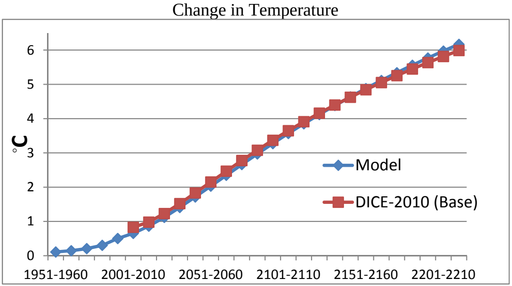
Model Predictions

- Atmospheric Carbon Stock

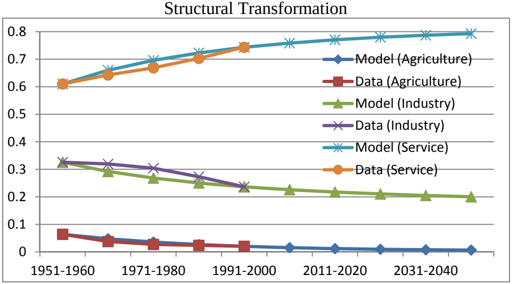
	1951 (targeted)	2011 (projected)
Data	662.50	834.04
Model without Q	662.50	859.71
Model with LQ	662.50	859.80
Model with CQ	662.50	859.02

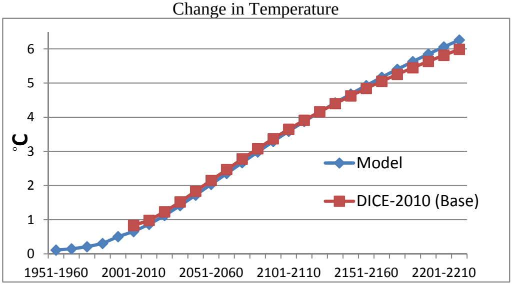
Model Predictions: Model without Q



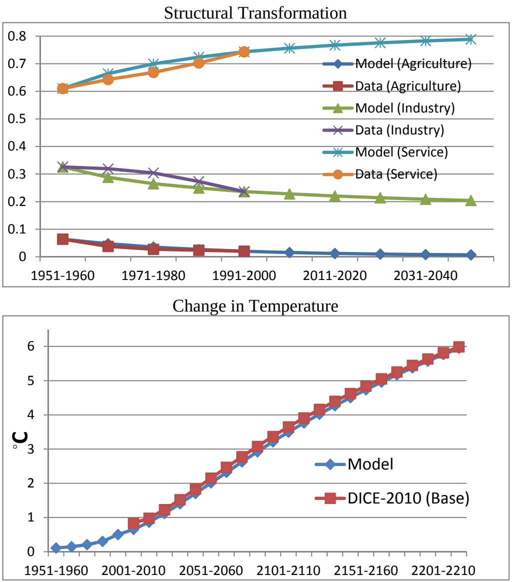


Model Predictions: Model with LQ





Model Predictions: Model with CQ



WTP

General Equilibrium

Reduction Rate	Model without Q	Model with LQ	Model with CQ
10%	0.022%	0.120%	0.351%
25%	0.055%	0.301%	0.907%
50%	0.105%	0.604%	1.935%
75%	0.149%	0.906%	3.145%
90%	0.171%	1.084%	4.013%

WTP

Partial Equilibrium

Reduction Rate	Model without Q	Model with LQ	Model with CQ
10%	0.010%	0.108%	0.374%
25%	0.026%	0.272%	0.904%
50%	0.051%	0.550%	1.953%
75%	0.074%	0.833%	3.215%
90%	0.087%	1.004%	4.132%

Impacts of Structural Transformation

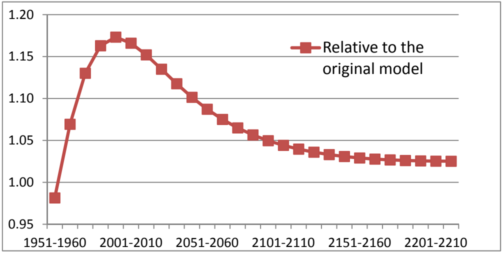
Experiment: fix the relative labor input of the industry sector to the market service sector at its initial level (1951-1960).

