# Lecture 3. Financial Sector and Decarbonization

- The financial sector will significantly be affected by climate risk and extreme weather events by stranded assets, financial risk, and financial sector instability ("stranded assets", BoE)
- Financial markets can be important for the acceleration of decarbonization but do not capture the externalities (positive and negative ones)
- The flow of financial resources (credit, equity, bonds, liquidity provision by CBs) directed to renewable energy research, innovation, and implementation of new energy sources is important
- We need to pay attention to financial flows and how they can be beneficial for the actors in the financial market (financial market as a bridge or roadblock?), beneficial: Sharpe ratio (Risk Return trade-off)
- Application of advanced modeling techniques and empirics needed for what is now called sustainable finance: **Asset pricing, static portfolio, dynamic portfolio, bond issuing**

# Lecture 3. 1. Financial Sector; Acceleration of decarbonization?

**Climate (sustainable) finance** (See ch. 8 of the book)

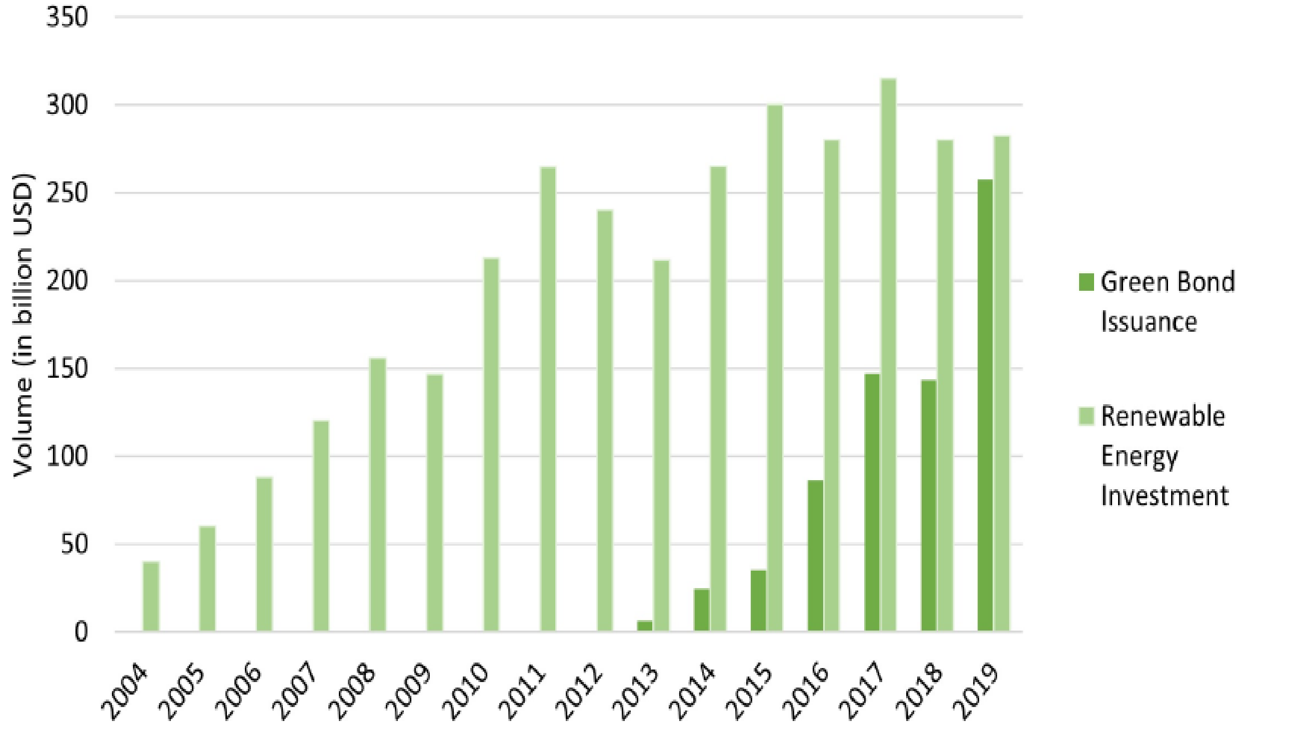
=> Financial market resources:

Can it be a **bridge** to

Decarbonization?

**=> Generic finance**:

- Self-financing
- Equity finance
- Bond finance
- Bank credit
- Crowd finance
- Portfolio shifts




Source: Bloomberg and Bloomberg New Energy Finance.

# Lecture 3. 2. Financial Sector; Short termism..

- Financial market as roadblock? (see Haldane and BoE): The tendency of financial intermediaries to overly favor short-term payoffs over long-term opportunities.
- Implications: Short-term behavior leads to inefficiencies and mispricing in financial, markets, including asset price bubbles and panics (Bushee [2001],
- Induces corporate myopia, which in turn has an adverse impact on investment, creation of long-term value, and hence economic growth, but ESG firms are now a new development
- Short-termism impacts negatively the efficiency of financial intermediation: There are three reasons for short-termism: 1) risk aversion, 2) decision horizon, and 3)  discount (see Semmler et al. 2021)
- We look at three financial instruments for the energy transition: 1) Asset prices, 2) static portfolios, and 3) dynamic portfolios

# Lecture 3.2. Financial Sector: Risk-taking investors, asset pricing and asset holding

## Price of an asset

- Discount rate $\delta$
- Future cash flows

=> Typical cases

- CAPM and CCAPM)

$$p_t = E_t \underbrace{\left[ \sum_{i=1}^{k} \left( \frac{1}{1+\delta} \right)^i d_{t+i} \right]}_{p_t \,=\, \text{fundamental value}} + E_t$$

=> Short-termism of financial

markets will be a roadblock:

- Green project evaluation
- See Haldane et al.

- => With risk premium $\delta$
- For project evaluation; higher

- Green assets and project evaluations:
- 1. If de-risking by the state, see Braga et al)
- 2. Preference of asset holders
- The green assets held

Decision horizon, $N$, iterations $T$, discount rate, $\delta$, and present value, $PV$

| [1.5pt] N = 6 | T = 40 | T = 40 | T = 40 | T = 40 | T = 40 |
|---|---|---|---|---|---|
| $\delta$ | 0.01 | 0.015 | 0.03 | 0.07 | 0.15 |
| $PV$ | $138.1 \geq Inv$ | $133.3 \geq Inv$ | $126.1 \geq Inv$ | $109.5 \geq Inv$ | $85 \leq Inv$ |

# Lecture 3. 3. Financial Sector; Static portfolio; Portfolio shifts

Reallocation from brown to green assets? (Markowitz Portfolio); Adding volatility

See Lichtenberger et al. (2022), in "Econometrics ", Sharpe ratio as measure

**Static portfolio**: benefits

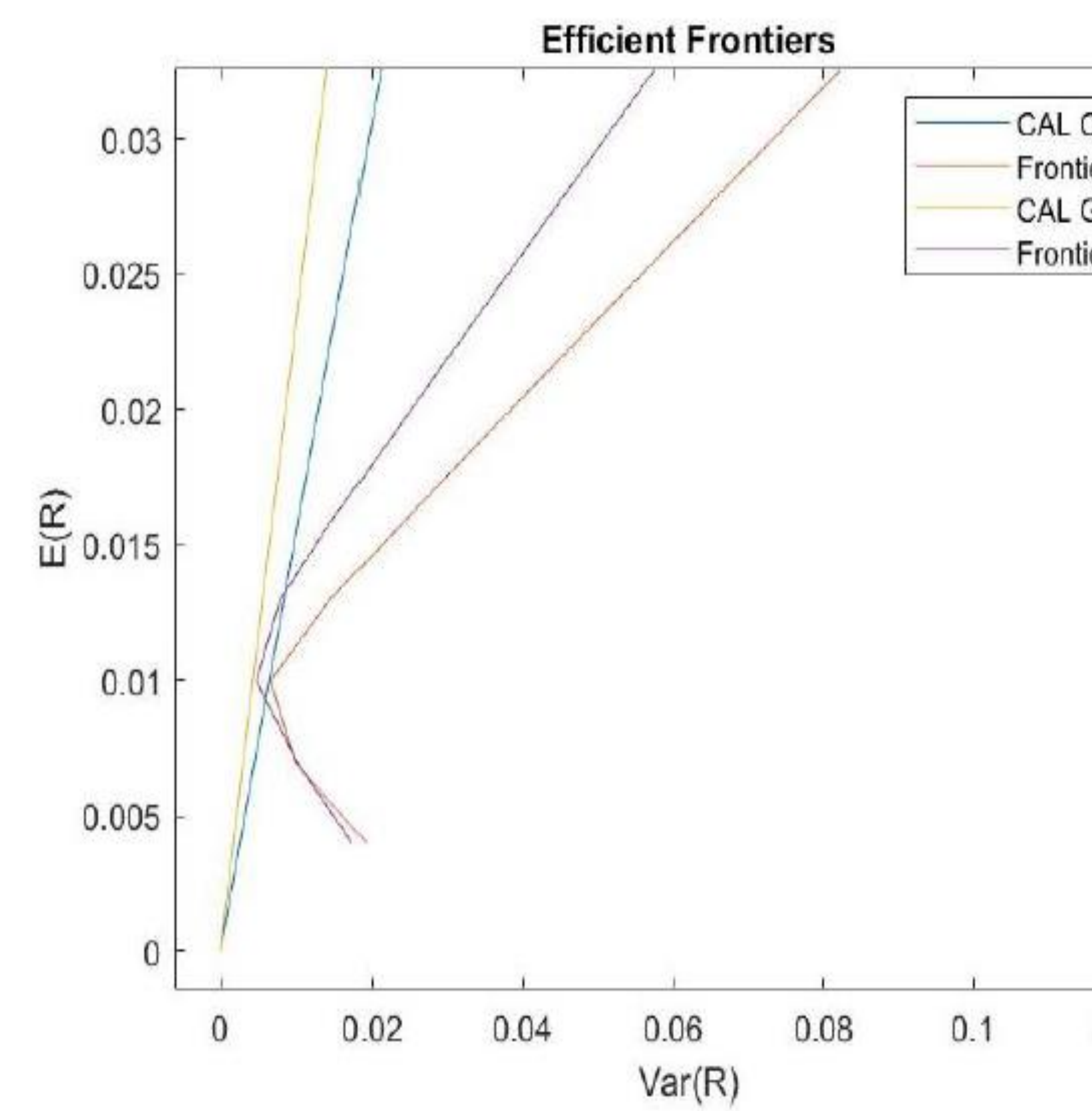
=> Performance of green and brown assets (in static portfolio)

- Green assets have lower returns (greenium),
  but a **higher Sharpe Ratio**, since **volatility is lower**
- Green assets as a larger fraction of portfolios,
  have lower volatility, higher SR, stabilize portfolios
- Green assets holdings lead to lower capital costs (WACC)

=> Markowitz efficient frontier:

- Efficient frontiers of the green bond (GB); corporate energy bonds (CB)
- Efficient frontiers and Markowitz efficient weights computed

=> Conclusion: Looking at the SR financial asset holdings can help accelerate the transition



# Lecture 3. 4. Financial Sector; Dynamic portfolio, adding to wealth dynamics

Reallocation from brown to green assets? (Merton Portfolio), solved through NMPC

=> **Dynamic portfolio**
performance (Merton):

- One or two risky assets in a Merton portfolio
- Difference between performance with negative and positive externalities?
- See the model with one risky asset (fluctuating) and one risky-free asset
- Merton's model with negative and positive externalities

$$\max_{v,c,\xi} \int_0^T e^{-\theta t}(\beta_1 log(v_t W_t) + (1-\beta_1) log(c_t W_t))dt$$

$$\text{s.t.} \quad \dot{W}_t = \xi_t R^e_{i,t} W_t + (1-\xi_t)\ R^f_t W_t - (v_t + c_t) W_t$$

$$R^f_t = constant$$

$$R^e_{i,t}(x_t) = (\xi_2\ sin(\xi_4 x_t) + \xi_5)(1 \pm \delta(v_t W_t))$$

# Lecture 3. 4. Financial Sector; Dynamic portfolio model (Merton), adding wealth dynami

**Dynamic portfolio**: Benefits or costs

=> Positive externality (Acemoglu/Aghion):

upper graphs $\delta(\cdot) > 0$

=> Negative externality:

lower graph with $\delta(\cdot) < 0$

=> Faster transition if financial market does better discriminate between the two cases and is not driven by short-termism

=> $\delta(\cdot) > 0$: Incentivized by some de-risking, subsidies, or green investors except lower returns,

