# Two Topics in Sustainable Finance: Climate Action and Gender Gap

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12. Weiterbildungstag der DGVFM: Sustainable Investments
27 Oct 2022

# Agenda: General

# Agenda: Environmental Aspect

# Agenda: Social Aspect

# Agenda: General

# ESG: Environmental, Social, and Corporate Governance

**Wikipedia**

ESG refers to frameworks designed to be integrated into an organization's strategy to create enterprise value by expanding the organizations objectives to include the identification, assessment and management of sustainability-related risks and opportunities in respect to all organizational stakeholders (including but not limited to customers, suppliers and employees) and the environment.

- Environmental aspect: focuses on preserving the natural world
- Social aspect: focuses on people and relationships include working to support diversity, equity, and inclusion movements
- Governance aspect: focuses on moving beyond how organizations have been typically governed in the past and enhance corporate governance

# This Talk

I will focus on **E** and **S**:

- Asset diversification versus climate action (with Christoph Hambel and Rick van der Ploeg), Working Paper, 2022.
- How well do women sell? (with Carina Fleischer und Farina Weiss), Working Paper, 2022.

# German Constitution: Grundgesetz

**Artikel 3**

(2) Männer und Frauen sind gleichberechtigt. Der Staat fördert die tatsächliche Durchsetzung der Gleichberechtigung von Frauen und Männern und wirkt auf die Beseitigung bestehender Nachteile hin.
(3) Niemand darf wegen seines Geschlechtes, seiner Abstammung, seiner Rasse, seiner Sprache, seiner Heimat und Herkunft, seines Glaubens, seiner religiösen oder politischen Anschauungen benachteiligt oder bevorzugt werden. Niemand darf wegen seiner Behinderung benachteiligt werden.

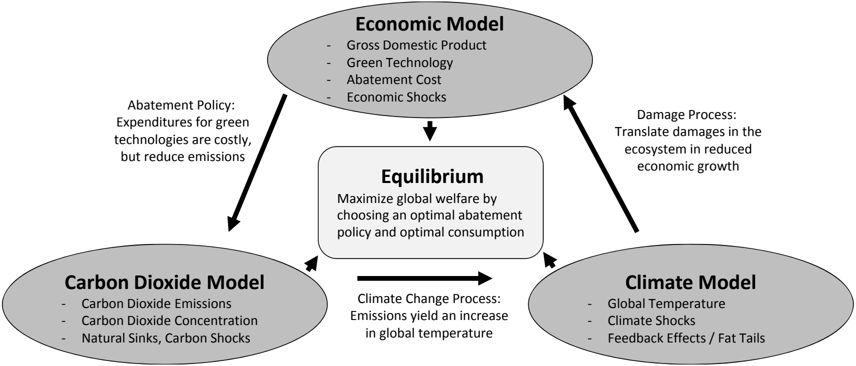
**Artikel 20a**

Der Staat schützt auch in Verantwortung für die künftigen Generationen die natürlichen Lebensgrundlagen und die Tiere im Rahmen der verfassungsmässigen Ordnung durch die Gesetzgebung und nach Massgabe von Gesetz und Recht durch die vollziehende Gewalt und die Rechtsprechung.

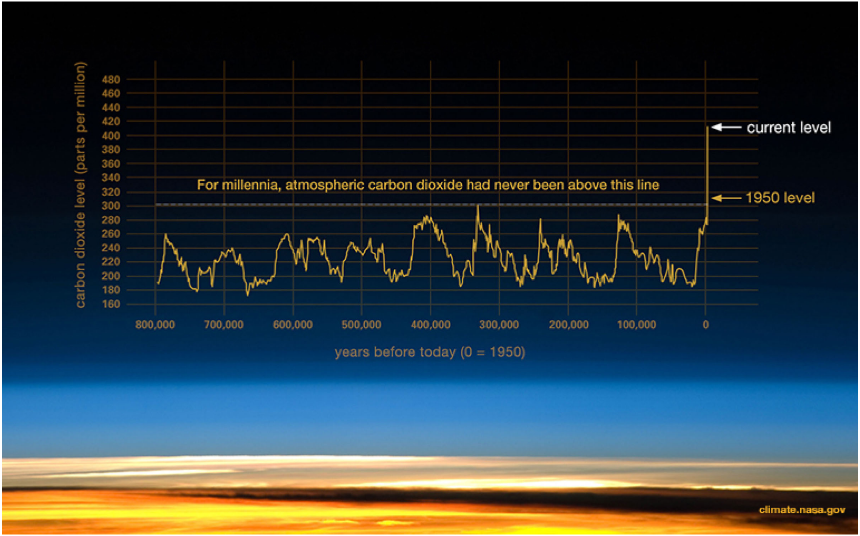
- Green factor
- Gender factor?

