Environmental impact investing

Tiziano De Angelis\(^1\), Peter Tankov\(^2\), Olivier David Zerbib\(^3\)

\(^1\) University of Leeds, \(^2\) CREST-ENSAE Paris, \(^3\) Tilburg University, ISFA and CREST

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https://ssrn.com/abstract=3562534
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Green / sustainable finance

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- **Impact investing**
  - 2015 Paris Agreement, article 2c: *Making finance flows consistent with a pathway towards low GHG emissions and climate-resilient development*
  - Voluntary or compulsory emissions reporting in different countries: article 173 of the Energy Transition law in France
  - A plethora of environmental indicators based on corporate GHG emissions and other factors including “Portfolio temperature”
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- **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:

- **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
Our contribution

- We present two continuous time models:
  - In the first model (Gaussian setting), green/regular investors have different beliefs about the expected stock returns depending on GHG emissions of companies.
  - In the second model (jump-diffusion setting), green investors internalize the environmental risk of brown stocks.

⇒ 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.
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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 $\sigma_s$ 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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Under regular investors’ probability measure $\mathbb{P}^r$, 

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

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

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

Here, $\theta(\psi_t) \in \mathbb{R}^n$ are decreasing functions describing financial impacts of environmental externalities, and $\psi_t$ are GHG emissions at date $t$ (deterministic).
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Under companies’s probability measure $\mathbb{P}^c$,

$$
\mathbb{E}_t^c(D_T) = D_t + \int_t^T \theta^c(\psi_s)ds.
$$
Investors’ preferences and optimization

Investors maximize expected exponential utility of terminal wealth $W_T$:

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

Wealth processes follow the dynamics

$$
W^j_t = w^j + \int_0^t (N^j_s)^\top dp_s,
$$

where $N^r,g_t$ 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 $\gamma^*$ 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 $t = 0$, $\alpha$ 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

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

and optimal numbers of shares held by investors in equilibrium are

\[
N^r_t = (1 - \alpha) \left(1 - \frac{1}{\gamma_g} \Sigma_t^{-1} \theta(\psi_t)\right) \quad \text{and} \quad N^g_t = \alpha \left(1 + \frac{1}{\gamma_r} \Sigma_t^{-1} \theta(\psi_t)\right),
\]
Externality premium

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

$$dp_t = dD_t + \gamma^* \sum_t 1 dt - \alpha \theta(\psi_t) dt$$

Since $\theta_i$ 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 \( (\psi^i_t)_{t \in [0,T]} \) at time \( t = 0 \) aiming to

- maximize their future valuation
- minimize the cost of reform to achieve the targeted emissions schedule.
Companies’ utility and optimization

Companies choose their emissions schedules $\psi^i_t \in [0, \mathcal{T}]$ at time $t = 0$ aiming to

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Therefore, $i$-th company chooses $(\psi^i_t)_{t \in [0, \mathcal{T}]}$ to maximize the objective:

$$\mathcal{J}^i(\psi^i, \psi^{-i}) = \mathbb{E}^c \left[ \int_0^\mathcal{T} e^{-\rho t} \left( p^i_t(\psi^i, \psi^{-i}) + c_i (\psi^i_t - \psi^i_0) \right) dt \right],$$

where $c_i$ is the marginal abatement cost, $\rho$ is the rate of time preference and $\psi^{-i}$ is the emissions schedule of the other companies.
Equilibrium emissions schedule

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

$$J^i(\psi^i,\psi^*,\bar{-i}) \geq J^i(\psi^i,\psi^*,\bar{-i}).$$
Equilibrium emissions schedule

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

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

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

$$c_i\psi_t^i + \beta^i_t \theta_t^i(\psi_t^i) + \alpha \beta_t \theta_t(\psi_t^i),$$

where

$$\beta^i_t = \frac{1 - e^{-\rho(T-t)}}{\rho} \quad \text{and} \quad \beta_t = \frac{e^{\rho t} - 1}{\rho}.$$
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$$c_i \psi^i_t + \beta^c_t \theta^c_i(\psi^i_t) + \alpha \beta_t \theta_i(\psi^i_t),$$

