Environmental impact investing

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Bachelier Finance Society One World Seminar

June 18, 2020

https://ssrn.com/abstract=3562534

Green / sustainable finance

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Green / sustainable finance

- Climate risks

  "Tragedy of the horizon", 2015 speech by Mark Carney, Bank of England:

  - *Catastrophic impacts of climate change beyond horizons of most actors*

  - *Climate change can affect financial stability through physical risks, liability risks and transition risks*

  - Network for Greening the Financial System

  - Climate risk measures and climate stress tests:

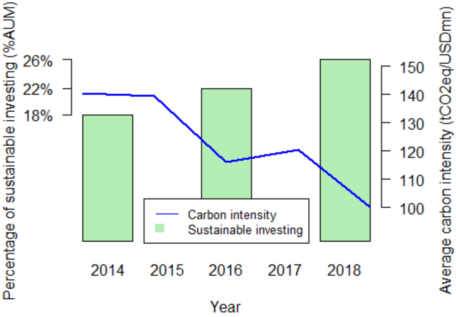
  Battiston, S. et al. (2017). A climate stress-test of the financial system. Nature Climate Change, 7(4).

- Beware of greenwashing

  - Green finance models are based on many ad-hoc assumptions, suffer from data availability problems and are exposed to deep uncertainties

Research question

Does green investing spur companies to reduce their GHG emissions?



Evolution of the proportion of sustainable investing relative to total managed assets over time, compared to the average carbon intensity (emission rate relative to revenue per year) of AMEX, NASDAQ and NYSE companies.

Related literature

- Mostly empirical in the past, but quantitative/modeling papers have started to appear recently
- Pastor et al. (2019); Pedersen et al. (2019); Zerbib (2019a): relationship between ESG integration and asset returns using a single-period model with investor disagreement
- Heinkel, Kraus, and Zechner (2001): single-period model in which green investors have the ability to exclude the most polluting companies
- Chowdhry, Davies, and Waters (2018): optimal contracting perspective: impact investors must hold a large enough financial claim to incentivize the company to internalize social externalities
- Oehmke and Opp (2019); Landier and Lovo (2020): general equilibrium models with regular and sustainable investors

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  - In the first model (Gaussian setting), green/regular investors have different beliefs about the expected stock returns depending on GHG emissions of companies

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- Investors and companies enter into a dynamic nonzero-sum game to determine their equilibrium strategies.

⇒ The increase in the proportion of green investments and the environmental stringency of green investors push companies to reduce their emissions.

⇒ When the environmental risk is internalized by green investors, brown companies have less incentive to mitigate their emissions compared to the deterministic externality setting.

The model with deterministic externalities: market

Arbitrage-free complete market with n risky stocks and a risk-free asset with zero interest.

Each stock is a claim on a single liquidating dividend D^i_T at horizon T:

$$D_T = D_0 + \int_0^T \sigma_t dB_t,$$

where $(B_s)_{s\in[0,T]}$ is a n-dimensional BM on filtered probability space $(\Omega, \mathcal{F}, \mathbb{P})$, describing the cash flow news and σ_s is a deterministic, $n \times n$ invertible matrix.

We denote the dividend forecast in $t \in [0, T]$ by

$$D_t = \mathbb{E}[D_T|\mathcal{F}_t] = D_0 + \int_0^t \sigma_s dB_s.$$

Investors and beliefs

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$$\mathbb{E}^r_t(D_T) = D_t.$$

Under green investors' probability measure $\mathbb{P}^g$,

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Under companies's probability measure $\mathbb{P}^c$,

$$\mathbb{E}^c_t(D_T) = D_t + \int_t^T \theta^c(\psi_s)ds.$$

Investors' preferences and optimization

Investors maximize expected exponential utility of terminal wealth W_T:

$$\mathbb{E}^j(1 - e^{-\gamma^j W_T^j}), \quad \gamma^j > 0, \quad j \in \{r, g\},$$

Wealth processes follow the dynamics

$$W_t^j = w^j + \int_0^t (N_s^j)^\top dp_s,$$

where $N_t^{r,g}$ are quantities of assets held by investors, and prices $(p_t)_{t\in[0,T]}$ are determined by the market clearing.