Wages will no longer be equalized between the industry and service sectors.

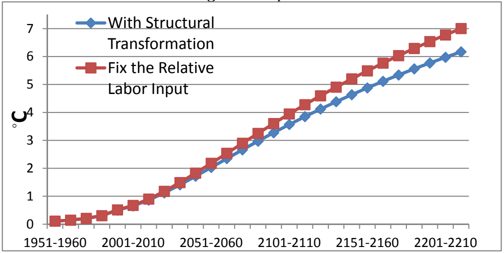
Impacts of Structural Transformation

Model without Q

CO$_2$/GDP

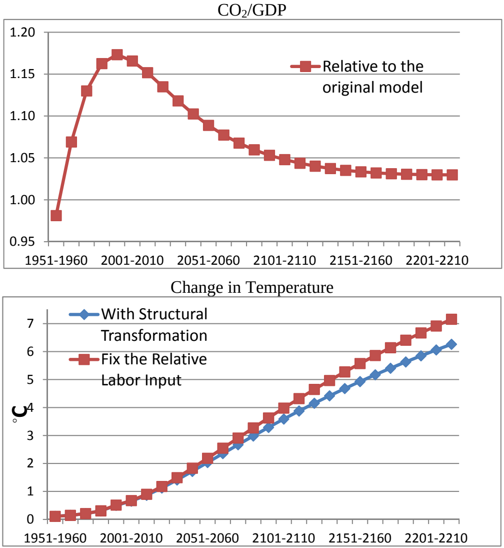


Change in Temperature



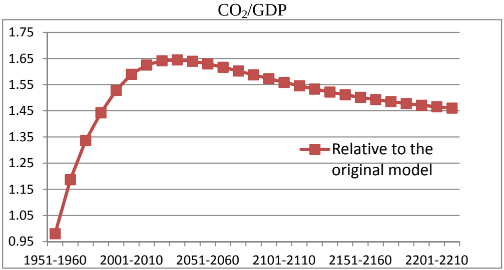
Impacts of Structural Transformation

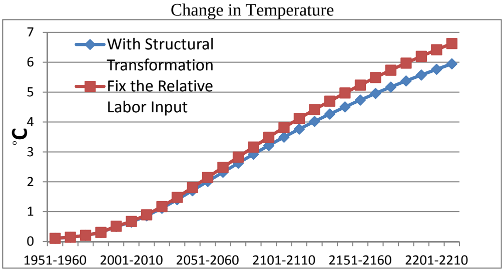
Model with LQ



Impacts of Structural Transformation

Model with CQ





Impacts of Structural Transformation

WTP (General Equilibrium)

With Structural Transformation

Reduction Rate	Model without Q	Model with LQ	Model with CQ
10%	0.022%	0.120%	0.351%
25%	0.055%	0.301%	0.907%
50%	0.105%	0.604%	1.935%
75%	0.149%	0.906%	3.145%
90%	0.171%	1.084%	4.013%

Fix the Relative Labor Input

Reduction Rate	Model without Q	Model with LQ	Model with CQ
10%	0.024%	0.128%	0.358%
25%	0.060%	0.321%	0.926%
50%	0.115%	0.645%	1.983%
75%	0.163%	0.971%	3.235%
90%	0.187%	1.164%	4.140%

Conclusion

- Improvements in abatement technology and the switch from high-carbon-content fuels to low-carbon-content fuels are not sufficient to explain the CO_2/output path.

- Structural transformations are part of the story in considering how carbon emissions evolve and influence climate changes.

- Introduction of non-separable environmental amenities into preferences can lead to large differences in the results derived in a Nordhaus-type structure for welfare analysis of climate-change policies.