A FINANCE APPROACH TO CLIMATE STRESS TESTING

Banque de France Workshop on Climate Change

ERASMUS UNIVERSITEIT ROTTERDAM

Henk Jan Reinders

Rotterdam School of Management, Erasmus University; The World Bank

Dirk Schoenmaker

Rotterdam School of Management, Erasmus University; CEPR

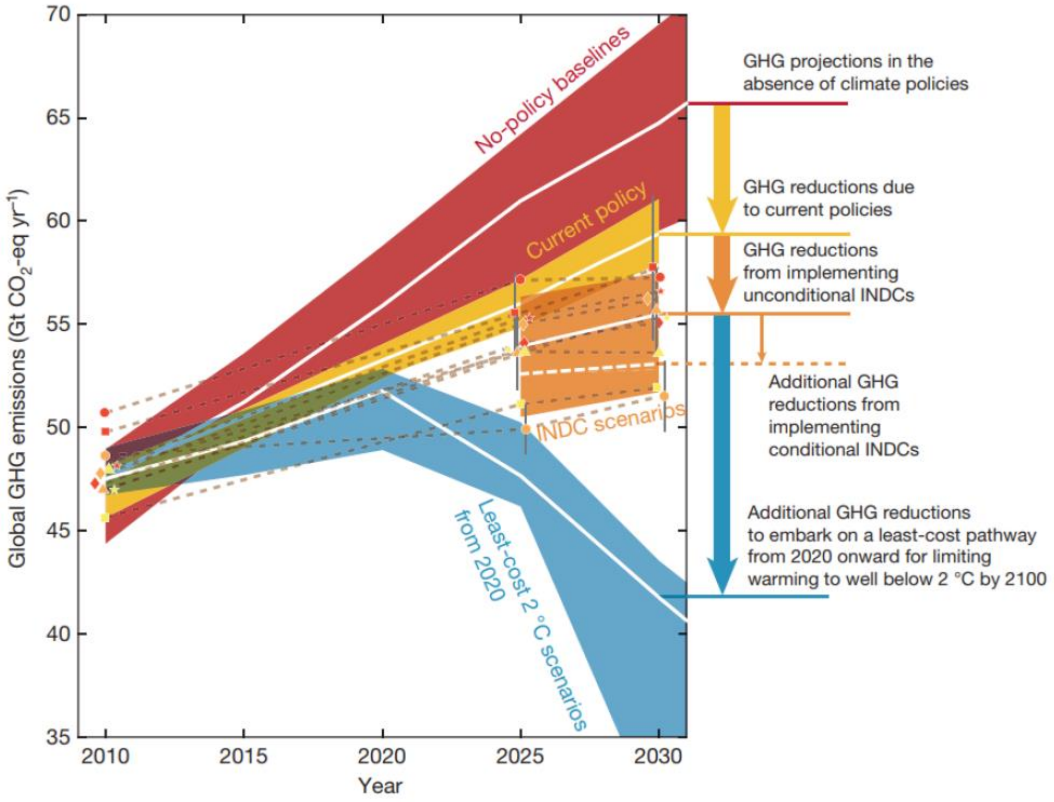
Mathijs van Dijk

Rotterdam School of Management, Erasmus University

Contents

Transition risk

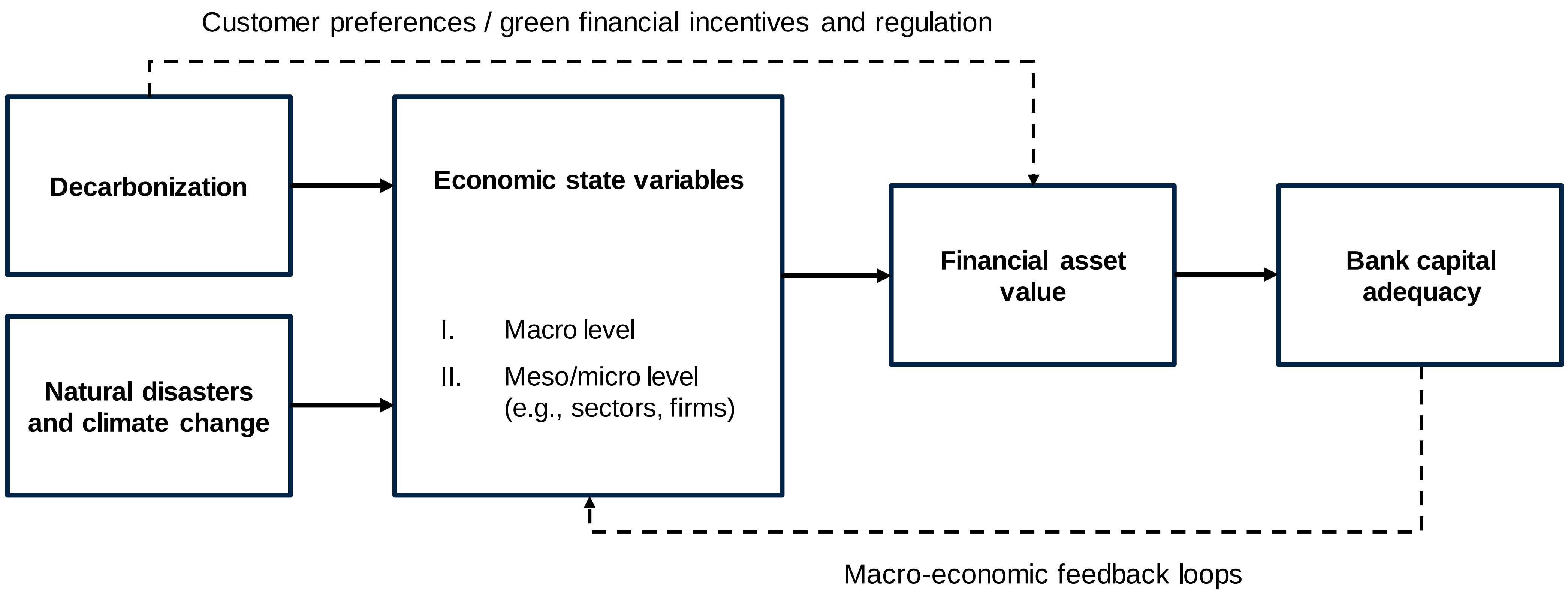
- **The 2015 Paris Agreement aims to limit global warming to well-below 2 degree Celsius**
- **Meeting this goal requires transition to a low-carbon economy**
  - Heavy industry (e.g., steel, cement)
  - Electricity production
  - Transportation
  - Buildings (e.g., heating)
  - Agriculture
- **Potential decarbonization drivers**
  - Climate policies (e.g., pricing, regulation, subsidies)
  - Technological developments
  - Changing consumer preferences
- **For financial institutions, this decarbonization poses transition risk**
  - Banks provide loans and equity to affected sectors
  - Banks provide loans with real-estate as collateral