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We denote by γ^* the global risk aversion, $\frac{1}{\gamma^*} = \frac{1}{\gamma^r} + \frac{1}{\gamma^g}$, and set $\alpha = \frac{\gamma^r}{\gamma^r + \gamma^g}$.

If two investors have the same relative risk aversion at time $t = 0$, α can be seen as the proportion of wealth held by green investors at $t = 0$.

Equilibrium price

Proposition

Given an emissions schedule $(\psi_t)_{t\in[0,T]}$, *equilibrium asset price is*

$$p_t = D_t - \int_t^T \mu_s ds \quad \textit{with} \quad \mu_t = \gamma^* \Sigma_t \mathbf{1} - \alpha\theta(\psi_t), \quad \Sigma_t = \sigma_t^\top \sigma_t,$$

and optimal numbers of shares held by investors in equilibrium are

$$N_t^r = (1-\alpha)\left(\mathbf{1} - \frac{1}{\gamma^g}\Sigma_t^{-1}\theta(\psi_t)\right) \quad \textit{and} \quad N_t^g = \alpha\left(\mathbf{1} + \frac{1}{\gamma^r}\Sigma_t^{-1}\theta(\psi_t)\right),$$

Externality premium

Diverging beliefs of lead to externality premium $-\alpha\theta(\psi_t)$:

$$dp_t = dD_t + \gamma^* \Sigma_t \mathbf{1} dt - \alpha\theta(\psi_t) dt$$

Since θ_i is a decreasing, returns increase with companies' emissions.

Premium can be positive $(\theta(\psi) < 0)$ or negative $(\theta(\psi) > 0)$.

Green investors overweigh assets with the higher positive externalities.

Companies' utility and optimization

Companies choose their emissions schedules $(\psi_t^i)_{t\in[0,T]}$ at time $t=0$ aiming to

- maximize their future valuation
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Therefore, i-th company chooses $(\psi_t^i)_{t\in[0,T]}$ to maximize the objective:

$$\mathcal{J}^i(\psi^i, \psi^{-i}) = \mathbb{E}^c \left[\int_0^T e^{-\rho t} \Big(p_t^i(\psi^i, \psi^{-i}) + c_i \left(\psi_t^i - \psi_0^i \right) \Big) dt \right],$$

where c_i is the marginal abatement cost, ρ is the rate of time preference and ψ^{-i} is the emissions schedule of the other companies.

Equilibrium emissions schedule

Optimal schedule ψ^*: Nash equilibrium, each company determines $\psi^{i,*}$ such that

$$\mathcal{J}^i(\psi^{*,i}, \psi^{*,-i}) \geq \mathcal{J}^i(\psi^i, \psi^{*,-i}).$$

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Solution: optimal emissions schedule maximizes for all $t \in [0, T]$ the quantity

$$c_i \psi^i_t + \beta^c_t \theta^c_i(\psi^i_t) + \alpha \beta_t \theta_i(\psi^i_t),$$

where

$$\beta^c_t = \frac{1 - e^{-\rho(T-t)}}{\rho} \quad \text{and} \quad \beta_t = \frac{e^{\rho t} - 1}{\rho}.$$