=> $\delta(\cdot) < 0$: tax on brown assets, or disclosure requirements

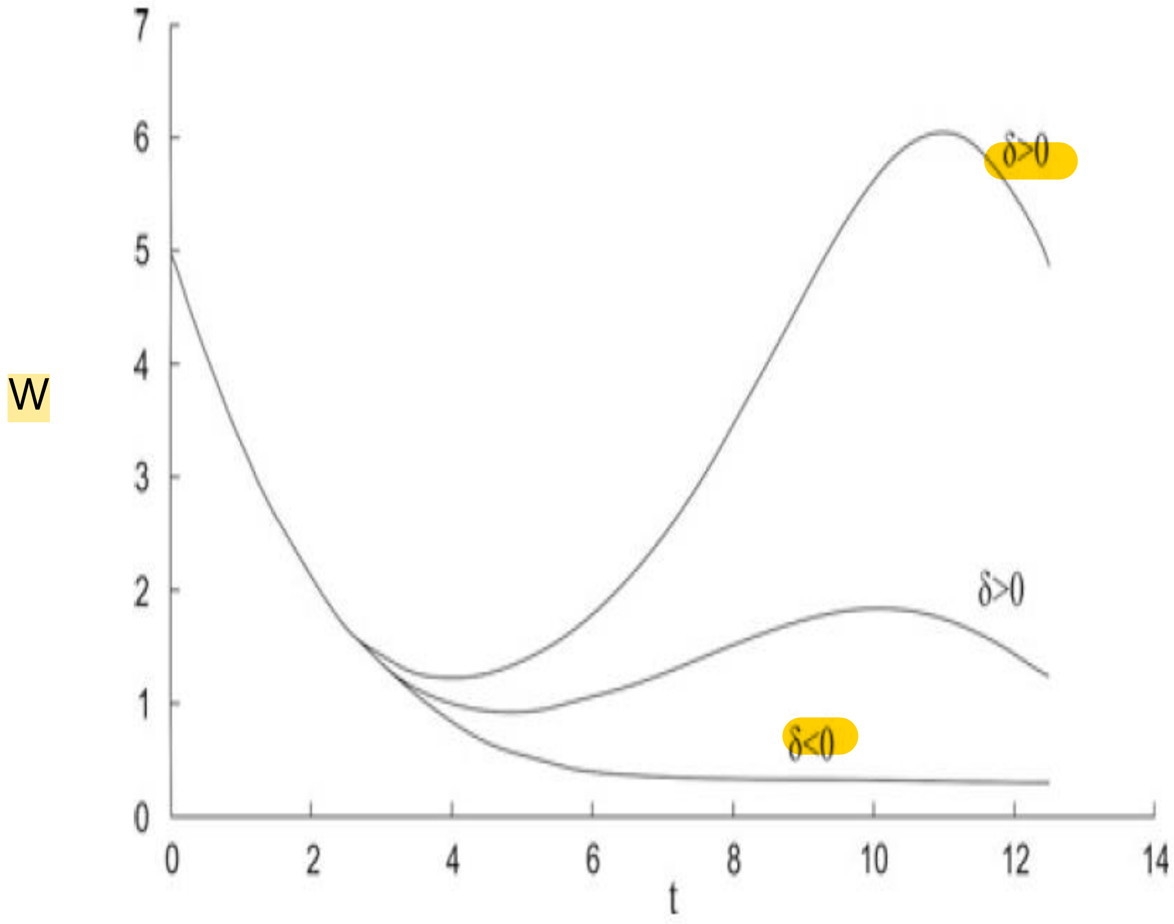
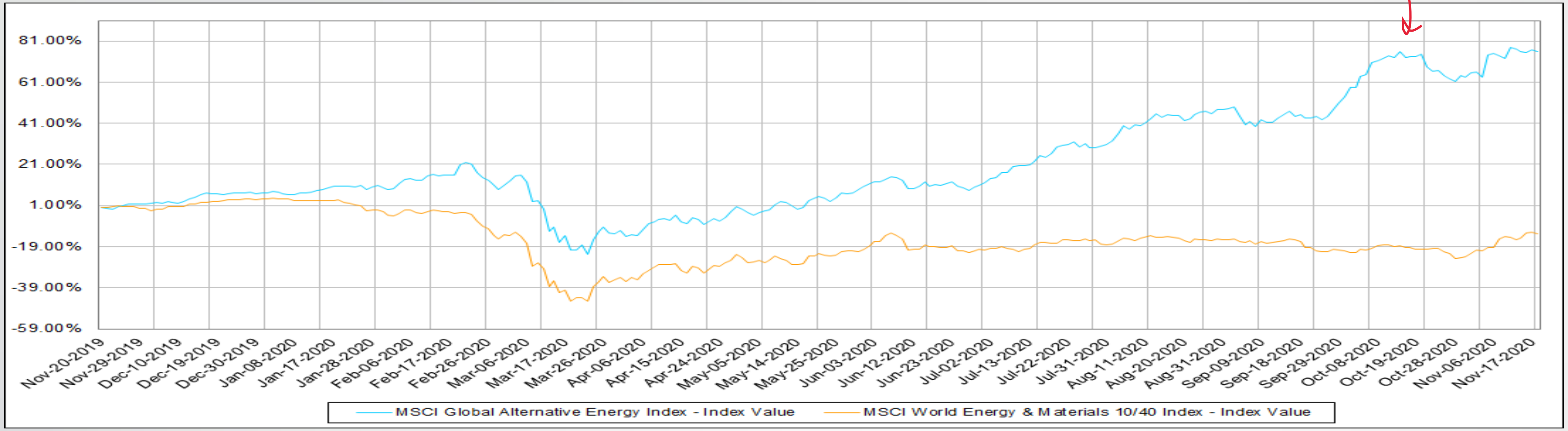
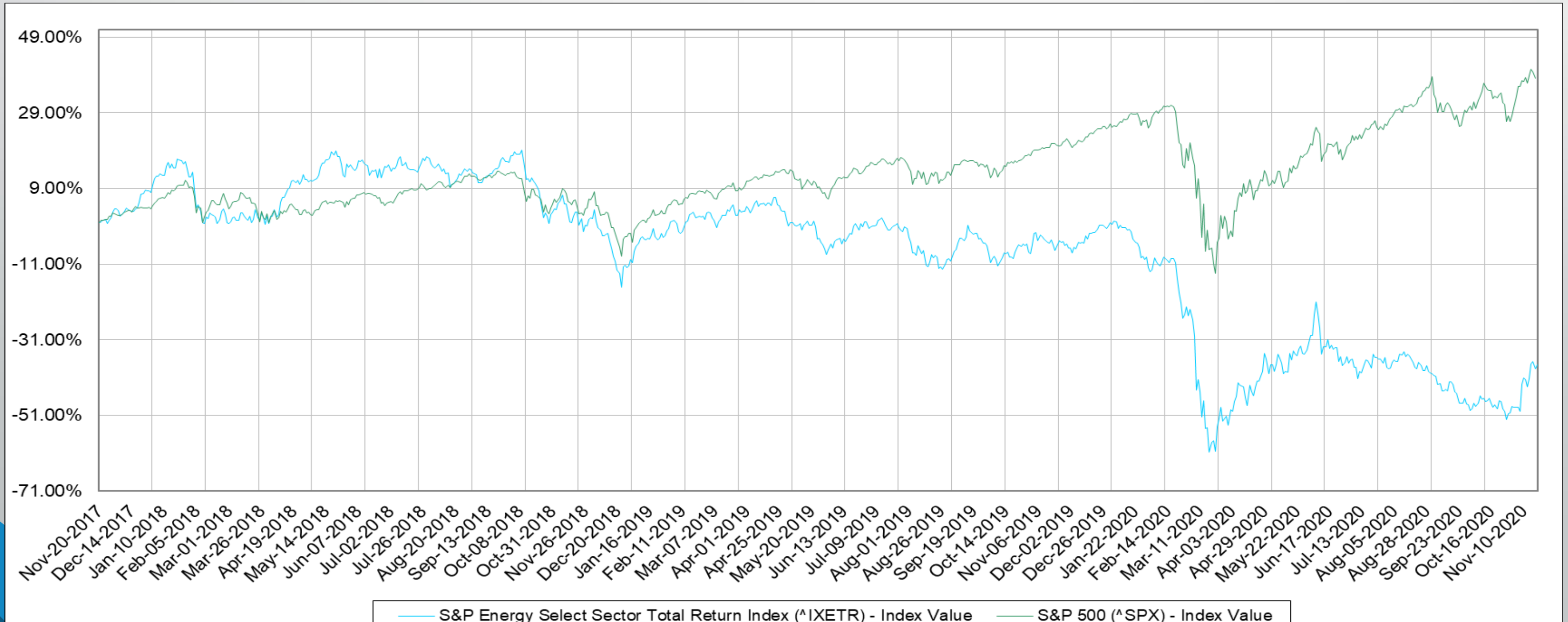



Figure: Solution path for wealth for different types of externalities for different values of $\delta($ and $N = 6$, $T = 25$. This figure shows trajectories of wealth for different types of externalities, tw upper graphs $\delta(\cdot) > 0$, lower graph with $\delta(\cdot) < 0$. It is assumed that $N = 6$ and $T = 25$

# Lecture 3. 5. Empirics: Green equity

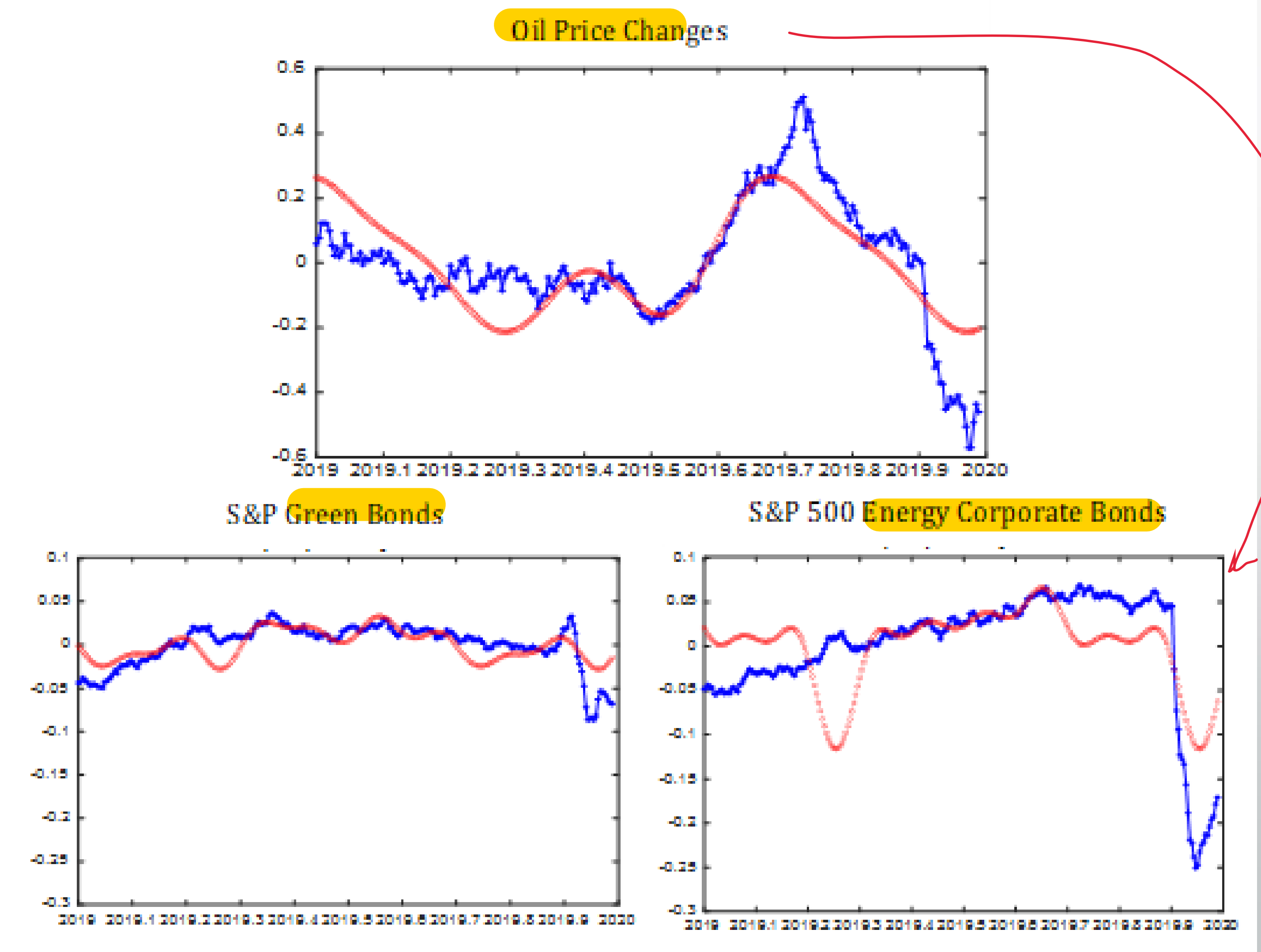



Financial market empirics: 1. Green vs. world energy index; 2. S&P vs. energy return index



# Lecture 3. 5. Empirics ; Green bonds Oil Prices, brown and green bonds

- Oil price is extremely volatile. **Fossil fuel securities strongly co-move with oil price** while green bond and equity returns are less impacted by oil price volatility. We visually observe this by running harmonic estimations (Appendix B).



# Lecture 3. 5. Empirics, Green bonds; Measure: SR

- Data sources:
  - Bloomberg Terminal from Jan 2017 – Sep 2020 (download date: Oct 01, 2020)
  - Bonds are herogeneous in terms of issuers, duration, country/currency and sectors:
    - the sectors with the most green bonds „Banks", „Real Estates", „Power Generation", „Utilities", „Government", „Supranationals", plus „Energy" sector to see the performance of fossil fuel related bonds
  - Green bonds (all available bonds downloaded); Conventional bonds (available S&P rating
- Performance measures:
- Yields of bonds (yield to maturity, current yield, current yield)
- Volatility (60 days, 90days, 120 days)
- Sharpe Ratio (SR): single asset, bundle of assets (portfolio)
- New methods:
- Pairing technique (green/conventional bonds, same issuer, same maturity, same currency, same sector)
- Regression with green bond dummy
- Regression tree
- Harmonic estimation
- Regime change modeling

# Lecture 3. 5. Empirics; Green bonds

- Green bonds (vs conventional bonds) have lower yields, lower volatility and on average higher Sharpe ratios. (Semmler et al., 2020)

- **Bond yields**: Green bonds show negative premium, see Kapraun and Scheins (2019),
  - Mostly…
  - Not in all sectors,,,,

- **Sharpe Ratio** roughly the same as fossil fuel assets, but for green bonds
  - yield lower (yield at issue, yield to maturity, current yield)
  - volatility lower
  - Sharpe Ratio:

$$Sharpe\ Ratio = \frac{R_p - R_f}{\sigma_p}$$

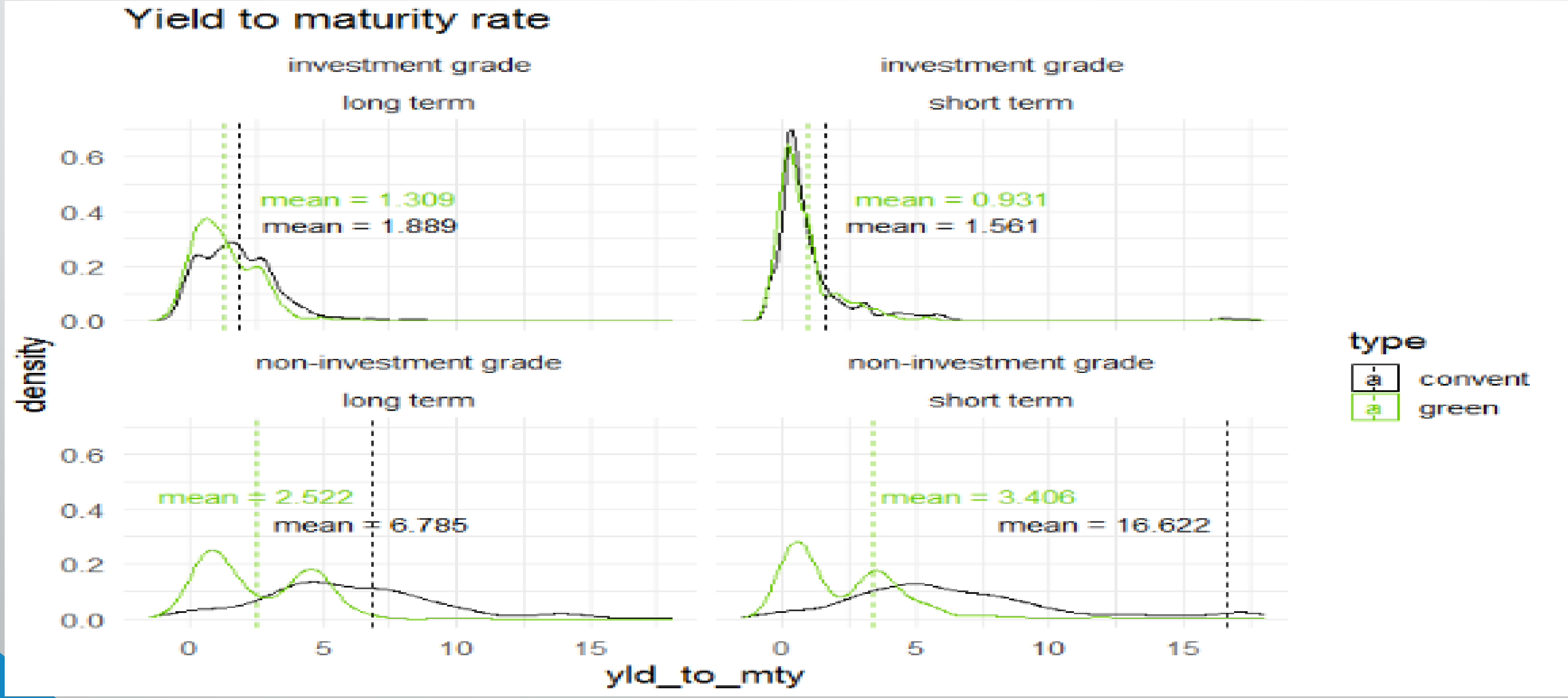
- **Green equity:**
  - Stock prices (ishare, brown and green ETS trading…hedged or non hedged)
  - Green equity….
- **Convertible bonds..**

# Lecture 3. 5. Empirics: Green bonds

Density plots on yield to maturity (right half)
by rating and duration for green and conventional bonds:

- Investment-grade = S&P rating equal to or greater than BBB, as in Schwab (2017)
- Long term bonds = duration greater than 10 years, as in Kenny (2019)