**First:** I summarize some facts about climate finance/economics

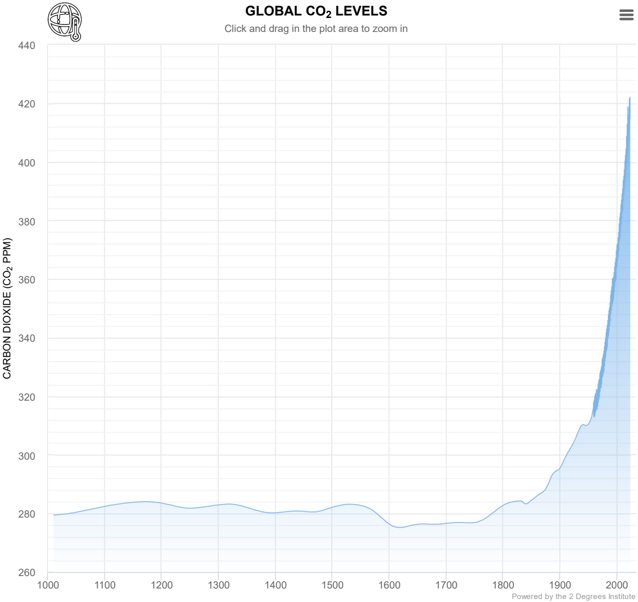
# Integrated Assessment Models



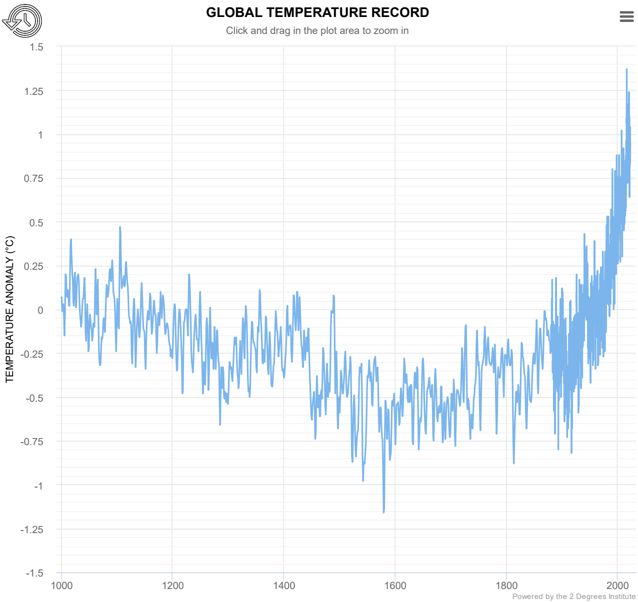
# $C0_2$ Concentration over 800,000 Years



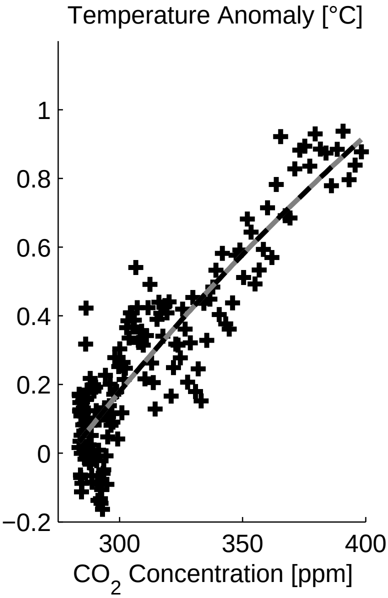
# $C0_2$ Concentration over 1000 Years



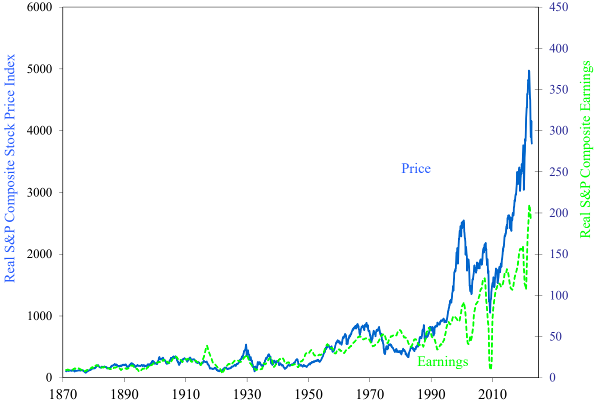
# Temperature over 1000 Years



# $CO_2$ Concentration and Temperature

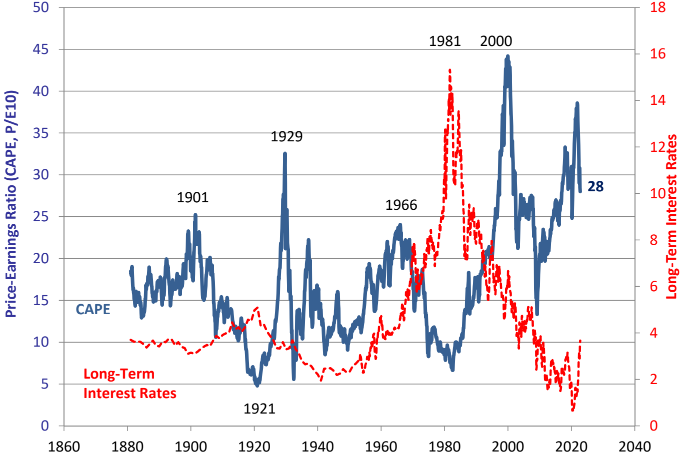


# Stock Markets: Price vs. Earnings




Stock Prices and Earnings of the S&P 500, 1871-2022.06 (Source: Robert Shiller's Homepage )

# Price-Earnings Ratio and Interest




PE-Ratio of S&P 500 and 10-Year Treasury Constant Maturity Rate (GS10), 1871-2022.06 (Source: Robert Shiller's Homepage)

# Empirical Asset Pricing

- Fama-French Model as workhorse model
- 3 Factors: market, value, size
- Extensions: momentum, ...
- Kenneth French's website is a treasure!

# Kenneth French's Website

Kenneth R. French - Data Librar | Bureau of Labor Statistics Data

https://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html   150%

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## Current Research Returns

In September 2021, we transitioned from using our proprietary links between CRSP and Compustat data to those provided by CRSP after examining their consistency. We also updated the eligible universe through time to apply time-sensitive evaluation of stocks on criteria such as whether they are investment funds.

| | August 2022 | Last 3 Months | Last 12 Months |
|---|---|---|---|
| **Fama/French 3 Research Factors** | | | |
| Rm-Rf | -3.78 | -3.47 | -14.93 |
| SMB | 1.39 | 6.29 | -6.18 |
| HML | 0.31 | -9.88 | 24.43 |
| **Fama/French 5 Research Factors (2x3)** | | | |
| Rm-Rf | -3.78 | -3.47 | -14.93 |
| SMB | 1.51 | 4.68 | -2.73 |
| HML | 0.31 | -9.88 | 24.43 |
| RMW | -4.80 | -2.29 | 10.29 |
| CMA | 1.31 | -10.00 | 18.72 |
| **Fama/French Research Portfolios** | | | |
| **Size and Book-to-Market Portfolios** | | | |
| Small Value | -2.23 | -5.62 | -1.06 |

# Factors: Market, Value, Size

The annual averages on the factors are

| | Market | Value | Size | real_rf |
|---|---|---|---|---|
| 1927-2021 | 8.87 | 4.22 | 3.02 | 0.28 |
| 1927-1979 | 8.36 | 5.36 | 4.67 | -0.25 |
| 1980-2021 | 9.51 | 2.77 | 0.94 | 0.95 |

- Value and size have become weaker!
- At the same time researchers have found more than 100 additional factors that might be pricing relevant

# Factor Zoo and Priced Factors

- Ivol anomaly
- Default anomaly
- Growth anomaly
- Betting against beta
- ...

