NATIONAL ACADEMIES *Sciences Engineering Medicine*

Incorporating Climate into Macroeconomic Modeling

Workshop | June 14–15, 2023

JUNE 2023

Session 2:
Climate and Macroeconomic Modeling Research Landscape

Macroeconomic Modeling and Climate Change in the Presence of Uncertainty

Lars Peter Hansen (University of Chicago)

Workshop on Incorporating Climate into Macroeconomic Modeling
Risks and Opportunities

Collaborators (climate economics): Barnett (ASU) and Brock (Wisconsin)

Collaborators (decision theory): Miao (Boston University), Sargent (NYU)
Cerreia-Vioglio, Maccheroni, Marinacci (Bocconi)

June 14, 2023

Challenge

> *"The economic consequences of many of the complex risks associated with climate change cannot, however, currently be quantified. ... these unquantified, poorly understood and often deeply uncertain risks can and should be included in economic evaluations and decision-making processes."*

Rising, Tedesco, Piontek, Stainforth, 2022

Haunted by Hayek's forewarning

"Even if true scientists should recognize the limits of studying human behaviour, as long as the public has expectations, there will be people who pretend *or* believe *that they can do more to meet popular demand than what is really in their power."*

From Hayek's Nobel address (1974)

For quantitative policy analysis, how should we acknowledge the limits to our understanding?

Uncertainty tradeoffs

- How much weight do we assign to:
  - best guesses
  - potentially bad outcomes

  when designing policy?
- Do we act now, or do we wait until we learn more?

What is the challenge?

Application:

- limits to our understanding of the potential economic impact of climate change
- three sources of uncertainty:
  - geosciences: CO_2 emissions today impact the future climate
  - economics: climate change in the future alters economic opportunities and social well-being
  - technology: research and development invested today may eventually lead to economically viable technologies

Which of these sources is of most concern for designing policy?

Decision theory under uncertainty

- allows for a broad perspective on uncertainty
  - risk - unknown outcomes with known probabilities
  - ambiguity - unknown weights to assign to alternative probability models - prior uncertainty
  - misspecification - unknown ways in which a model might give flawed probabilistic predictions - likelihood uncertainty
- includes formulations that are dynamic and recursive and can be implemented with dynamic programming type methods

Suggests better ways for conducting uncertainty quantification for dynamic economic models used for private sector planning and governmental policy assessment.

What we are aiming for

Computationally tractable methods for exploring subjective uncertainty including potential model misspecification and ambiguity across models

Goals:

- assess the impact of uncertainty on climate policy outcomes
- isolate the forms of uncertainty that are most consequential for these outcomes.

Navigating uncertainty

Probability models we use in practice are misspecified, and there is ambiguity as to which among multiple models is the best one.

- aims:
  - use models in sensible ways rather than discard them
  - use tools from probability and statistics to limit the type and amount of uncertainty that is entertained
- input: aversion - dislike of uncertainty about probabilities over future events
- implementation: target the uncertainty components with the most adverse consequences for the decision maker
- outcome: an uncertainty adjusted probability measure pertinent for valuation along with robust decision rules

Uncertainty quantification

Two questions:

- **How much** uncertainty aversion should we impose?
  - trace through sensitivity to the choice of penalty parameters or constraints
  - inspect the impact on the implied worst-case distributions from min-max problem
- **Which source** of uncertainty matters the most?
  - activate the robustness concerns one source at a time
  - compare the decision outcomes to those from a decision problem with all concerns activated simultaneously

Social valuation

What does asset valuation provide?

Asset pricing theory: how do markets assess the investment opportunities in the face of uncertain future net payoffs?

- "assets" include financial, physical, human, organizational and environmental "capital"
- associated with each asset is a prospective sequence of net payoffs to investments (payoffs can be negative)
- apply these tools to social instead of market valuation!!

The social cost of climate change and social value of research and development are asset prices with uncertain social "cash flows."

Social valuation under ambiguity and misspecification aversion

- use discounted expected values of social cash flows as is typical in cost-benefit analyses
- but expectations are constructed using the minimizing probabilities in order to capture the full uncertainty adjustments

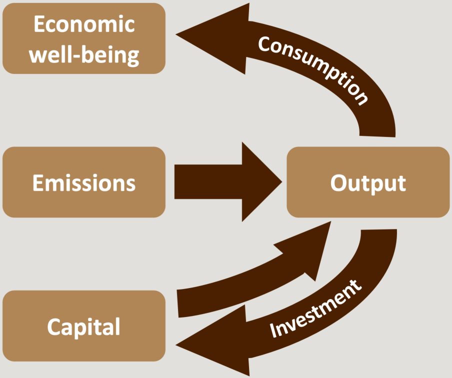
Apply stochastic discounting under a probability measure inferred from a planning problem.

Climate policy under uncertainty

- There are many calls for immediate climate policy implementation.
- Existing limits to our understanding of the timing and magnitude of climate change impacts have led to apprehension by some.
- We study how a decision-maker confronts uncertainty in a setting where:
  - there will be future information about damage severity
  - but the value of further empiricism in the near term is limited
  - research and development can hasten the uncertain discovery a green technology
  - includes both Brownian and jump risk

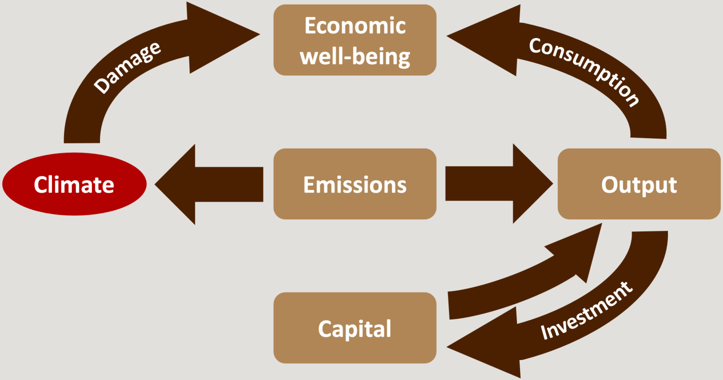
Modeling Framework

(without climate change)