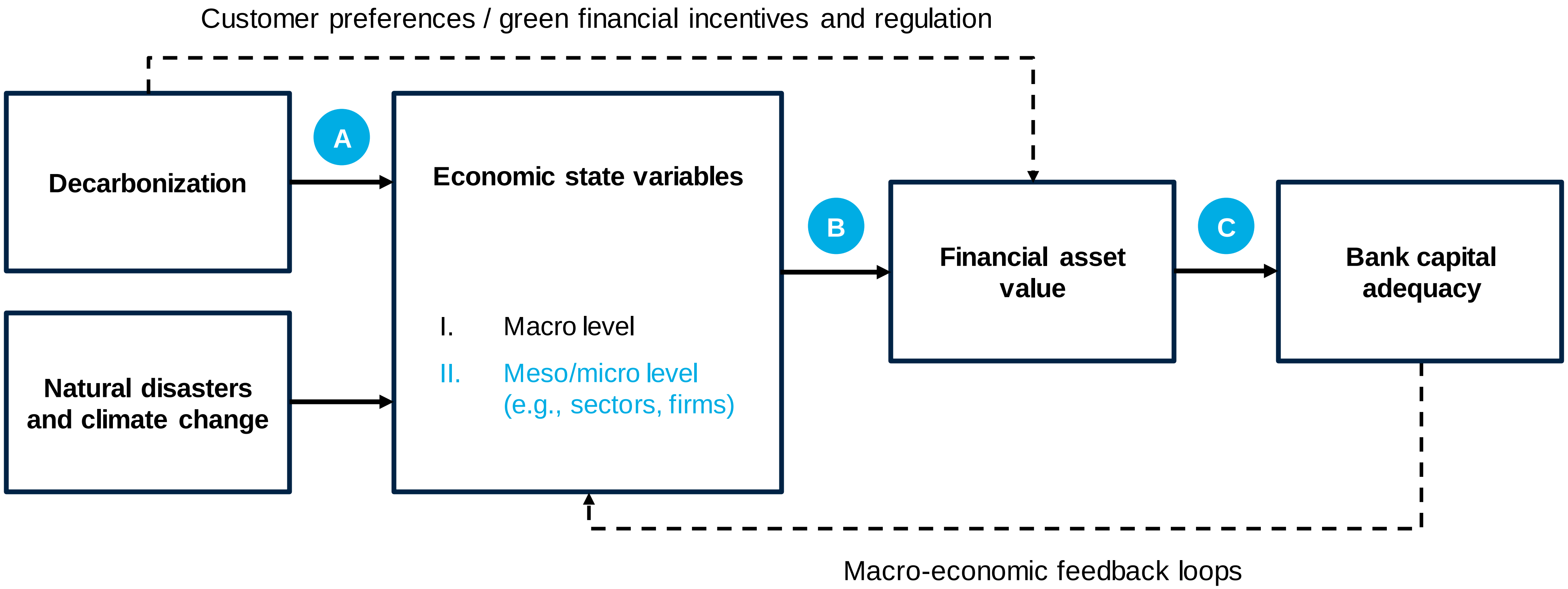
Aim and contribution

- Several studies have started to explore how adverse climate scenarios can affect the value of financial institutions' balance sheets (e.g., Battiston et al 2017; Vermeulen et al 2019, Hallegatte et al 2022). Typically these papers employ macro-models to determine economic and financial impacts.
- We develop a vulnerability model that links carbon tax scenarios to the market value of equity and debt on an industry level, using a tractable (finance) approach that combines a discounted cash flow model with a Merton-style structural credit risk model.
- Especially for banks in Europe it is crucial to include debt instruments, since the majority of bank assets are subordinated in nature (only 2% are equity investments).
- We illustrate the use of our model by performing a stress test of the Dutch banking sector, based on granular loan exposure data obtained from the Dutch Central Bank.

Climate stress testing



Modeling approach



Modeling approach

A

- **We estimate asset valuation shocks per 2-digit industry and real estate segment (*k*) by comparing the negative cash flows of a carbon tax to total asset value.**

$$\xi_k = \frac{NPV_{tax,k}}{Total\ asset\ value_k}$$

- **Account for pass-through ($\varphi_{k,t}$) and reduction of carbon intensity (γ_k) over time, for example by substituting inputs (e.g., green for brown electricity) and by making additional investments (e.g., carbon filters).**

$$NPV_{tax,k} = \sum_{t=0}^{T} (1 - r_k)^t * \gamma_{k,t}(1 - \varphi_{k,t})(-\tau_t)$$

- **Shocks for firms are calibrated using carbon emissions data (scope 1) obtained from Trucost and firm level data obtained from the Bureau van Dijk Orbis database.**

Modeling approach

B

- **We extend calibrate a Merton contingent claims model to allocate asset valuation losses to junior (equity-like), and senior (debt-like) claim holders of the asset.**

