Understanding Macro and Asset Price Dynamics During the Climate Transition

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Zoom Seminar, National Bank of Ukraine, 6 November 2020

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Motivation

Climate change has dramatic long-term consequences for the global economy, which should be priced by the market

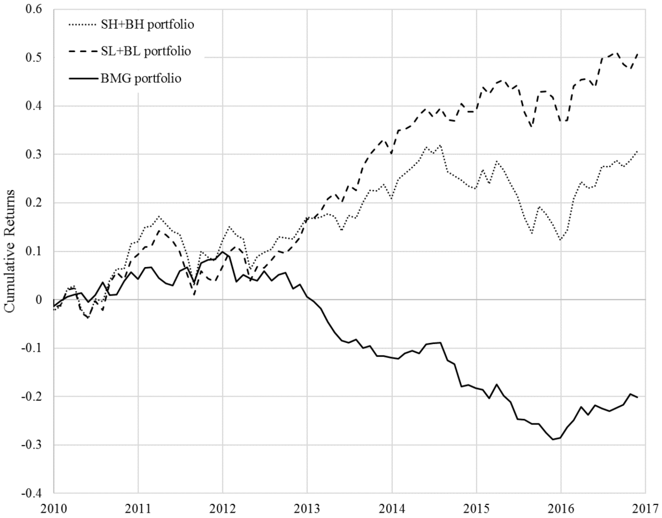
- negative effect on temperature-sensitive firms
- negative effect on “dirty” (greenhouse gas emitting) firms due to environmental policies

Our Paper

Focus on the pricing of climate change risks in the oil (fossil fuel, coal) sector

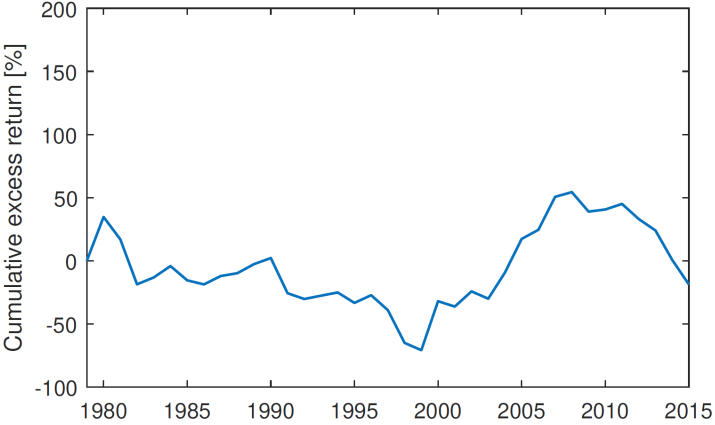
- advantage: fossil fuel firms are clearly “dirty” (negatively affected by environmental policies), no need for statistical categorization
- empirical analysis: do we see appropriate discounts for climate risks in the oil sector?
- economic model: what would asset pricing theory predict?

Carbon Risk Portfolio Returns



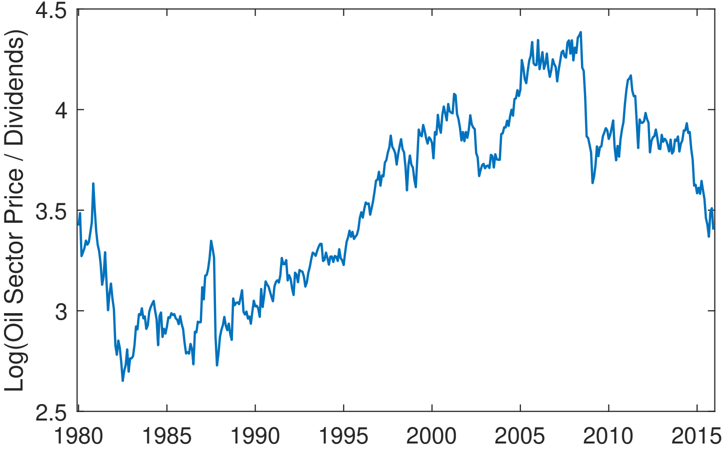
- Returns of a portfolio with large exposure to carbon risk (source: Görgen et al. 2018)