**Question**

Are carbon emissions by a firm another priced factor?

# Do Investors Care about Carbon Risk?

## Bolton and Kacperczyk (2021, JFE)

- Stocks of firms with higher total CO2 emissions earn higher returns ("sin stocks")
- Investors are already demanding compensation for their exposure to carbon emission risk

**Why?**

- Preference related explanations
- Policy tipping (stranded assets)

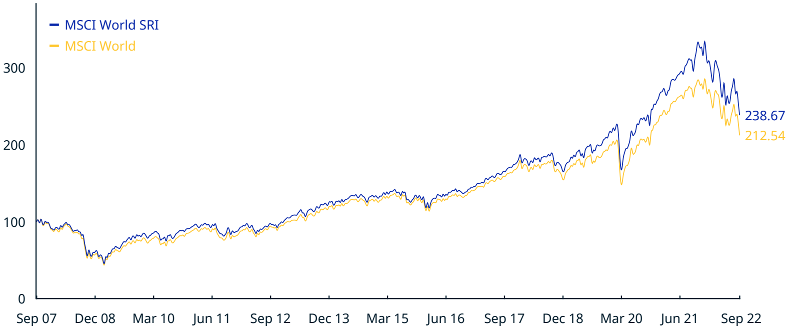
# Carbon Premium

- There will always be small and big firms
- There will always be growth and value firms
- So there could potentially be value and size premia
- However, if we decarbonize the economy, then there will not be any carbon-emitting firms
- Eventually, there is no room for a carbon premium

# MSCI World SRI Index vs. MSCI World Index

MSCI World SRI Index includes large and mid-cap stocks across 23 Developed countries. It provides exposure to firms with outstanding ESG ratings and excludes firms whose products have negative social/environmental impacts

**CUMULATIVE INDEX PERFORMANCE — GROSS RETURNS (USD) (SEP 2007 – SEP 2022)**




SRI: Socially Responsible Investment (SRI). Source: MSCI

# MSCI World SRI vs. MSCI World: Annual Returns

| | SRI | All | SRI-All |
|---|---|---|---|
| 2021 | 27.62 | 22.35 | 5.27 |
| 2020 | 20.48 | 16.5 | 3.98 |
| 2019 | 30.54 | 28.4 | 2.14 |
| 2018 | -6.17 | -8.2 | 2.03 |
| 2017 | 24.34 | 23.07 | 1.27 |
| 2016 | 8.36 | 8.15 | 0.21 |
| 2015 | -1.05 | -0.32 | -0.73 |
| 2014 | 4.45 | 5.5 | -1.05 |
| 2013 | 28.04 | 27.37 | 0.67 |
| 2012 | 13.95 | 16.54 | -2.59 |
| 2011 | -5.01 | -5.02 | 0.01 |
| 2010 | 11.17 | 12.34 | -1.17 |
| 2009 | 33.1 | 30.79 | 2.31 |
| 2008 | -37.6 | -40.33 | 2.73 |
| Av | 10.87 | 9.80 | 1.08 |
| Av 08-14 | 6.87 | 6.74 | 0.13 |
| Av 15-21 | 14.87 | 12.85 | 2.02 |

**There is "something dynamic" going on**

# Agenda: Diversification vs. Climate Action

# Intro: Asset Diversification versus Climate Action

- Climate change impacts all areas of human life.
- It also impacts economic activity.
- To avoid carbon-dioxide emissions, emissions-free technologies and renewable energies are developed
- There are different opinions about how urgent it is to transition to a less carbon-intensive economy.
- We are interested in the **interplay between financial considerations and policies to mitigate climate change**

## Two Key Questions

- First, does the financial need to diversify assets hamper or help the fight against climate change?
- Second, how does climate change affect the pricing of green and dirty assets?

We document a dynamic interdependence between the financial goal to diversify assets and the environmental goal to reduce carbon emissions.

# Economic Model and Carbon Dioxide Model

- Stochastic macroeconomic growth model with **two capital stocks** and **two energy sources**.
- The **green** sector takes a carbon-free energy form as input (green energy)
- The **dirty** sector is carbon-intensive and production requires fossil fuel whose combustion leads to carbon emissions.
- **Investments and capital reallocation** from the dirty to the green capital stock are both subject to adjustment costs.
- **Emissions** are proportional to fossil fuel use.

# Climate Model

- Exploiting recent advances in climate science, we assume that **global temperature** is **proportional to cumulative emissions**.
- We allow for **three potential channels** for the effect of climate change on economic activity.
  - First, higher temperature leads to higher share of damages in pre-damage **level** of output as in the seminal DICE model.
  - Second, higher temperatures might negatively affect the **growth rate** of capital
  - Third, higher temperatures may increase the Poisson risk of a **climate-related disaster**

# Main Findings: Diversification vs. Climate Action

- We establish a **crucial dynamic relation** between **climate action** and the **economic motive to diversify**.
- **Initially**, the dirty capital stock dominates the economy
- Thus there are **two complementary goals**:
  - the first one is to mitigate climate change and thus to decarbonize the economy
  - the second goal is to diversify the economy, which is a purely financial goal.
- Both goals incentivize the agent to actively reduce the dirty capital stock.
- The speed of the transition towards a zero-emissions economy is thus amplified by the diversification motive.
- Over time, however, the two **goals become conflicting** and a trade-off arises.

