The economics of climate change impacts on agriculture: ongoing work using Ricardian approaches

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1. Traditional Ricardian Method

- Land values reflect the long-term profitability of land uses (Mendelsohn, Nordhaus and Shaw 1994)
- Equilibrium relationship between climate and land values
- Regress land value on climate, soils, and economic control variables
- Captures adaptation by farmer though adaptation is a black box (not explicit)
- Structural Ricardian: adaptation options

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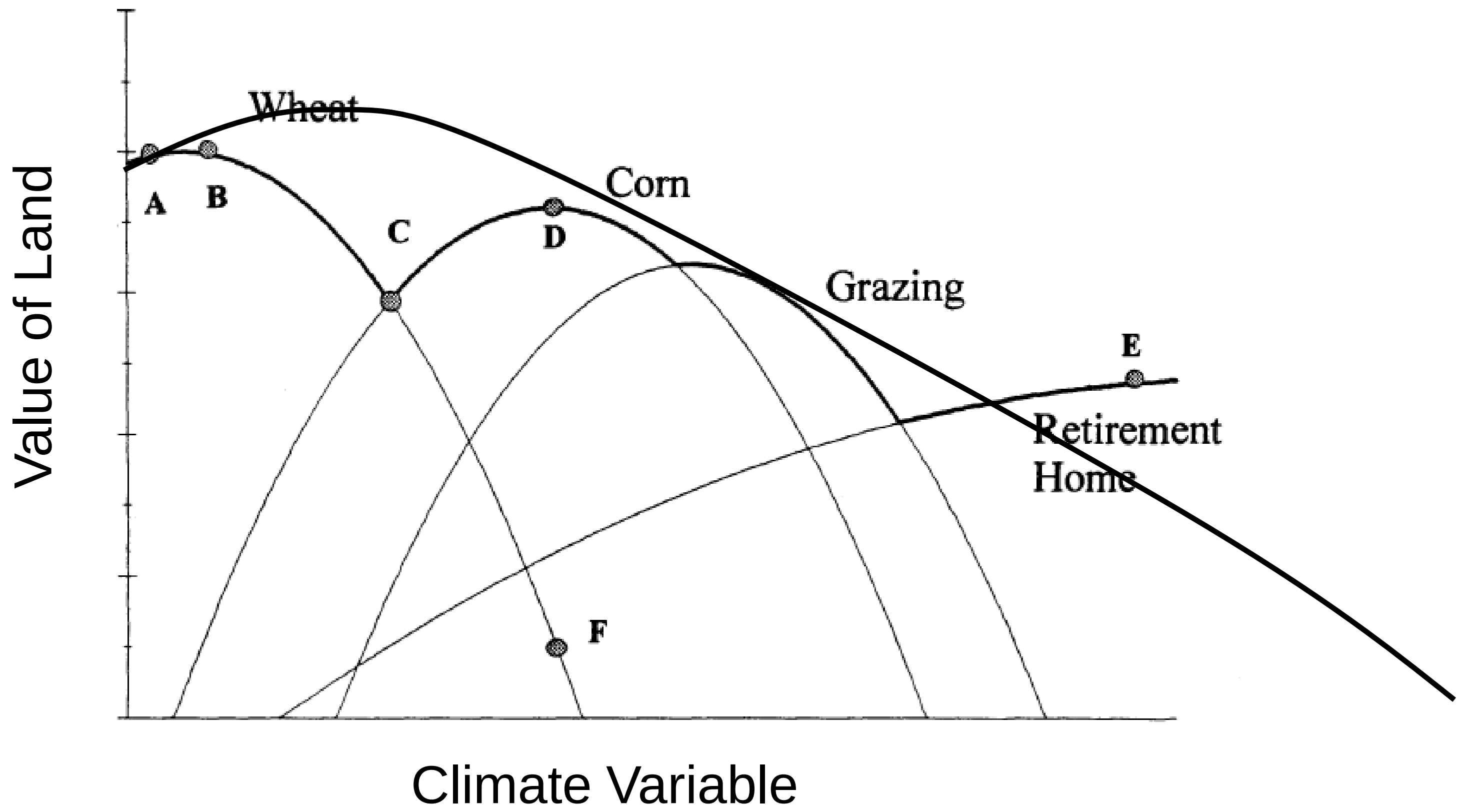
2. Land Value and Climate



Source: Mendelsohn, Nordhaus and Shaw (AER, 1994)

3. The Traditional Ricardian Model

- Land value:

$$V = \int \left[PQ\left(I,C,G,S\right) - R' I \right] e^{-\delta t} dt \qquad (1)$$

- Ricardian model:

$$V = f(\mathbf{X}, \mathbf{Z}, C) \qquad (2)$$

  - ***X*** time varying control variables
  - ***Z*** time invariant control variables
  - ***C*** climate variables

- Estimation:

$$V_i = X_i \boldsymbol{\beta} + Z_i \boldsymbol{\gamma} + C_i \varphi + u_i \qquad (3)$$

4. Climate Marginals and Impacts

- Typically quadratic climate surface, seasonal temperature and precipitations

- Climate marginals

$$dV_i / dC_{k,i} = \varphi_k + \varphi_{k-sq} C_{k,i} \quad (4)$$

- Aggregate welfare impact

$$W_t = \sum_i \left[V_{i,t}(C_1) - V_{i,t}(C_0) \right] F_{i,t} \quad (5)$$

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5. Ricardian Studies

- The technique has been applied to:
  - United States (MNS 1994; Wolfram Schlenker et al. 2005)
  - Africa (Pradeep Kurukulasuriya et al. 2006; Niggol Seo and Robert Mendelsohn 2008)
  - South America (Niggol Seo and Robert Mendelsohn 2008)
  - China (Jinxia Wang et al. 2008)
  - and several other countries around the world

- The results imply that moderate warming will tend to be good for temperate and polar countries but harmful for low latitude countries

6. Repeated Cross Section

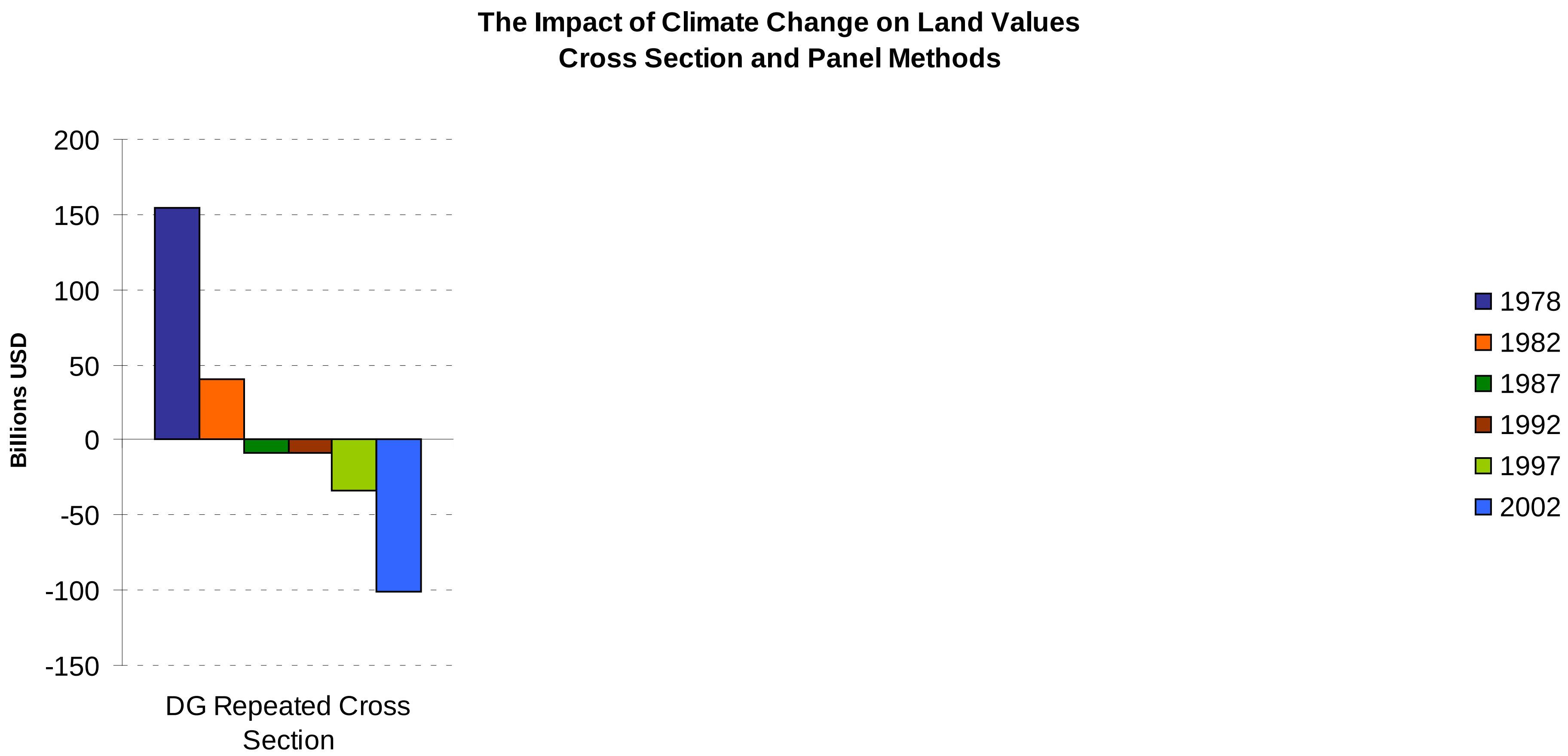
- Oliver Deschenes and Michael Greenstone (DG), AER 2007 recently extended the Ricardian method by applying it to panel data from the United States