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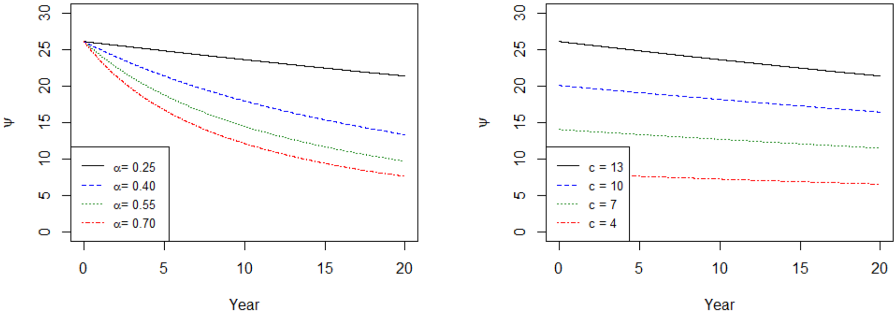
Assuming $\theta_i(x) = \kappa_0 - \frac{\kappa}{2}x^2$ and $\theta^c_i(x) = \kappa^c_0 - \frac{\kappa^c}{2}x^2$, for $x \geq 0$, where κ, κ^c, κ_0 and κ^c_0 are positive constants, the optimal emissions schedules are

$$\psi^{*,i}_t = \frac{c_i}{\beta^c_t \kappa^c + \alpha \beta_t \kappa}$$

Equilibrium emissions schedule: example



Emissions schedules, according to several values of the proportion of green investors (α, left), and the marginal abatement cost (c, right).

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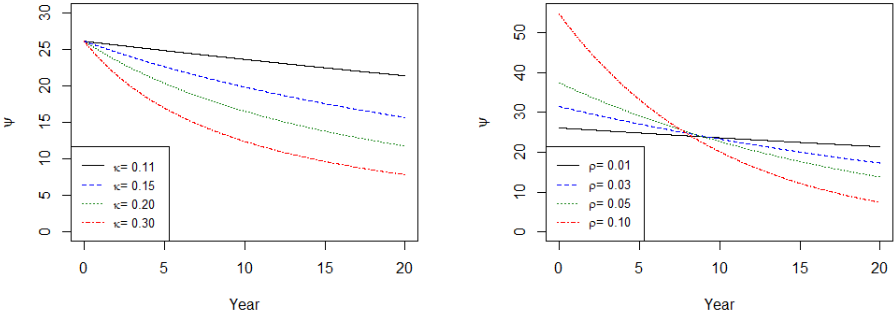

Emissions schedules, according to several values of the green investors stringency (κ, left), and the rate of time preference (ρ, right).

Model with environmental risk: financial market

A fundamental feature of climate risks is their deep uncertainty

We analyze the effect of climate uncertainty on investor behavior by assuming that green investors internalize climate risks as future random shocks on expected asset pay-offs

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The market is no longer complete, and the liquidating dividend is given by

$$D_T = D_0 + \int_0^T \sigma_t dB_t + \sum_{k=1}^{\mathcal{N}_T} Y_k,$$

where B and σ are as before, Y_k are independent random variables (environmental shocks) with distribution ν_t and $\mathcal{N}$ is a Poisson process with time-dependent intensity $(\Lambda_t)_{t\geq 0}$

Investors' beliefs

Regular / green investors and companies have diverging views about the intensity of future environmental shocks.

We denote the intensities under $\mathbb{P}^r = \mathbb{P}$ and $\mathbb{P}^g$ by Λ_t and Λ_t^g.

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Let

$$L_t(u) := \int_{\mathbb{R}^n} e^{u^\top z} \nu_t^\psi(dz),$$

for $t \in [0, T]$ and $u \in \mathbb{R}^n$.

We assume that $L_t(u) < \infty$ for all $t \in [0, T]$ and $u \in \mathbb{R}^n$.