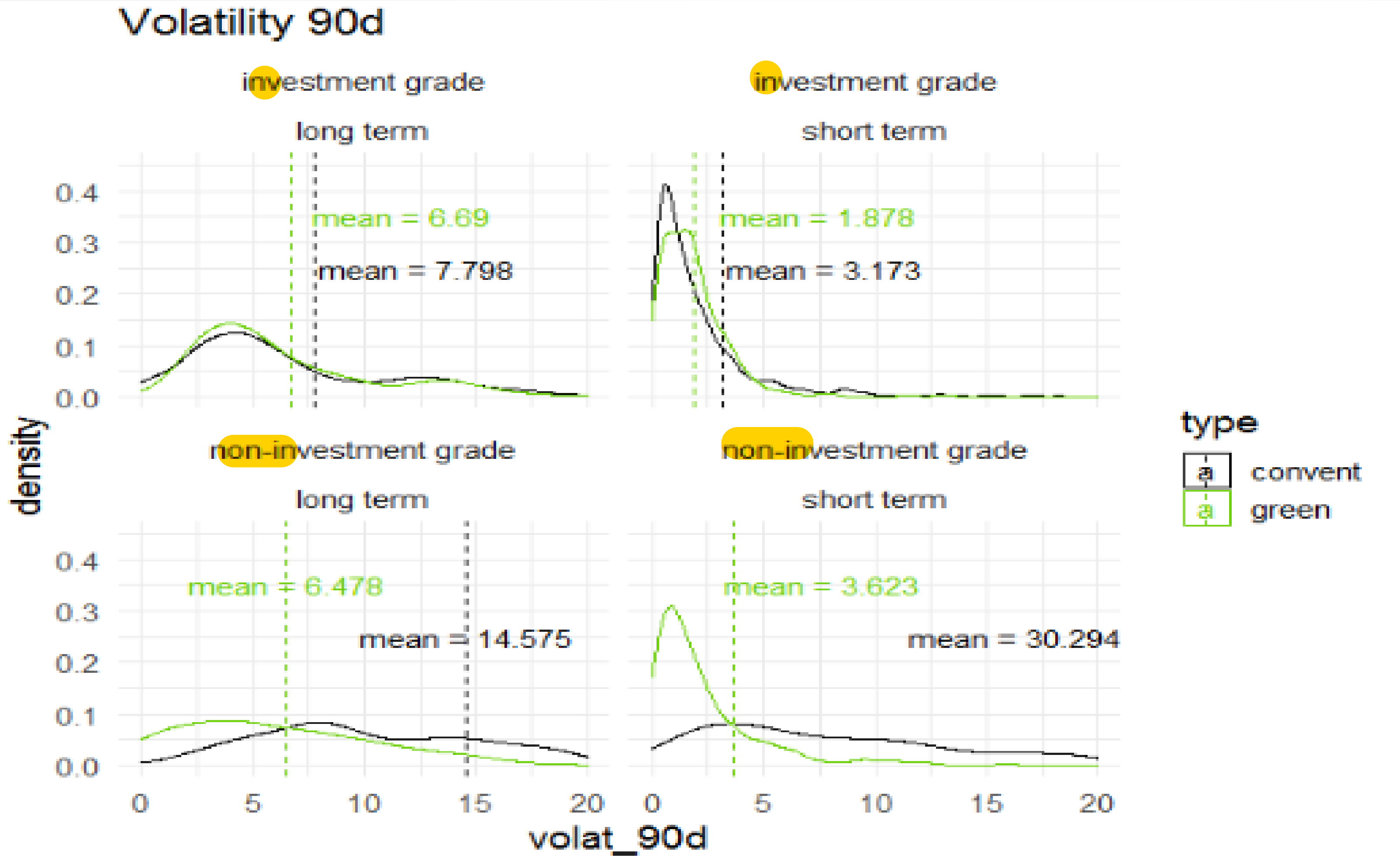
→ lower yields for green bonds



# Lecture 3. 5. Empirics: Green bonds

Density plots for the 90-day volatility, by rating and duration for green and conventional bonds again

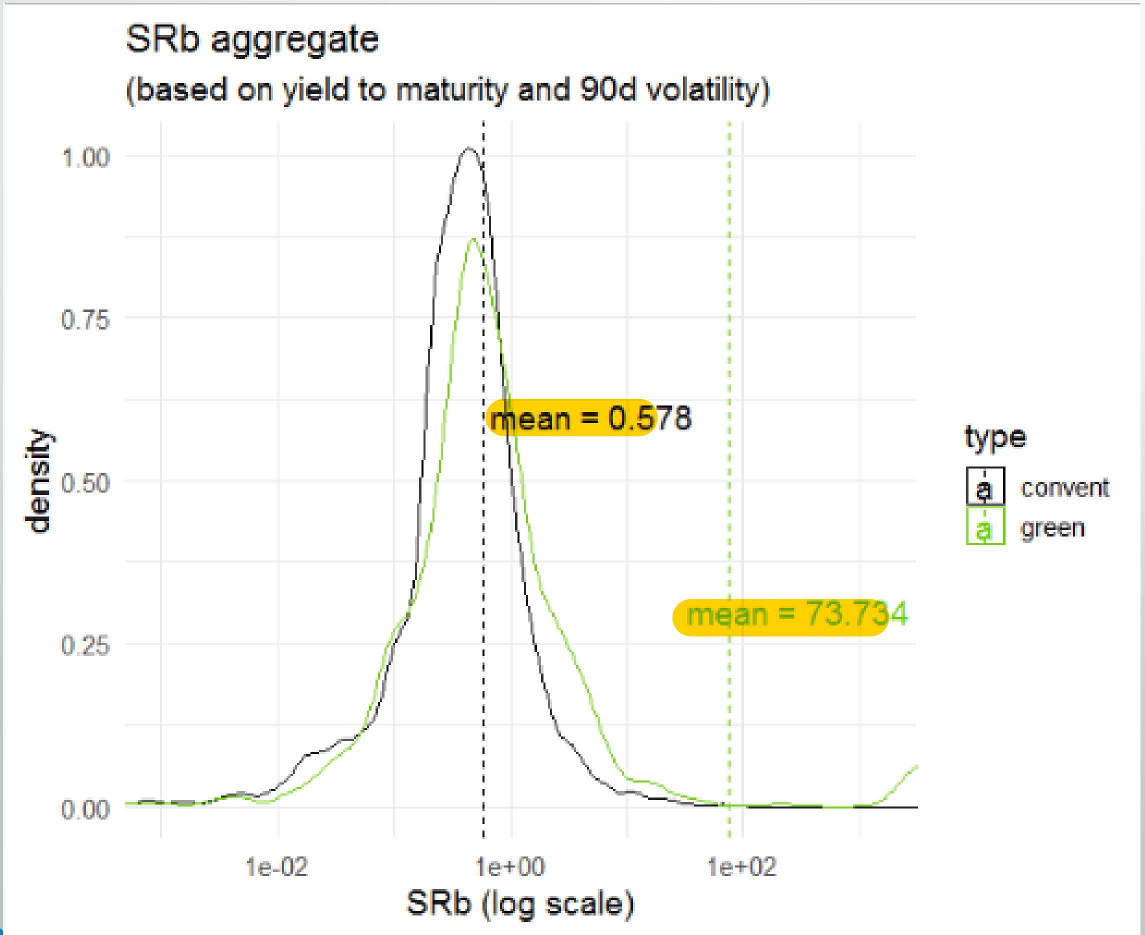
→ lower volatilities for green bonds



# Lecture 3.5. Empirics: Green bonds

Density plots of bond specific Sharpe ratios (SRb; see eq. 1) for green and conventional bonds based on yield to maturity rate and 90-day volatility
[ the bond specific Sharpe ratio is similar to the classic portfolio Sharpe (SRp, see eq. 2) ]

→ higher SRb for green bonds

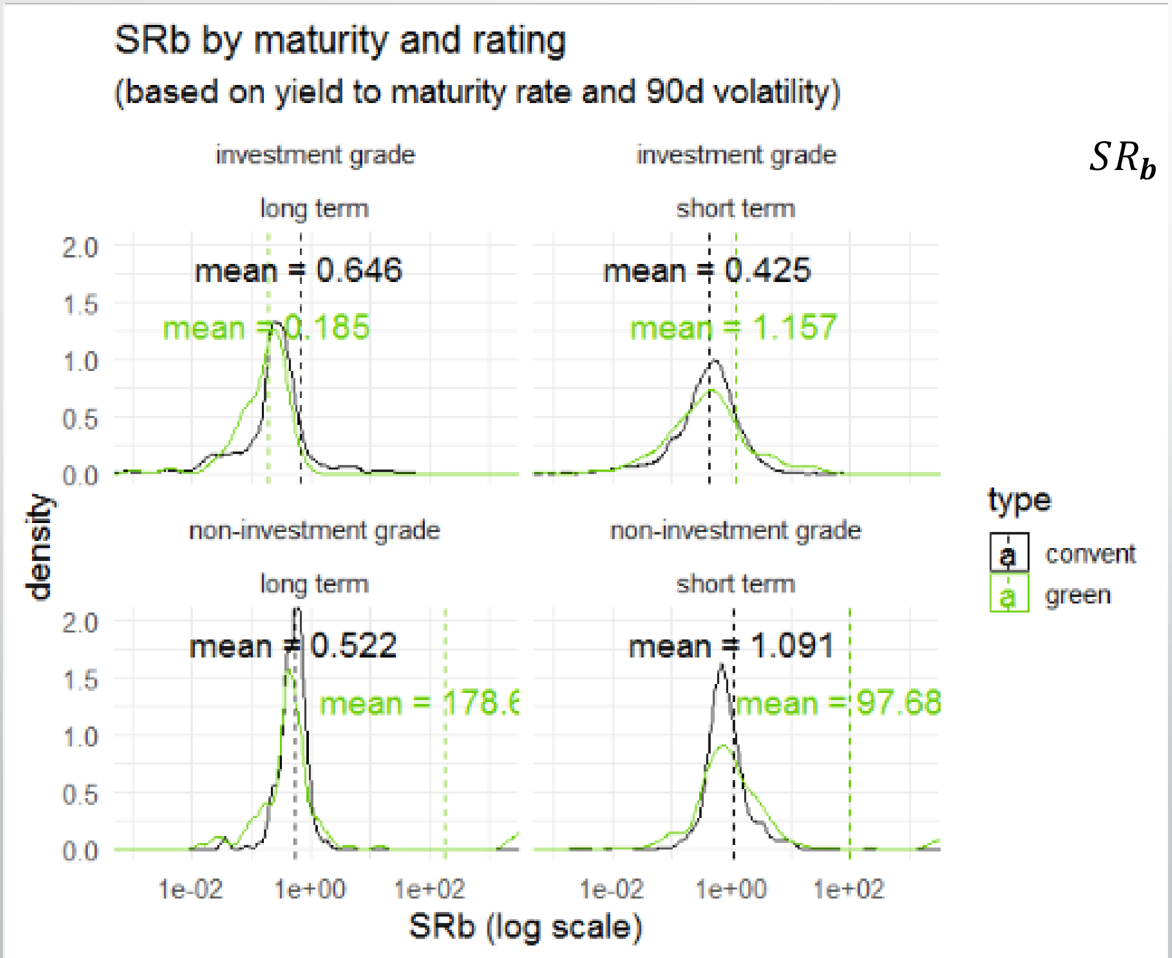



$$SR_{\boldsymbol{b}} = \frac{R_{\boldsymbol{b}} - R_f}{v_p} \qquad (Eq. \mathbf{1})$$

$$SR_p = \frac{\overline{R_p} - R_f}{\sigma_p} \qquad (Eq. \mathbf{2})$$

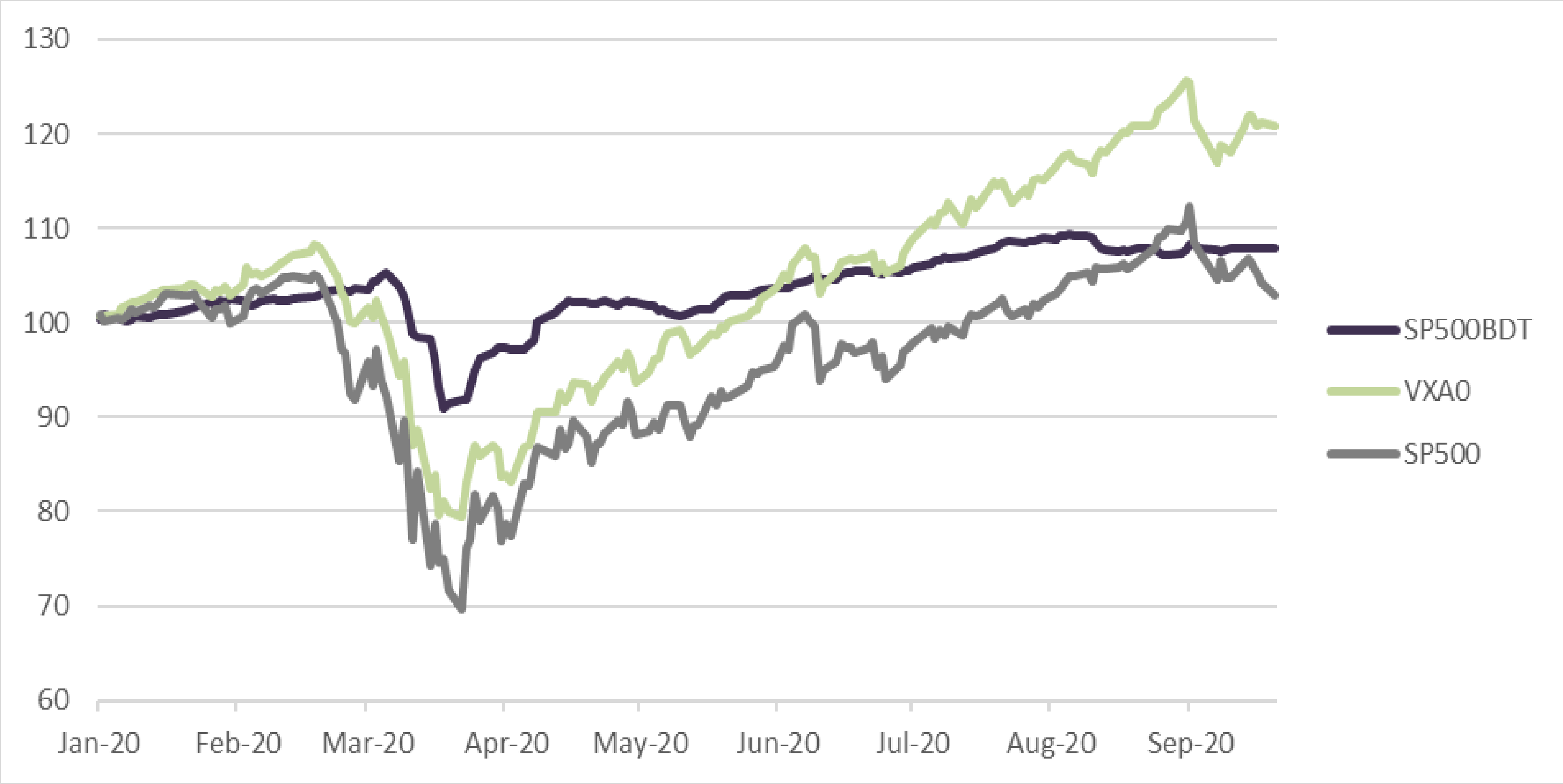
Density plots of bond specific Sharpe ratios (SRb; see eq. 1) for green and conventional bonds based on yield to maturity rate and 90-day volatility for different maturities and investment grades

→ mostly higher SRb for green bonds




$$SR_{\boldsymbol{b}} = \frac{R_{\boldsymbol{b}} - R_f}{\mathbf{v}_p} \qquad (Eq. \mathbf{1})$$

# Lecture 3. 5. Empirics: Convertible bonds;
# How to get from bonds to equity?




**A surge in the convertible bond market has been observed in 2020 after the COVID-19 crisis.** In the US, new convertible bonds summed up to $77 billion as of September, an increase of 45% over 2019 and of 200% over 2015.[a] The convertible bond market index (ICE BofA US Convertible Index – VXA0) outperformed other market indices such as the S&P 500 Bond Index (SP500BDT) and the S&P 500 (SP500). In 2020,[b] the VXA0 Yield-to-date returns (YTD) was 20.9% while the SP500BDT was 7.85% and the SP500 2.97% (Figure B3.1).