Oil-Minus-Market Returns



- Returns of a portfolio that buys oil sector firms (Fama-French classification) and sells the market (without oil)

Oil-Sector Price-Dividend Ratio



- Log price-dividend ratio of the U.S. oil sector

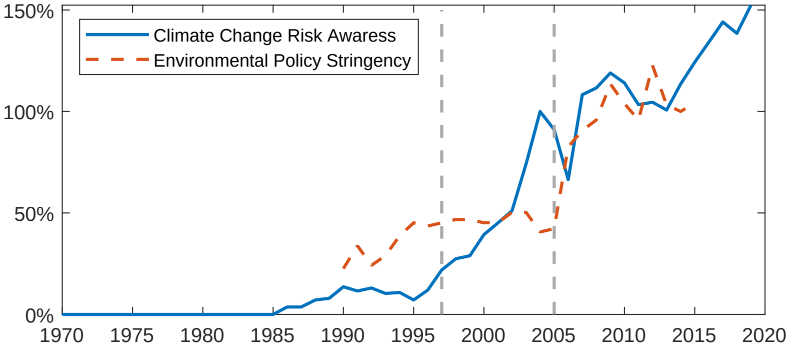
The Need for Thorough Empirical Analysis

- No clear picture based on oil-minus-market returns
- Price-dividend ratio relatively high, fell only since 2008 (coincident with bust of commodity price boom)
- Thorough empirical analysis needed (along the lines of Chen, Hou, and Stulz, 2015 or Minton, Stulz, and Taboada, 2019)
  - use market-to-book ratios as a valuation measure
  - employ panel regression setup to control for market-wide valuation trends and other important variables
  - analyze whether the oil sector's valuation has changed within the last 10–20 years (e.g., since 2005, coincident with the introduction of the Kyoto protocol)

Climate Policy Awareness

- The awareness of climate change and related risks has notably increased over the last 10 to 20 years
- As of now, according to World Bank (2019), about 20% of worldwide greenhouse gas emissions are covered by a carbon price, while this number was virtually 0% in the year 2000
- We construct a simple Climate Change Risk Awareness Index normalized to 100% in 2004 based on the number of occurrences of the term “climate change risk” in the literature and in search volumes on Google (data from Google Ngram on a yearly basis from 1970 to 2008 and data from Google Trends on a monthly basis from 2004)
- Existing measure of environmental policy stringency in the United States is provided by the OECD

Climate Policy Awareness (Cont'd)



Related Literature (Non-Exhaustive List)

- Balvers et al. (2017); Bansal et al. (2017): Positive temperature risk premia
- Oestreich and Tsiakas (2015); Görgen et al. (2018); In et al. (2018): Firm performance in relation to carbon emission intensity
- Ilhan et al. (2020): Higher tail risk of dirty firms
- Nordhaus (1992, 2006, 2008): Estimation of the social cost of carbon and optimal policy response to climate change risks using economic models
- Barnett (2018): Concentrates on the oil sector and climate policy uncertainty; his model predicts increased oil extraction, lower oil spot price, lower oil firm value in the presence of uncertain climate policy

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The Data

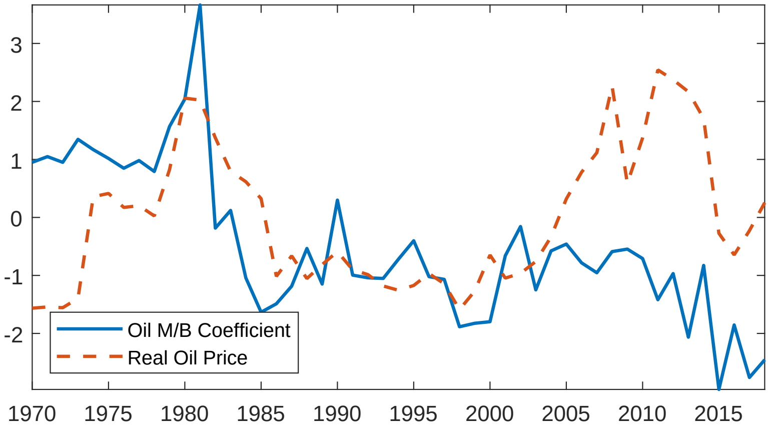
	mean	sd	min	p25	p50	p75	max
mtob	3.1183	12.6253	0.0059	0.9653	1.6340	2.9608	1000.0000
cash_ratio	1.5118	10.9443	-0.1198	0.1170	0.3550	1.1230	3031.0580
debt_assets	0.4793	0.2154	-0.3180	0.3178	0.4898	0.6330	11.6930
logat	5.0441	2.1877	-4.7105	3.4797	4.9020	6.5177	13.1841
rd_sale_1000	0.0017	0.1042	0.0000	0.0000	0.0000	0.00002	26.9570