- They conducted a series of cross sectional analyses for 1978, 1982, 1987, 1992, 1997, and 2002

$$V_{i,t} = X'_{i,t}\boldsymbol{\beta}_t + Z'_i\,\boldsymbol{\gamma}_t + C'_i\,\varphi_t + u_{i,t} \qquad (6)$$

- They report that the resulting welfare from each regression varied a great deal across time suggesting that the Ricardian method is not reliable

7. The Omitted Variable Problem



8. The DG Method

- DG propose to use a fixed-effect model:

$$P_{i,t} = \alpha_i + \lambda_t + X'_{i,t}\,\varphi_t + W'_{i,t}\,\boldsymbol{\beta}_t + u_{i,t} \tag{7}$$

- Focus on short term weather fluctuations

- Similar approach used also by Melissa Dell, Benjamin Jones, and Benjamin Olken to study the impact of climate change on economic growth (NBER Working Paper No. 14132, June 2008)

9. Towards a Panel Ricardian Method

- Ricardian Model with panel data

$$V_{i,t} = X'_{i,t}\boldsymbol{\beta} + Z'_{i}\boldsymbol{\gamma} + C'_{i}\varphi + u_{i,t} \qquad (8)$$

- Estimation
  - Pooled regression
  - Two-stages Hsiao model

10. The Two-Stages Hsiao Model

- First, land value is regressed on the time varying variables with county fixed effects:

$$V_{i,t} = X_{i,t}^{'}\boldsymbol{\beta} + \mathbf{e}\alpha_i + \varepsilon_{i,t} \qquad (9)$$

- where **e** is a vector of county fixed effects (dummies) and ε is the resulting error term.

- Second, the time-mean residuals are regressed on the time invariant variables:

$$\overline{V_i} - \overline{X}_i^{'}\hat{\boldsymbol{\beta}}_{CV} = \mathbf{e}\alpha_i + \overline{\varepsilon_i} = Z_i^{'}\boldsymbol{\gamma} + C_i^{'}\varphi + \overline{u}_i \qquad (10)$$

11. Model and Control Variables

- Log-linear model
- Weights equal to farmland
- Dependent variable: value of land ($/ha)
- Quadratic climate surface
    - four seasons
    - temperatures and precipitations

12. Model and Control Variables

- Time varying control variables
  - Income, density, density squared, share of greenhouses, government transfers, house price index, time dummies

- Time constant control variables
  - soil characteristics, geographic variables, surface water withdrawals

13. Climate Marginals (Hsiao Model)

	Temperature (°C)			Precipitations (mm)	
	Hsiao	Pooled		Hsiao	Pooled
Annual	-1.4% (-9.7% , 6.8%)	-1.4% (-9.7% , 7%)	Annual	0.55% *** (0.20% , 0.90%)	0.55% *** (0.22% , 0.88%)
Winter	-26.4% *** (-35.5% , -17.3%)	-26.6% *** (-35.3% , -18%)	Winter	0.46% *** (0.13% , 0.79%)	0.47% *** (0.14% , 0.80%)
Spring	21.1% *** (11.3% , 30.8%)	17.1% *** (7.5% , 26.7%)	Spring	0.35% (-0.15% , 0.84%)	0.20% (-0.28% , 0.67%)
Summer	-31.4% *** (-43.6% , -19.1%)	-33.1% *** (-43.5% , -22.7%)	Summer	0.47% *** (0.19% , 0.76%)	0.48% *** (0.22% , 0.74%)
Autumn	35.3% *** (12.4% , 58.1%)	41.4% *** (19.4% , 63.3%)	Autumn	-0.73% *** (-1.18% , -0.28%)	-0.60% *** (-1.02% , -0.17%)

Note: Standard errors corrected for spatial correlation, cutoff point at 3 degrees. * p<0.01; ** p<0.05; *** p<0.01.

- Seasonal marginals all significant by they do compensate each other

14. Test of Hsiao and Pooled Model

- Test for Hsiao model
  - Time-mean residuals

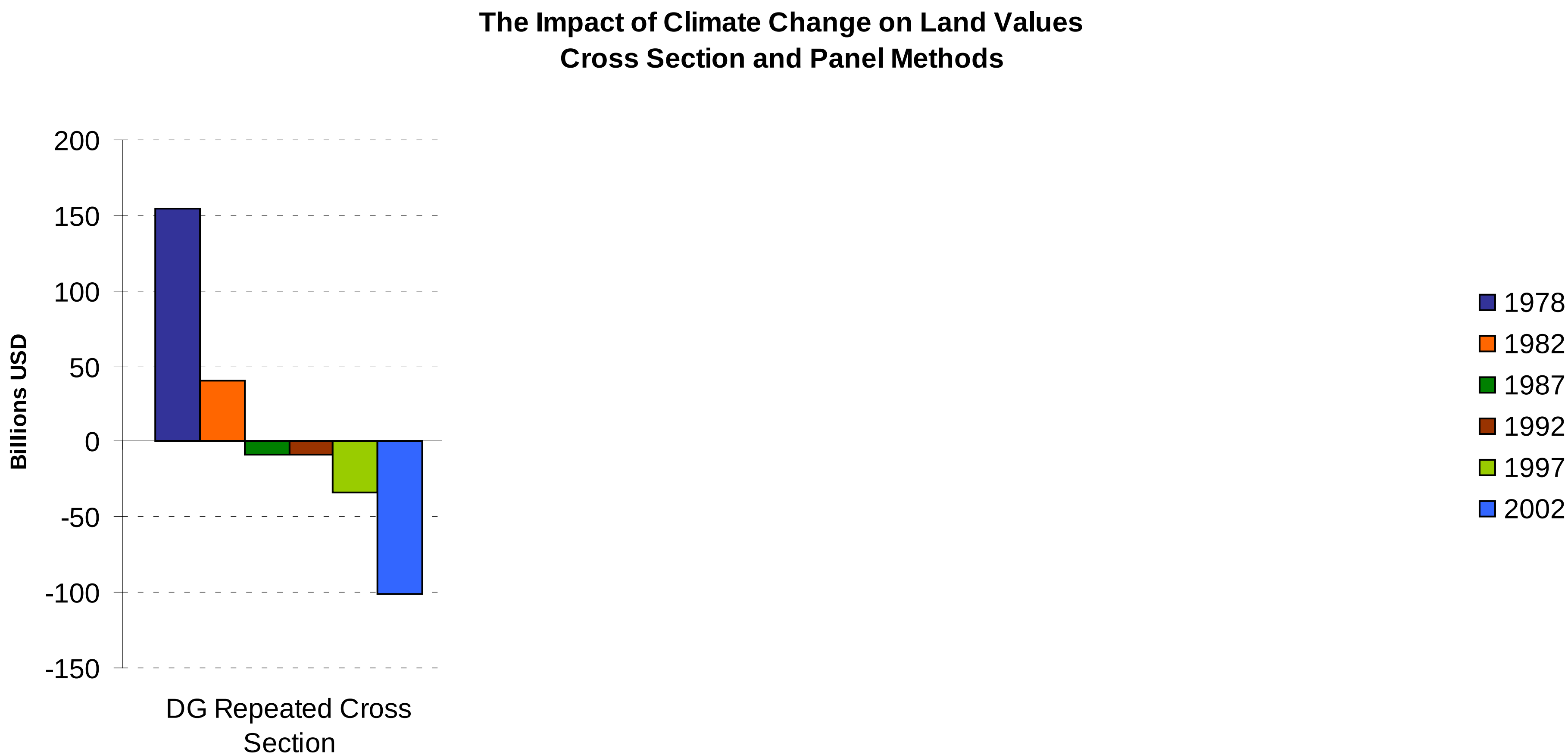
$$\bar{V}_i - \bar{X}_i^{'}\hat{\boldsymbol{\beta}}_{CV} = \mathbf{e}\alpha_i + \bar{\varepsilon}_i = Z_i^{'}\boldsymbol{\gamma} + C_i^{'}\varphi + \bar{u}_i \qquad (11)$$