# Lecture 3. 6. Conclusions

➢ **Summing up:**

- Green bonds => Sharpe ratio higher, but different for sectors, countries and currencies. Thus, empirical results are still mixed: should one use just conventional bonds to scale up green investments? Role of the Sharpe ratio for specific green finance is significant.
- Green bonds needed to capture preference and cost shifts, GBs are project specific (see EU classifications), it is a new (infant) market: governance and experience matters, learning by doing, insufficient high-quality data, temporary or long-run
- Other ways of financing the transition: self-financing, credit from banks, equity finance, static and dynamic portfolios

➢ **Scaling up of green investments** through sustainable finance is needed now:

- Green investments (mitigation, adaptation) should be supported but will there be an orderly or disorderly transition? Is de-risking by the public reasonable (see Arrow, Stiglitz), should it be part of the fiscal and monetary programs these days? see US IRA, and CBs climate action networks.
- But is there a long-run debt problem? "Better to leave to the next generations manageable debt than unmanageable disasters" (Stiglitz), and see Convertible bonds

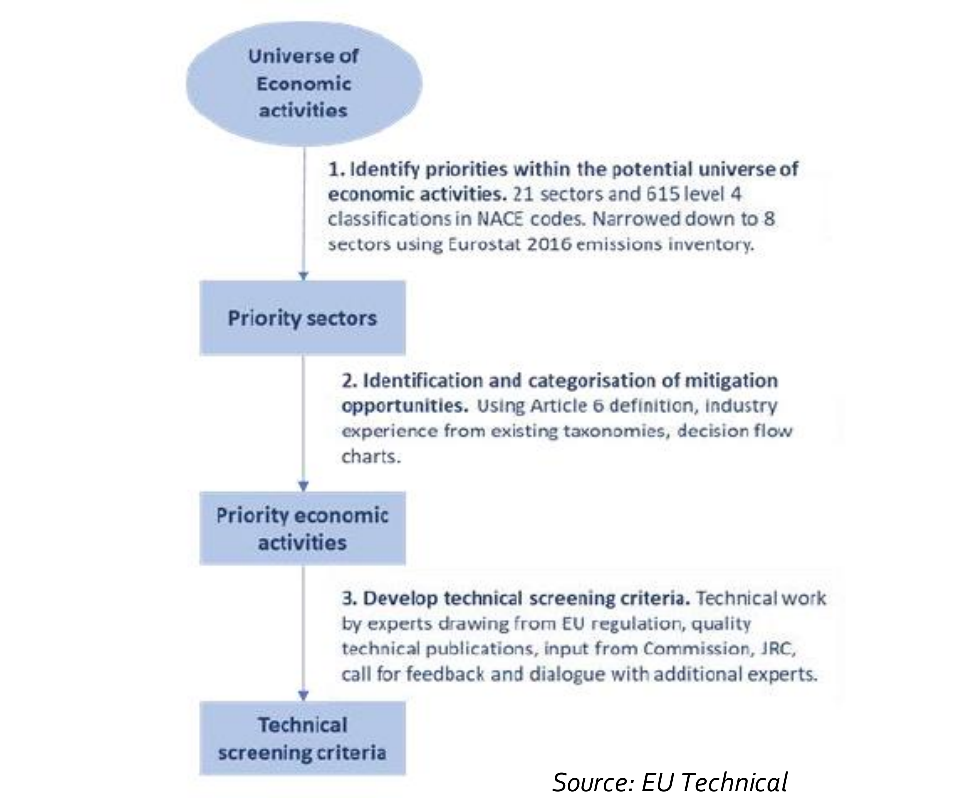
# Lecture 3. References

## Some references:


- Lichtenberger, A., J. Braga and W. Semmler (2022), in "Econometrics "
- Mittnik, S., Semmler, W., and A. Haider (2020). Climate Disaster Risks–Empirics and a Multi-Phase Dynamic Model. Econometrics, MDPI, Open Access Journal, 8(3), 1-27.
- Semmler, W., J. Braga, A. Lichtenberger, M. Toure, and E. Hayde (2021). Fiscal policies for a low-carbon economy, World Bank report, Nov.
- Semmler, W., K. Lessmann, and I. Tahri (2020). Energy Transition, Asset Price Fluctuations, and Dynamic Portfolio Decisions (May 15, 2020). Available at SSRN: https://ssrn.com/abstract=3688293

# Appendix: EU Taxonomy for sustainable activities

- It creates a EU standard to classify assets and investment according with their climate benefits, following new technological trends and indicator (Technical Expert Group on Sustainable Finance).
- Organized by sector and technology, it provide references to classify climate change mitigation and climate change adaptation activities, including criteria for do no significant harm to other environmental objectives
- It adds up to EU Green Bond Standard → enable green finance activities.




*Source: EU Technical Expert Group (2020)*

- Back

# Appendix: Germany - Sovereign Green bonds (1st issuance 2020)

The eligible green expenditures of €12.3 billion are split among five sectors and mapped to the six European environmental objectives set out in the EU Sustainable Finance Taxonomy[12]:

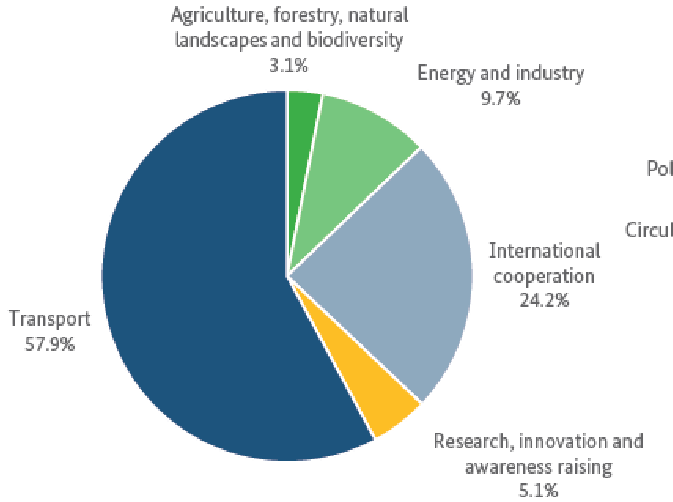



Figure 1: Breakdown by sector

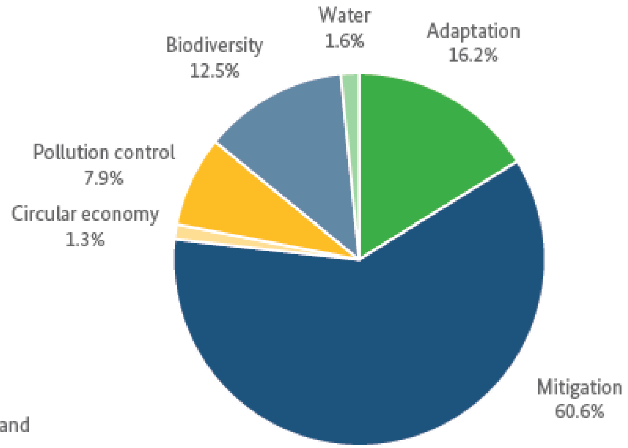



Figure 2: Breakdown by EU environmental objective

*Source: DE Federal Ministry of Finance (2021)*

- Back

## Appendix: Green convertible bonds?

- The convertible bond market index (ICE BofA US Convertible Index – VXA0) outperformed other market indices such as
  - the S&P 500 Bond Index (SP500BDT)
  - and the S&P 500 (SP500).
- In 2020 the VXA0 Yield-to-date returns (YTD) was 20.9% while the
  - SP500BDT was 7.85%
  - and the SP500 2.97%

**Figure B2.1. Yield-to-date returns for convertible bond index vis-à-vis other market indices**


Note: Base 100, on 12/31/2019
Source: Bloomberg and S&P

- [Back](#)

## Appendix: Measurement problem

➤ **Measurement problems:**

- How can one make positive externalities measurable: through R&D spending, human capital, green infrastructure…; i.e. social returns of green bonds; lower $CO_2$ emission and less disasters? Endogenous Growth theory?
- How can we make negative externalities measurable: measuring the effect on asset prices of carbon tax, disclosure effects, land prices after disasters, relative stock prices, portfolio shifts, green start up firms, bank exposures?

# Appendix: Asset Prices and Financial Market: Model

**Baseline Model (roadblock due to** **short-termism** **and):**

$$\max_{\{c,\pi\}} \mathbb{E}\left\{\int_t^N e^{-\delta_0(s-t)} F(c_s W_s) ds\right\}$$

$$\text{s.t.} \quad \dot{W}(t) = \pi_t r_t^e W_t + (1-\pi_t) r^f W_t - c_t W_t - X(\Pi_t, W_t)$$

Risky asset: $r_i^e(t) = \alpha_{1,i}\sin(\alpha_{2,i}t) + \alpha_{3,i}$ -free asset: $r^f$

(harmonic estimation

no drift):

Discounting: $\varphi_\alpha(\tau) = \exp\{(\alpha-1)\delta_0\tau - \alpha\log(1+\delta_1\tau)\}$

Adjustment cost: $X(\Pi_t, W_t) = x(\pi_t)W_t$ $x(\pi) = \frac{1}{2}\theta\pi_t^2,$

Time horizon : N

# Appendix: Asset Prices and Financial Market: Model

**Extended model (with negative and positive externalities)**:

$$V(W,x,t) \equiv max_{\{u_s,c_s,\pi_s\}} \mathbb{E}\{\int_t^N e^{-\delta_0(s-t)} F(c_s W_s, u_s W_s) ds\}$$

$$s.t. \dot{W}(t) = \alpha_t (r_t^e - r^f) W_t + r^f W_t - (u_t + c_t) W_t - X(\Pi_t, W_t)$$

Risky asset: $r^e(t) = (\alpha_1 \sin(\alpha_2 t) + \alpha_3)(1 \pm \mu(u_t W_t))$ free asset: $r^f$

(with drift):

Discounting: $\varphi_\alpha(\tau) = \exp\{(\alpha - 1)\delta_0 \tau - \alpha \log(1 + \delta_1 \tau)\}$

Decision variables: $u_t = \frac{U_t}{W_t}$ $c_t = \frac{C_t}{W_t}$

Time horizon : N

Fossil fuel (-), green energy (+): ... $(1 \pm \mu(u_t W_t))$

# Appendix: Asset Prices and Financial Market: Numerical Results

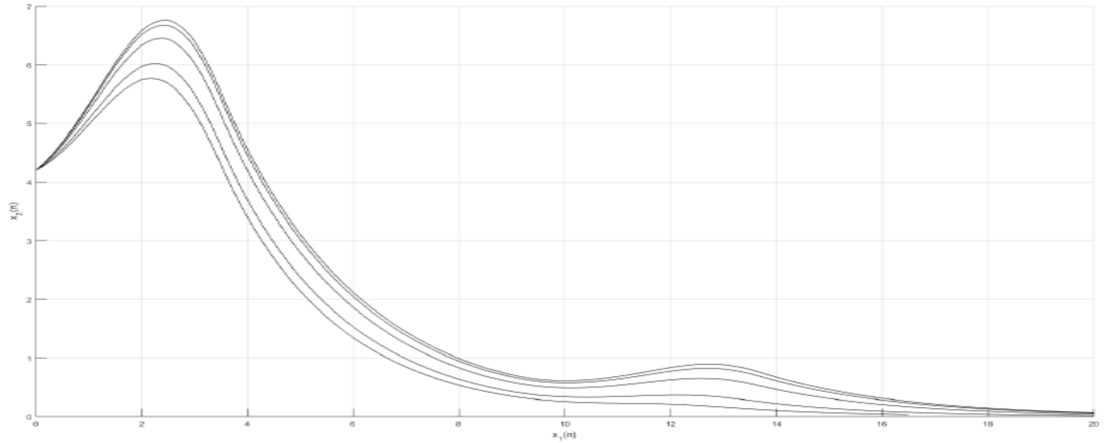



Figure 1: Solutions path of wealth for different discount rates, $\delta$=0.01, 0.015, 0.03, 0.07, 0.15; log utility

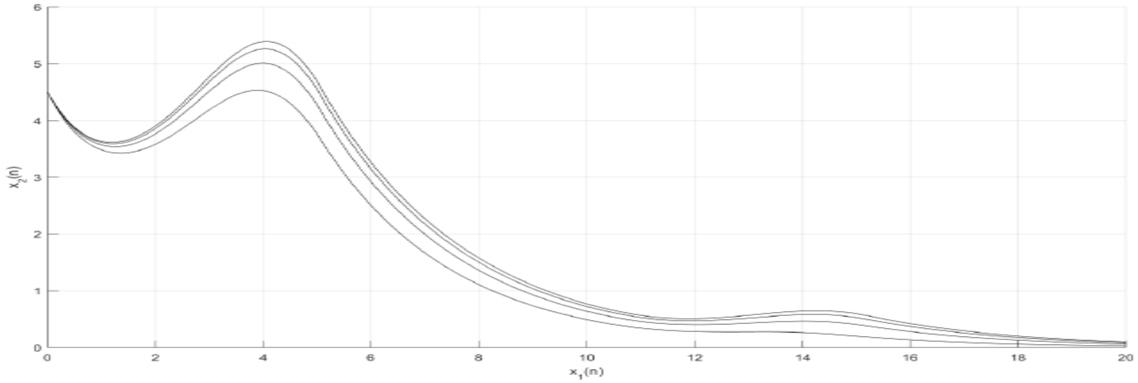



Figure 2: Solutions path of wealth for different discount rates, $\delta$=0.01, 0.015, 0.03, 0.07, 0.15; power utility

# Appendix: Asset Prices and Financial Market: Numerics

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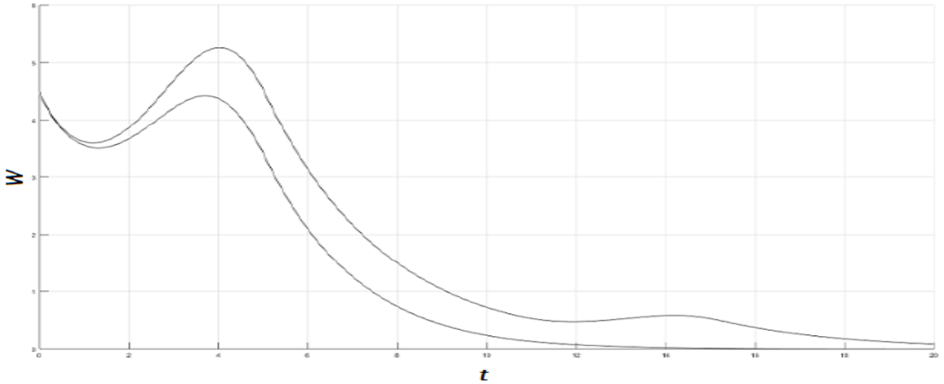



Figure 3: Solutions path of wealth for different types of discount factors, $\delta = 0.03$; upper figure, exponential discounting ($\alpha = 0$), lower figure, hyperbolic discounting ($\alpha = 1$)

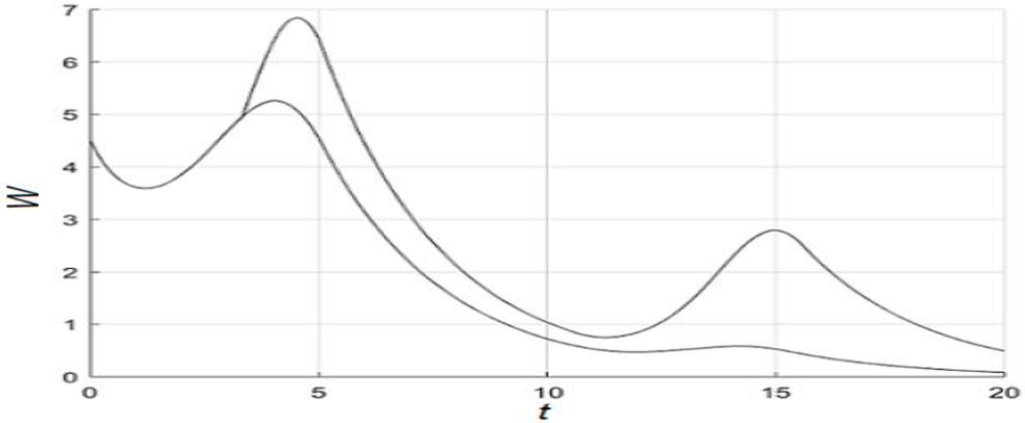



Figure 4: Solutions path of wealth as a result of change of $\alpha_1$ from 0.05 to 0.08 at $t = 8$

# Appendix: Asset Prices and Financial Market: Numerical Results

Upper graph

N=8, μ ( · ) =2.5

lower graph,

N=6

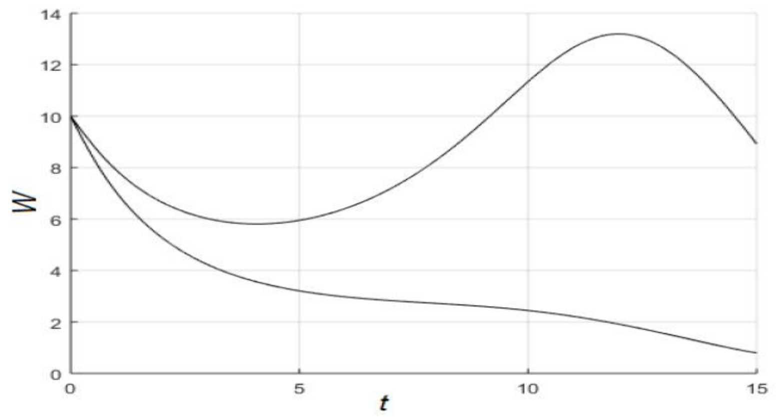



Figure 5: Solutions path of wealth for different time horizon, $\delta = 0.03$; upper figure, $N = 8$, lower figure, $N = 6$