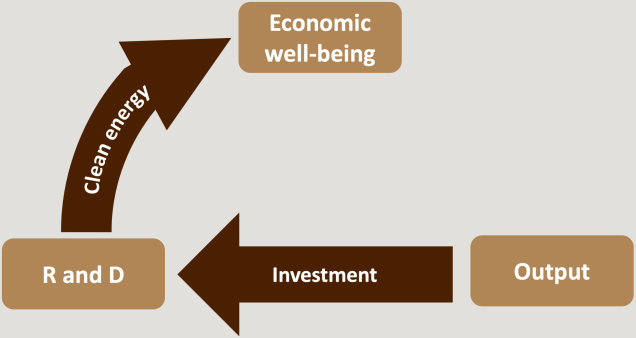


Modeling Framework

(including climate change)



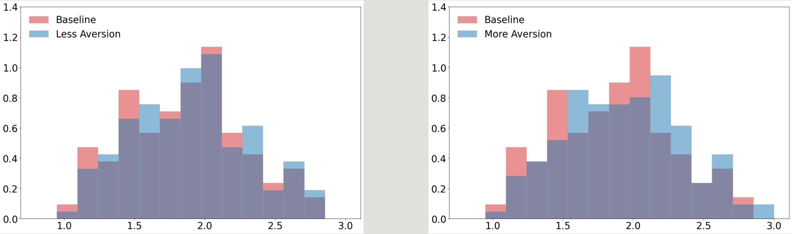
Modeling Framework
(including research and development)



Three sources of uncertainty

- emissions impact on climate
- climate impact on economic damages
- returns to investment in new green technology

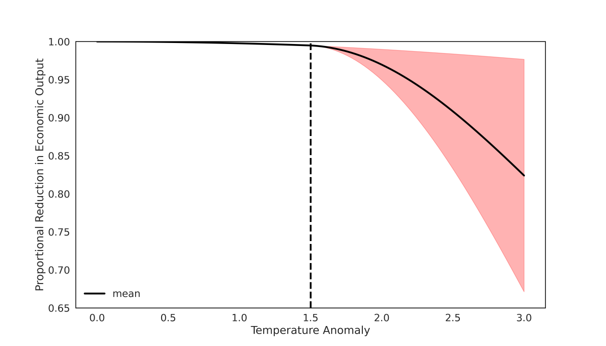
Climate sensitivity uncertainty



(a) Less Aversion

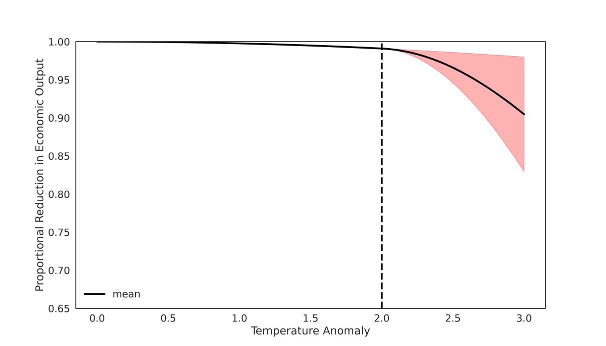
(b) More Aversion

Damage functions



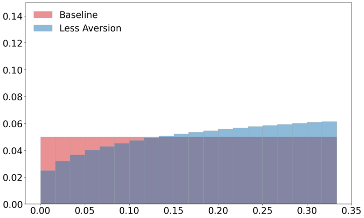
Range of possible damage functions for a temperature anomaly of $1.5°C$.

Damage functions

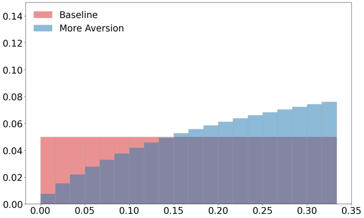


Range of possible damage functions for a temperature anomaly of $2°C$.

Damage curvature uncertainty

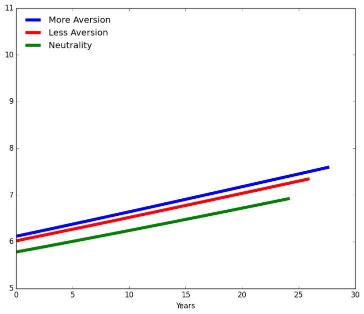


(a) Less Aversion

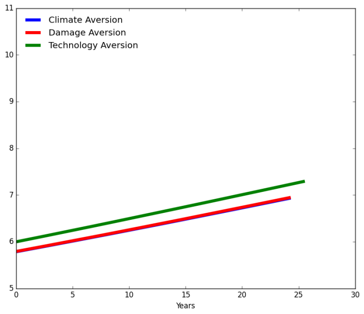


(b) More Aversion

Social value of R&D



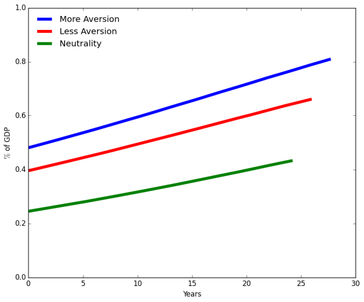
(a) Uncertainty Aversion Comparison



(b) Uncertainty Channel Comparison

Simulated pathways of the logarithm of the social value of R&D. The baseline trajectories abstract from intrinsic randomness. The pathways stop when the temperature anomaly reaches $1.5°C$.

Robust R & D



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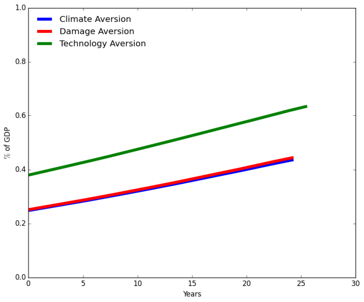
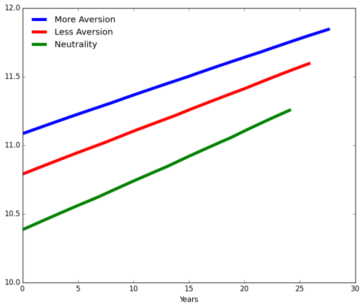


(b) Uncertainty Channel Comparison

Simulated pathways of R&D investment as a fraction of GDP. The baseline trajectories abstract from intrinsic randomness. The pathways stop when the temperature anomaly reaches $1.5°C$.