  - Time-specific residuals

$$V_i - X_i^{'}\hat{\boldsymbol{\beta}}_{CV} = \mathbf{e}\alpha_i + \varepsilon_i = Z_i^{'}\boldsymbol{\gamma}_t + C_i^{'}\varphi_t + u_i \qquad (12)$$

- Test for Pooled model
  - Time-specific coefficients
  - F-tests on weather the coefficients are the same across time

15. A Comparison Across Models



- F-tests:
  - Coefficients of temperature variables are stable across time but coefficients of the precipitation variables are not

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16. Impacts and Adaptation

- Climate coefficients can be used to estimate
  - climate marginals (at different locations)
  - impacts of climate change (at county- and nation-level)

- Importance of climate scenario used
  - Level of concentrations (global mean temperature)
  - Climate change scenario (modelling team)

- Important implications for:
  - Distribution of impacts
  - Total impacts
  - Planning of adaptation

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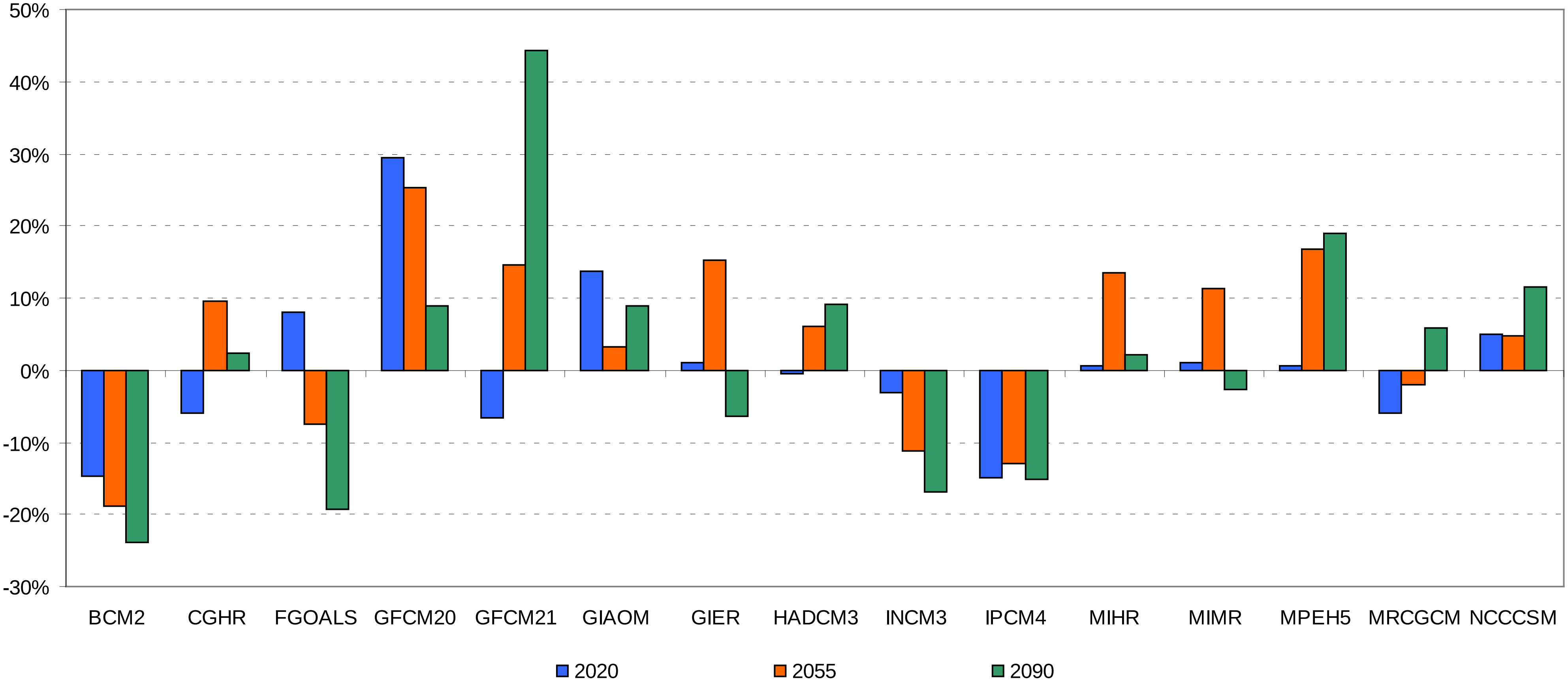
17. On-going work - Preliminary

- Analysis over all scenarios available from AR4
- Preliminary: need to check all data and results

- Huge uncertainty:
  - large confidence intervals for econometric estimates
  - level of GHGs concentrations
  - distribution of climate change over the USA

- Identify areas in which there is greater/lesser agreement on future climate change

18. Impact as % of land value - SRES B1



- SRES B1 - 1.1-2.9 ºC in 2100

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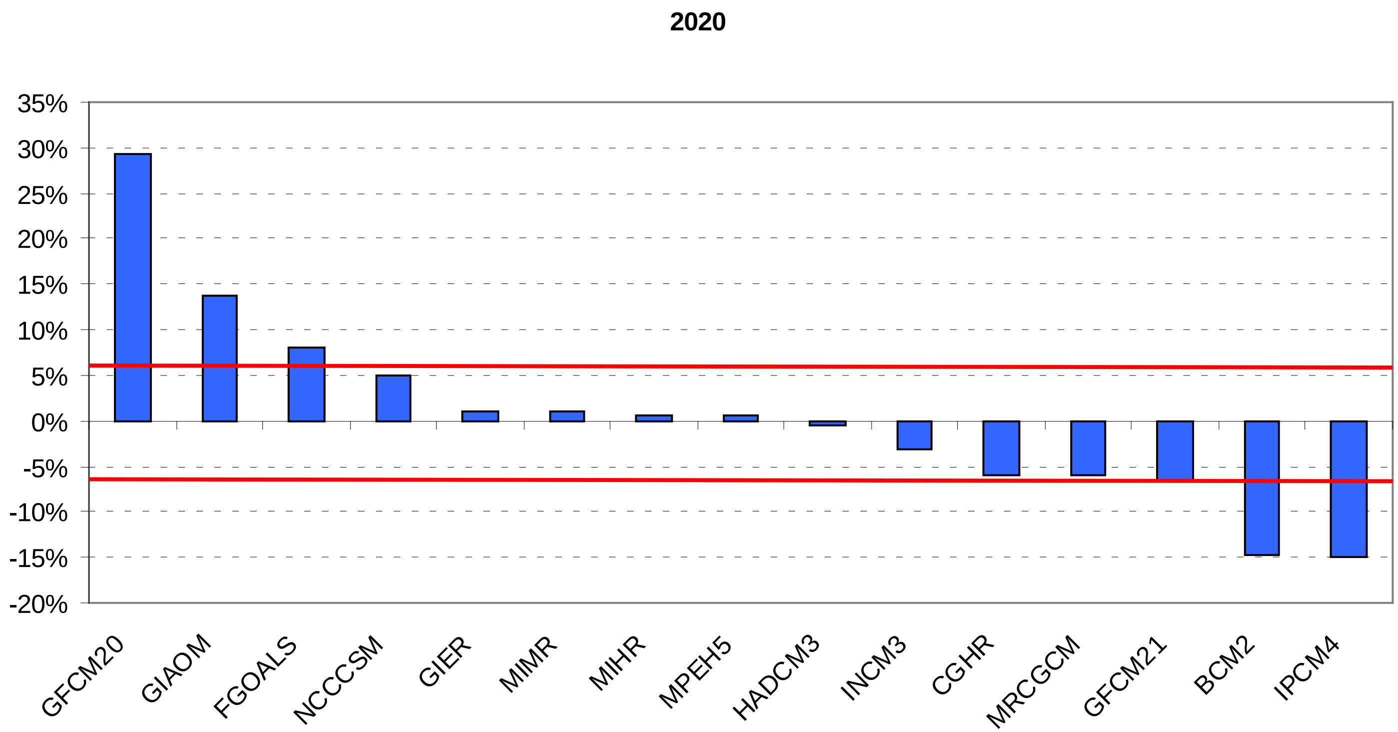
19. Impact as % of land value - 2055