# Main Findings: Diversification vs. Climate Action

- From a **diversification perspective**, the process should be stopped if there is a balance between green and dirty capital.
- From an **environmental perspective** the dirty capital stock should eventually be run down completely.
- Our various calibrations show that this does not occur unless climate change is perceived as extremely severe (relative to the global warming damages allowed for in well-established models such as the DICE model by Nordhaus).
- Effectively, **diversification** considerations **prevent** the agent from driving the **carbon-intensive capital stock to zero**.

# Main Findings: Equilibrium Riskfree Rate and Risk Premia

- We analyze the dynamics of the risk-free rate and risk premia during the transition from a carbon-intensive towards a zero-emissions economy.
- To separate economic from climate effects, our model involves the risk of **macroeconomic disaster shocks** as in Barro (2006).
- Therefore, our model can generate a **high equity premium** and a **low risk-free rate** as observed in historical data
- For an economy affected by **climate change** our findings are different:
  - Regardless of how climate change affects the economy, the **risk-free interest** rate **decreases** in response to rising temperatures.
  - By contrast, **risk premia** are only significantly affected if we allow for potential **climate disasters** for which the probability of them occurring increases with temperature.
  - Without such disasters, the impact on risk premia is moderate.

# Agenda: Diversification vs. Climate Action

# Production of Goods

- Final goods can be produced in **two sectors**
- The outputs of these two sectors are **perfect substitutes**
- There are a **green** and **dirty** sector.
- Outputs of both sectors are given by the **Cobb-Douglas** production functions

$$Y_n = A_n K_n^{1-\eta_n} F_n^{\eta_n} \Lambda_n(T), \qquad n = 1, 2,$$

- $K_n$ is the capital stock of sector $n$
- $T$ denotes the global average temperature increase measured relative to the beginning of the industrial revolution.
- The rate of energy use in sector $n$ is denoted by $F_n$
- $F_1$ **green energy** and $F_2$ **fossil fuel use**
- Since the two final goods are perfect substitutes in consumption, aggregate output is $Y = Y_1 + Y_2$.

# Investments in Green and Dirty Capital

**Capital stock dynamics** of green and dirty sector are given by

$$\begin{aligned}
\mathrm{d}K_1 &= \Big(I_1 - \frac{1}{2}\phi_1\frac{I_1^2}{K_1} + R - \frac{1}{2}\kappa\frac{R^2}{K_1} - (\delta_1^k + \xi_1 T)K_1\Big)\mathrm{d}t + K_1\sigma_1\mathrm{d}W_1 \\
&\quad - K_{1-}\Big(\ell_e\mathrm{d}N_e + \ell_c\mathrm{d}N_c\Big), \\
\mathrm{d}K_2 &= \Big(I_2 - \frac{1}{2}\phi_2\frac{I_2^2}{K_2} - R - (\delta_2^k + \xi_2 T)K_2\Big)\mathrm{d}t + K_2\sigma_2\mathrm{d}W_2 \\
&\quad - K_{2-}\Big(\ell_e\mathrm{d}N_e + \ell_c\mathrm{d}N_c\Big)
\end{aligned}$$

- $\phi_n$, $n = 1, 2$, are the investment adjustment cost parameters
- $\kappa$ is the capital reallocation cost parameter
- $W_1$ and $W_2$ are two correlated Brownian motions
- $N_e$ and $N_c$ are two independent point process capturing economic and climate disaster risk
- $\lambda_e$ constant, $\lambda_c = \lambda_c(T)$ can be temperature dependent

# Damage Specifications in the Literature

Example. Green sector, dirty sector analogously

$$Y_1 = A_1 K_1^{1-\eta_1} F_1^{\eta_1} \boldsymbol{\Lambda_1(T)}$$

$$\begin{aligned} \mathrm{d}K_1 = &\Big(I_1 - \frac{1}{2}\phi_1 \frac{I_1^2}{K_1} + R - \frac{1}{2}\kappa \frac{R^2}{K_1} - (\delta_1^k + \xi_1 T) K_1\Big)\mathrm{d}t + K_1 \sigma_1 \mathrm{d}W_1 \\ &- K_{1-}\Big(\ell_e \mathrm{d}N_e + \ell_c \mathrm{d}N_c\Big), \end{aligned}$$

- **Level** impact
- **Growth rate** impact
- **Disaster** impact

# Emissions and Temperature

- Following Allen et al. (2009), Matthews et al. (2009), and IPCC (2014), among others, we assume that global average **temperature** $T$ is **driven by cumulative emissions** $E_t = \int_0^t \varepsilon_s \mathrm{d}s$ measured in gigatons of carbon (GtCs)

$$T_t = T_0 + \vartheta E_t + \int_0^t \sigma_T(T_s)\mathrm{d}W_{3s},$$

- $T_0$ is the current temperature and $\vartheta$ denotes the transient climate response to cumulative emissions (TCRE).
- $W_3$ denotes a third standard Wiener process that is independent of $W_1$ and $W_2$.
- The diffusion coefficient $\sigma_T$ might potentially increase in temperature to capture unpredictable positive feedback loops in the climate system.

# Emissions and Temperature

**Current emissions** are

$$\varepsilon = \nu F_2$$

where

- $F_2$ is the rate of fossil use in energy units
- $\nu = \nu(t, T, K_1, K_2)$ **emission intensity** per unit of fossil fuel (state dependent and might depend on technological progress)

Consequently,

**Temperature Dynamics**

$$\mathrm{d}T = \beta F_2 \mathrm{d}t + \sigma_T \mathrm{d}W_3,$$

where $\beta = \vartheta\nu$ depends on $t$, $T$, $K_1$, and $K_2$.