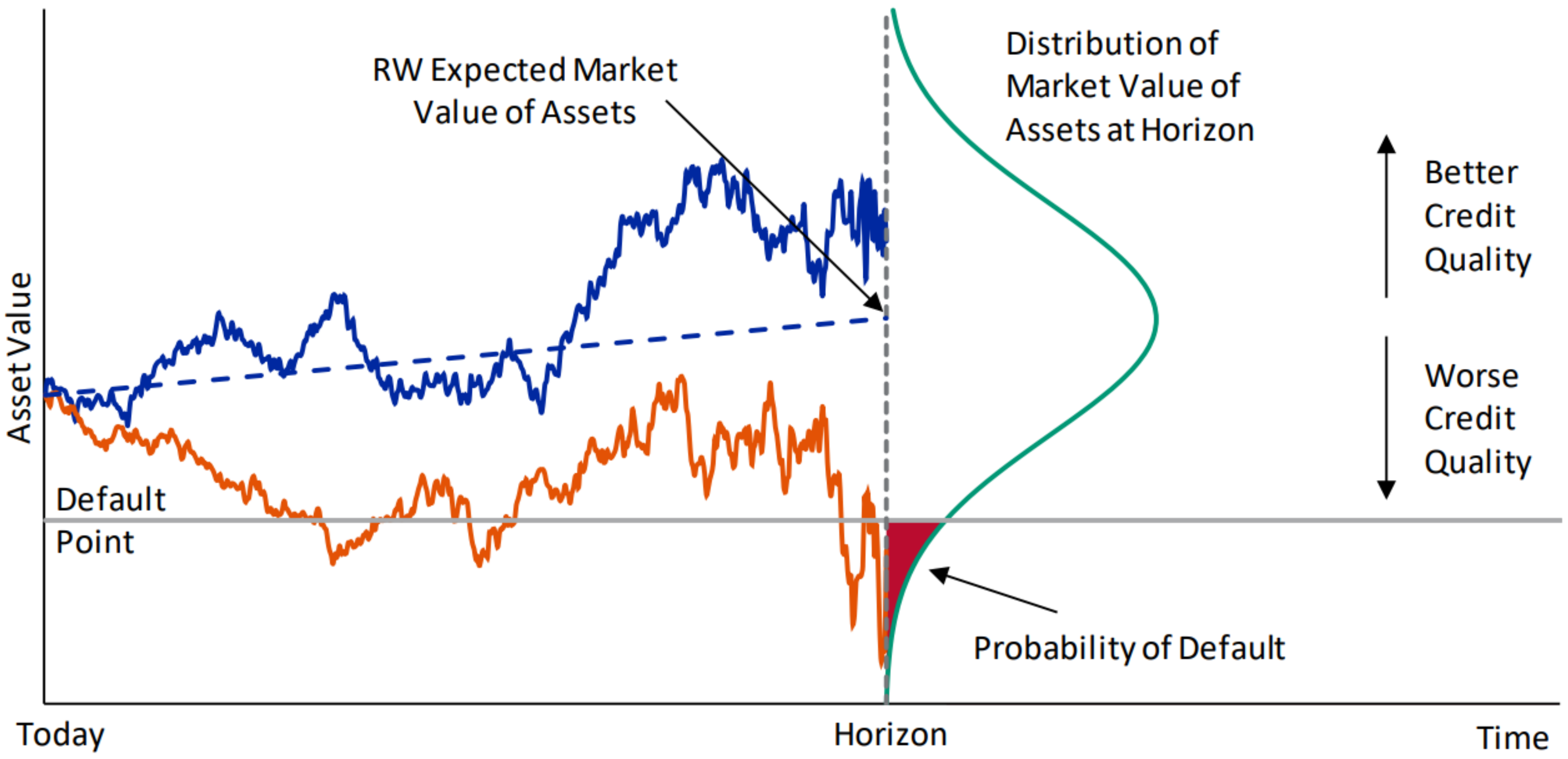
$$\vartheta_{E,k}, \vartheta_{D,k} = f_{Merton}(\xi_k, \Theta_k)$$

- **Instead of using the Merton (1974) model to determine the market value of debt, we introduce an asset valuation shock (ξ_k) and derive an expression for the debt valuation shock (ϑ_D) and equity valuation shock (ϑ_E)**

$$\vartheta_D = \frac{{MV_D}^*}{MV_D} = \frac{1 - \left(N(-d_2^*)\right) - \left((1-\xi)/R\, e^{-r(T-t)}\right)N(-d_1^*)}{1 - \left(N(-d_2)\right) - (1/R\, e^{-r(T-t)})N(-d_1)} \qquad d_1 = \frac{\ln(\frac{V_t}{L}) + (r + \frac{{\sigma_V}^2}{2})(T-t)}{\sigma_V\sqrt{T-t}} \qquad d_2 = \frac{\ln(\frac{V_t}{L}) + (r - \frac{{\sigma_V}^2}{2})(T-t)}{\sigma_V\sqrt{T-t}}$$