Social cost of global warming



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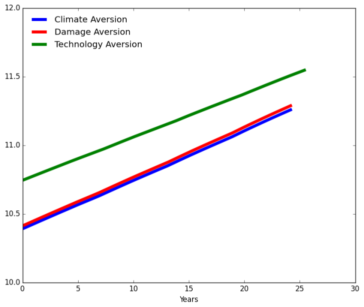
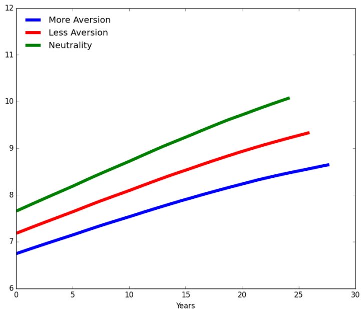


(b) Uncertainty Channel Comparison

Simulated pathways for logarithm of the social cost of global warming. The baseline trajectories abstract from intrinsic randomness. The pathways stop when the temperature anomaly reaches $1.5°C$.

Carbon emissions



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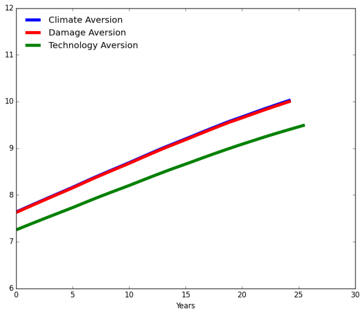

(b) Uncertainty Channel Comparison

Simulated pathways of emissions. The baseline trajectories abstract from intrinsic randomness. The pathways stop when the temperature anomaly reaches $1.5°C$.

Concluding remarks

- Uncertainty matters for policy tools like the social cost of global warming and social investment in green research and development.
- Understanding the sources of uncertainty, broadly conceived, used by the private sector and by governments will make economic policy more effective.

Syracuse University
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Multisector Climate-Energy Models

Peter J Wilcoxen

National Academies Workshop on Incorporating Climate into Macro Modeling

June 2023

Overview

- General structure of multisector models
- Illustrative results
- Parameter uncertainty and limits on precision
- Challenges and research needs

High level model structure

G-Cubed Global Model

World

Regions

Australia
China
Europe
India
Japan
OPEC
Rest of OECD
Rest of World
Russia
United States

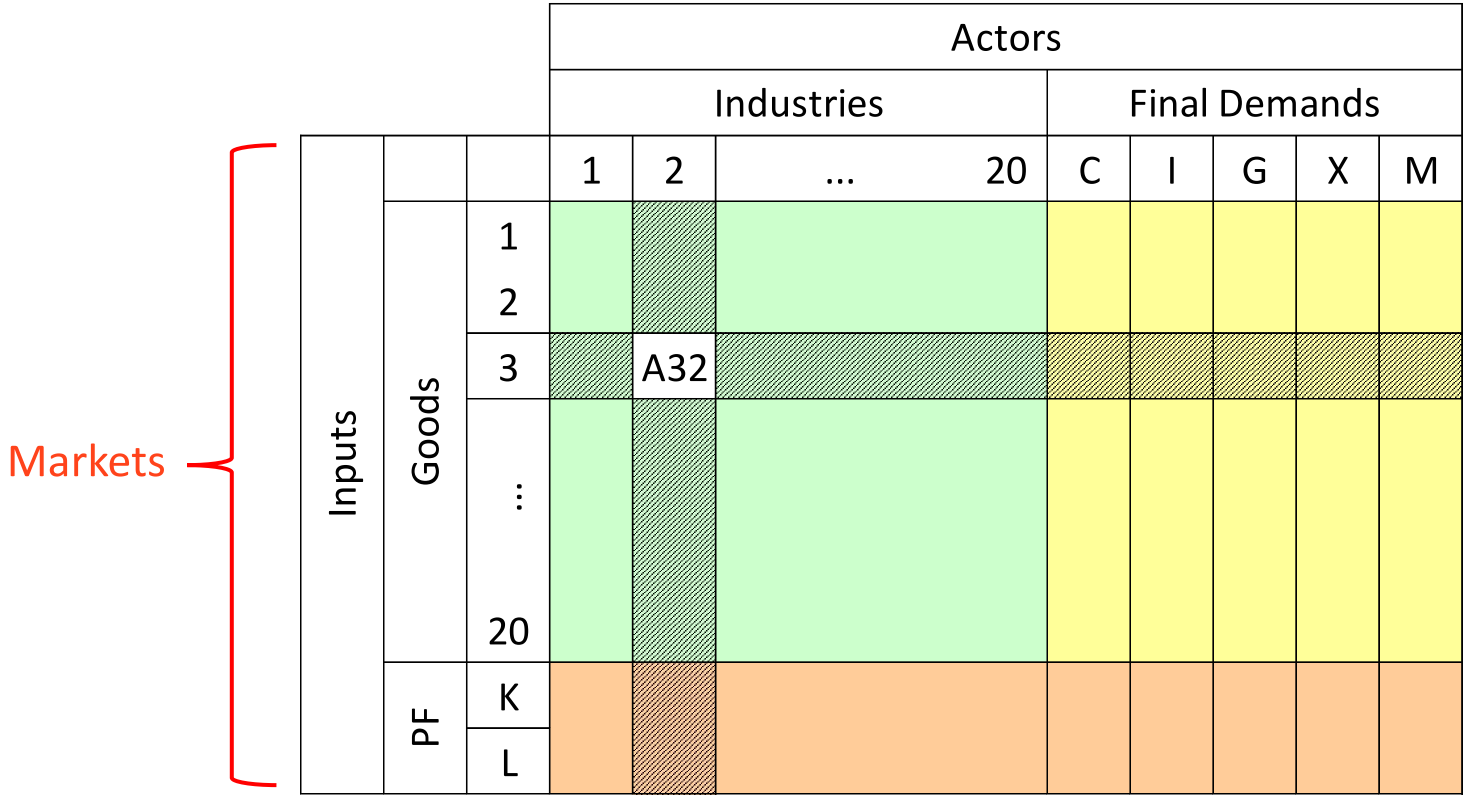
Actors in each

Producers
Households
Government

Producing sectors in each

Electric Utilities	Transportation
Gas Utilities	Services
Refining	Coal Gen
Coal Mining	Gas Gen
Crude Oil	Oil Gen
Gas Extraction	Nuclear
Mining	Wind
Agriculture	Solar
Durables	Hydro
Nondurables	Other Gen

