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Cascading Effects of Carbon Price Through the Value Chain: Impact on Firms' Valuation

T. Adenot, M. Brière, P. Counathe, M. Jouanneau, T. Le Berthe, T. Le Guenedal, *Amundi*

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Motivation

- **Central bankers are now used to conduct stress tests of banks' exposures to climate risk**
  - see for example Allen et al. (2020), Battiston et al. (2017), Alogoskous et al. (2021)

- **A number of supervisors already considered the extension of climate stress tests to investors**
  - insurance companies and pension funds (Vermeulen et al. (2018), EIOPA (2022))

- **Climate stress tests are still not widespread in the investment management industry, despite the recent recommendation by ESMA (2022)**

- **Our paper proposes a simple stress testing exercise for listed companies in the MSCI World – can be applied to any portfolio**

Our Contribution

- **A new method of portfolio stress tests for carbon price shock**
  - **accounting for worldwide supply-chain interactions at the sector level**
  - **integrating firm level carbon intensity metric**

- **Main results**
  - **Most impacted sectors are Energy, Utilities and Materials**
    - 7% earnings shock with a carbon price at USD50
    - Reach 22% and 47% for Utilities with a carbon price at USD100 and 300
  - **When accounting for supply chain relationships, several low carbon intensive sectors are impacted**
    - Information technology, consumer discretionary, consumer staples : 4% earnings shock (CO_2 at USD50)
    - Information technology 8% and 23% earnings' shock (CO_2 at USD100 and 300)
  - **The introduction of a carbon price could distort the investment universe**
    - Sector composition distorted towards less intensive sectors such as financials and health care

Related Literature

- Analysis of macroeconomic impact of **sector disruptions propagated via production networks** (Gabaix 2011, Acemoglu et al. 2012, Joya & Rougier 2019)

- Cahen-Fourot et al. (2019) use an **Input-Output (IO) model** to assess the exposure of economic systems to **capital stranding cascades**

- Gemechu et al. (2014), Mardones and Mena (2020), and Muñoz and Mardones (2016) simulate the impact of the **introduction of a specialized carbon tax** (agriculture, polluants) on all sectors in Spain/Chile through a Leontief (1970) model

- **General equilibrium models** (Guo et al., 2014 ; Siriwardana et al., 2011 ; Devulder and Lisack, 2020) simulate the effects of carbon price/ tax on firms' profits while making assumptions on economic agents' behavior

Overview of the Methodology

- **Shock carbon price uniformly** (across sectors and countries)

- Given firm **specific carbon intensities** and **sector-level interdependencies** between inputs and outputs, one can propagate the carbon cost across sectors and estimate the impact on **firms' output**

- Derive impact on **firms' earnings**
  - Assuming **price elasticity** of consumers' demand is equal to 1 (monetary value of what is purchased stays constant with the introduction of the carbon tax)
  - No **pass-through** of firms' carbon costs to consumers

- Derive impact on **firms' market cap**
  - Assuming firms' **market value proportional to earnings** and firms do not change their structure of production with higher carbon price

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Carbon Price Scenarios

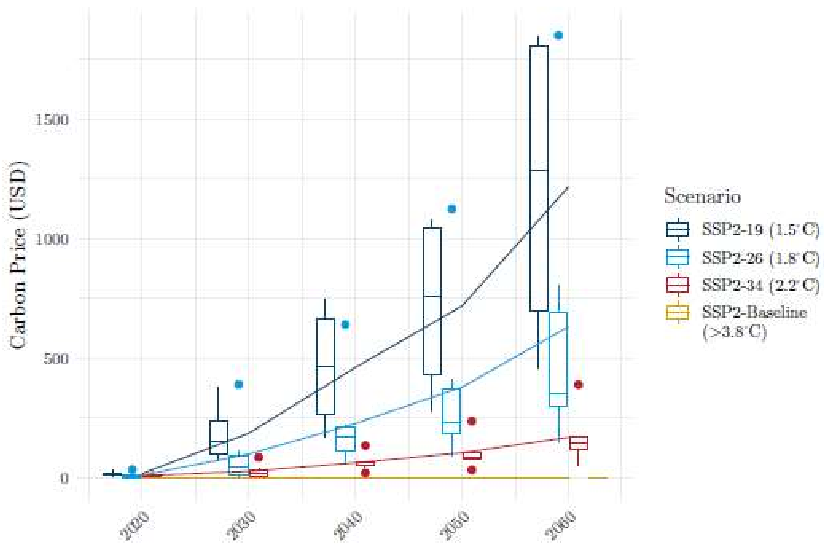

Figure: Long-term carbon price evolution in the different SSP scenarios in IIASA database