- We calibrate emission intensity such that BAU emissions are close to uncontrolled path in DICE
- Also $\varepsilon = 0$ if $K_2 = 0$, i.e., there are no carbon emissions if the dirty capital stock has been fully phased out

# Dividends, Consumption, and Preferences

- The dividend of a sector is defined as the sector's residual cash flow net of investments and energy costs,

$$D_n = Y_n - I_n - b_n F_n,$$

  where
  - $b_1$ denotes the cost of one unit of renewable energy
  - $b_2$ the cost of one unit of fossil fuel
- In **equilibrium**, aggregated dividends must equal aggregate consumption, i.e.,

$$C = D_1 + D_2.$$

# Dividends, Consumption, and Preferences

- We assume that our economy is populated by a representative agent with recursive preferences:

$$J(t, K_1, K_2, T) = \sup_{I_1, I_2, R, F_1, F_2} \mathbb{E}_t \Big[ \int_t^\infty f(C_s, J(s, K_{1s}, K_{2s}, T_s) \mathrm{d}s \Big],$$

  where $f$ is an EZ aggregator with unit EIS

- For unit EIS and an arbitrary level of risk aversion $\gamma$, this aggregator takes the form

$$f(C, J) = \delta(1-\gamma) J \log \left( \frac{C}{[(1-\gamma)J]^{\frac{1}{1-\gamma}}} \right)$$

  where $C$ denotes consumption and $\delta$ the rate of time impatience.

# Bellman Equation

The value function $J = J(t, K_1, K_2, T)$ satisfies

$$
\begin{aligned}
0 = \max_{I_1, I_2, R, F_1, F_2} \Big\{ & J_t + \delta(1-\gamma) J \log\left( \frac{Y_1 + Y_2 - I_1 - I_2 - b_1 F_1 - b_2 F_2}{[(1-\gamma)J]^{\frac{1}{1-\gamma}}} \right) + J_T \beta F_2 \\
& + \frac{1}{2} J_{TT} \sigma_T^2 + J_{K_1} \left( I_1 - \frac{1}{2}\phi_1 \frac{I_1^2}{K_1} + R - \frac{1}{2}\kappa \frac{R^2}{K_1} - (\delta_1^k + \xi_1 T) K_1 \right) + \frac{1}{2} J_{K_1 K_1} K_1^2 \sigma_1^2 \\
& + J_{K_2} \left( I_2 - \frac{1}{2}\phi_2 \frac{I_2^2}{K_2} - R - (\delta_2^k + \xi_1 T) K_2 \right) + \frac{1}{2} J_{K_2 K_2} K_2^2 \sigma_2^2 + J_{K_1 K_2} K_1 K_2 \sigma_1 \sigma_2 \rho_{12} \\
& + \lambda_e \mathbb{E}[J(K_1(1-\ell_e), K_2(1-\ell_e), T) - J] \\
& + \lambda_c(T) \mathbb{E}[J(K_1(1-\ell_c), K_2(1-\ell_c), T) - J] \Big\}
\end{aligned}
$$

## Solution (Separation)

The solution to the HJB equation has the following form

$$
J(t, K_1, K_2, T) = \frac{1}{1-\gamma} (K_1 + K_2)^{1-\gamma} G(t, T, S(K_1, K_2)) = \frac{1}{1-\gamma} K^{1-\gamma} G(t, T, S),
$$

where the reduced-form value function $G$ satisfies a PDE

# Optimal Investment

- Optimal **investment** in sector $n \in \{1, 2\}$ reads

$$I_n = \frac{K_n}{\phi_n}\left(1 - \frac{1}{q_n}\right),$$

where $\phi_n$ is strength of the adjustment costs and

$$q_n = \frac{C}{\delta(1-\gamma)}\frac{J_{K_n}}{J}$$

is **Tobin's Q** of sector $n$.

- Investment rates are
  - small if adjustment costs are high
  - large if the sectoral Tobin's Q is high
- The sectoral Tobin's Q is bigger than one, since installing capital is costly

# Optimal Reallocation

- The optimal **reallocation** from dirty to green capital is

$$R = \frac{K_1}{\kappa}\left(1 - \frac{q_2}{q_1}\right).$$

- Rate at which carbon-intensive capital is converted into carbon-free capital is proportional to carbon-free capital stock.
- Reallocation
  - decreases in the Tobin's Q of the dirty sector
  - increases in the Tobin's Q of the green sector.
- This conversion rate is small if adjustment costs are high

# Optimal Energy Use and SCC

- **Optimal use** of green energy and fossil fuel follow from

$$\eta_1 A_1 \Big(\frac{F_1}{K_1}\Big)^{\eta_1 - 1} \Lambda_1(T) = b_1, \qquad \eta_2 A_2 \Big(\frac{F_2}{K_2}\Big)^{\eta_2 - 1} \Lambda_2(T) = b_2 + \tau_f,$$

  where the optimal Pigouvian **social cost for using one unit of fossil fuel** is
  $$\tau_f = \frac{\beta C}{\delta(\gamma - 1)} \frac{J_T}{J}.$$

- Marginal product of the green capital stock is equal to the marginal cost of one unit of green energy
- For dirty capital stock, marginal costs plus the external effects

**Social Cost of Carbon (SCC)**

The social cost of burning one ton of carbon is
$$\tau_c = \tau_f / \nu = \frac{\vartheta C}{\delta(\gamma - 1)} \frac{J_T}{J},$$
where $\nu$ is the emission intensity per unit of fossil fuel

The optimal SCC increases in consumption reflecting that higher economic activity leads to higher carbon taxes

# Agenda: Diversification vs. Climate Action

# Calibration Strategy

- In the past, the influence of climate change on asset markets has been negligible
- **Historical impact of climate change on the economy** has been, if anything, **moderate**, at least in developed countries (see, e.g., Dell et al.)
- **First**, we calibrate production by disregarding climate damages
- **Second**, we calibrate the damage specification

# Calibration: Capital

- **Capital volatility** is $\sigma_1 = \sigma_2 = 0.02$ matching the observed volatility of consumption or output (e.g., Wachter (2013)).
- **Instantaneous correlation** $\rho_{12} = 0$ (later robustness checks)
- However, comovement between capital stocks is driven by macroeconomic disasters (above 90% in simulations).
- **Recovery rates**, $Z_i = 1 - \ell_i$, $i \in \{e, c\}$, power distributions over $(0, 1)$ with parameters $\alpha_i > 0$
- To calibrate the macroeconomic **jump-size distribution**, we follow Barro et al. and estimate $\alpha_e = 8$ and $\lambda_e = 0.088$.