Markets, actors and transactions within each economy



Final Demands

- C Households
- I Investment
- G Government
- X Exports
- M Imports

Primary Factors

- K Capital
- L Labor

Column 2 shows demands by industry 2

Row 3 shows demands for good 3

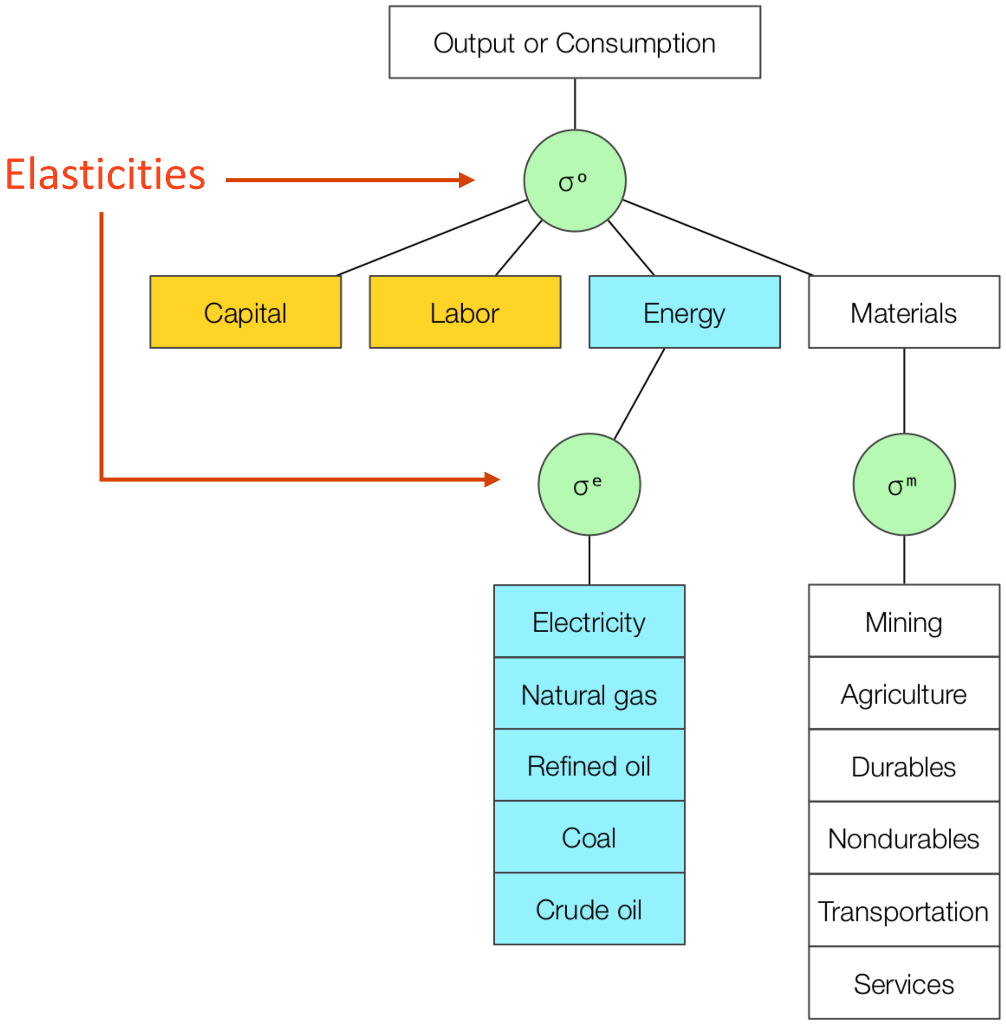
A32 is demand for good 3 by industry 2

Green: intermediate demands

Yellow: final demands

Orange: primary factors

Demand model for each sector



- All agents are subject to budget constraints
- Buyers respond to prices
- Price sensitivity estimated using historical data

Behavioral links between periods

- Investment by forward-looking firms
  - Maximize present value of dividend stream
- Saving by forward-looking households
  - Must satisfy intertemporal budget constraint
- Government borrowing
  - Must repay or service debt indefinitely
- International borrowing:
  - Must repay via future trade surpluses

Importance of foresight:

- Explicitly intertemporal decisions
- Anticipated climate impacts
- Anticipated policy changes
- Policy risk

What drives GDP growth?

- GDP built up from components:
  - Income side — sum of payments to labor and capital
  - Expenditure side — sum of expenditures on final demands
- Typical drivers of GDP growth:
  - Labor force — usually exogenous
  - Capital formation — usually endogenous
  - Productivity — varies
  - Terms of trade — short run, international models
  - Employment or unemployment — short run, unusual

Factor mobility is also important

- Labor migration may be limited
  - Between regions
  - Between occupations or industries
- Physical capital may be immobile
  - Specific to regions
  - Specific to sectors
- Low mobility = slower adaptation to shocks

Example application

- Decline in productivity in durables
  - Shifts down permanently by 1% in year 5 (shock anticipated)
  - Could arise from a regulation OR climate impacts