– **We consider 3 uniform CO_2 price scenarios compatible with 3 SSP scenarios x horizon**

- **USD 50** ~ SSP2-26 (1.8℃) in 2030
- **USD 100** ~ SSP2-19 (1.5℃) in 2030
- **USD 300** ~ SSP2-19 (1.5℃) in 2040

– **The methodology is compatible with regional tax rates/carbon prices**

Source: IIASA data, authors' calculations

Leontief Input Output Model

- **Aims at quantifying and representing the interdependencies between various sectors in an economy or different regional economies**

  - This methodologies builds on Leontief Input output model (Leontief, 1970)
  - We consider a fixed-proportions production function

- **Each sector j makes use of the inputs from sector i in fixed proportion aij**

$$a_{ij} = \frac{x_{ij}}{x_j} \quad 1 \leq i \leq n \quad 1 \leq j \leq n \qquad (1)$$

  - Where xij represents what is sold by sector i to sector j
  - xj is what is produced by sector j

Leontief Input Output Model

– Matrix representation of sector dependencies

Inter-industry matrix (Z)		Country 1		Country 2		Final demand (f)	Total use (x)
		Sector A.1	**Sector B.1**	**Sector A.2**	**Sector B.2**		
Country 1	**Sector A.1**	A.1 products used by A.1	A.1 products used by B.1	A.1 products used by A.2	A.1 products used by B.2	Consumption of A.1 products	Intermediate production + Final demand
	Sector B.1	B.1 products used by A.1	B.1 products used by B.1	B.1 products used by A.2	B.1 products used by B.2	Consumption of B.1 products	
Country 2	**Sector A.2**	A.2 products used by A.1	A.2 products used by B.1	A.2 products used by A.2	A.2 products used by B.2	Consumption of A.2 products	
	Sector B.2	B.2 products used by A.1	B.2 products used by B.1	B.2 products used by A.2	B.2 products used by B.2	Consumption of B.2 products	
Value added (v)		Value added in A.1	Value added in B.1	Value added in A.2	Value added in B.2		
Total supply (x^T)		Intermediate consumption + Value added					

Source: Cahen-Fourot et al. (2019)

Leontief Input Output Model

Matrix representation of sector dependencies

Assuming:

- y_i, the final demand for sector i, exogenous
- x_i, the production of sector i, and x_{ij} its demand for inputs are endogenous

the Input-Output model can be represented in a matrix form as:

$$X = AX + Y \quad X \in \mathbb{R}^{n\times 1} \quad A \in \mathbb{R}^{n\times n} \quad Y \in \mathbb{R}^{n\times 1} \qquad (2)$$

where:

$$X \equiv \begin{pmatrix} x_1 \\ \vdots \\ x_n \end{pmatrix} \quad A \equiv \begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{pmatrix} \quad Y \equiv \begin{pmatrix} y_1 \\ \vdots \\ y_n \end{pmatrix} \quad \text{and (2) becomes:} \quad X = (I - A)^{-1} Y \qquad (3)$$

The matrix $(I - A)^{-1}$ is called the **Leontief inverse**. The element in position ij of this matrix represents the impact of a change in final demand in the j-th sector on the i-th sector.

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Leontief Price Model

- **The input-output approach can be used to analyse the price structure of goods and services offered in each sector**
  - Assuming that firms set their prices at their marginal costs (Leontief, 1970)
  - We calculate the unitary price of sector i production

When there is no carbon price (baseline)

$$p_i = (1+\tau_i)\left[\sum_{j=1}^{n} p_j a_{ij} + \underbrace{v_i}_{v_i = wl_i + rk_i}\right] \quad \text{, in matrix form:} \quad P = (I - (A_\tau)^T)^{-1} V \tag{9}$$

where w is the price of labor, l_i is the coefficient of labor intensity, r is the cost of capital, k_i is the coefficient of capital intensity. $V = (v_1, .., v_n)^T$ the vector of value added in each sector, and the matrix A_τ^T, is the transpose of the matrix of direct requirements:

$$(A_\tau)^T \equiv \begin{pmatrix} a_{11} + (1 - \frac{1}{(1+\tau_1)}) & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} + (1 - \frac{1}{(1+\tau_n)}) \end{pmatrix} \tag{10}$$