- 90% confidence interval, omitting top and bottom two models

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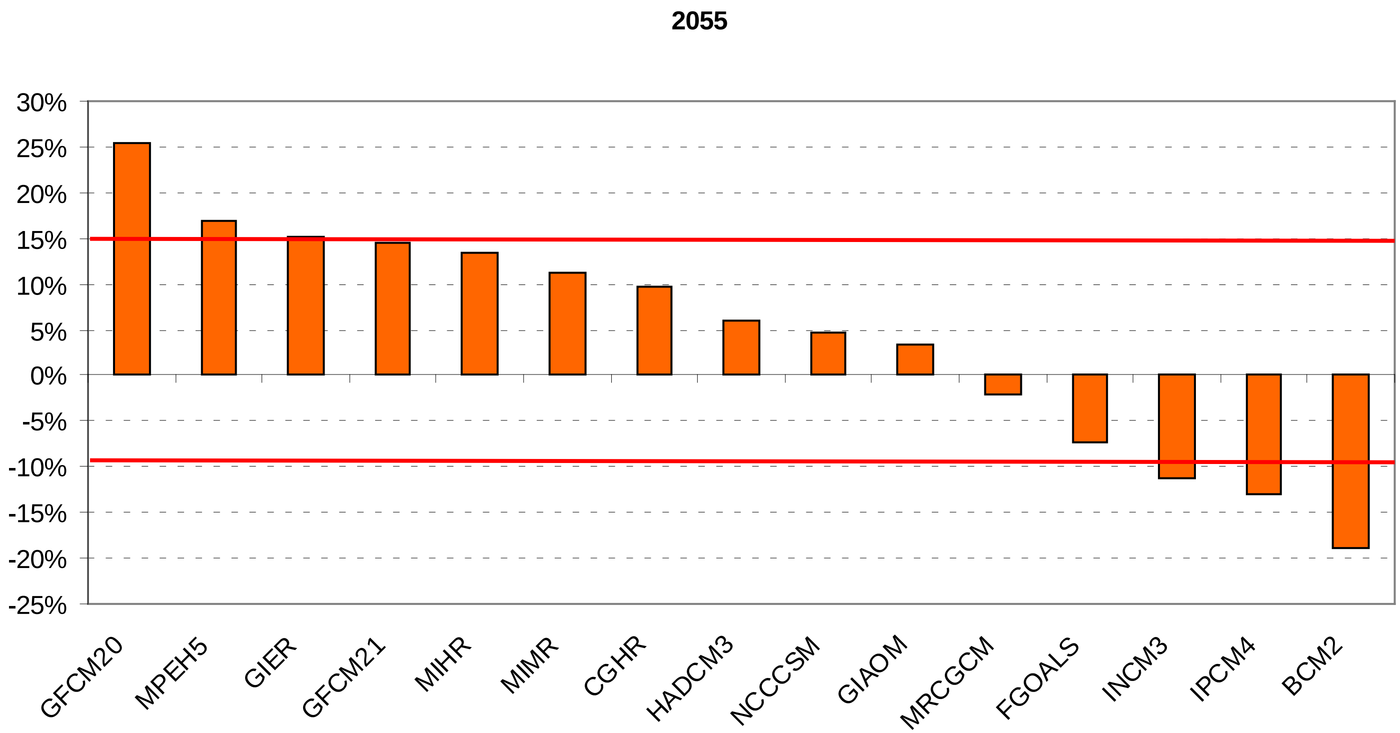
20. Impact as % of land value - 2055



- 90% confidence interval, omitting top and bottom two models

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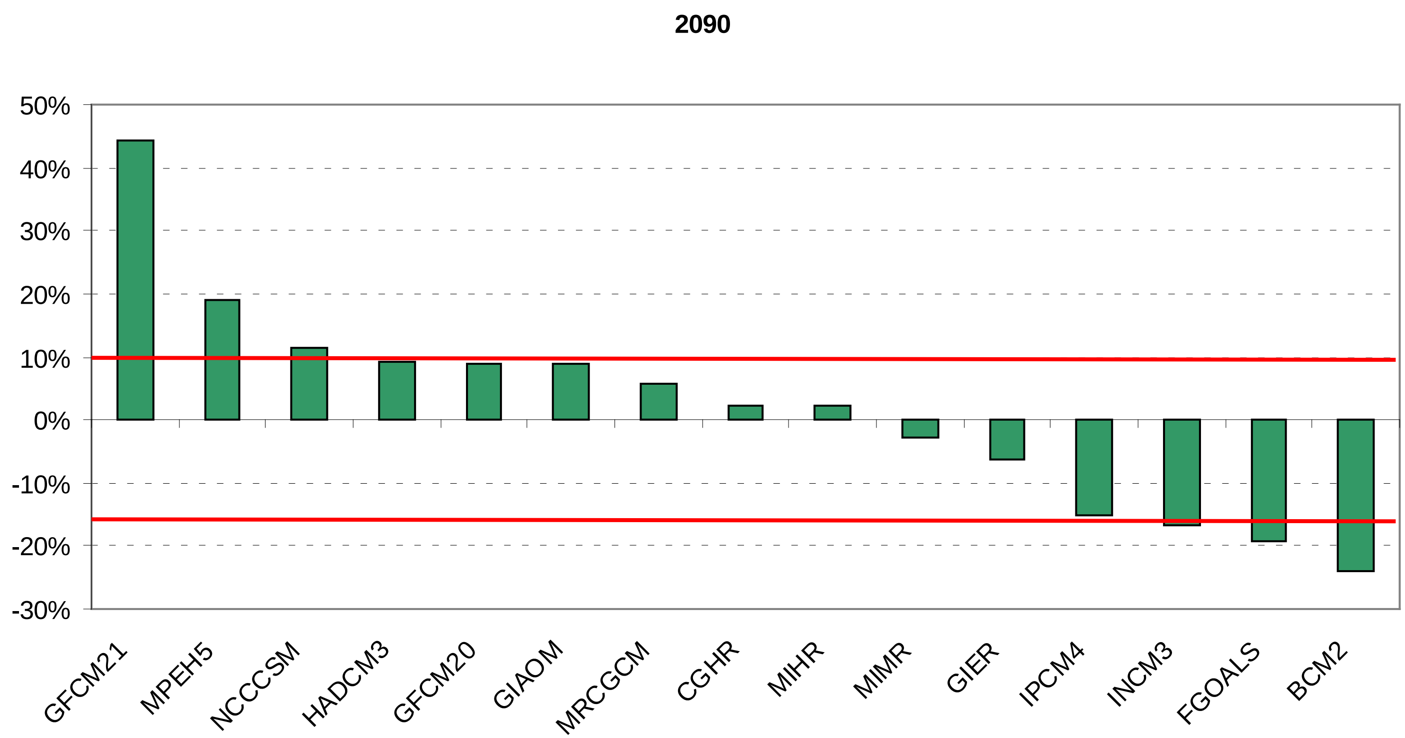
21. Impact as % of land value - 2055