- Data span: 1970–2018
- Standard CRSP/Compustat firm data set (about 4,000 firms on average)
- Variables:
  - mtob: market-to-book equity ratio
  - cash_ratio: cash to total assets
  - debt_assets: debt to total assets
  - logat: log of total assets
  - rd_sale_1000: rd expenditure to sales (times 1000)

Regressions: Fossil-Fuel Firms

	(1)	(2)	(3)	(4)	(5)	(6)
	mtob	mtob	mtob	mtob	mtob	mtob
fossil_dummy	-0.326	-0.298	-0.226	-0.326	-0.298	-0.226
	(-1.21)	(-1.08)	(-0.79)	(-1.21)	(-1.08)	(-0.79)
ccrai	0.0132***	0.0143***	0.0246***	0.0132***	0.0143***	0.0246***
	(5.19)	(5.68)	(9.33)	(5.18)	(5.67)	(9.32)
fossil_ia_ccrai	**-0.0131*****	**-0.0153*****	**-0.0115*****	**-0.0131*****	**-0.0152*****	**-0.0115*****
	(-3.68)	**(-4.31)**	**(-3.17)**	**(-3.68)**	**(-4.31)**	**(-3.17)**
cash_ratio		0.0258**	0.0217**		0.0258**	0.0217**
		(2.29)	(2.25)		(2.29)	(2.25)
debt_assets		5.165***	6.994***		5.167***	6.996***
		(8.55)	(9.91)		(8.56)	(9.91)
logat			-0.615***			-0.615***
			(-14.42)			(-14.42)
rd_sale_1000				0.244	0.391	0.314
				(1.31)	(1.61)	(1.56)
N	163972	163972	163784	163972	163972	163784

Year-Oil Sector Interaction Dummies



- Usage of same regression setup but with yearly dummies instead of the climate change risk awareness index
- Valuation stable from 1985 to 2005 and declining afterwards
- Correlation between Real Oil Price and Oil M/B Coefficient: 0.52*** from 1970 until 2000; 0.08 from 2001 until 2018

Robustness Checks

- Results hold if only oil firms are used in the regression
- Results become insignificant if only coal firms are used (very few coal firms in the sample)
- Results only marginally significant when OECD's Environmental Policy Stringency Index is used instead of CCRAI
- Results robust to inclusion of additional control variables:
  - real oil price
  - firm's return on assets
  - firm's return on equity
- When using absolute changes instead of levels for CCRAI and MTOB, results remain intact but become insignificant

Summary of Empirical Results

- Valuation of U.S. oil firms has declined since roughly 2005 relative to other firms
- These findings would be in line with
  - lower expected future cash flows due to stricter climate policies, which are not fully reflected by book equity
  - higher (future) risk premia leading to a current devaluation