Upper two graphs

same as above

Lower graph

N=2; μ ( · ) =2

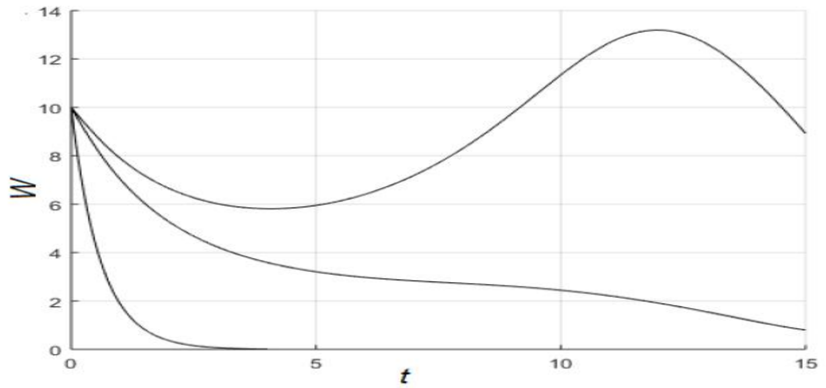



Figure 6: Solutions path of wealth for different time horizon, two upper graphs $\mu(\cdot) > 0$, low graph $\mu(\cdot) = 0$, $T = 30$

# Appendix: Asset Prices and Financial Market: Numerical Results

**Extended model:**

Time horizon, N,

and

externalities:

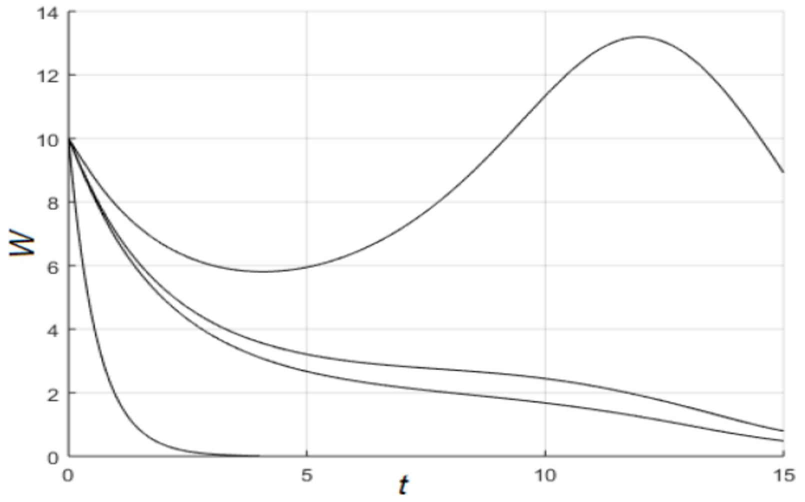



Figure 7: Solutions path of wealth for different time horizons

Figure 7 shows four graphs. the upper graph, $N = 8$; the two graphs below, $N = 6$, with the term $(1 + \mu(u_t W_t))$, and $N = 6$, with the term $(1 - \mu(u_t W_t))$, representing external cost of fossil fuel use; finally the lowest graph, $N = 2$, and here the term $(1 \pm \mu(u_t W_t) = 1$ which implies that $\mu(\cdot) = 0$.

# Appendix: Asset Prices and Financial Market: Numerical Results

## **Extended model** with **convertible bonds**:

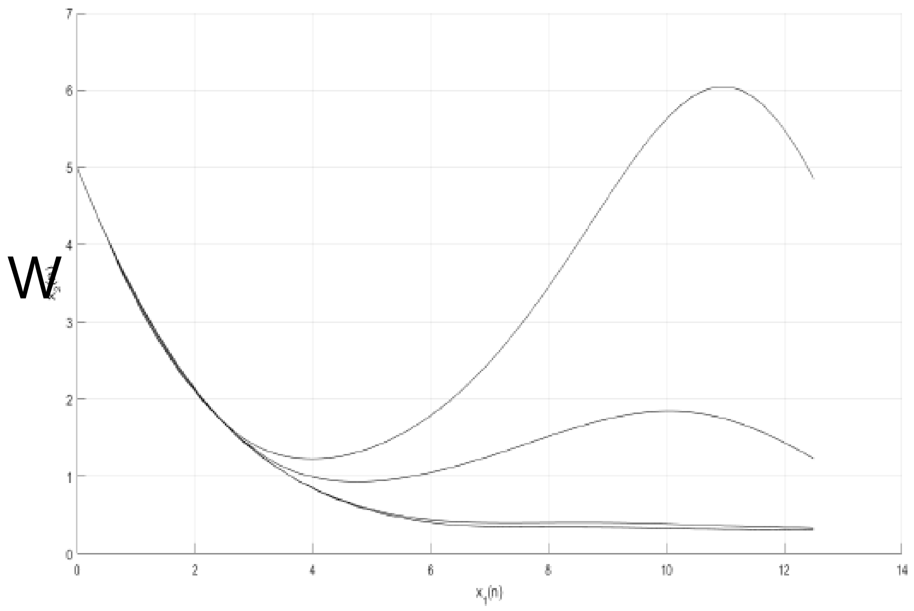



Figure 2: Solutions path of wealth for different types of externalities, two upper with graphs $\mu(\cdot) > 0$, lower graphs with $\mu(\cdot) < 0$, $N = 6$, $T = 25$

- The **lower graphs** represents the latter effect with mostly fossil fuel bonds held in the portfolio facing a carbon tax, requirements of $CO_2$ disclosure, and higher default risks. We use parameterization of $\mu(\cdot) = -0.2$ in term $(1-\mu(uW))$
- The **middle graph**, with returns from fossil fuel; still be higher than in the lower graphs, but this represents some temporary effect where some risk premia are captured in returns which however might lead to a loss in returns in the longer run.
- The **upper graph,** with the term $(1+\mu(uW))$, innovation effort is spent (human capital), exerting some positive externality effect on the asset returns, => convertible bonds (for example renewable energy start-up firm)

# Appendix: **Financial Market - Empirics: Green bonds**

Regression approach: the main goal is to determine the effect of a green bond on the expected return of bonds (eq. 3)--- is there a negative green bond premium?

- Dependent variable:
  - (A) yield to maturity rate (log) or
  - (B) bond specific Sharpe ratio SRb (log)

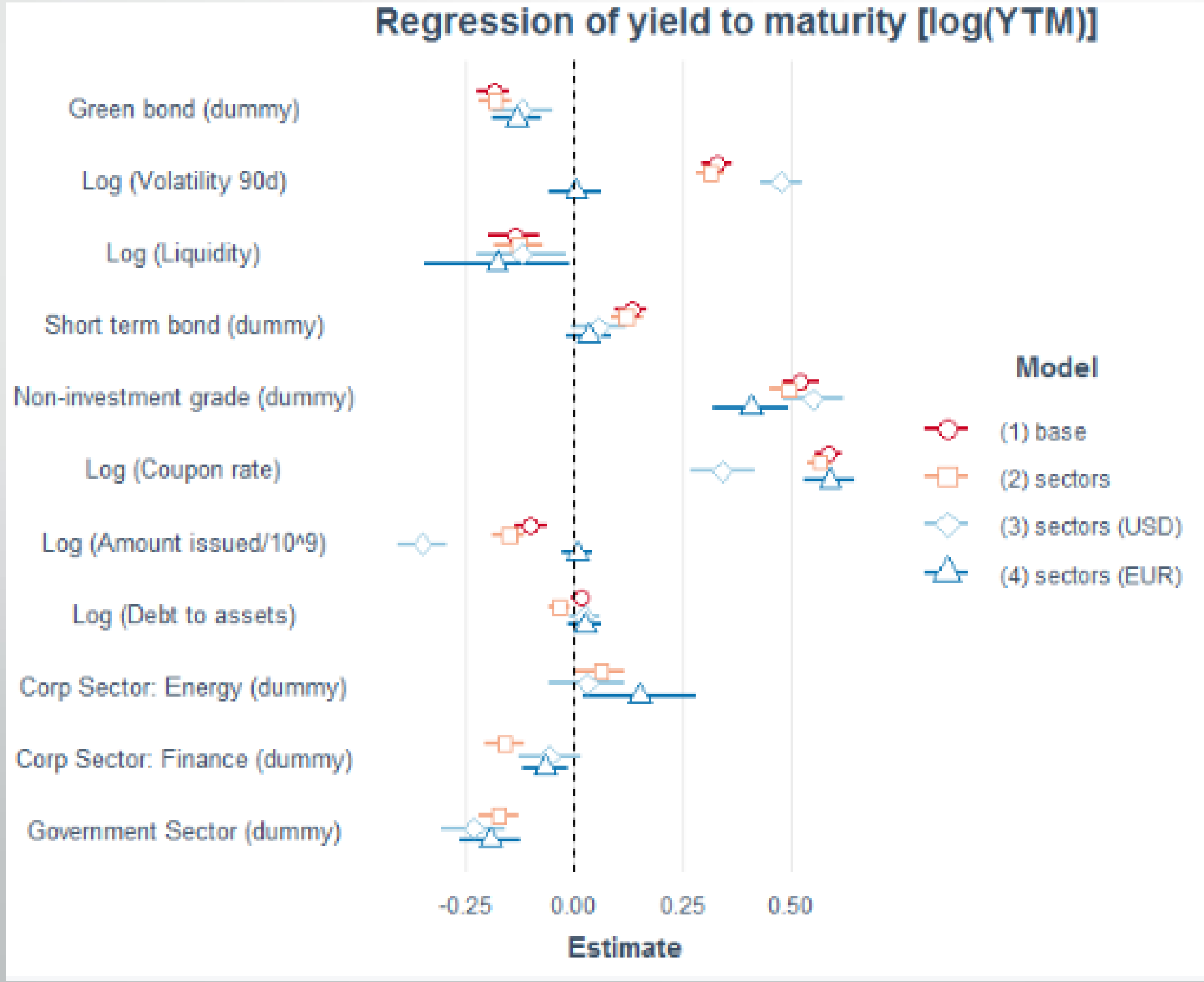
- 4 different models for regressors (drivers of yields):
  - (1) variables:
    - X1: green dummy variable
    - X2: the S&P rating
    - X3: the maturity structure
    - X4: the coupon rate;
    - X5: the liquidity (bid minus ask price);
    - X6: and the amount issued (in billions)
    - X7: debt to assets ratio;
    - X8: the 90 day volatility rate;
  - (2) variables: as (1) + sectors
    - $S_1$ energy sector:
    - $S_2$ finance sector
    - $S_3$ government sector
    - $S_4$ utilities sector
  - (3) variables: as (2) but only USD bonds
  - (4) variables: as (2) but only EUR bonds

$$log(Y_{i,c}) = \beta_0 + \beta_1 \cdot X_{1,i,c} + \sum_{k=2}^{3} \beta_{k,c} X_{k,i,c} + \sum_{k=4}^{8} \beta_{k,c} log(X_{k,i,c}) + \sum_{l=1}^{4} \gamma_{l,c} S_{l,i,c} + \epsilon_{i,c} \ (Eq. \mathbf{3})$$

# Appendix: **Financial market - Empirics: Green bonds**

Plot for multivariate linear regression on the yield to maturity rate (YTM) of conventional and green bonds (January 2017 – September 2020)

→ green bonds show a consistent negative effect on the yield to maturity rate

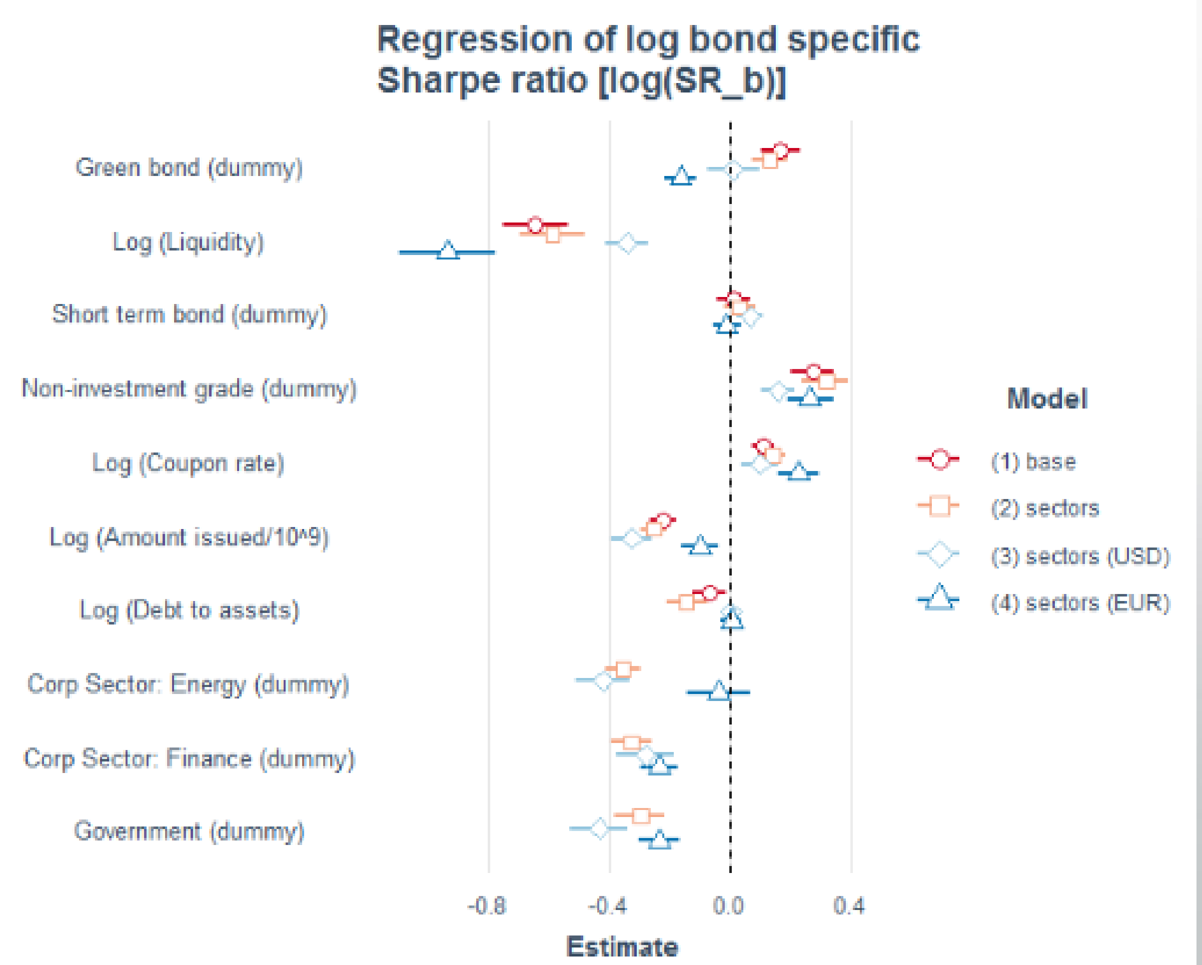



(1) $R^2 = 0.72$
(2) $R^2 = 0.73$
(3) $R^2 = 0.78$
(4) $R^2 = 0.45$

# Appendix: **Financial market - Empirics: Green bonds**

Plot for multivariate linear regression on the bond specific Sharpe ratio (SRb) of conventional and green bonds (January 2017 – September 2020)

→ green bonds show a positive effect on SRb for models (1) and (2)
→ … but not when controlling for different currencies, as models (3) for USD and (4) for EUR show




(1) $R^2 = 0.15$
(2) $R^2 = 0.17$
(3) $R^2 = 0.23$
(4) $R^2 = 0.25$

# Appendix: **Financial market - Empirics: Green bonds**

Table for paired bonds regarding the mean differences of green minus conventional bond measures.