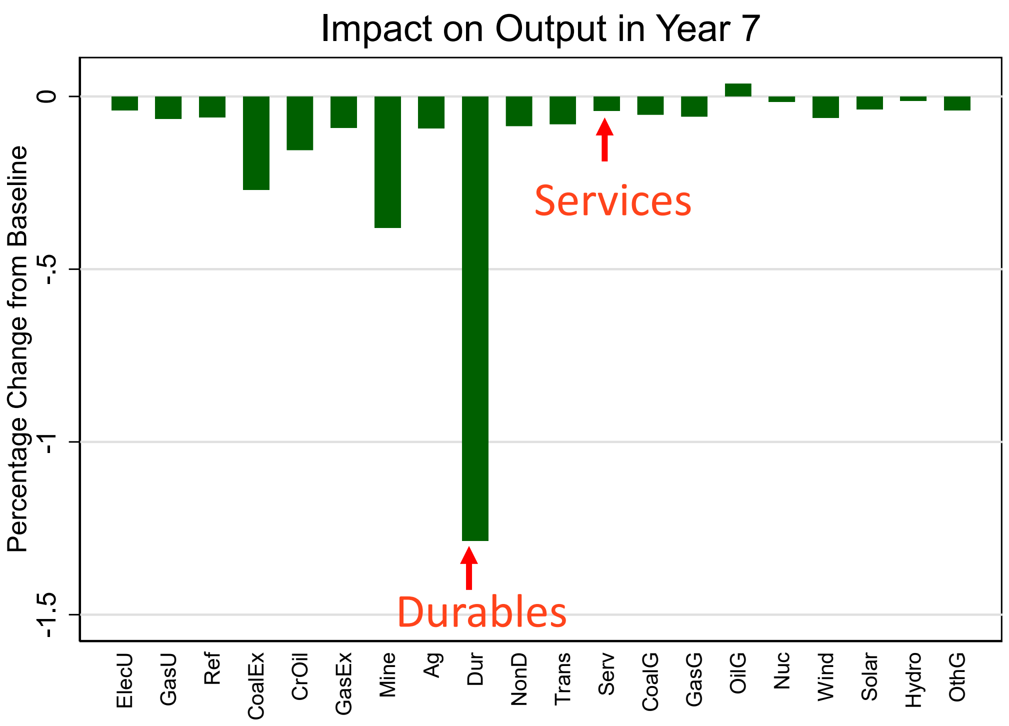
Unusual features of the model

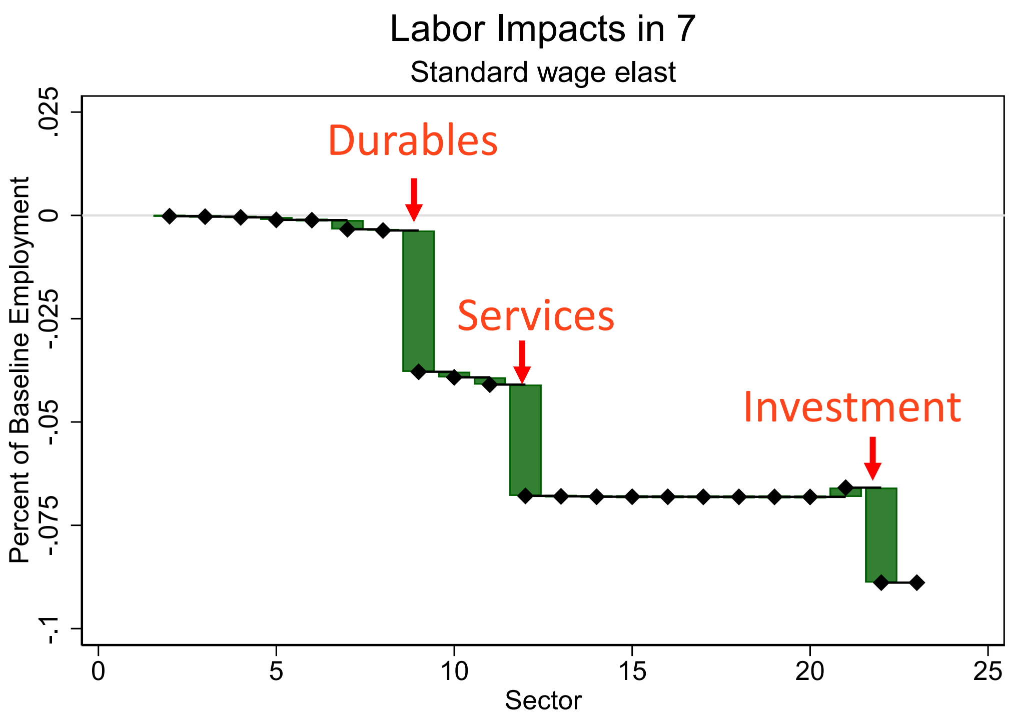
- Mix of intertemporal agents
  - 30% perfect foresight
  - 70% liquidity constrained
- Sector specific capital stocks
  - Adjustment cost model of investment
- Detailed treatment of financial markets
  - Equity in each sector
  - Government debt, international debt
  - Foreign currencies
  - Money supply and central bank policy
  - Risk premia on all financial assets
- Nominal wages adjust slowly
  - Unemployment can occur
  - Full employment in long run
- Full bilateral trade
  - Financial assets can also be traded
  - Capital inflows accumulate into debt
  - Debt repaid via trade surpluses