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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 $\kappa, \kappa^c, \kappa_0$ and $\kappa^c_0$ are positive constants, the optimal emissions schedules are

$$\psi^{*,i}_t = \frac{c_i}{\beta^c_t \kappa^c + \alpha \beta_t \kappa}.$$
Emissions schedules, according to several values of the proportion of green investors ($\alpha$, left), and the marginal abatement cost ($c$, right).
Equilibrium emissions schedule: example

Emissions schedules, according to several values of the green investors stringency ($\kappa$, left), and the rate of time preference ($\rho$, right).
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

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

where $B$ and $\sigma$ are as before, $Y_k$ are independent random variables (environmental shocks) with distribution $\nu_t$ and $N$ 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 $\Lambda_t$ and $\Lambda^g_t$. 

The distribution of shock sizes $\nu_t$ does not depend on the probability measure, but depends on the emissions $\psi$, we denote it by $\nu_{\psi t}$.

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

Let $\int_{\mathbb{R}^n} e^{u^\top z} \nu_t^\psi (dz)$, 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 $u \in \mathbb{R}^n$. 

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Equilibrium asset price

Proposition

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

\[ \Lambda_t \nabla L_t ( - \gamma^g (1 - N^r_t) ) - \gamma^g \Sigma_t (1 - N^r_t) - \Lambda_t \nabla L_t (-\gamma^r N^r_t) + \gamma^r \Sigma_t N^r_t = 0. \]

The equilibrium price process is unique and given by

\[ p_t = D_0 + \int_0^t \sigma_s dB_s + \sum_{k=1}^{N_t} Y_k - \int_t^T \mu_s ds \]

with drift

\[ \mu_t = \gamma^r \Sigma_t N^r_t - \Lambda_t \nabla L_t (-\gamma^r N^r_t). \]
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 $\Lambda^g_t = h^{-1} \Lambda^g t$, and shock sizes are multiplied by $\nu^h, \psi (A) = \nu^\psi (\{x \in \mathbb{R}^n : hx \in A\})$.

Introduce the first and second moments of environmental risk:

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

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

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The limit of small and frequent environmental shocks

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

$$N_{g,h} = \left(1 - h(1 - \alpha)\Sigma_t^{-1}\pi(\psi_t)\right)N_{g,0} + O(h^2),$$

where $N_{g,0}$ is the quantity held in the case of deterministic externalities.
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By comparison with the deterministic case, green investors decrease their overall absolute allocation to risky assets, since $\|N_{g,h}\| < \|N_{g,0}\|$. 
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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

\[ \mathbb{E}[dp^i_t] = \gamma^* \sum^i dt - \alpha \theta_i(\psi^i_t) dt, \]

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

\[ \psi^i_t = \frac{c_i}{\alpha \beta_t \kappa} \]
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$$\psi^i_t = \frac{c_i}{\alpha \beta_t \kappa}$$

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

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

where $w$ is the weight of $i$-th industry in the holdings of a sample of green funds and $w_{i,t}^b$ is the market weight.
Empirical illustration: externality premium

We estimate the following econometric specification:

\[ r_t^i = c + \gamma \text{Cov}(r^i, r^m) - \tilde{\alpha} \tilde{\theta}_i(\psi^i_t) + \varepsilon_t^i \]
Empirical illustration: externality premium

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<table>
<thead>
<tr>
<th>Industry</th>
<th>Externality premium (%annual return)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precious metals</td>
<td>0.18</td>
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<tr>
<td>Coal</td>
<td>0.15</td>
</tr>
<tr>
<td>Mining</td>
<td>0.13</td>
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<tr>
<td>Consumer goods</td>
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<tr>
<td>Health care</td>
<td>-0.06</td>
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<tr>
<td>Food</td>
<td>-0.07</td>
</tr>
<tr>
<td>Electrical equipment</td>
<td>-0.69</td>
</tr>
</tbody>
</table>
Empirical illustration: emissions

We estimate the following econometric specification:

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

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

$$\tilde{\alpha}_t = \frac{\text{Market value of U.S. stocks in green funds holdings at } t}{\text{Total market value of U.S. stocks in } t}$$
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We find that $\beta$ is negative and highly significant: when the percentage of green assets $\tilde{\alpha}$ doubles, the carbon intensity $\psi$ drops by 5.3% the following year.
Thank you

Thank you for your attention!
References