# Calibration: Production and Preferences

- **Ignoring climate change**, optimal energy use implies a linear production function $Y_n = A_n^* K_n$ with productivity

$$A_n^* = A_n^{\frac{1}{1-\eta_n}} \left(\frac{\eta_n}{b_n}\right)^{\frac{\eta_n}{1-\eta_n}}.$$

- To calibrate preferences, adjustment costs and TFP, we use a special case of our **model with aggregate capital stock**
- Like Pindyck and Wang (2013), we **match**
  - real consumption growth rate of 2%,
  - average consumption fraction of GDP of 75%
  - initial risk-free interest rate of $r_0^f = 0.8\%$
  - equity premium of 6.3% and a Tobin'Q of 1.5
- We **calibrate** a time-preference rate of $\delta = 0.05$, a risk aversion of $\gamma = 5.288$, adjustment costs of $\phi_1 = \phi_2 = 18.12$, and TFPs of $A_1^* = A_2^* = 0.1$.

# Calibration: Energy Costs

- Following van den Bremer and van der Ploeg (2019), we use energy shares of $\eta_i = 0.066$ and set the cost of fossil fuel to $b_2 = \$540/\text{tC}$
- We use a higher price of green energy of $b_1 = \$810/\text{etC}$ (developed countries)
- Solving for $A_i$ yields the sector-specific productivities $A_1 = 0.851$ and $A_2 = 0.828$
- We choose the reallocation cost parameter $\kappa = 1$ such that the model-predicted optimal global av. temperature increase is approximately $4^\circ$C after 200 years, which is in line with the optimal temperature evolution in latest version of DICE

# Calibration: Damage Specification

**Level Impact (L–I)**

- Damage function in DICE is inverse quadratic:

$$\Lambda(T) = \frac{1}{1 + \theta_i T^2}$$

- Nordhaus (2017) calibrates the damage function so that damages at $3^\circ\mathrm{C}$ are 2.08% of pre-damages output
- This gives $\theta_i = 0.00236$

**Disaster Impact (D–I)**

- Data on climate-related events for 42 countries over the period from 1911 to 2015
- See Loayza et al. (2012) and Karydas and Xepapadeas (2019)
- We calibrate

$$\lambda_c(T) = \lambda_{c0} + \lambda_{c1} T$$

with $\lambda_{c0} = 0.003$ and $\lambda_{c1} = 0.096$.

- Power distribution for the recovery rate $Z_c$ yields $\alpha_c = 65.67$.

# Calibration: Damage Specification

## Growth Rate Impact (G–I)

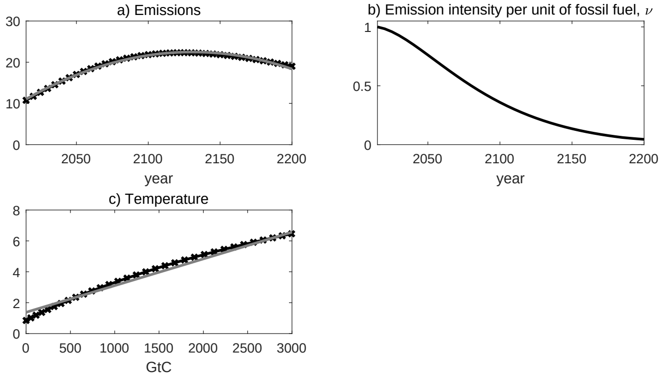
- To allow a meaningful comparison with climate disaster risk, we calibrate the damage parameters $\xi_n$ such that the growth rate impact equals the expected climate disaster impact.
- Therefore, we set $\xi_n = \lambda_{c1}\mathbb{E}[\ell_c]$, which gives $\xi_n = 0.00144$.

## Summary: Three Damages Specifications for Global Warming

| Specification | Calibration |
|---:|---|
| Level Impact (L–I) | $\theta_i = 0.00236$ |
| Disaster Impact (D–I) | $\lambda_c(T) = 0.003 + 0.096T$, $\alpha_c = 65.67$ |
| Growth Rate Impact (G–I) | $\xi_i = 0.00144$ |

# Calibration: Climate System

## **Strategy:** Match BAU in DICE




Panel (a) shows carbon dioxide emissions in the BAU-scenario in DICE (black crosses). The gray line depicts the BAU evolution in our model. The emission intensity per unit of fossil fuel is plotted in Panel (b). Panel (c) shows the relation of cumulative emissions and temperature increase in DICE. The gray line shows a linear least-squares fit to this data. The slope of this straight line gives a TRCE of $1.8^\circ$C/TtC.