Impacts 2 years after decline

Shock raises cost of durables

- Demands for inputs decline
- Capital formation slows

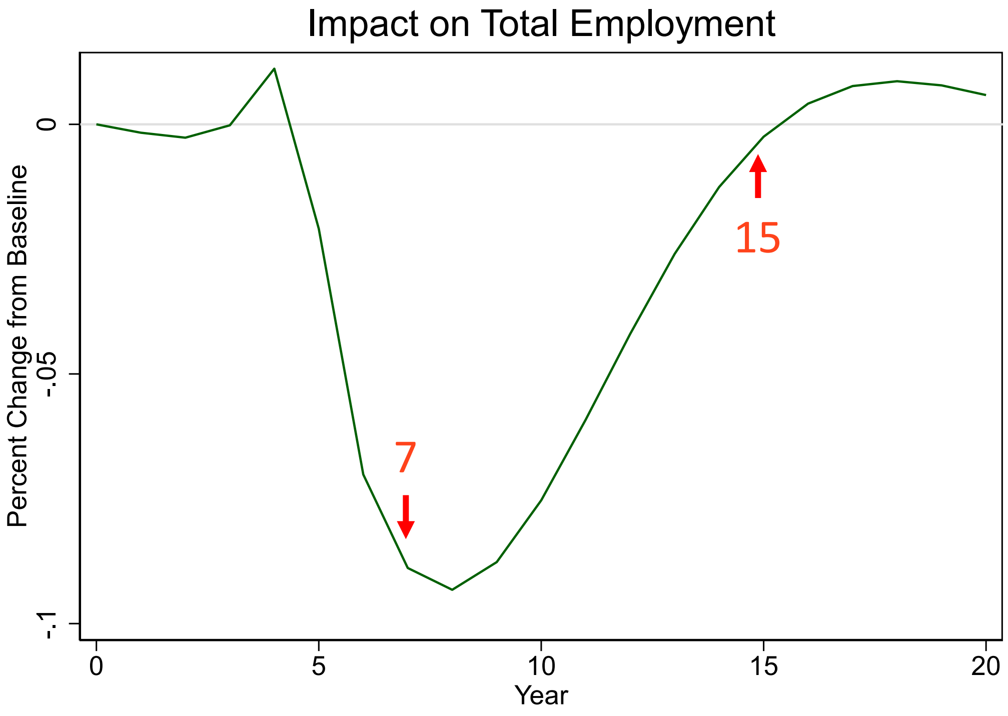


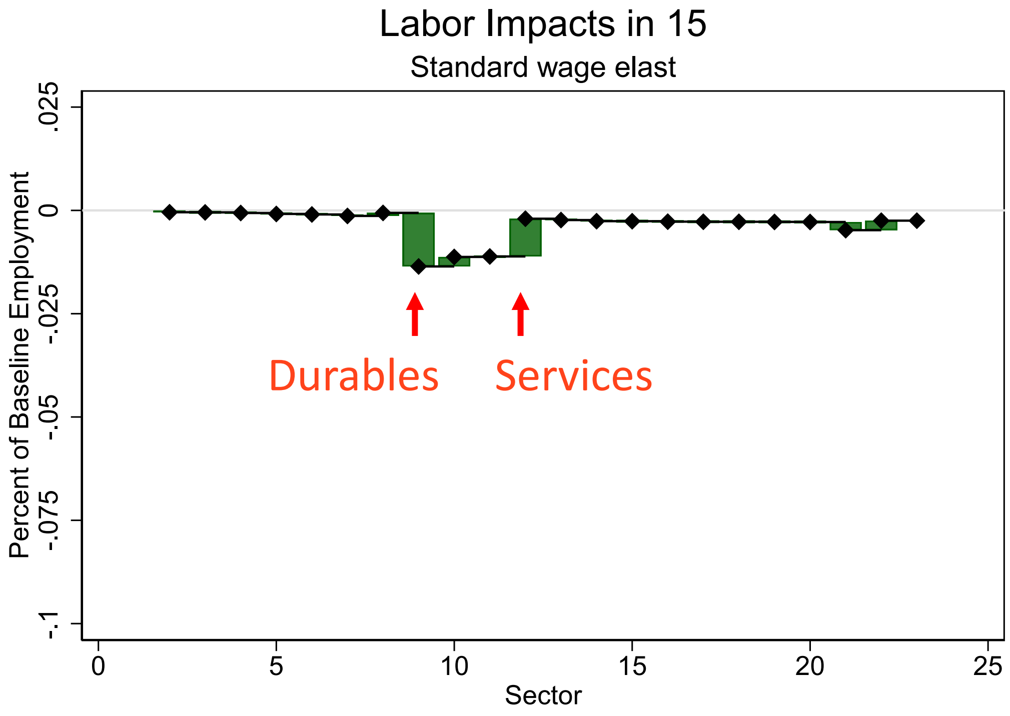


Impact varies considerably across sectors: not reflected well in aggregate results

Impact on employment over time

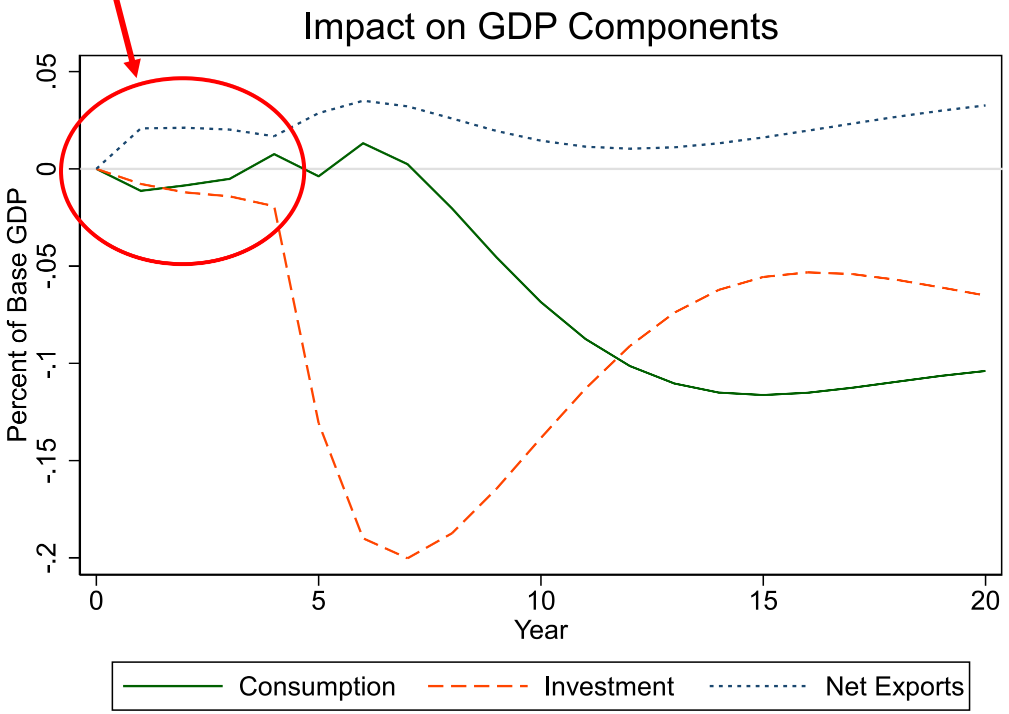
Permanent change in employment by industry