The results for our paired bond subset is in line with the findings of Kapraun & Scheins (2019)

In this subset we see that

→ Green bonds have on average lower yield at issue (yai) rates than conventional bonds

→ … but higher yield to maturity rates (ytm)

→ And that green bonds show higher bond specific Sharpe ratios, no matter how they're computed

  → … it holds for all different volatility measures (30d, 90d, 260d)

  → … and all different forms of bond yields

| Measurement | Yield at issue (yai) | Yield to maturity (ytm) |
|---|---|---|
| **(a) Mean yield difference:** $avg(yield_{green} - yield_{convent})$ | -0.424 | 0.300 |
| **(b) Mean SRb difference for 30d volatility:** $avg(SRb_{green}^{30d} - SRb_{convent}^{30d})$ | 1.05 | 2.12 |
| **(c) Mean SRb difference for 90d volatility:** $avg(SRb_{green}^{90d} - SRb_{convent}^{90d})$ | 0.997 | 2.96 |
| **(d) Mean SRb difference for 260d volatility:** $avg(SRb_{green}^{260d} - SRb_{convent}^{260d})$ | 1.19 | 3.50 |

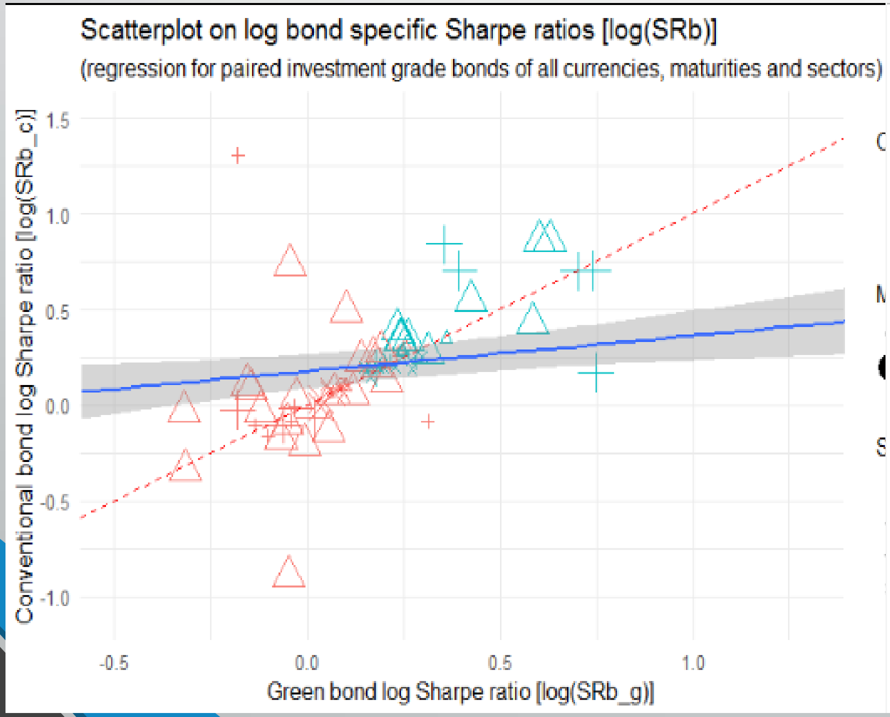
# Appendix: **Financial market - Empirics: Green bonds**

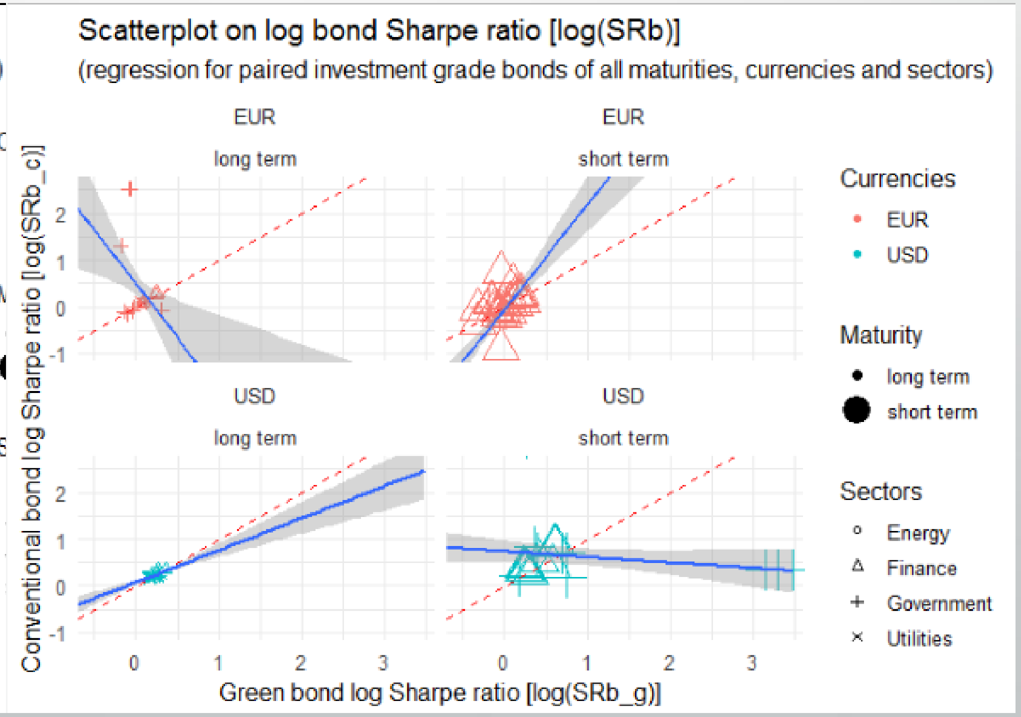
Scatterplots for paired bonds regarding the <u>bond specific Sharpe ratio SRb (log)</u> of paired green bonds (x-axis) and paired conventional bonds (y-axis)

With this depictions we see that

→ Green bonds can achieve higher Sharpe ratios: The regression line (blue) from left to right moves below the 45° line (red) which shows a consistent trend that when moving from lower to higher Sharpe ratio bonds the performance of green bonds improves compared to conventional bonds

→ Heterogeneity regarding the different currencies and maturities can be related to a small sample bias as our subset of data consists of less than 150 pairs of bonds



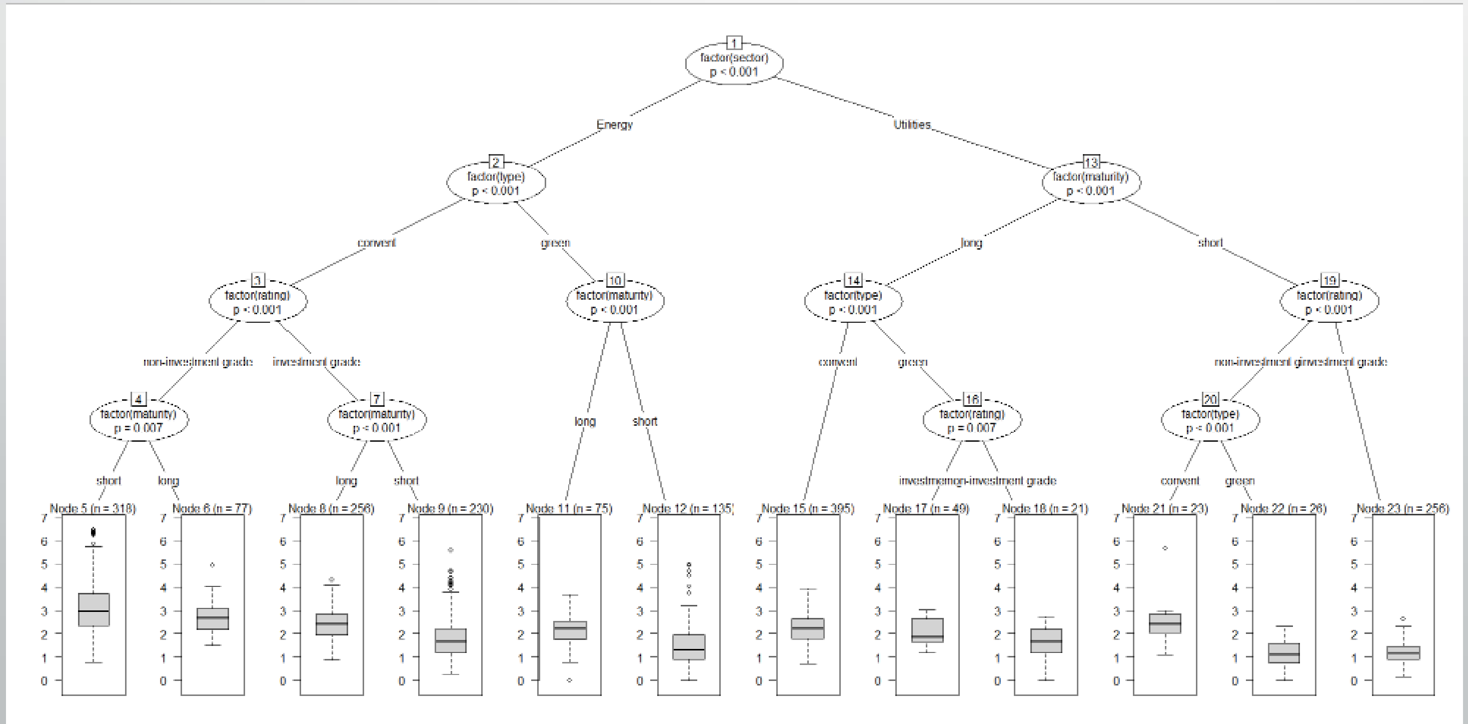



# Appendix: **Financial market - Empirics: Green bonds**

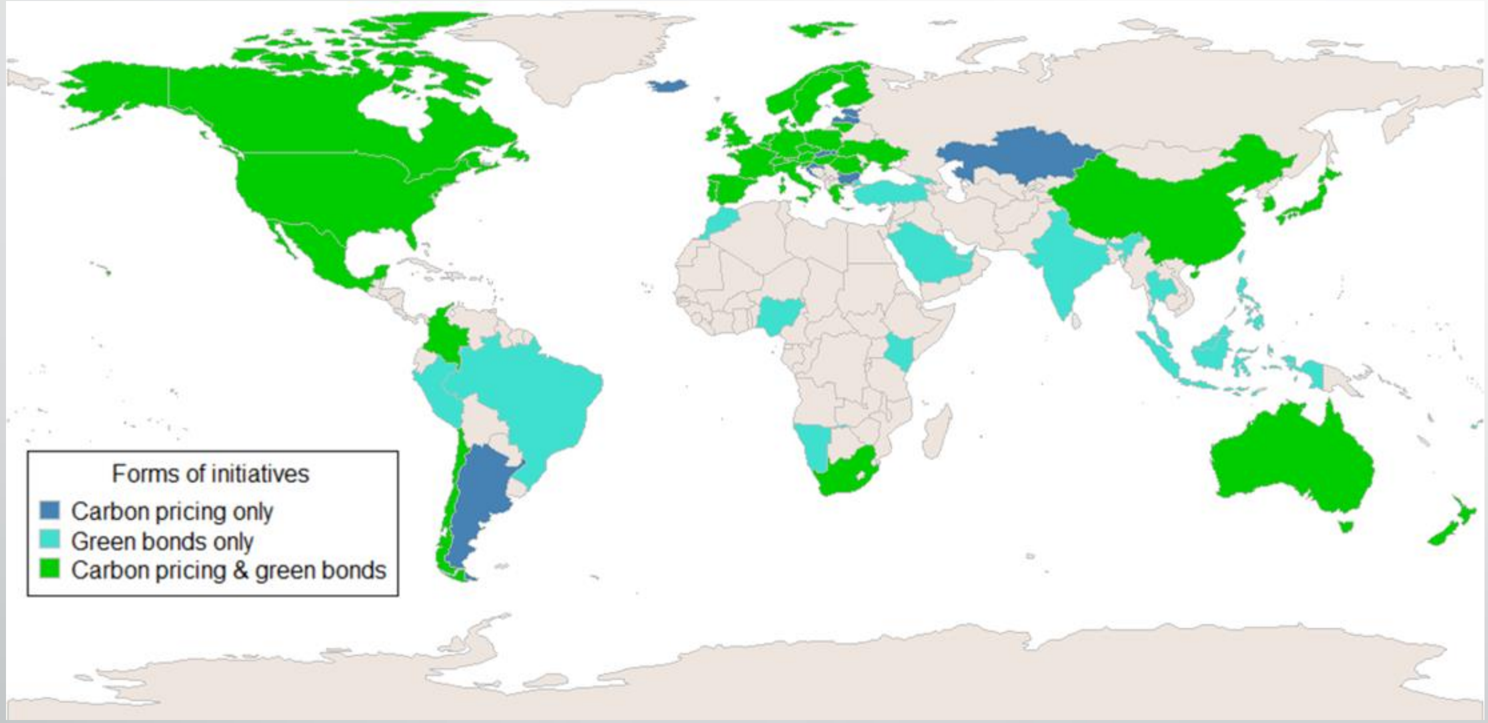
CART analysis on the 90 day volatility for bond types, sectors, ratings and maturities

→ General results of volatility classification

1. Conventional bond volatatility always higher than green bond volatility
2. Sectors matter: energy highest, finance and government lowest
3. Top 3 factors of the highest volatility branch are:
    1. Energy sector
    2. Conventional bonds
    3. Non-investment grade



**Appendix:** Countries worldwide where carbon pricing initiatives were implemented and/or green bonds were issued




*Source: Bloomberg Terminal data and World Bank Carbon Pricing Dashboard (10/2020)*

*Note: Carbon pricing initiatives implemented as of October 2020. Green bonds issued between January 2017 and October 2020.*

** In the US carbon pricing initiatives were only implemented in several states, not nationally. In certain countries carbon pricing initiatives were implemented on a national and subnational level (e.g. Canada, China, Mexico).*

# Appendix: Taking Stock; Overview on carbon tax and green bonds

- **Carbon pricing and green bond initiatives:** growing but still concentrated in high income countries (especially Europe) and China (classified as Upper-middle income). Though, we find a low % of GHG emissions covered in advanced countries.