# Calibration: Climate System

- We **calibrate** the **emission intensity** per unit of fossil fuel $\nu$ such that in the **BAU** scenario, the model **matches** the BAU carbon emissions in **DICE-2016R**
- **Emission intensity**:

$$\nu(t, K_1, K_2) = \frac{p(t)}{K_1 + K_2}$$

  where $p(t) = p_0 + p_1 t + p_2 t^2$.
- Least-squares: $p_0 = 11.03$, $p_1 = 0.1979$, $p_2 = -8.554 \times 10^{-4}$
- **Carbon emissions** are thus $\varepsilon_t = \nu_t F_{2t} = p(t) S_t f_{2t}$.
- Calibration ensures that carbon emissions are zero if dirty capital stock is not used and production of dirty goods is zero
- Emission intensity decreases over time as in DICE-2016R
- We take a **TCRE** of $\beta = 1.8°\text{C}/\text{TtC}$ in line with DICE

# Benchmark Calibration

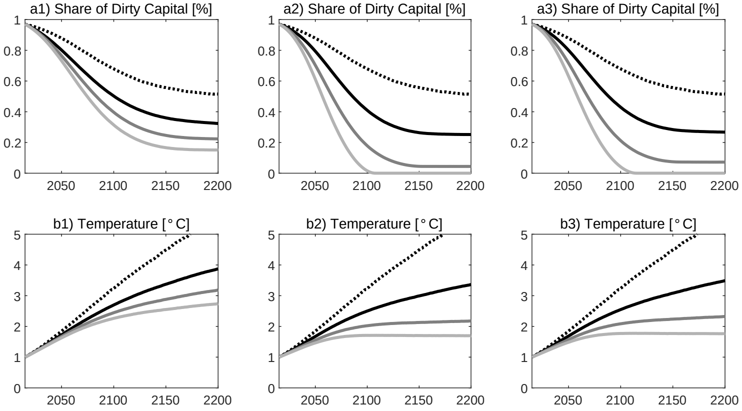
| | | |
|---|---|---|
| | **Preferences** | |
| $\delta$ | time-preference rate | 0.05 |
| $\gamma$ | relative risk aversion | 5.288 |
| $\psi$ | elasticity of intertemporal substitution | 1 |
| | **Economic Model** | |
| $Y_0$ | initial GDP (trillion US \$) | 75.8 |
| $S_0$ | initial share of dirty capital | 0.94 |
| $A_1$ | green productivity | 0.851 |
| $A_2$ | brown productivity | 0.828 |
| $b_1$ | fossil fuel costs (\$ per tC) | 540 |
| $b_2$ | green energy costs (\$ per etC) | 810 |
| $\eta_n$ | energy share in production | 0.066 |
| $\phi_n$ | investment adjustment cost parameter | 18.12 |
| $\sigma_n$ | annual capital volatility | 0.02 |
| $\alpha_e$ | macroeconomic jump size parameter | 8 |
| $\lambda_e$ | macroeconomic disaster intensity parameter | 0.088 |
| $\kappa$ | capital reallocation cost parameter | 1 |
| $\rho_{12}$ | instantaneous correlation | 0 |
| | **Climate Model** | |
| $T_0$ | initial temperature ($^\circ$C) | 1 |
| $\sigma_T$ | temperature diffusion coefficient | 0.015 |
| $\vartheta$ | TCRE ($^\circ$C/TtC) | 1.8 |
| $p_0$ | emission intensity parameter | 11.03 |
| $p_1$ | emission intensity parameter | 0.1979 |
| $p_2$ | emission intensity parameter | $-8.554 \times 10^{-4}$ |

# Agenda: Diversification vs. Climate Action

# Abatement and Diversification Motives

- Two **opposing effects**
  1. Dirty capital causes negative externality
     $\Longrightarrow$ **abatement motive**
  2. Agent is risk averse and thus dislikes variation
     $\Longrightarrow$ **diversification motive**
- **Phase 1: Dirty capital dominates**
  - Economy is not well-diversified
  - Diversification motive accelerates climate action until full diversification is reached
- **Phase 2: After full diversification is reached**
  - Abatement and diversification are conflicting targets
  - Transition towards low-carbon economy is slowed down
- **Equilibrium**
  - Economy does not stop at the level of full diversification
  - Overall optimum is below level of full diversification
  - Dirty capital might not be extinct

# Dirty Capital Share for Increasing Intensities of Damages




Simulation of the share of dirty capital and global average temperature for the three damage specifications (level, disaster, growth rate) until the year 2200. The black dotted lines show the results for a hypothetical scenario without damages from climate change. Black solid lines: standard calibration. Gray lines: damage parameters are twice as high. Light lines: damage parameters three times higher.

# Calibration: Increasing Intensities of Damages

| Impact | Benchmark | Double Impact | Triple Impact |
|---|---|---|---|
| Level | $\theta_i = 0.00236$ | $\theta_i = 0.00472$ | $\theta_i = 0.00708$ |
| Disaster | $\lambda_c(T) = 0.003 + 0.096T$ | $\lambda_c(T) = 0.003 + 0.192T$ | $\lambda_c(T) = 0.003 + 0.288T$ |
| Growth Rate | $\xi_i = 0.00144$ | $\xi_i = 0.00288$ | $\xi_i = 0.00432$ |

The table summarizes the different damage specifications that are used in previous figure

# Equilibrium Asset Pricing

- Duffie and Epstein (1992) show that for continuous-time recursive utility the **stochastic discount factor** has the form

$$H_s = \exp\left(\int_0^s f_J(C_u, J_u)\, du\right) f_C(C_s, J_s),$$

where $J_s$ denotes the time-$s$ value of the value function.