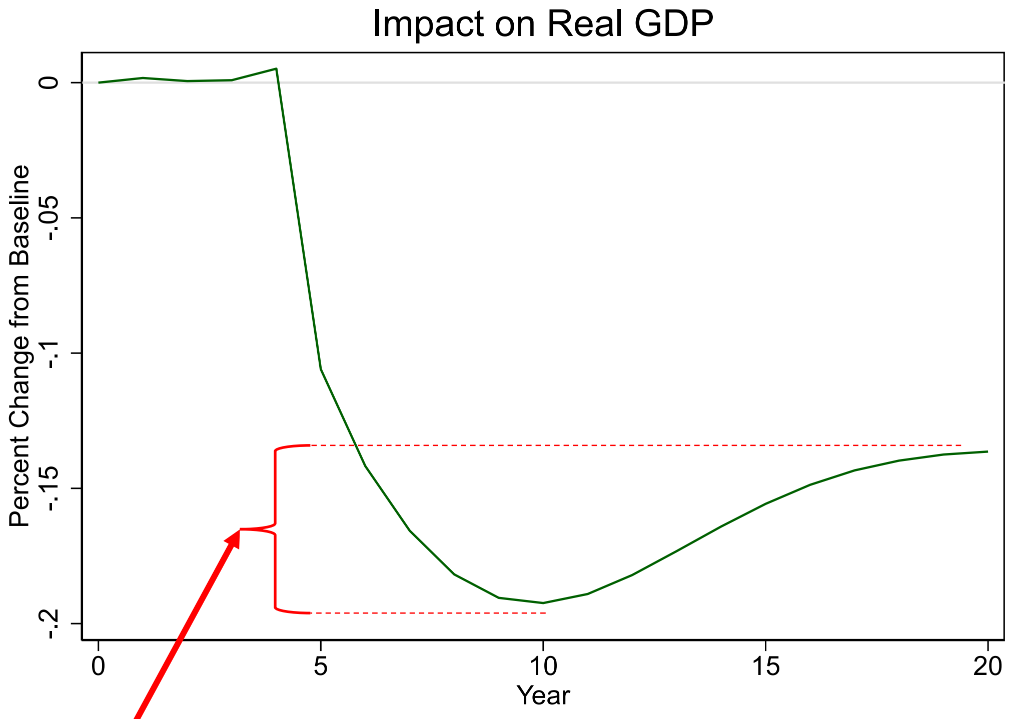




Impact on GDP and its components

Anticipation of policy





Impact of unemployment

Precision limited by parameter uncertainty

Parameters

Parameter	Value	Std. Error
α_1^p	-0.5299	0.0028
α_2^p	-0.2559	0.0043
α_3^p	-0.0165	0.0032
β_{11}^{pp}	-0.0158	0.0014
β_{12}^{pp}	-0.0237	0.0013
β_{13}^{pp}	0.0502	0.0009
…	…	…
β_2^{hm}	-0.0087	0.0004
β_3^{hm}	0.0051	0.0003

Covariance matrix

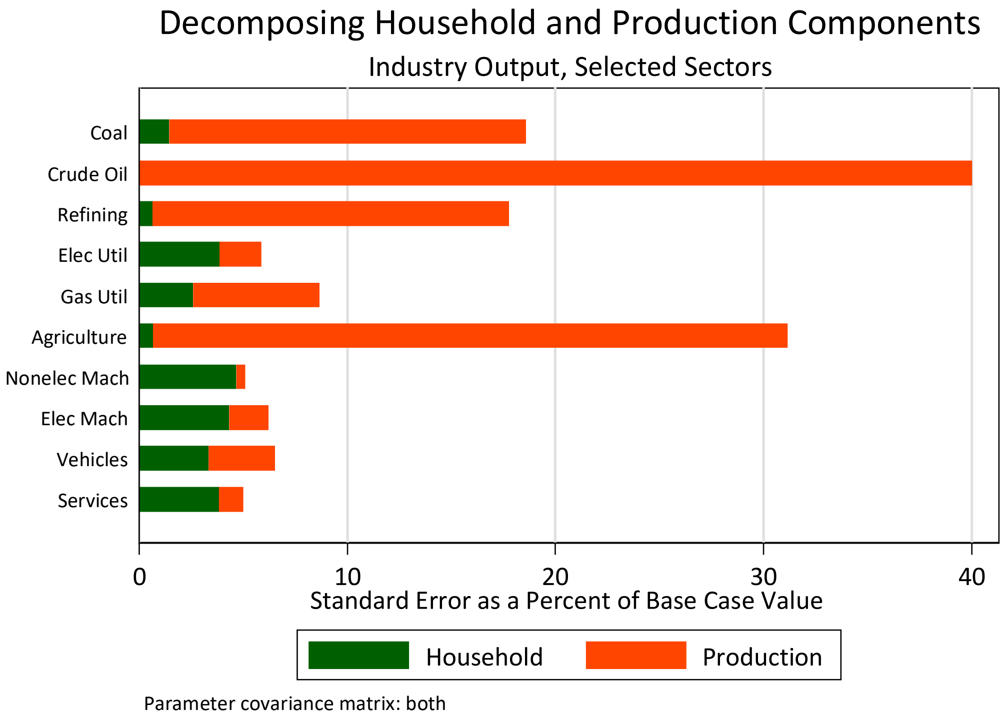
	α_1^p	α_2^p	α_3^p	β_{11}^{pp}	β_{12}^{pp}	β_{13}^{pp}	…	β_3^m
α_1^p	7.92E-06	1.30E-06	1.78E-06	-8.24E-07	-3.47E-07	4.21E-08	…	-1.54E-07
α_2^p		1.87E-05	7.43E-07	1.25E-07	-4.38E-07	6.78E-08	…	-6.03E-08
α_3^p			1.02E-05	-6.15E-08	7.96E-08	-2.48E-07	…	-8.80E-07
β_{11}^{pp}				1.97E-06	-2.30E-07	1.75E-07	…	-1.71E-09
β_{12}^{pp}					1.58E-06	-2.78E-07	…	-3.78E-09
β_{13}^{pp}						7.98E-07	…	-1.07E-08
…							…	…
β_3^m								8.20E-08