Table 1. Carbon taxation and ETS initiatives by country income level, 2020

| Country Income Classification | Carbon taxation | | ETS | | Total* | |
|---|---|---|---|---|---|---|
| | Number of Initiatives (%) | GHG emissions covered (%) | Number of Initiatives (%) | GHG emissions covered (%) | Number of Initiatives (%) | GHG emissions covered (%) |
| High Income | 32.14% | 3.6% | 36.90% | 13.18% | 69.05% | 16.76% |
| Upper-Middle Income | 4.76% | 1.50% | 16.67% | 2.60% | 23.81% | 4.19% |
| Lower-Middle income | 3.57% | 0.53% | 3.57% | 0.00% | 7.14% | 0.53% |
| Total | 40.48% | 5.60% | 57.14% | 15.80% | 100.00% | 21.49% |

Table 2. Green bonds issued: Share per country income level, 2010-02/2020

| Country income classification | Total bonds | Investment grade share | Long term bonds share |
|---|---|---|---|
| High Income | 66.1% | 66.15% | 45.13% |
| Upper-Middle Income | 20.43% | 16.81% | 16.25% |
| Lower-Middle income | 3.47% | 36.33% | 14.27% |
| Multilateral Organization | 9.96% | 87.27% | 35.90% |
| Total | 100.00% | 57.14% | 37.24% |

# Appendix: Macro models; Guidance for policy -- Carbon tax and green bonds

- Advances in macro models with more **comprehensive treatment** of **preferences, climate related infrastructure, mitigation and adaptation policies, different technologies, carbon taxation and green bonds** (see Type 1 and 2 models)
- See also **multi-phase models** in Type 3 and Type 4 → allow a better evaluation of different policies during different **time phases and regimes.**

### Type 1 – Basic IAM (DICE 2008)

- Emissions only affect output and consumption
- Emissions work through a damage function via temperature only
- Emissions come from industrial activities, not from extracted fossil fuels
- Adaptation measures are not included
- Multiple equilibria and instabilities are not featured
- No Green Bonds
- Only single-phase model

### Type 2 – Extended IAMs

- Extended welfare function includes emission disutilities
- Mitigation and adaptation policy measures included
- Production has two types of inputs (renewables and non-renewables) but emissions come only from non-renewable energy sources
- Non-linearities included

### Type 3 – Macro policy augmented models

- Carbon taxation as possible macro policy
- Green bonds as possible macro policy
- Models with green bonds include multiple regimes to issue and pay back bonds (multiple-phase model)

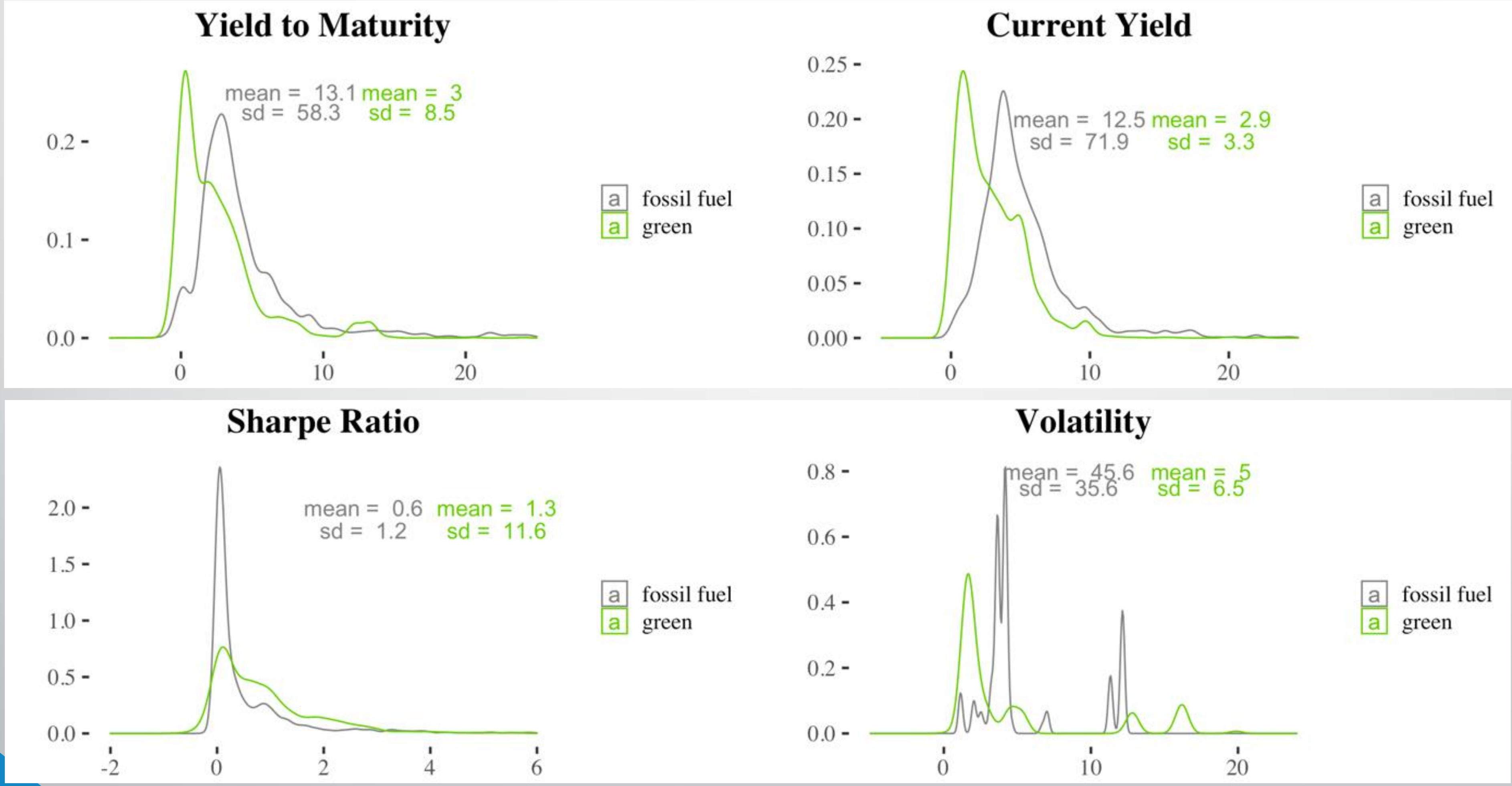
### Type 4 – Synthesis models

- Combination of model extensions of:
  - Extended IAM type 2 models (emission disutility, adaptation, reneweble energy)
  - Macro policy augmented type 3 models (carbon tax, green bonds, multiple phase dynamics, disaster shocks)

Semmler et al. (2020)

## **Appendix: Financial market**: Roadblock or Bridge

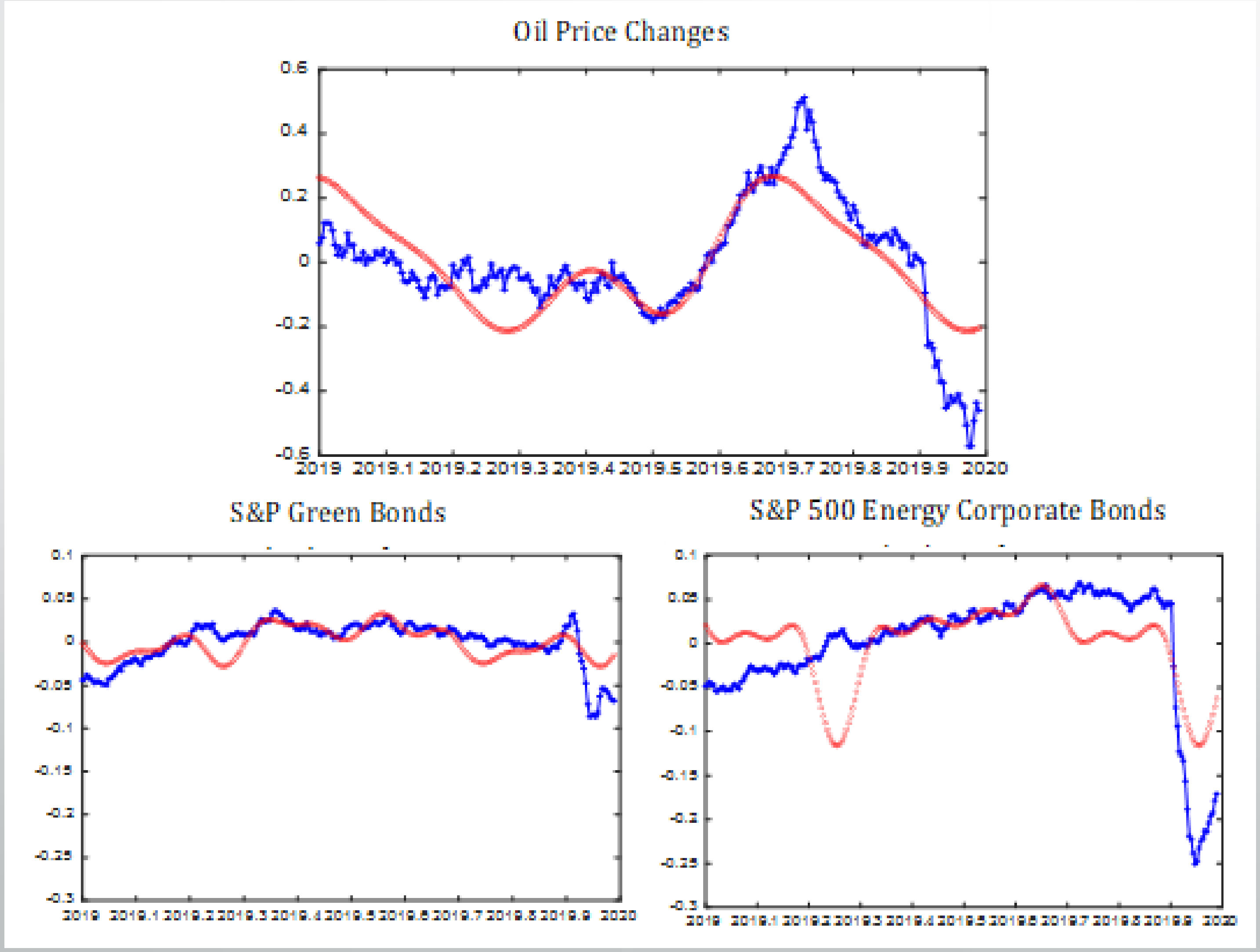
- Green bonds (vs fossil fuel bonds) have lower yields, lower volatility and similar Sharpe ratios. The volatility is higher in oil dependent countries (Semmler et al., 2020)




Semmler et al. (2020)

# **Appendix: Business cycles**: Oil Prices, brown and green bonds (for countercyclical policy)

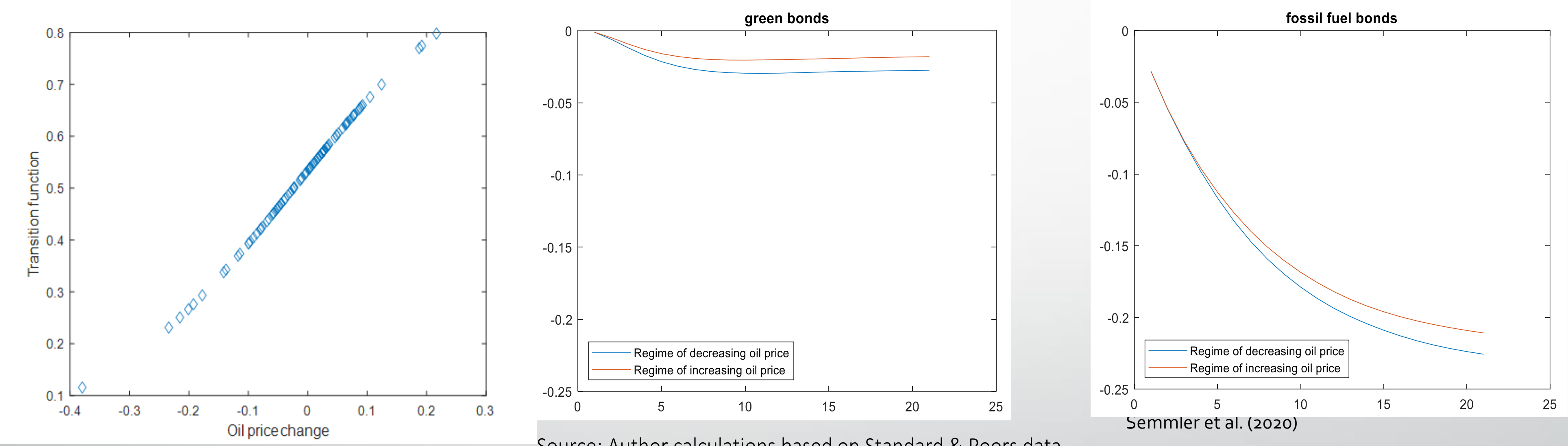
- Oil price is extremely volatile**. Fossil fuel securities strongly co-move with oil price** while green bond and equity returns are less impacted by oil price volatility. We visually observe this by running harmonic estimations (Appendix B).



# **Appendix: Business cycle;** Oil Prices, brown and green bonds (countercyclical policy)

- Using a LVSTAR Regime-switching model, we also find **that oil price change regimes do not impact significantly Green bonds but clearly impacts fossil fuel bond yields.** We run linearity tests and observe a non-linear behavior for fossil fuel bonds when oil price change is the transition variable.

Figure: Left Transition function; Right: -Impulse-response behavior under a decreasing and an increasing oil price regime




Semmler et al. (2020)

Source: Author calculations based on Standard & Poors data.

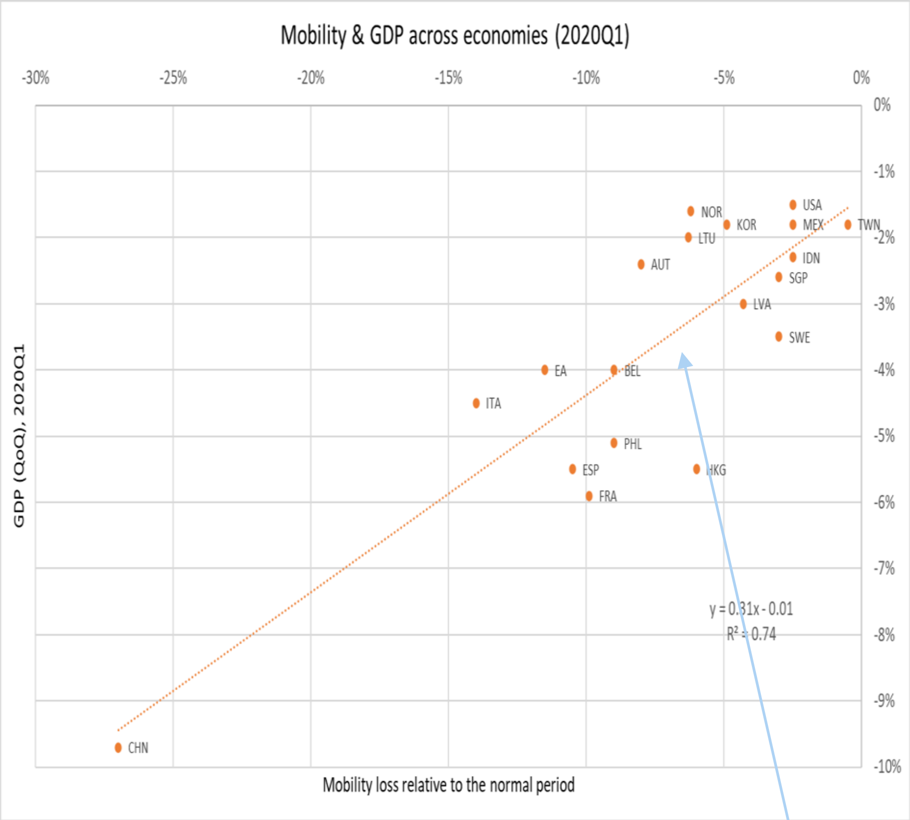
⇒ Green bonds are a good hedging instrument against oil price fluctuations in portfolios, in particular low fat-tail correlations

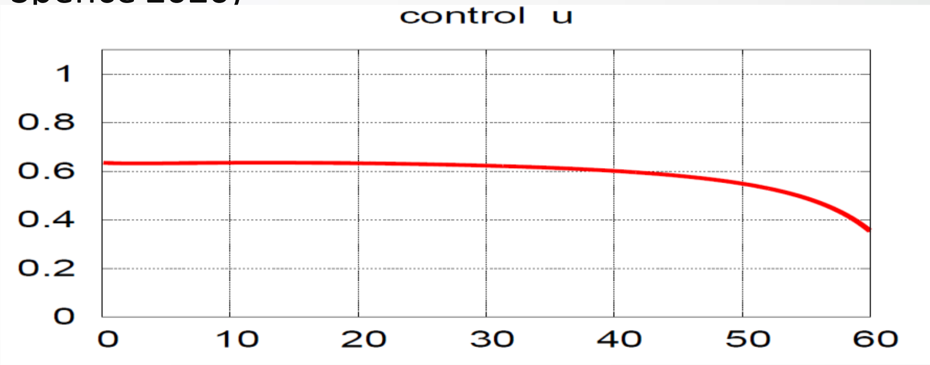
⇒ Low capital costs for green project and good instrument for green countercyclical investment.