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Leontief Price Model

- **The input-output approach can be used to analyse the price structure of goods and services offered in each sector**
  - With carbon price

Carbon shock price structure

The new unitary price of sector i affected by carbon pricing (p_i^{ε}) follows:

$$p_i^{\varepsilon} = (1+\epsilon_i)(1+\tau_i)\left[\sum_{j=1}^{n} p_j^{\varepsilon} a_{ij} + v_i\right] \quad \text{or in matrix form,} \quad P(\varepsilon) = \left[(I - A_{\tau}^{\varepsilon})^{-1}\right]^T V \qquad (11)$$

Modified requirement Mardones and Mena, 2020

The matrix A_{τ}^{ε} of *direct requirements* is thus modified to account for the carbon price impact. It includes both carbon price and ad-valorem tax rates (respectively noted ε and τ).

$$(A_{\tau}^{\varepsilon})^T \equiv \begin{pmatrix} a_{11} + (1 - \frac{1}{(1+\tau_1)(1+\varepsilon_1)}) & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} + (1 - \frac{1}{(1+\tau_n)(1+\varepsilon_n)}) \end{pmatrix} \qquad (12)$$

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Leontief Price Model

– **Estimation of price shock related to the introduction of the carbon price**

Price shock vector

Assuming constant sector value added V we can write:

$$P = (I - (A_\tau)^T)^{-1} V \quad \text{and} \quad P(\varepsilon) = \left[(I - A_\tau^\varepsilon)^{-1} \right]^T V \tag{13}$$

$$\text{which gives} \quad P(\varepsilon) = \left[(I - A_\tau^\varepsilon)^{-1} \right]^T (I - (A_\tau)^T) P \tag{14}$$

Impact ratio

Assuming the monetary value of what is purchased by consuming sectors constant before and after the introduction of the carbon price we write

$$\mathcal{R}_i = \frac{x_i^\varepsilon}{x_i} = \frac{p_i}{p_i^\varepsilon} \tag{14}$$

Carbon Cost

- **Carbon cost of a dollar unit of production for a firm k:**

$$\varepsilon_i^k = \varphi * m_i^k$$

  - Where φ is the **carbon price** and m_i^k the firm **carbon intensity**

Upstream emissions

The vector of total (direct and indirect) upstream emission intensities M can be calculated using the Leontief inverse (Mardones & Mena, 2020) as:

$$M = (I - A^T)^{-1} \times G \quad (5)$$

where $G = (g_1, .., g_n)^T$ the vector of sector direct GHG emission intensities

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Carbon Cost

Issuer based direct + indirect emission

Let us consider:

- issuer k part of the i-th sector
- with a direct emission intensity g^k
- the vector of direct plus indirect emission intensities m^k

It can be written as follows:

$$m_i^k = \underbrace{m_i}_{\text{Sector direct + indirect intensity}} + \underbrace{\left(g^k - g_i\right)}_{\text{Issuer direct intensity relative to its sector}} \tag{15}$$

where m_i is the sector direct and indirect (upstream) intensity, g^k is the direct emission intensity of issuer k belonging to sector i.

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Impact on Firms' Earnings and Market Cap

- The shock at the issuer level can be approximated with:

$$ES^k = \frac{\text{EBITDA}^k(0) - \text{EBITDA}^k(\varphi)}{\text{EBITDA}^k(0)} = 1 - \mathcal{R}_i^k(\varepsilon^k)$$

where $\mathcal{R}_i^k(\varepsilon^k)$ is the impact ratio measuring the reduction in demand due to the introduction of the carbon price on the issuer k and ES^k the earning shock.

- Assuming that the firm equity value is proportional to its earnings, then the change in market cap is equal to the change in earnings

Impact on Index Composition

Equity index shock

The shock is fully passed on the equity price such as:

$$\Delta E_k(\varphi) = (\mathcal{R}_i^k(\varepsilon^k) - 1) \times \mathrm{EV}_k(0) \tag{23}$$

For each firm, its new weight in the index depends on the experienced earning shock, leading to a shock to its market capitalization.

$$E_k(\varphi) = E_{k,0} - ES_k \times \mathrm{EV}_k(0) \quad \text{and} \quad w_k(\varphi) = \frac{E_k(\varphi)}{\sum_k^N E_k(\varphi)} \tag{24}$$

where $E_k(\varphi)$ is the estimation of float-adjusted market capitalization of the firm k after the introduction of a carbon price φ, and $w_k(\varphi)$ is the corresponding weight in the index

Data

- **Financial data**
  - Firm-level Earnings before Interest, Taxes and Depreciation (EBITDA) from FactSet.