Merton (1974) structural credit risk model

B



Merton model calibration

B

- We use representative samples from the Orbis database to obtain estimates of leverage and asset volatility for firms by sector.
  - For listed firms, we link these samples to Thomson Reuters Datastream to obtain market estimates for asset volatility.
  - For non-listed firms, we estimate asset value volatility using a cross-sectional regression model.
- For residential mortgages, we disaggregate exposures to different types of dwellings (i.e., apartments, terraced houses, and detached houses) per loan-to-value (LTV) bucket and per remaining maturity bucket.
  - To obtain a measure the volatility of real estate assets, we use indices of average sales prices that are obtained from the Dutch statistical office (CBS) Statline database.
- Calculate outcomes based on standard Merton (1974) model and Merton (1976) jump diffusion model

Merton model calibration

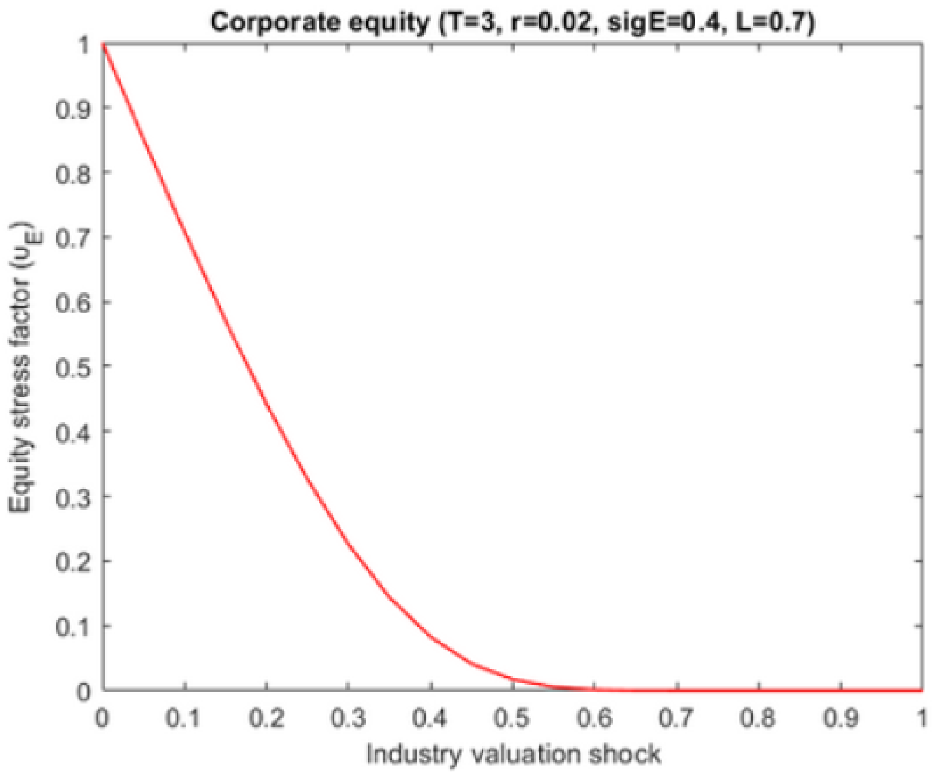
B

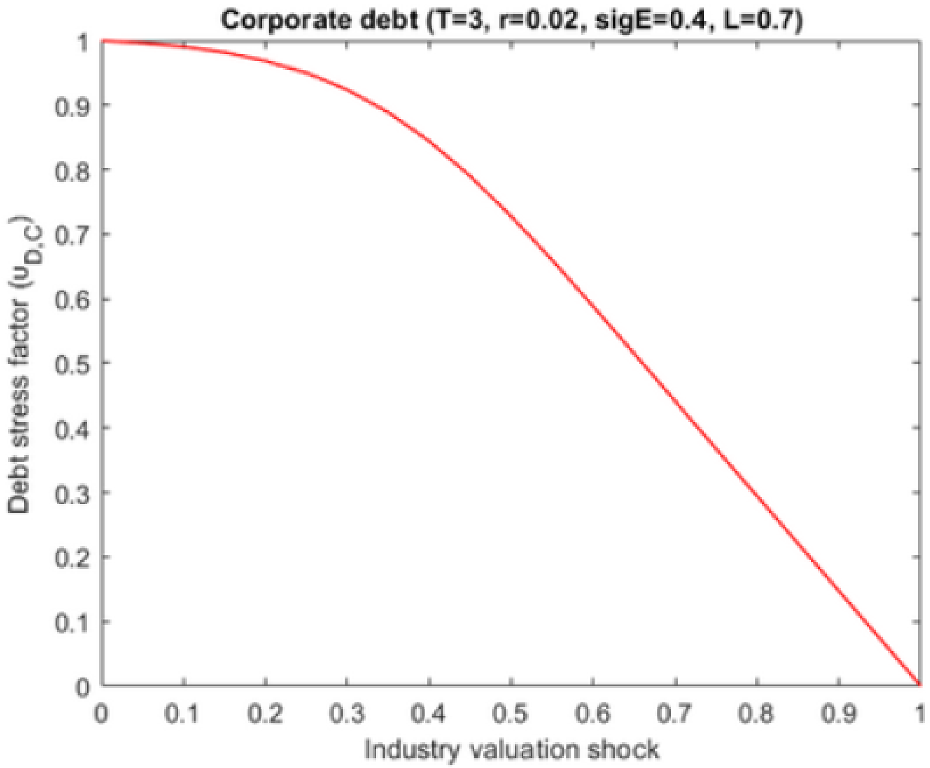
Prediction model for asset volatility of non-listed firms

	Model 1	Model 2	Model 3	Model 4
Total assets (natural logarithm)	-0.031*** (-9.54)	-0.016*** (-4.88)	-0.019*** (-6.32)	-0.031*** (-10.02)
Return on assets	-0.000 (-0.30)	-0.001*** (-2.64)	-	-
Leverage ratio	-	-0.502*** (-13,88)	-0.486*** (-13.66)	-
Liquidity ratio	-	0.005*** (3.41)	0.005*** (3.50)	-
Country fixed effects	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes
R-squared	0.26	0.37	0.37	0.26
N	1,532	1,521	1,537	1,548

Merton model calibration

B





Banking sector stress test

C

- Using our calibrated model, we estimate total market value loss (TMVL) for the banking sector in the Netherlands, for which we use detailed and proprietary exposure data on corporate loans and residential mortgages from the Dutch central bank (DNB).