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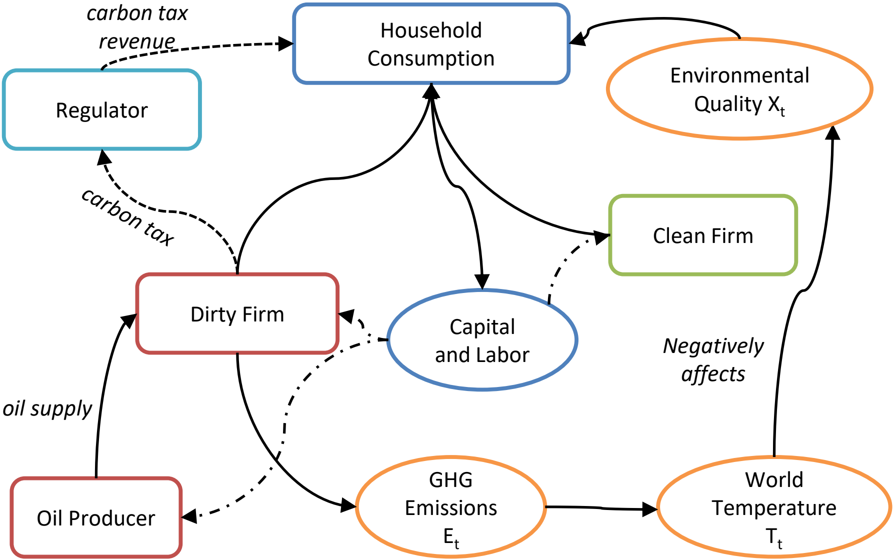
A Bird Eye's View on the Model



Households, Final and Intermediate Goods Sectors

- Households with Epstein-Zin preferences consume final goods and also obtain utility from environmental quality

$$v(C_t, X_t) = \left[(1-\theta)C_t^{1-\frac{1}{\rho}} + \theta(A_t X_t)^{1-\frac{1}{\rho}}\right]^{\frac{1}{1-\frac{1}{\rho}}}$$

$$V_t = \left[(1-\beta)v(C_t, X_t)^{1-\frac{1}{\psi}} + \beta\left(E_t[V_{t+1}^{1-\gamma}]\right)^{\frac{1-\frac{1}{\psi}}{1-\gamma}}\right]^{\frac{1}{1-\frac{1}{\psi}}}$$

- Environmental quality is negatively affected by rising temperatures in a non-linear fashion following Nordhaus (1992)

$$X_t = \frac{\bar{X}}{1 + \kappa_{x,1} T_t^{\kappa_{x,2}}}$$

- Households do not obtain utility from leisure, aggregate labor supply fixed

$$1 - \ell = L_{c,t} + L_{d,t} + L_{o,t}$$

- Capital is owned by households and rented out to the production sectors
- Capital creation is subject to convex adjustment costs

Final and Intermediate Goods Sectors

- Final goods are produced using intermediate goods from the clean and the dirty sector

$$Y_t = \left(Y_{c,t}^{1-\frac{1}{\epsilon}} + Y_{d,t}^{1-\frac{1}{\epsilon}} \right)^{\frac{1}{1-\frac{1}{\epsilon}}}$$

- Clean sector's production function

$$Y_{c,t} = (A_t L_{c,t})^{1-\alpha} K_{c,t}^{\alpha}$$

- Dirty sector's production function

$$Y_{d,t} = (A_t L_{d,t})^{1-\alpha} Z_t^{\alpha}$$
$$Z_t = \left((1-\iota) K_{d,t}^{1-\frac{1}{o}} + \iota O_t^{1-\frac{1}{o}} \right)^{\frac{1}{1-\frac{1}{o}}}$$

Oil Sector

- Oil is extracted at a constant rate κ_o from the stock of oil wells

$$O_t = E_t = \kappa_o U_t$$

- Therefore, we do not model oil inventories
- The number of oil wells accumulate according to

$$U_{t+1} = (1 - \kappa_o) U_t + N_t$$

- New oil wells are produced according to the following production function

$$N_t = (A_t L_{o,t})^{1-\tau} K_{o,t}^{\tau}$$

- Capital creation is subject to convex adjustment costs

Emissions and Temperature

- Dirty goods production causes greenhouse gas emissions according to the following accumulation equation:

$$\mathcal{E}_{t+1} = (1-\eta)\mathcal{E}_t + \frac{\xi_d}{A_t} \cdot Y_{d,t}.$$

- The parameter η controls reduction in greenhouse gas emissions due to natural processes
- The stock of greenhouse gas emissions affects temperature as follows:

$$T_{t+1} = \nu T_t + \chi \mathcal{E}_{t+1} + \sigma_T T_{t+1} \varepsilon^T_{t+1}.$$