- 90% confidence interval, omitting top and bottom two models

22. Ranking of models

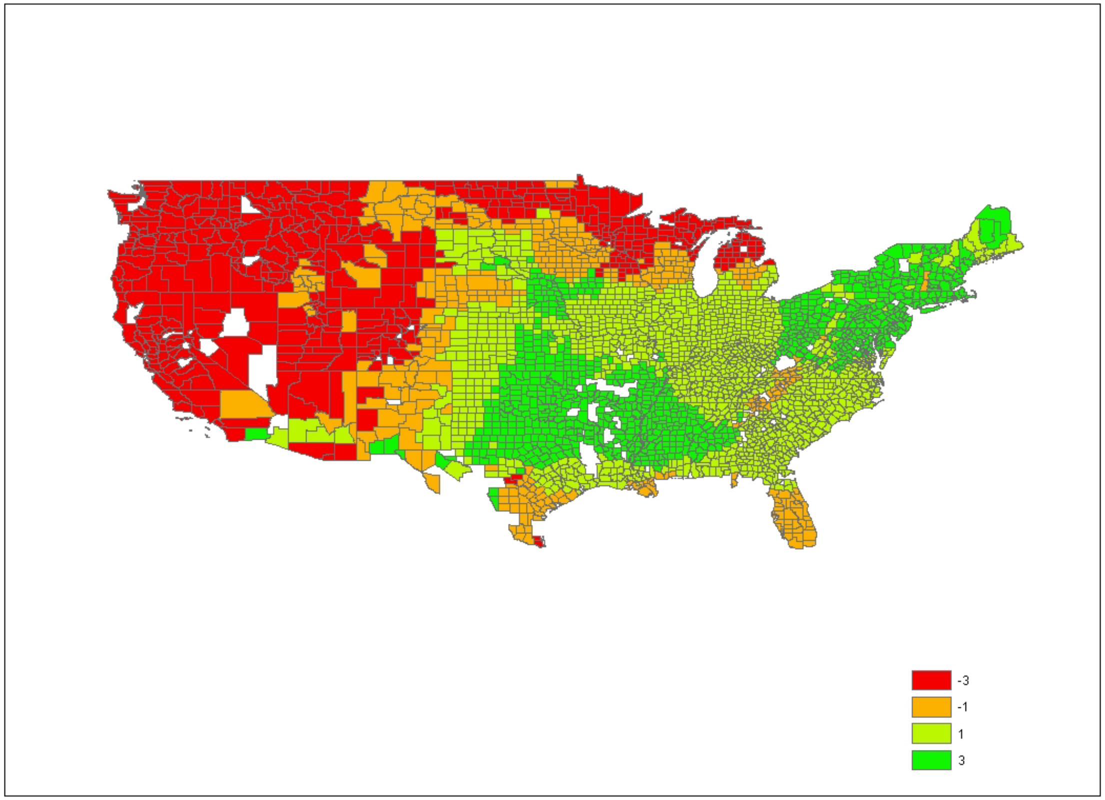
	2020	2055	2090
BCM2	14	15	15
CGHR	11	7	8
FGOALS	3	12	14
GFCM20	1	1	5
GFCM21	13	4	1
GIAOM	2	10	6
GIER	5	3	11
HADCM3	9	8	4
INCM3	10	13	13
IPCM4	15	14	12
MIHR	7	5	9
MIMR	6	6	10
MPEH5	8	2	2
MRCGCM	12	11	7
NCCCSM	4	9	3

#1 - highest benefits (lowest damages)

#15 - lowest benefits (highest damages)

There are a few remarkable cases in which models switch relative ranking over the years

23. Further developments - 1



Value equal to 3 means that the three model all predict benefits; a value equal to -3 means that all models predict a negative impact. If the index is equal to -1 or to 1 the models do not predict impacts consistently; a negative sign implies the predominance of negative estimates, a positive sign implies the predominance of positive estimates.

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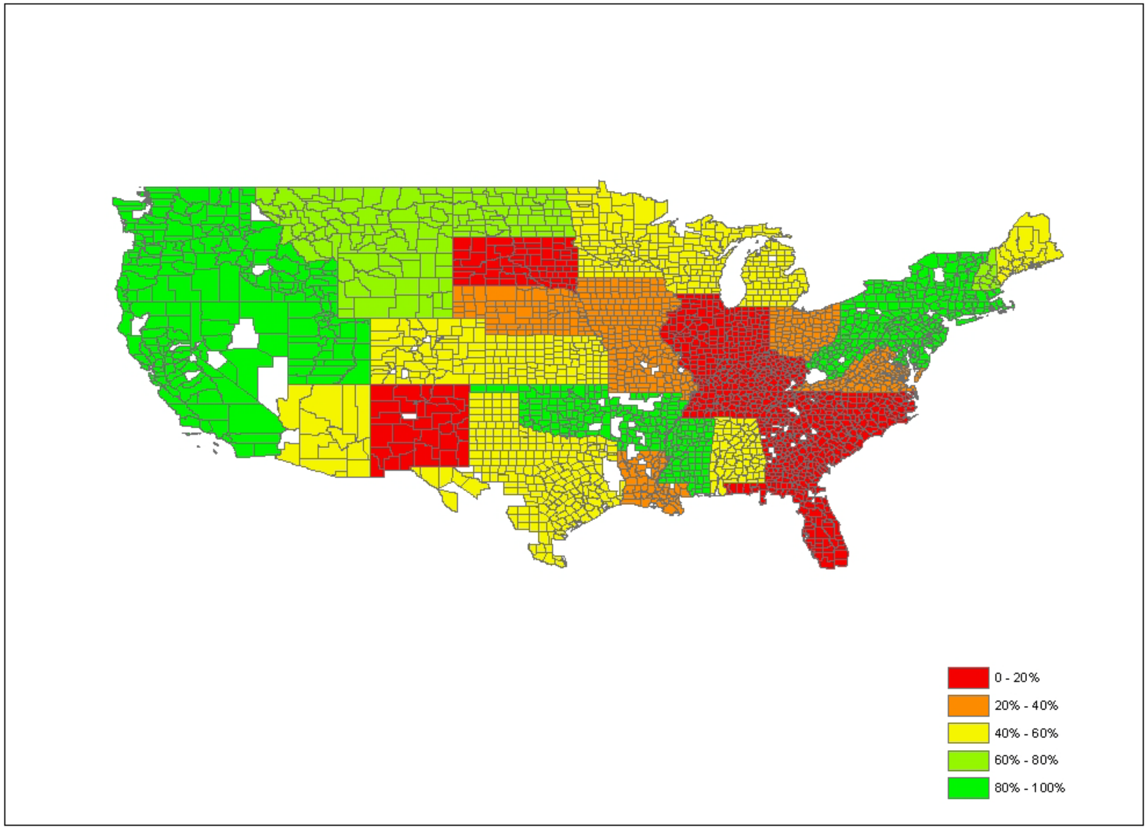
24. Further developments - 2



Percentage of total number of counties for which all models predict consistently climate change impacts (both positive and negative).

25. Summary

- When panel data is available, a Panel Ricardian Method can be applied, preserving climate as explanatory variable

- The method we employed can be extended to other research topics in the hedonic literature

- Future research:
  - multi-climate scenario analysis
  - alternative formulation of the climate surface
  - additional climate variables

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27. Time Varying Variables

Table 3A—Coefficients of Time Varying Variables in the Hsiao and Pooled Model

Model	Hsiao	Pooled Model		Hsiao	Pooled Model
Income (1,000 $)	0.00538	0.00914	1982 dummy	-0.0366	-0.0309
	(3.5)	(4.71)		(-4.51)	(-1.87)
Density (persons/m^2)	0.00466	0.00184	1987 dummy	-0.351	-0.477
	(6.08)	(9.21)		(-30)	(-22.6)
Density sq	-3.45E-06	-1.21E-06	1992 dummy	-0.468	-0.511
	(-5.25)	(-5.95)		(-43.1)	(-26.7)
Share of greenhouses (%)	0.291	0.331	1997 dummy	-0.4	-0.424
	(1.86)	(2.58)		(-33)	(-21.5)
Government transfers ($/ha)	-0.00105	0.00178	2002 dummy	-0.344	-0.4
	(-9.49)	(10.2)		(-23.2)	(-18.4)
Median Value Houses (1,000 $)	0.00614	0.00601	Constant	7.2	—
	(18.2)	(17.8)	Adjusted R-Squared	0.96	—

Notes: t-statistics in parenthesis.