$$\text{TMVL} = \sum_{k=1}^{n} \vartheta_{E,k} * exposure_{E,k} + \vartheta_{D,k} * exposure_{D,k}$$

- Our exposure dataset includes the three largest banks in the Netherlands that collectively cover 79% of total assets in the Dutch banking sector.
- We differentiate our scenarios by assuming either an abrupt (overnight) or smooth (10-year phase-in period) of the tax and by assuming either a regional application (no cost pass-through from firms to consumers) or a global application (50% cost pass-through from firms to consumers).

Asset value shock estimates (ξ_k)

€100 / tonne carbon tax		**Scenario I** • Regional • Abrupt	**Scenario II** • Regional • Phase-in	**Scenario III** • Global • Abrupt	**Scenario IV** • Global • Phase-in
A.01	Crop and animal production, hunting and related service activities	0.15	0.12	0.08	0.06
A.02	Forestry and logging	0.66	0.49	0.35	0.24
B.05	Mining of coal and lignite	0.05	0.04	0.03	0.02
B.06	Extraction of crude petroleum and natural gas	0.31	0.22	0.16	0.11
B.07	Mining of metal ores	0.19	0.13	0.10	0.06
B.08	Other mining and quarrying	0.26	0.18	0.14	0.09
B.09	Mining support service activities	0.30	0.21	0.16	0.11
C.16	Manufacture of wood and of products of wood and cork	0.08	0.05	0.04	0.03
C.17	Manufacture of paper and paper products	0.13	0.10	0.07	0.05
C.19	Manufacture of coke and refined petroleum products	0.54	0.40	0.32	0.22
C.20	Manufacture of chemicals and chemical products	0.18	0.14	0.11	0.08
C.23	Manufacture of other non-metallic mineral products	0.54	0.47	0.42	0.35
C.24	Manufacture of basic metals	0.60	0.56	0.54	0.50
D.35	Electricity, gas, steam and air conditioning supply	0.35	0.27	0.21	0.16
E.36	Water collection, treatment and supply	0.51	0.39	0.27	0.19
E.38	Waste collection, treatment and disposal activities	0.81	0.58	0.43	0.29
H.49	Land transport and transport via pipelines	0.11	0.09	0.07	0.05
H.50	Water transport	0.20	0.15	0.11	0.08
H.51	Air transport	0.74	0.52	0.39	0.26