- Temperature shocks are induced by ε^T_{t+1} and the volatility of these shocks increases with the level of temperature

Environmental Regulation

- The environmental regulator imposes a carbon tax τ_t on the dirty sector that is set at a fraction θ_t of the optimal tax τ_t^*

$$\tau_t = \theta_t \tau_t^*$$
$$\theta_t = (1-\rho_\theta)(1-\mu_\theta) + \rho_\theta \theta_t + \sigma_\theta \varepsilon_{t+1}^\theta$$

- Climate policy shocks are induced by ε_{t+1}^θ, allowing for an analysis of the effects of changing climate policy
- The optimal tax τ_t^* restores the social planner equilibrium
- The tax is paid by the dirty firms and thus shows up in the dividend definition

$$D_{d,t} = p_{d,t} Y_{d,t} - R_{d,t}^K K_{d,t} - \omega_t L_{d,t} - p_{o,t} O_t - \tau_t Y_{d,t}$$

- The tax revenues are transferred to the household (Pigouvian tax)

Model Variant: "Zero Awareness" Model

- We are interested in three time periods:
  1. the time before any awareness of climate change risks and zero carbon tax ("Zero Awareness" model / pre-transition period)
  2. the transition period from the "Zero Awareness" model to the "Full Awareness" model
  3. the time when climate change risks are fully accounted for and the temperature becomes stationary again at a higher level ("Full Awareness" model / post-transition period)
- The model just discussed can be calibrated to become the "Full Awareness" model
- To have a model that reflects the "Zero Awareness" time period, we make the following small adjustments to the model:
  1. exogenous temperature process ($\bar{T} = 0.425$):
  $$T_{t+1} = (1-\nu)\bar{T} + \nu T_t + \varepsilon^T_{t+1}$$
  2. set $\chi = 0$ so that emissions do not play a role in the model which implies an optimal carbon tax of 0 (it is like setting $\mu_\theta = 1$ and $\sigma_\theta = 0$)

Calibrated Parameters

Parameter		Value
Preferences		
Subjective discount factor	β	0.96
Relative risk aversion	γ	10
Intertemporal elasticity of substitution	ψ	2
Environmental quality share in utility bundle	θ	0.3
Elasticity of substitution between env. quality and consumption	ρ	0.4
Labor market		
Leisure share	ℓ	2/3
Production Sectors		
Elasticity of substitution between clean and dirty sector	ε	3
Capital share of intermediate goods production	α	0.31
Oil share in CES aggregate of capital and oil	ι	0.06
Elasticity of substitution between physical capital and oil	o	0.5
Capital share of oil wells production	τ	0.4
Oil extraction rate	κ_o	0.025
Depreciation rate of capital	δ	0.06
Average growth rate	μ	0.0227
Capital adjustment costs	ζ	12
Volatility of productivity risk	σ_A	0.0317

Calibrated Parameters (Cont'd)

Parameter		Value	
		Zero Awareness	Full Awareness
Emissions and Temperature			
(Perceived) climate sensitivity to emissions	χ	**0**	**0.1**
Emissions intensity of dirty sector	ξ_d	**0.15**	
Undamaged environmental quality level	$\bar{X}$	**0.1**	
Temperature-sensitivity of clean sector	$\kappa_{c,1}$	0.0144	
Temperature-sensitivity of clean sector	$\kappa_{c,2}$	2	
Carbon retention rate	ν	0.966	
Atmosphere recovery rate	η	0.02	
Volatility of temperature shocks	σ_T	0.0714	
Carbon Tax			
Average carbon tax relative to optimal tax	μ_θ	**1**	**0**
Persistence of carbon tax	ρ_θ	0.98	
Volatility of policy shocks	σ_θ	**0**	**0.025**

Simulated Moments

- The following moments are produced by the "Zero Awareness" Model
- The data column corresponds to moments in U.S. macroeconomic data for the period 1960–1995 (i.e. pre-transition period)