- **Emission data**
  - Issuer-level GHG emission Data from Trucost: Scope 1 emissions intensity for all firms in our investment universe.
  - Sector-level GHG emissions: Sector-level average intensities of GHG emissions (Scope 1) from Exiobase on 43 countries and 5 rest of the World regions split up between 163 sectors.

- **Coverage**
  - We can provide an estimate of the earning shock for 94% of the firms belonging to the MSCI World Index (covering 96% of the total market capitalization of the index).

- **Financial data and carbon intensities are retrieved as of December 2019**

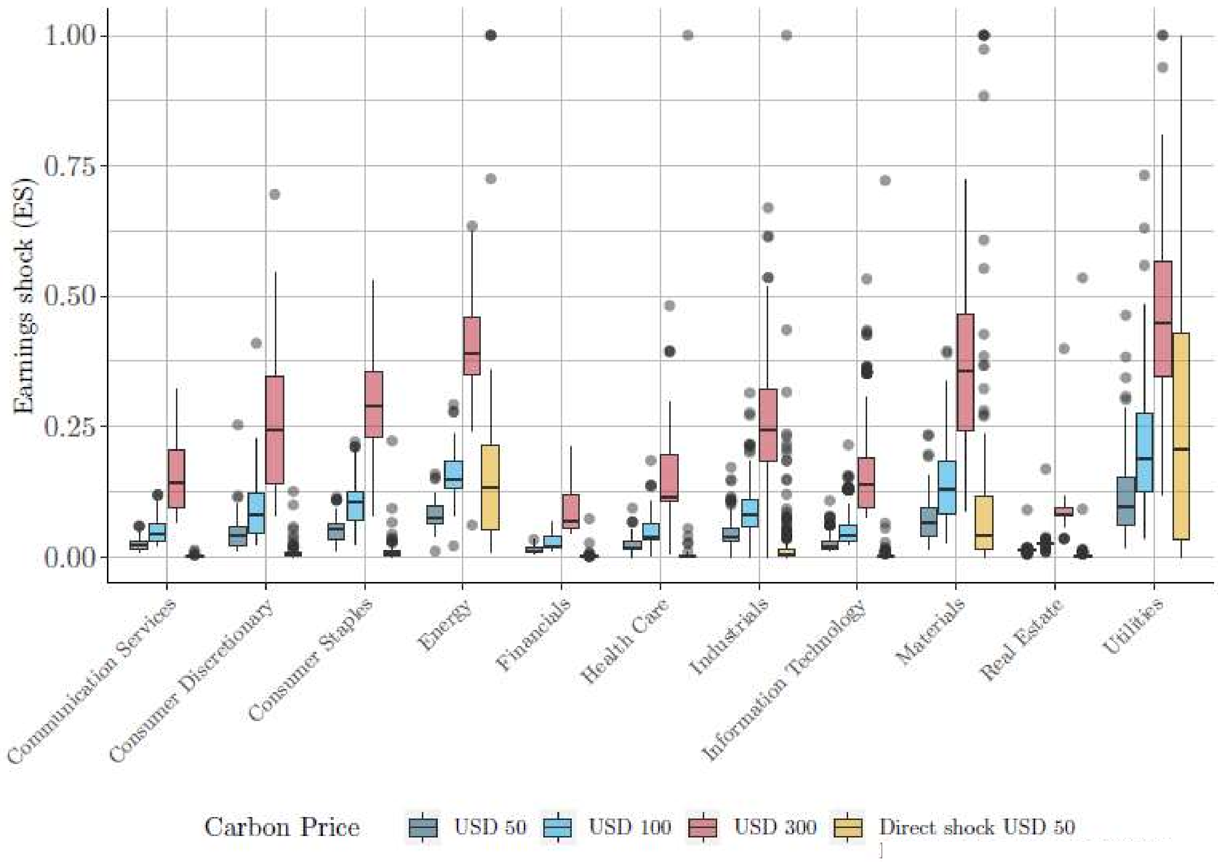
World Input Output Database

- **We use the World Input-Output Database (WIOD), last updated in 2015**
  - widely used by scholars to measure global value chains (see for example Timmer et al., 2014; Wang et al., 2013)
  - Covers 43 countries plus the ‘rest of the world’ region
  - Our universe of firms is split between 55 private sectors within each country: $(44 \times 55)^2$ matrix