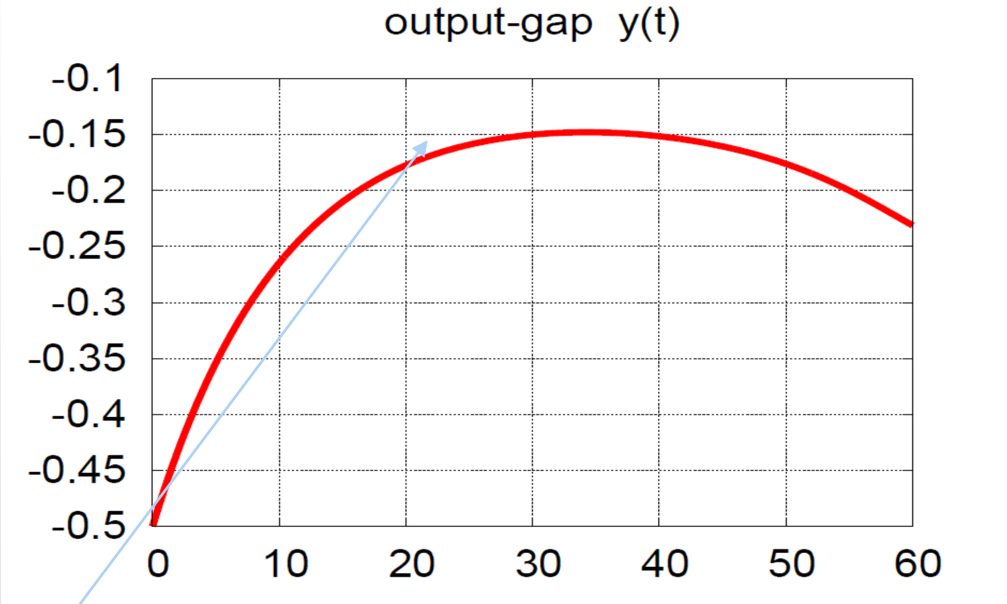
## Appendix: Green Recovery? Recovering from Pandemic recession with carbon tax and green bonds? See Semmler/Henry/Maurer 2021

Model type: Three components of a non-linear model of recovery

- dynamic equations for spread of infectious disease
- macro model with decision variable (control: social distancing, u)
- output gap driven by non-linear recovery, not linear (see Spence 2020)




**Linear versus non-linear recovery**

# Appendix: Sustainable debt?

- **Financial markets** with its **short-termism** and **stranded assets** can be a **roadblock** for low carbon economy
- **Financial market** can be a **bridge** to low carbon economy**:** help to **mobilize financial resources** to move forward with **green transition** and **green countercyclical policy---** to recover growth and jobs.
- Yet, using **green** policy tools for **recovery** with respect to jobs and employment **may exhibit non-linearities**, see last slide
- Can it be done with keeping the **debt sustainable?** Blanchard rule: Growth rates higher than interest rates ; currently low interest rate and low capital cost.
- Yet there is **difference of advanced countries and EM**: **EM** face less fiscal space and higher capital costs -- now even less fiscal space since there is resource **price and export bust** and huge **recovery cost.**
- Moving back to **sustainable debt?** Is there a debt restructuring needed? And what type of taxes needed? Use of a **wealth tax?**

## Appendix: Financing of Renewable Energy Firms (and households)

=> what major types of entry barriers exist, what sources of finance are available?

- self-financing,
- equity finance,
- bank loans,
- bond issuing on the capital markets,
- venture capital, crowd finance,
- tax breaks and subsidies etc.,
- what sources of finance have become relevant for the different types of energy sources in the US and Europe?

# Appendix: CBs, climate risks, and energy transition, see Braga, Chen, Semmler (2023)

We presume in a finite horizon decision model a quadratic objective function given by eq. (2).

$$Min_{i(.)} \int_0^T e^{-\rho t}[w_\pi(\pi(t)-\pi_s)^2 + w_y(y(t)-y_s)^2 + w_l(l(t)-l_s)^2 + w_i i(t)^2]dt \tag{2}$$

The CB exogenously sets the policy targets given by $\pi_s$, $y_s$, and $l_s$. Eq. (2) assigns a quadratic penalty to the deviation of each variable from their target value, and defines weights for each target. The weights are given by $w_\pi$, $w_y$, $w_l$ , and $w_i$.[12] Furthermore, the objective functional faces constraints given by the macro behavior of each variable. The state variables are represented by the following dynamic state equations:

$$\dot{\pi}(t) = -\alpha_1\pi(t) + \alpha_2 y(t), \quad with \quad \pi(0) = \pi_0 \tag{3}$$

$$\dot{y}(t) = -\beta_1 y(t) - \beta_2(i(t) + \sigma(y(t)) - \pi(t) - r) \quad with \quad y(0) = y_0 \tag{4}$$

$$\dot{l}(t) = \gamma_1 l(t) + \gamma_2(y(t)) - \gamma_3(i(t) + \sigma(y(t))) - \gamma_4\pi(t), \quad with \quad l(0) = l_0 \tag{5}$$

$$\dot{m}(t) = -\sigma_1(m(t) - m_s) + \frac{\sigma_2(y(t) + d(t))}{g_r(s)(\sigma_3 l(t) + \sigma_4 d(t)) + \sigma_5}, \quad with \quad m(0) = m_0 \tag{6}$$

# Appendix: Climate risks and energy transition

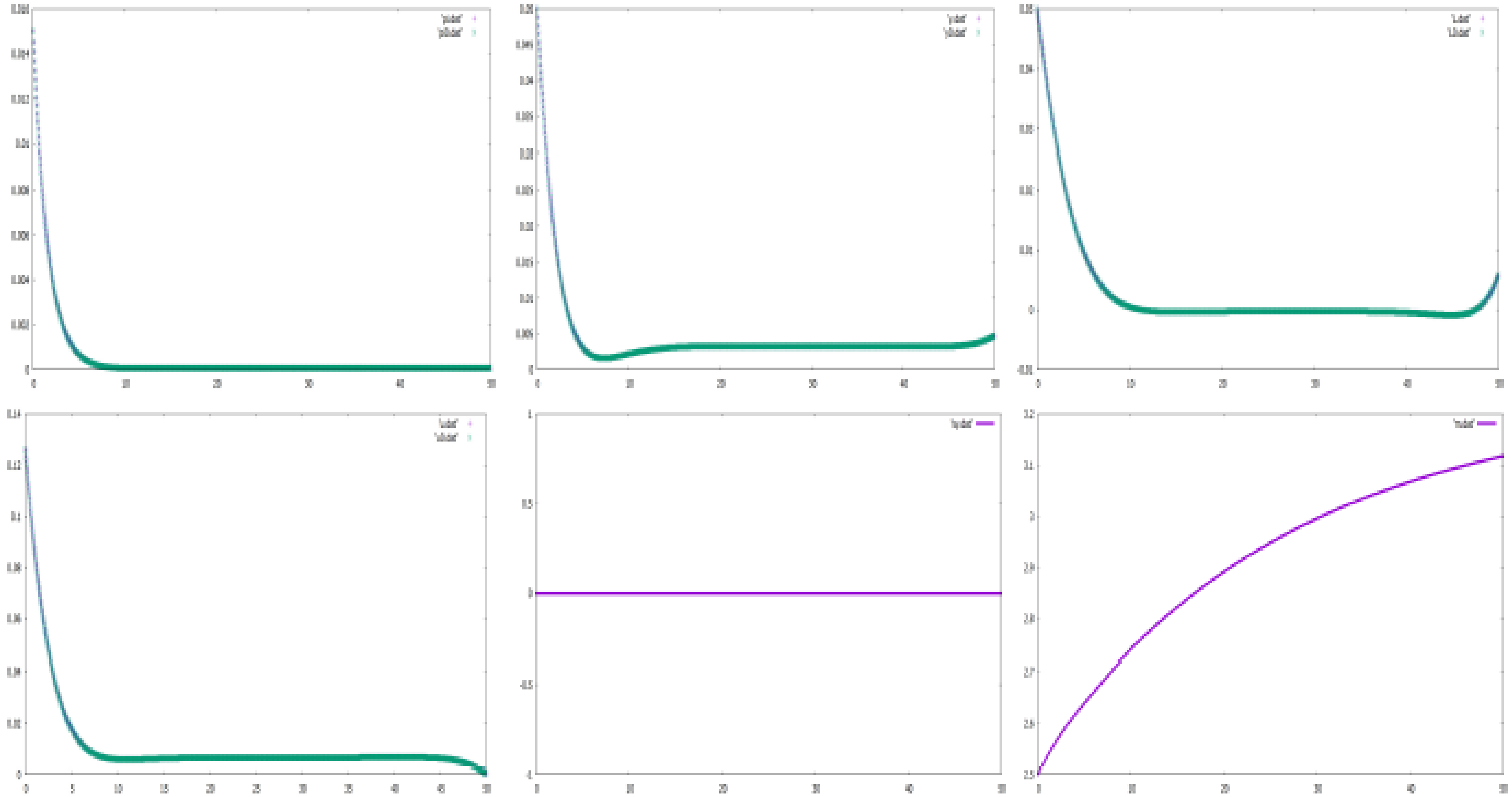


Figure 3: Model Simulation 1: Above: Inflation rate, positive output gap and credit flow; Below: interest rate ($u$), risk premium ($sy$), and emission ($m$) (when $g_r(s) = 0$or 1); emission control implicitly through $g_r(s)$ with time depending switches, as soon as interest rate moves down to 2%

# Appendix: Climate risks and energy transition

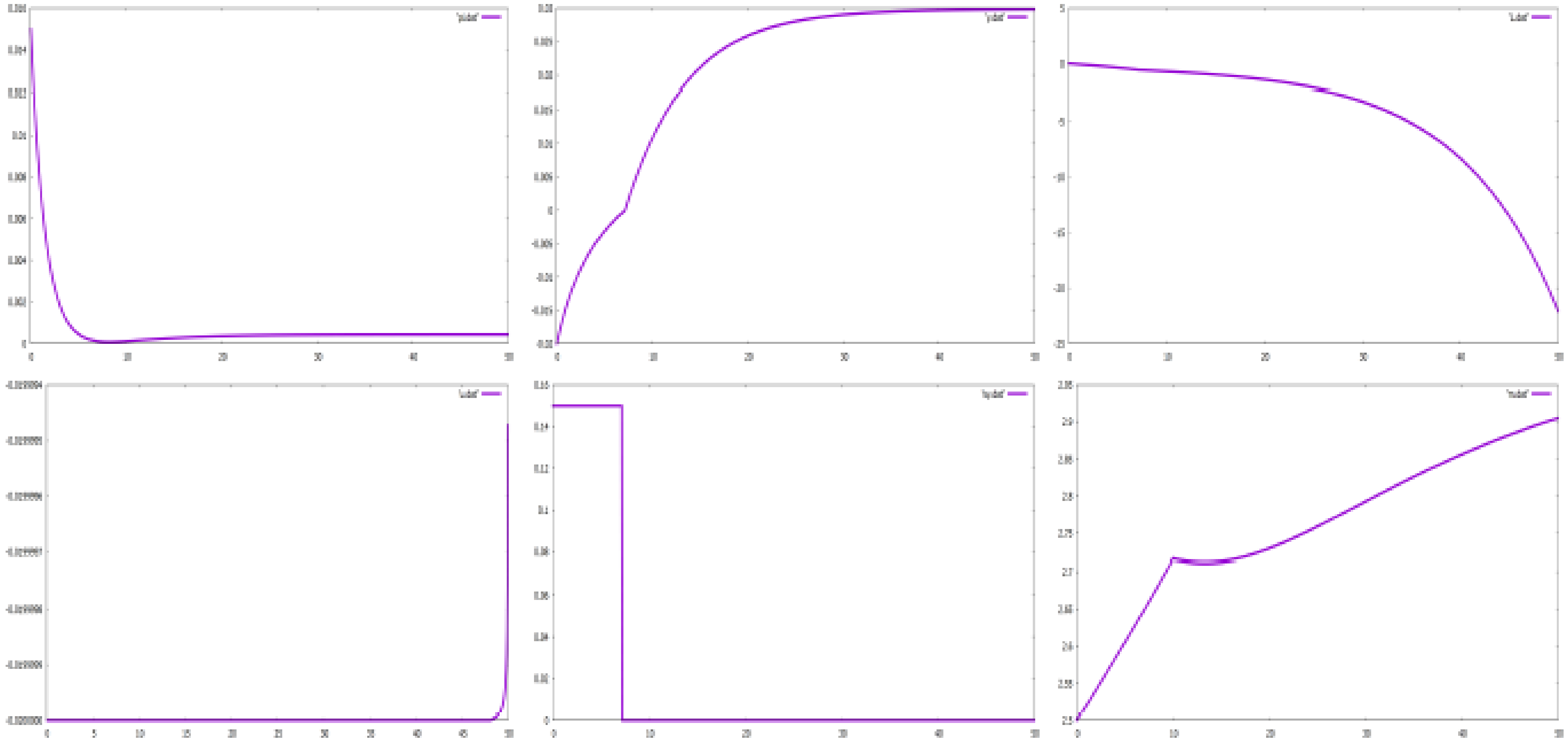


Figure 4: Simulation 2: Above: Inflation rate, negative output gap, and credit flow; Below: interest rate, risk premium and emission (when $g_r(s) = 0$ up to period 10 then $g_r(s) = 1$); time depending regime change, risk premium stays high as long as the output gap is negative; emission curve first increasing then flattening when credit flow for decarbonization is phased in.

# Appendix: Climate risks and energy transition
# with decision and transmission delays (see Aghion et al. on cost of delays)

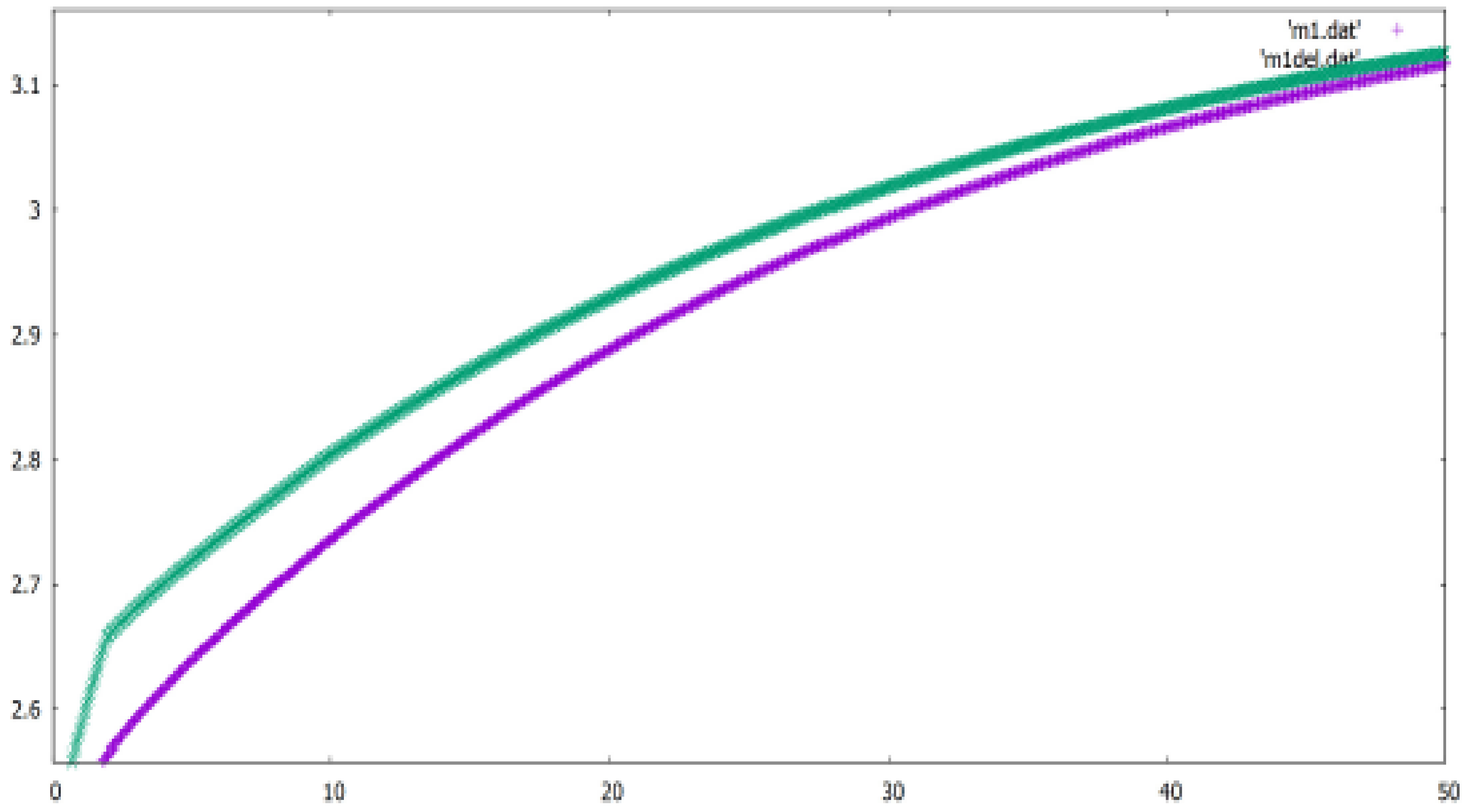



Figure 5: Upper graph: Model solution with delay, Lower graph: no delay; both graphs with regime switching $g_r(s)$ of credit flows

# Appendix: Cost trends