Moment	Data	Model
$E[I/Y]$	12.80	19.62
$E[p_d Y_d/(p_c Y_c + p_d Y_d + p_o O)]$	20.87	25.57
$E[p_c Y_c/(p_c Y_c + p_d Y_d + p_o O)]$	74.74	69.91
$E[p_o O/(p_c Y_c + p_d Y_d + p_o O)]$	4.39	4.51
$E[\Delta y]$	2.27	2.27
$\sigma(T)$	14.59	14.58
$\sigma(\Delta y)$	2.20	2.20
$\sigma(\Delta c)$	1.21	1.97
$\sigma(\Delta i)$	8.62	3.12

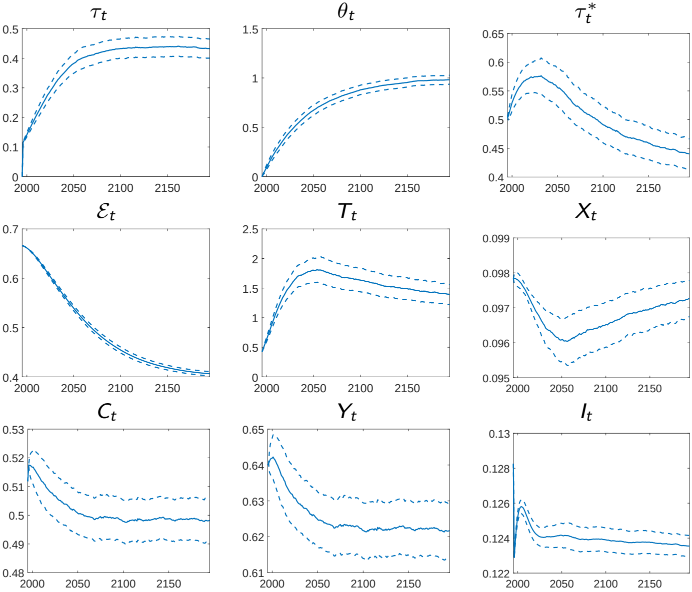
Transition Dynamics: Motivation

- The optimal carbon tax level has not been set yet by the policy makers
- What would our model predict if the carbon tax level increases to a higher level over time, alongside higher temperature levels?
- One can expect that this is going to happen over the next decades until at some point an optimal level of the carbon tax might be achieved and the equilibrium temperature has stabilized
- This transition period is of high interest as it probably corresponds to the present times

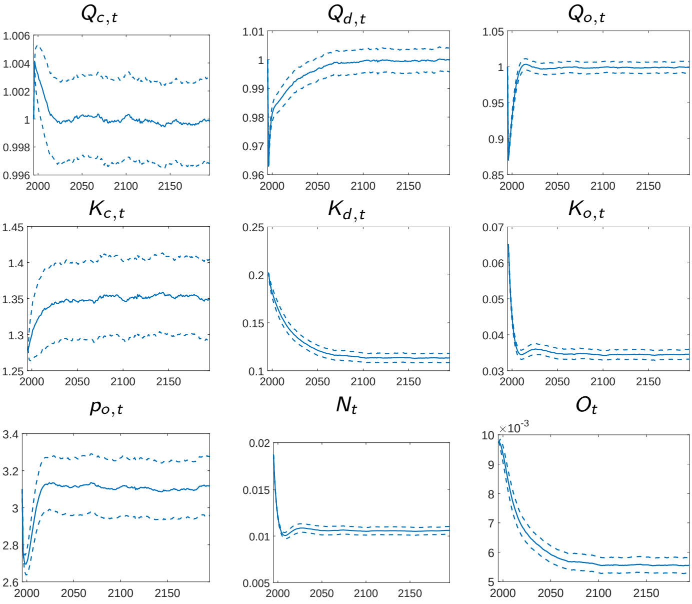
Transition Dynamics: Methodology

- We let the economy converge/transition from the "Zero Awareness" model (no carbon tax, emissions do not affect temperature) to the "Full Awareness" model (optimal carbon tax, emissions affect temperature)
- Therefore, we evaluate the macroeconomic and asset pricing effects of higher temperatures and a stricter climate policy
- We simulate 1,000 economies for 200 years each and depict the average paths in the following graphs
- Stochastic shocks are allowed to happen during the entire period