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28. Time In-Variant Variables - Climate

Table 3B—Coefficients of Time Invariant Variables in the Hsiao and Pooled Model

Model	Hsiao	Pooled Model		Hsiao	Pooled Model
Temp Winter	-0.259 (-9.42)	-0.26 (-20.7)	Prec Winter	0.00708 (4.19)	0.00737 (9.32)
Temp Winter sq	-3.08E-03 (-2.46)	-4.18E-03 (-7.14)	Prec Winter sq	-1.81E-05 (-2.68)	-1.97E-05 (-6.42)
Temp Spring	0.374 (5.42)	0.359 (11.3)	Prec Spring	1.78E-02 (5.04)	1.54E-02 (9.18)
Temp Spring sq	-6.93E-03 (-2.04)	-8.00E-03 (-5.09)	Prec Spring sq	-8.16E-05 (-4.42)	-7.67E-05 (-8.77)
Temp Summer	-0.752 (-6.82)	-0.661 (-12.8)	Prec Summer	0.00453 (1.39)	0.0049 (3.22)
Temp Summer sq	9.56E-03 (4.24)	7.18E-03 (6.71)	Prec Summer sq	1.18E-06 (0.0667)	-6.80E-07 (-0.0828)
Temp Autumn	0.259 (1.68)	0.215 (3.06)	Prec Autumn	-0.0208 (-4.7)	-0.0203 (-10.5)
Temp Autumn sq	3.60E-03 (0.706)	7.62E-03 (3.22)	Prec Autumn sq	8.75E-05 (3.58)	9.26E-05 (8.5)

Notes: t-statistics in parenthesis.

29. Time Invariant Variables - Control

Table 3B—Coefficients of Time Invariant Variables in the Hsiao and Pooled Model

Model	Hsiao	Pooled Model		Hsiao	Pooled Model
Salinity	-0.093	-0.102	Permeability	-0.0516	-0.0484
	(-1.09)	(-2.59)		(-2.05)	(-3.16)
Flooding	-0.238	-0.254	Latitude	-8.04E-03	-4.88E-03
	(-2.18)	(-5.32)		(-0.295)	(-0.391)
Wet index	0.225	0.154	Elevation (m)	-4.37E-04	-4.58E-04
	(4.25)	(6.22)		(-2.36)	(-5.45)
K-factor	-1	-1.04	Distance metro areas (Km)	-7.52E-04	-8.12E-04
	(-3.58)	(-7.53)		(-7.73)	(-18.1)
Length of slope	1.20E-04	9.45E-05	Surface water use (lt/ha/day)	0.0727	0.0738
	(1.28)	(2.26)		(9.64)	(21.7)
Sand	0.241	0.111	Constant	5.62	12.2
	(1.93)	(1.72)		(2.39)	(11.4)
Clay	-0.106	-0.109			
	(-1.59)	(-2.65)			
Moisture Level	1.27	0.789	Adjusted R-squared	0.80	0.84
	(2)	(2.81)			

Notes: t-statistics in parenthesis.

30. Spatial Correlation

Table 3B—Coefficients of Time Invariant Variables in the Hsiao Model
Standard Errors Corrected for Spatial Correlation (cutoff 3 degrees)

Model	Hsiao	Hsiao Sp Corr		Hsiao	Hsiao Sp Corr
Temp Winter	-0.259	-0.259	Prec Winter	0.00708	0.00708
	(-9.42)	(-5.59)		(4.19)	(2.81)
Temp Winter sq	-3.08E-03	-3.08E-03	Prec Winter sq	-1.81E-05	-1.81E-05
	(-2.46)	(-1.68)		(-2.68)	(-1.83)
Temp Spring	0.374	0.374	Prec Spring	0.0178	0.0178
	(5.42)	(3.51)		(5.04)	(3.78)
Temp Spring sq	-6.93E-03	-6.93E-03	Prec Spring sq	-8.16E-05	-8.16E-05
	(-2.04)	(-1.56)		(-4.42)	(-3.31)
Temp Summer	-0.752	-0.752	Prec Summer	0.00453	0.00453
	(-6.82)	(-4.18)		(1.39)	(1.12)
Temp Summer sq	9.56E-03	9.56E-03	Prec Summer sq	1.18E-06	1.18E-06
	(4.24)	(2.7)		(0.0667)	(0.05)
Temp Autumn	0.259	0.259	Prec Autumn	-0.0208	-0.0208
	(1.68)	(1.15)		(-4.7)	(-3.19)
Temp Autumn sq	3.60E-03	3.60E-03	Prec Autumn sq	8.75E-05	8.75E-05
	(0.706)	(0.52)		(3.58)	(2.53)

Notes: t-statistics in parenthesis.

31. Data - 1

- Agriculture data for Census years 1978, 1982, 1987, 1992, 1998, 2002 for each county of the US
- Weather station data on 30 year normals across US (7400 weather stations)
- Climate change
  - Uniform +2.7 ºC and + 8% precipitation
  - SRES A2 (600ppm CO_2-eq; +3.5 ºC)

32. Data - 2

- Soils data from US Department of Agriculture (about 5 million samples of soil aggregated at county level)
- Water use data from US Geological Survey
- Socio-economic variables from a variety of sources
- Balanced panel of 2,914 counties out of the 3,048 counties in Lower 48 States
- Cover 97% of US farmland

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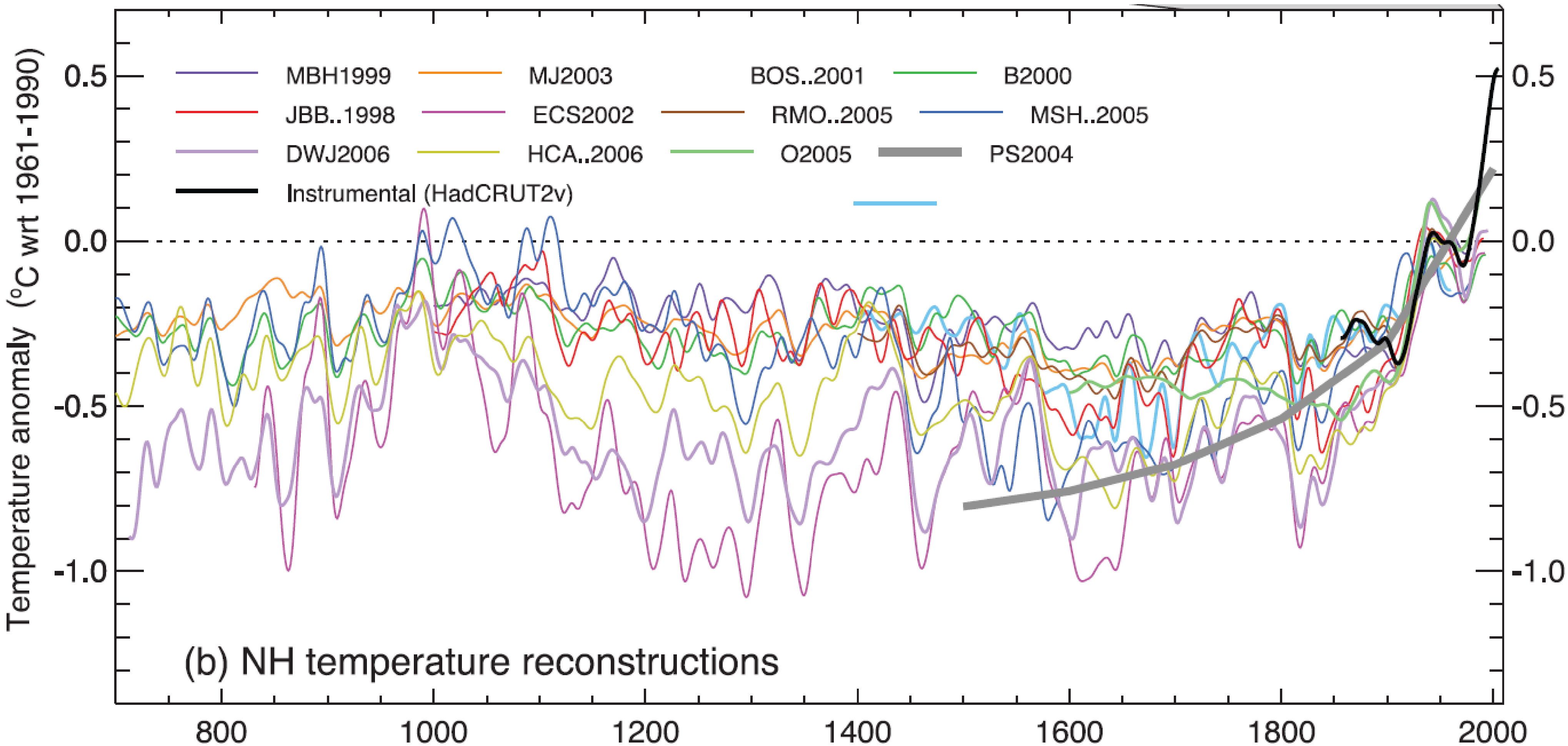
33. Looking Back at the Past