Main results

€100 / tonne carbon tax	Scenario I • Regional • Abrupt	Scenario II • Regional • Phase-in	Scenario III • Global • Abrupt	Scenario IV • Global • Phase-in
Corporate loans and debt	13,428	7,919	5,068	2,884
Corporate equity	0	0	0	0
Residential mortgages	152	117	181	139
Total (three largest banks)	13,580	8,036	5,249	3,023
Total (market estimate)	17,190	10,172	6,647	3,827
% of CET1 capital	**14.3%**	**8.5%**	**5.5%**	**3.2%**
% of total assets	0.7%	0.4%	0.3%	0.2%

Main results

€200 / tonne carbon tax	Scenario I • Regional • Abrupt	Scenario II • Regional • Phase-in	Scenario III • Global • Abrupt	Scenario IV • Global • Phase-in
Corporate loans and debt	29,637	21,816	14,300	7,741
Corporate equity	0	0	0	0
Residential mortgages	335	253	405	303
Total (three largest banks)	29,972	22,069	14,705	8,044
Total (market estimate)	37,939	27,935	18,614	10,182
% of CET1 capital	**31.6%**	**23.3%**	**15.5%**	**8.5%**
% of total assets	1.6%	1.2%	0.8%	0.4%

Main results

- **The majority of losses for our €100 / tonne estimates are driven, in declining order, by exposure to the manufacture of coke and refined petroleum products (C.19), air transport (H.51), the extraction of crude petroleum and natural gas (B.06), waste collection, treatment and disposal activities (E.38), and electricity, gas, steam and air conditioning supply (D.35). Together, these five industries drive between 46% and 60% of total market value losses in the corporate and mortgage portfolios across the four scenarios.**
- **Besides our main results, we provide the results for a specific scenario that estimates the market value losses for the Dutch banking sector in case a major share of fossil fuel assets becomes stranded. We find that market value losses for this specific scenario amount to €2.1 billion. This equals 1.8% of total CET1 capital in the Dutch banking sector and 0.1% of total assets. Hence, an unburnable carbon scenario alone does not seem to affect the Dutch banking sector severely.**
- **We provide several sensitivity analyses. Looking at (a) a long-term zero percent interest rate, (b) higher than expected adaptation by firms (e.g. due to better technology), (c) allowing for within sector variation leverage and asset volatility, and (d) allowing for sudden adjustments in asset value based on a jump diffusion model.**

Limitations

1. **Data availability**

   - Not all the required data to calibrate our model is available on a firm level. We hence have to make some assumptions on relevant parameters as well as on the representativeness of our samples in a given industry (e.g., some information is only available for listed and often larger firms).

2. **Focus on first order effects**

   - Our study focuses on the first order effects of carbon taxation on asset valuation and then on banks. We hence do not account for second order effects, such as effects on other firms along the value chain or in the rest of the economy (e.g., due to the use of tax proceeds for subsidies and increased demand for low-carbon substitutes).

3. **Assumptions in the financial modeling**

   - We rely on several standard assumptions commonly used in financial modelling. We address the this by conducting a range of sensitivity analyses.

Take aways

- Results point to the substantial impact that climate-related policies can have on the market value of assets on the balance sheets of banks in the Netherlands. By tractably modelling the vulnerability of financial assets to carbon taxation, our analysis highlights the importance of debt exposures for their contribution to overall losses, and in particular the corporate loans and debt portfolio.

- In severe scenarios, climate policies may lead to substantial losses in the banking sector and our research, therefore, underlines the importance of adequately addressing the interlinkages between climate policies and financial stability (e.g., steering away from investments in long-term assets that are not compatible with a low carbon economy).