Transition Dynamics



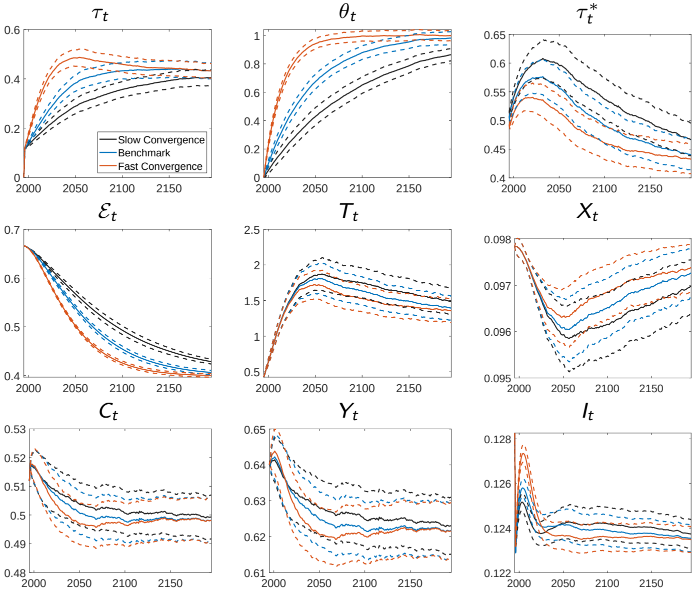
Transition Dynamics (Cont'd)



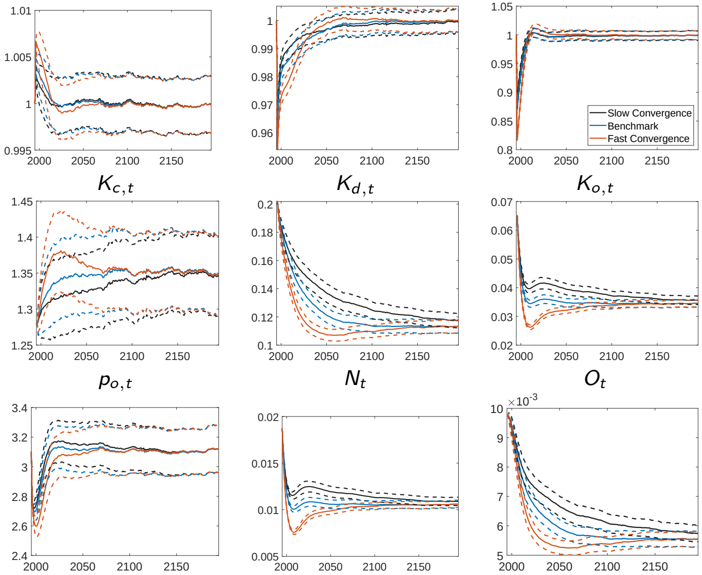
The Importance of the Speed of Transition

- The economic consequences of implementing the carbon tax might differ substantially across different speeds of transition to the optimal tax
- In our benchmark model it took on average around 200 years to reach optimal carbon taxation
- What are the economic and environmental consequences of slower of faster convergence?
- This is what we try to answer with the following sensitivity analysis:
  - Slow Convergence: $\rho_\theta = 0.99$
  - Benchmark: $\rho_\theta = 0.98$
  - Fast Convergence: $\rho_\theta = 0.95$