Equilibrium asset price

Proposition

The optimal numbers of shares for regular investors in equilibrium is the unique solution of

$$\Lambda_t^g \nabla L_t(-\gamma^g(\mathbf{1} - N_t^r)) - \gamma^g \Sigma_t(\mathbf{1} - N_t^r) - \Lambda_t \nabla L_t(-\gamma^r N_t^r) + \gamma^r \Sigma_t N_t^r = 0.$$

The equilibrium price process is unique and given by

$$p_t = D_0 + \int_0^t \sigma_s dB_s + \sum_{k=1}^{\mathcal{N}_t} Y_k - \int_t^T \mu_s ds$$

with drift

$$\mu_t = \gamma^r \Sigma_t N_t^r - \Lambda_t \nabla L_t(-\gamma^r N_t^r).$$

The limit of small and frequent environmental shocks

We identify the first order correction for environmental risk in the case of small but frequent shocks

Assume the intensity of shocks as seen by the green investors is $\Lambda^{g,h}_t = h^{-1}\Lambda^g_t$, and shock sizes are multiplied by h: $\nu^{h,\psi}(A) = \nu^\psi(\{x \in \mathbb{R}^n : hx \in A\})$

Introduce the first and second moments of environmental risk:

$$\theta(\psi_t) = \Lambda^g_t \int_{\mathbb{R}^n} z\nu^\psi_t(dz), \qquad \pi(\psi_t) := \Lambda^g_t \int_{\mathbb{R}^n} z\, z^\top \nu^\psi_t(dz), \qquad \text{for } t \in [0, T].$$

For simplicity, we assume that regular investors do not internalize risk: $\Lambda = 0$.

The limit of small and frequent environmental shocks

As $h \to 0$, the quantity of assets held by green investors in equilibrium satisfies

$$N^{g,h} = \Big(\mathbf{I} - h(1-\alpha)\Sigma_t^{-1}\pi(\psi_t)\Big)N^{g,0} + O(h^2),$$

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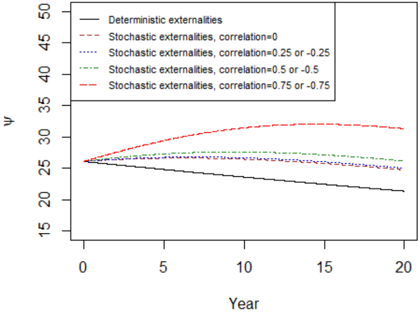
Equilibrium emissions schedule: example



Emissions schedules of a brown company (marginal abatement cost $c_2 = 13$) in the deterministic case and in the stochastic case for different levels of correlation with the asset of the second company in the market (marginal cost $c_1 = 0.5$).

For all correlation values, the brown company increases its emissions compared to the deterministic case.

Empirical illustrations

We illustrate two conclusions of the simple model with empirical data:

the equilibrium price

$$\mathbb{E}[dp_t^i] = \gamma^* \Sigma_t^i dt - \alpha\theta_i(\psi_t^i)dt,$$

and the emission schedule (assuming companies do not internalize externalities):

$$\psi_t^i = \frac{c_i}{\alpha\beta_t\kappa}$$

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Since we do not have access directly to $\theta(\psi)$, we construct a proxy

$$\tilde{\theta}_i(\psi_t^i) = \frac{w_{i,t} - w_{i,t}^b}{w_{i,t}^b},$$

where w is the weight of i-th industry in the holdings of a sample of green funds and w_i^b is the market weight

Empirical illustration: externality premium

We estimate the following econometric specification:

$$r_t^i = c + \gamma \mathrm{Cov}(r^i, r^m) - \tilde{\alpha}\tilde{\theta}_i(\psi_t^i) + \varepsilon_t^i$$

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Industry	**Externality premium (%annual return)**
Precious metals	0.18
Coal	0.15
Mining	0.13
Consumer goods	-0.01
Health care	-0.06
Food	-0.07
Electrical equipment	-0.69

Empirical illustration: emissions

We estimate the following econometric specification:

$$\log(\psi_{i,t+1}) = c + f_i + \beta \log(\tilde{\alpha}_t) + \varepsilon_t^i,$$

where ψ is the CO2 emission intensity of companies and $\tilde{\alpha}_t$ is the proxy for the proportion of green investor wealth, defined by

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We find that β is negative and highly significant: when the percentage of green assets $\tilde{\alpha}$ doubles, the carbon intensity ψ drops by 5.3% the following year.

Thank you

Thank you for your attention!

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