IPCC FAR, Ch 6, Fig 6.10.

Reconstructions using multiple climate proxy records.

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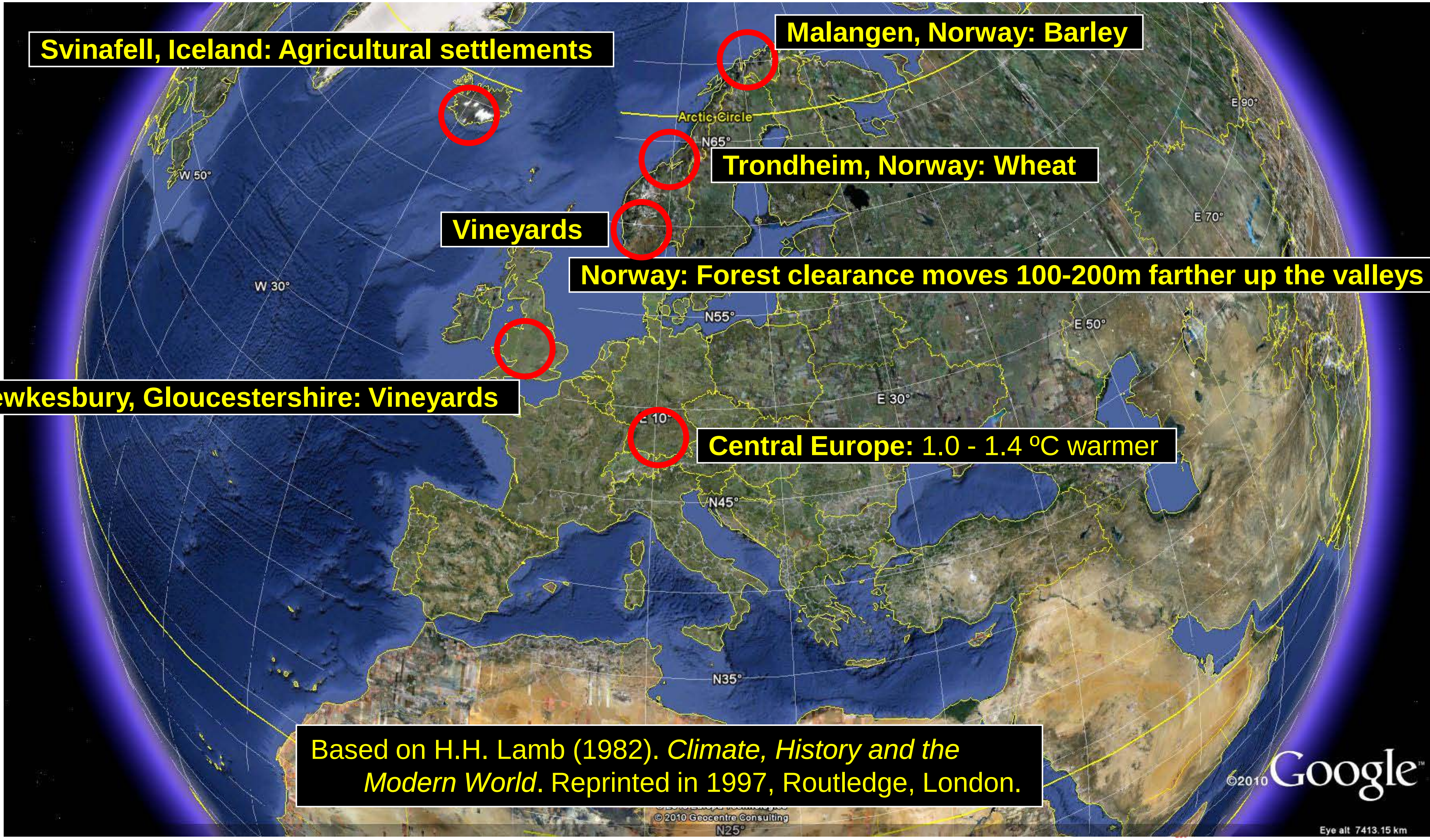
34. Adapting to a Changing Climate



35. Ricardian Studies

- The technique has been applied to:
  - United States (MNS 1994; Wolfram Schlenker et al. 2005)
  - Africa (Pradeep Kurukulasuriya et al. 2006; Niggol Seo and Robert Mendelsohn 2008)
  - South America (Niggol Seo and Robert Mendelsohn 2008)
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  - and several other countries around the world

- The results imply that moderate warming will tend to be good for temperate and polar countries but harmful for low latitude countries

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- Land values reflect the long-term profitability of land uses (Mendelsohn, Nordhaus and Shaw 1994)
- Equilibrium relationship between climate and land values
- Regress land value on climate, soils, and economic control variables
- Captures adaptation by farmer though adaptation is a black box (not explicit)

37. Improved Cross-Section - 1

- Improve climate variables
  - DG use average climate from 1970 to year of Census
  - We use 1970-2000 climate normals

- Measuring aggregate impact:
  - Welfare impact

$$W_t = \sum_i \left[V_{i,t}(C_1) - V_{i,t}(C_0) \right] F_{i,t} \qquad (6)$$

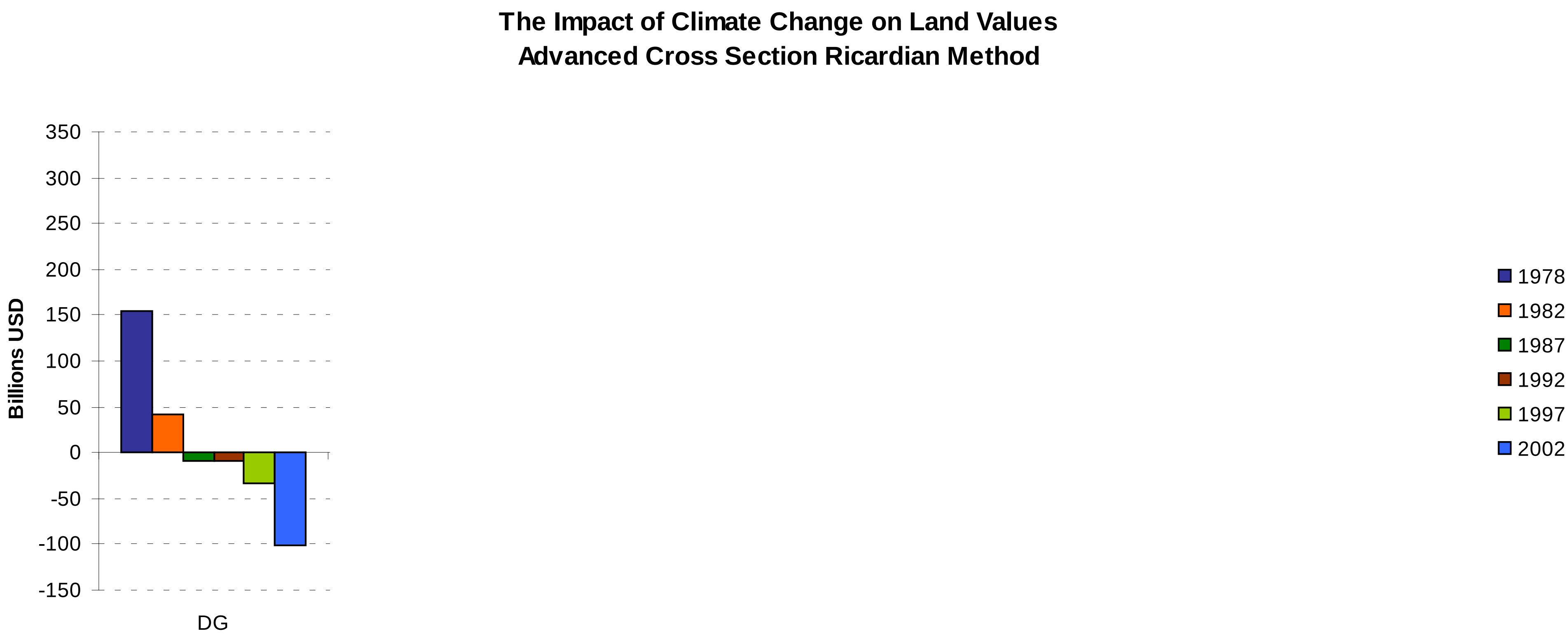
  - DG use different data of farmland for every year to test whether climate coefficients are stable over time
  - We use average farmland