Transition Dynamics: Sensitivity w.r.t. ρ_θ



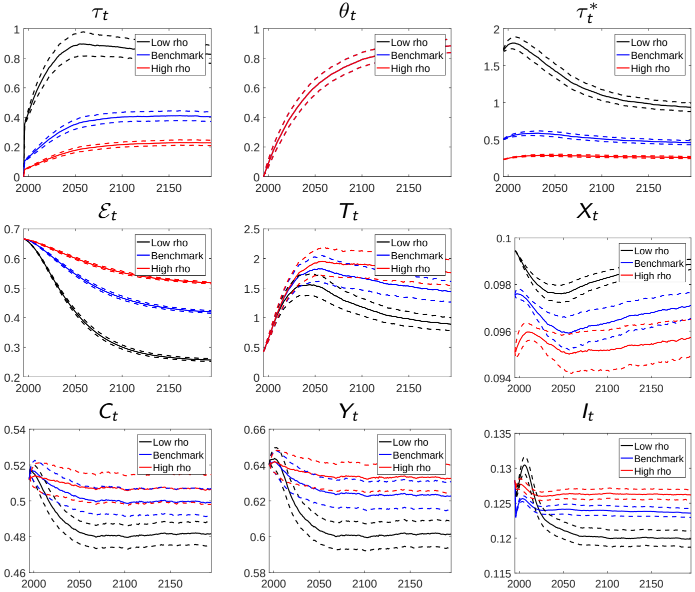
Transition Dynamics: Sensitivity w.r.t. ρ_θ



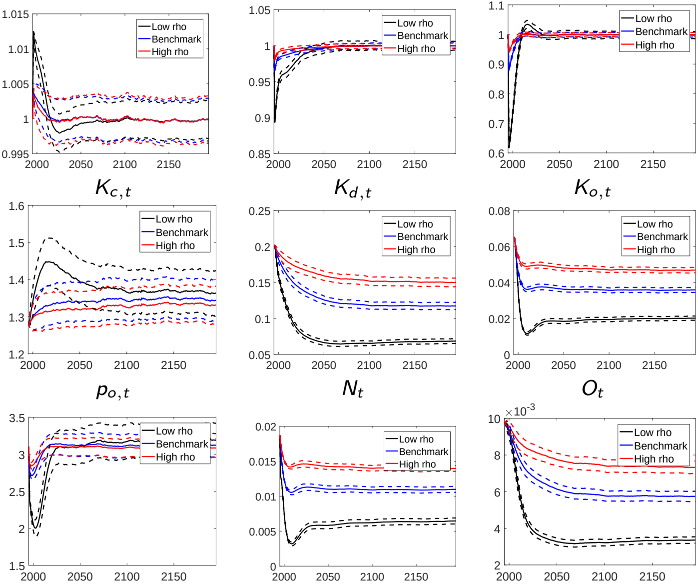
The Importance of the Elasticity of Substitution Between Consumption and Environmental Quality

- An important assumption in our model is the degree of complementarity between consumption of final goods and environmental quality
- If there was perfect substitutability between consumption goods and environmental quality, there would be not much of a climate change externality in our model
- What are the economic and environmental consequences of higher or lower complementarity?
- This is what we try to answer with the following sensitivity analysis:
  - Low rho: $\rho = 0.3$
  - Benchmark: $\rho = 0.4$
  - High rho: $\rho = 0.5$

Transition Dynamics: Sensitivity w.r.t. ρ



Transition Dynamics: Sensitivity w.r.t. ρ



Summary of Theoretical Results

- The “Zero Awareness” model reproduces U.S. macroeconomic data before 1995 relatively well
- The transition from the “Zero Awareness” to the “Full Awareness” economy is expected to lead to
  - reallocation of capital to the clean sector
  - declines in consumption and output, but also lower emissions
- Our sensitivity analysis reveals
  - faster convergence to the optimal carbon tax is more costly but limits the temperature increase and the optimal carbon tax level
  - complementarity in the utility bundle is of high importance to have pronounced macroeconomic and asset pricing effects

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Summary of Results and Outlook

- The conducted empirical analyses suggest that fossil fuel firms (oil and coal firms) lost value relative to other firms in the economy since 2005 due to a higher awareness of climate change risks
- The economic model incorporates a negative climate change externality from the consumption of dirty intermediate goods that are produced using oil and a regulator levying a carbon tax on dirty goods producers
  - the model is in line with our empirical findings and predicts a valuation decline of fossil fuel firms in the beginning of the transition period
  - the transition to a higher carbon tax leads to smaller dirty and oil sectors, but to a larger clean sector
- Future work:
  - do “green” investment trends play a role?