- Applying Ito's lemma gives it dynamics

$$\frac{\mathrm{d}H}{H_-} = \frac{\mathrm{d}f_c(C_-, J_-)}{f_c(C_-, J_-)} + f_J(C, J)\mathrm{d}t$$

- $J$ is the value function with representation (see above)

$$J(t, K_1, K_2, T) = \frac{1}{1-\gamma} K^{1-\gamma} G(t, T, S),$$

## Equilibrium

The SDF follows the dynamics

$$\frac{\mathrm{d}H}{H_-} = -r^f \mathrm{d}t + \Theta_W^\top \mathrm{d}W + \sum_{i\in\{e,c\}} ((1-\ell_i)^{-\gamma} - 1)\mathrm{d}N_i - \Theta_N \mathrm{d}t$$

with $W = (W_1, W_2, W_3)^\top$. The equilibrium risk-free rate $r^f$ is

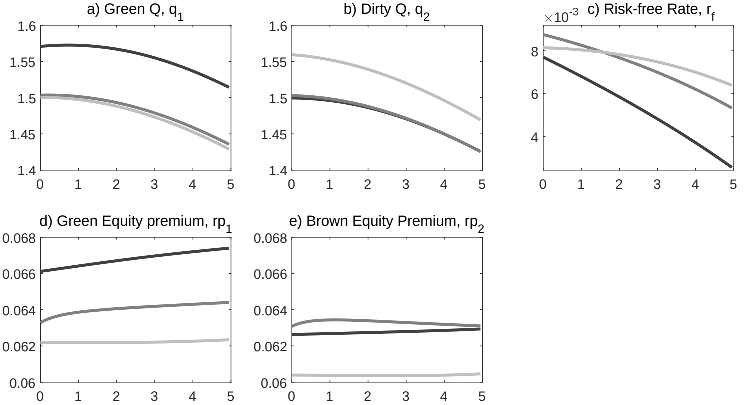
$$r_t^f = \underbrace{\delta + \mu_c(t, S_t, T_t) - \gamma\|\sigma_c(t, S_t, T_t)\|^2}_{\text{standard diffusion risk}} - \underbrace{\sum_{i\in\{e,c\}} \lambda_i(T_t)\mathbb{E}_t[\ell_i(1-\ell_i)^{-\gamma}]}_{\text{disaster risk}}$$
$$- \underbrace{\langle \sigma_g(t, S_t, T_t) + (\gamma-1)\sigma_c(t, S_t, T_t), \sigma_k(S_t) - \sigma_c(t, S_t, T_t)\rangle}_{\text{temperature diffusion risk}}$$

The market price of diffusion risk and the market price of jump risk are

$$\Theta_{Wt} = \underbrace{-\gamma\sigma_k(S_t)}_{\text{standard risk}} + \underbrace{\sigma_g(t, S_t, T_t) + \sigma_k(S_t) - \sigma_c(t, S_t, T_t)}_{\text{temperature risk}},$$

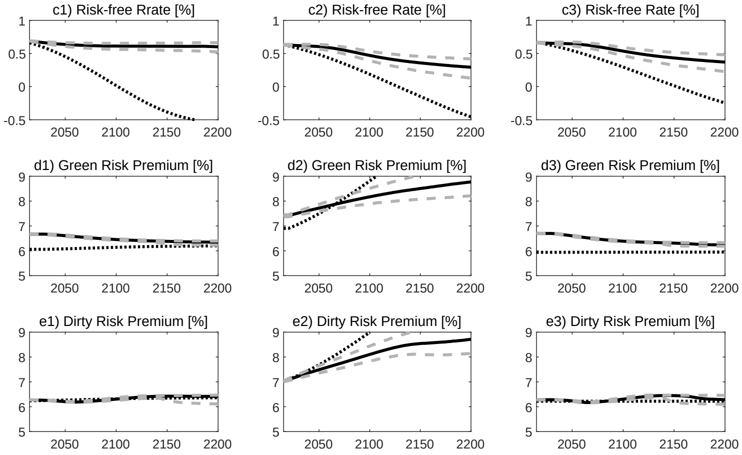
$$\Theta_{Nt} = \sum_{i\in\{e,c\}} \lambda_i(T_t)\mathbb{E}[(1-\ell_i)^{-\gamma} - 1].$$

# Asset Pricing Quantities: Level Impact




**Asset Pricing vs. Temperature and Share of Dirty Capital.** On the horizontal axis is temperature in the range from 0°C to 5°C. The lines represent various levels of the capital share: dark lines depict $S = 0.95$, gray lines refer to $S = 0.5$, and light lines to $S = 0.05$.

# Asset Pricing Quantities: Comparison of Impacts




The figure depicts the simulation of asset pricing quantities for the three damage specifications level impact ($1^{\mathrm{st}}$ column), disaster impact ($2^{\mathrm{nd}}$ column) and growth rate impact ($3^{\mathrm{rd}}$ column) until the year 2200. The black dotted lines show the results for the BAU scenario.

# Evolution of Temperature and the Social Cost of Carbon

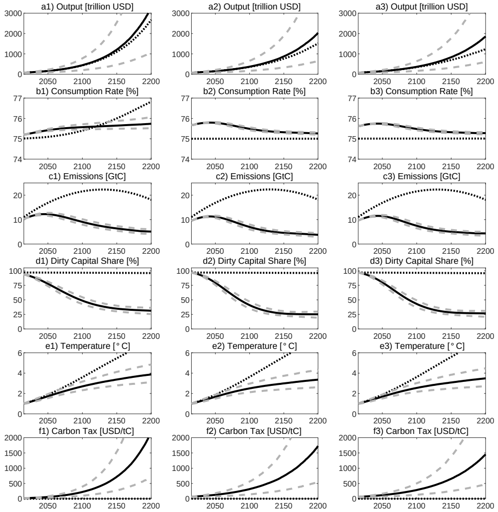



Figure depicts the simulation of real economy for three damage specifications until 2200. Optimal paths are depicted by solid and BAU paths by dotted lines. Dashed lines show 5% and 95% quantiles of the optimal solution.

# Agenda: Diversification vs. Climate Action

# Conclusion

- The transition towards an emissions-free economy is affected by diversification motives.
- Diversification and climate action are initially complementary goals.
- At a certain point, however, the two goals become conflicting and a trade-off arises.
- We have also analyzed the dynamics of risk premia and the risk-free rate during the transition towards a low-carbon economy.
- From the perspective of policy makers, our findings are challenging.
- Initially agents should be intrinsically motivated to take climate action, simply to reach diversified asset holdings.
- If policy makers wish to incentivize agents to reduce the carbon-intensive capital stock beyond its optimal share, then they must counter the positive effects of diversification.