$$W_t = \sum_i \left[V_{i,t}(C_1) - V_{i,t}(C_0) \right] E[F_{i,t}] \qquad (7)$$

38. Improved Cross-Section - 2

- Larger sample of counties
  - from 2124 to 2914
  - from 72% to 97% of US agricultural land
- Log linear functional form (impact proportional to land value)
- Enhanced set of covariates
  - Surface water withdrawals (largely exogenous, time constant)
  - Opportunity cost of land (time varying)

39. Advanced Cross Section Method



40. Welfare Results of Improvements

Model	DG	Improved Climate	Improved Climate and Expected Farmland	Improved Climate, Expected Farmland and More Counties
1978	154.70	134.14	128.50	137.00
	15.0%	*13.0%*	*16.0%*	*13.4%*
1982	40.80	101.58	99.59	92.68
	4.0%	*10.7%*	*12.4%*	*9.1%*
1987	-8.70	25.57	25.26	36.51
	-0.8%	*4.0%*	*3.1%*	*3.6%*
1992	-8.10	34.23	35.42	33.01
	-0.8%	*5.5%*	*4.4%*	*3.2%*
1997	-33.50	22.50	23.93	13.02
	-3.2%	*3.2%*	*3.0%*	*1.3%*
2002	-101.00	-46.74	-48.52	-54.91
	-9.8%	*-5.4%*	*-6.0%*	*-5.4%*

Notes: All dollar figures are in billions of 2000 USD. Percentage impacts are in parenthesis. Welfare impacts correspond to a uniform increase of temperature of 2.7°C and of 8 percent of precipitation.

41. Welfare Results of Improvements

Model	Improved Climate, Expected Farmland and More Counties	Loglinear	Loglinear with Additional Variables
1978	137.00 *13.4%*	281.53 *27.5%*	127.32 *12.5%*
1982	92.68 *9.1%*	190.70 *18.7%*	98.31 *9.6%*
1987	36.51 *3.6%*	112.54 *11.0%*	-52.31 *-5.1%*
1992	33.01 *3.2%*	101.87 *10.0%*	-50.38 *-4.9%*
1997	13.02 *1.3%*	90.09 *8.8%*	15.17 *1.5%*
2002	-54.91 *-5.4%*	47.71 *4.7%*	37.60 *3.7%*

Notes: All dollar figures are in billions of 2000 USD. Percentage impacts are in parenthesis. Welfare impacts correspond to a uniform increase of temperature of 2.7°C and of 8 percent of precipitation.

42. A Comparison Across Models

Model	Hsiao Time Varying	Pooled Time Varying	Repeated Cross Section
1978	31.87 (3.1%)	9.47 (0.9%)	127.32 (12.5%)
1982	9.15 (0.9%)	3.91 (0.4%)	98.31 (9.6%)
1987	6.47 (0.6%)	18.44 (1.8%)	-52.31 (-5.1%)
1992	18.32 (1.8%)	5.51 (1.8%)	-50.38 (5.3%)
1997	28.33 (2.8%)	19.49 (1.9%)	15.17 (1.5%)
2002	-6.22 (-0.6%)	-14.57 (-1.4%)	37.60 (-3.7%)

Note: All dollar figures are in billions of 2000 USD. Percentage impacts are in parenthesis. Welfare impacts correspond to a uniform increase of temperature of 2.7°C and of 8 percent of precipitation.

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Density	0.00466	0.00184	1987 dummy	-0.351	-0.477
	(6.08)	(9.21)		(-30)	(-22.6)
Density sq	-0.00000345	-0.00000121	1992 dummy	-0.468	-0.511
	(-5.25)	(-5.95)		(-43.1)	(-26.7)
Share of greenhouses	0.291	0.331	1997 dummy	-0.4	-0.424
	(1.86)	(2.58)		(-33)	(-21.5)
Government transfers	-0.00105	0.00178	2002 dummy	-0.344	-0.4
	(-9.49)	(10.2)		0	(-18.4)
House price index	0.00614	0.00601	Constant	7.2	—
	(18.2)	(17.8)	Adjusted R-Squared	0.96	—

Notes: t-statistics in parenthesis.

Table 3B—Coefficients of Time Invariant Variables in the Hsiao and Pooled Model

Model	Hsiao	Pooled Model		Hsiao	Pooled Model
Temp Winter	-0.259 (-9.42)	-0.26 (-20.7)	Salinity	-0.093 (-1.09)	-0.102 (-2.59)
Temp Winter sq	-0.00308 (-2.46)	-0.00418 (-7.14)	Flooding	-0.238 (-2.18)	-0.254 (-5.32)
Temp Spring	0.374 (5.42)	0.359 (11.3)	Wet index	0.225 (4.25)	0.154 (6.22)
Temp Spring sq	-0.00693 (-2.04)	-0.008 (-5.09)	K-factor	-1 (-3.58)	-1.04 (-7.53)
Temp Summer	-0.752 (-6.82)	-0.661 (-12.8)	Length of slope	0.00012 (1.28)	0.0000945 (2.26)
Temp Summer sq	0.00956 (4.24)	0.00718 (6.71)	Sand	0.241 (1.93)	0.111 (1.72)
Temp Autumn	0.259 (1.68)	0.215 (3.06)	Clay	-0.106 (-1.59)	-0.109 (-2.65)
Temp Autumn sq	0.0036 (0.706)	0.00762 (3.22)	Moisture Level	1.27 (2)	0.789 (2.81)
Prec Winter	0.00708 (4.19)	0.00737 (9.32)	Permeability	-0.0516 (-2.05)	-0.0484 (-3.16)
Prec Winter sq	-0.0000181 (-2.68)	-0.0000197 (-6.42)	Latitude	-0.00804 (-0.295)	-0.00488 (-0.391)
Prec Spring	0.0178 (5.04)	0.0154 (9.18)	Elevation	-0.000437 (-2.36)	-0.000458 (-5.45)
Prec Spring sq	-0.0000816 (-4.42)	-0.0000767 (-8.77)	Distance metro areas	-0.000752 (-7.73)	-0.000812 (-18.1)
Prec Summer	0.00453 (1.39)	0.0049 (3.22)	Surface water use	0.0727 (9.64)	0.0738 (21.7)
Prec Summer sq	0.00000118 (0.0667)	-0.00000068 (-0.0828)	Constant	5.62 (2.39)	12.2 (11.4)
Prec Autumn	-0.0208 (-4.7)	-0.0203 (-10.5)			
Prec Autumn sq	0.0000875 (3.58)	0.0000926 (8.5)	Adjusted R-squared	0.80	0.84

Notes: t-statistics in parenthesis.