Household parameters in IGEM, a 35-sector model of the US

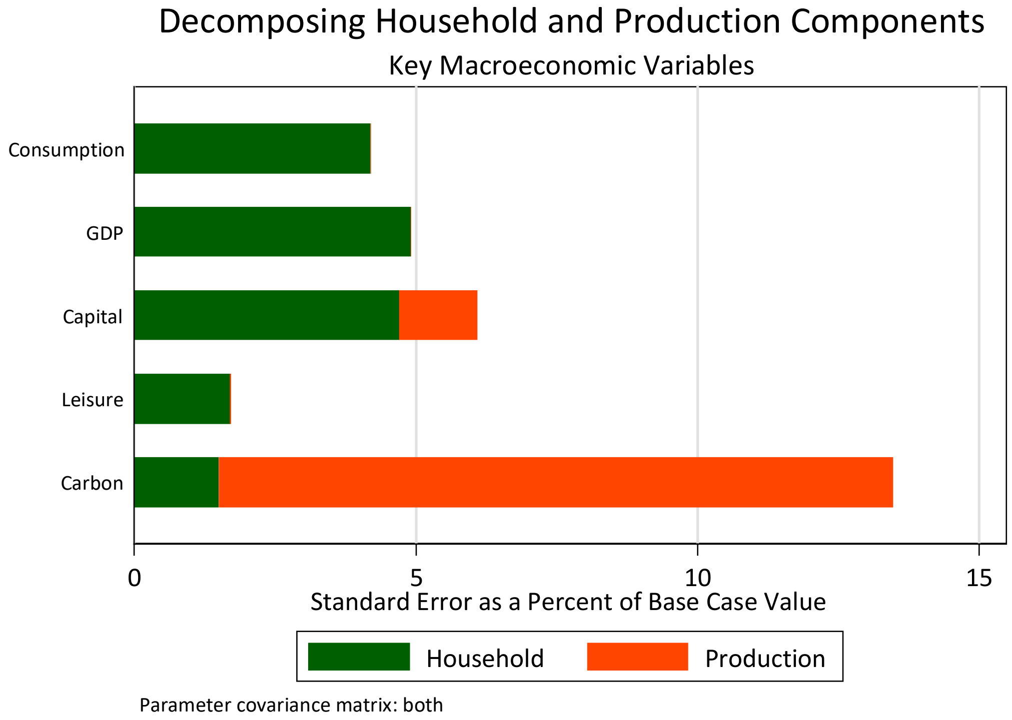
Implications for model results

Standard errors in results implied by parameter covariance

Industry output



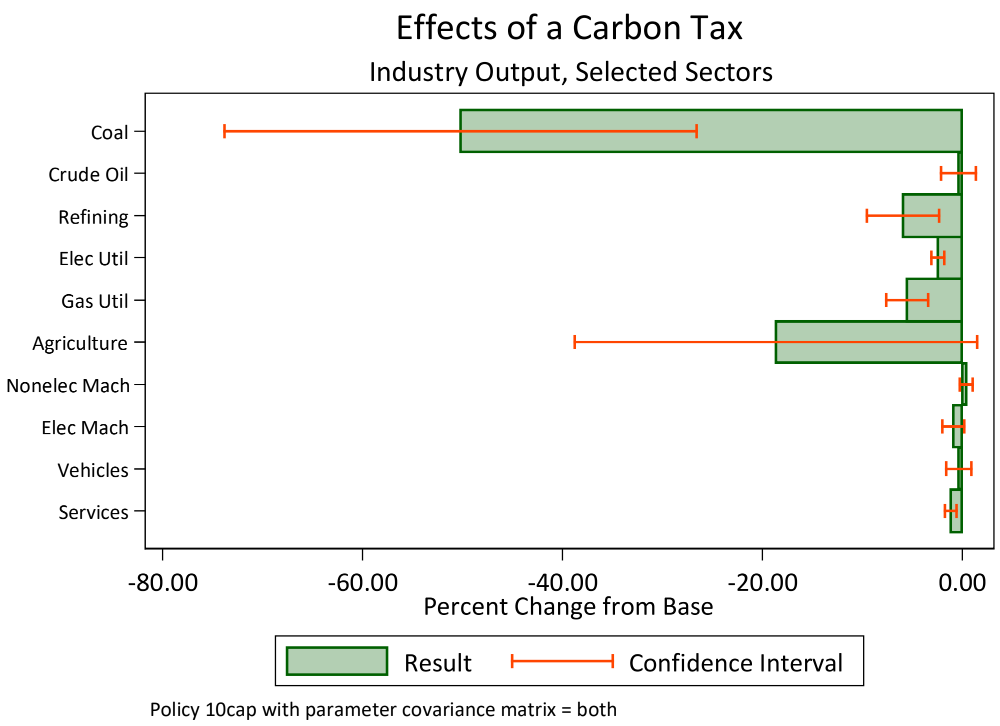
Macro variables



Production uncertainty can be large; macro uncertainty smaller and driven by household parameters

Confidence intervals for policy results

Industry output



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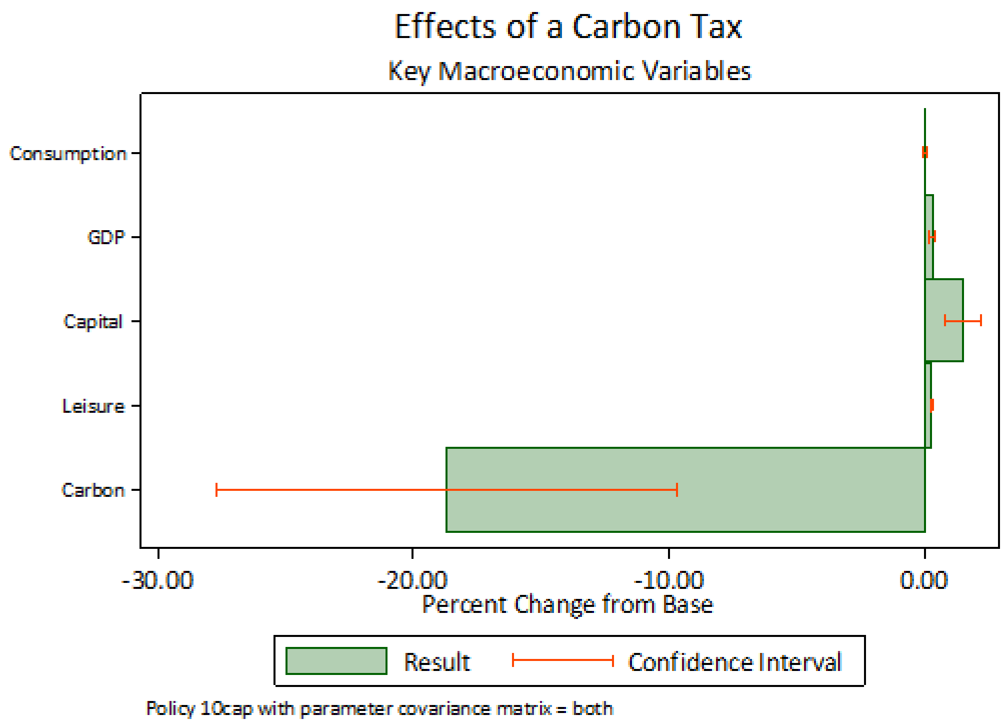

Results vary in significance. Also, differences between models may not be significant.

Challenges and research needs

- Modeling transition policies
  - Need high degree of energy sector detail
- Modeling climate impacts
  - Need high degree of geographic detail
- Capturing macroeconomic impacts
  - Need detailed treatment of labor markets and mobility
  - Need international trade and capital flows from interactions with policies abroad
  - Need risk premia on financial assets
- Will need to link models:
  - Data requirements and transparency needs preclude single model
- Need to be aware of uncertainty and limits on precision

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Questions?

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Selected references

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