- **Pros: relationships directed and quantified**
- **Cons: static, estimated only at sector/country level, low frequency updates**

Impact on Firms

- **Earnings shock due to the introduction of a carbon price of USD50, 100 & 300 per ton of CO2eq**



- When only direct emissions considered, only Utilities, Energy and Materials impacted (28.1%, 20.4% and 13.4%)
- Twice smaller impact when considering the cross sectional diffusion
- Impact rises rapidly with higher carbon price

Source: Factset, Exiobase, Trucost, authors' calculations

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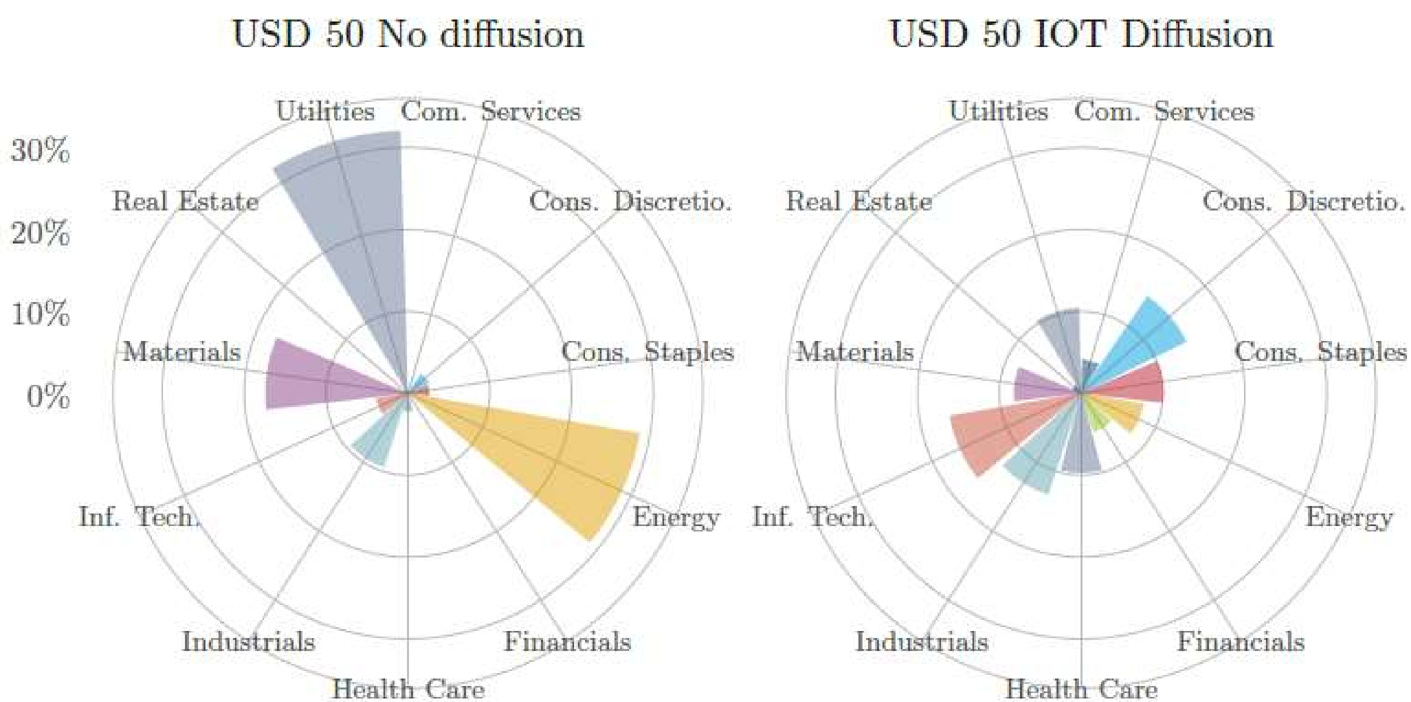
Impact on Sectors

– **Relative Contributions of GICS sectors earnings' shocks**

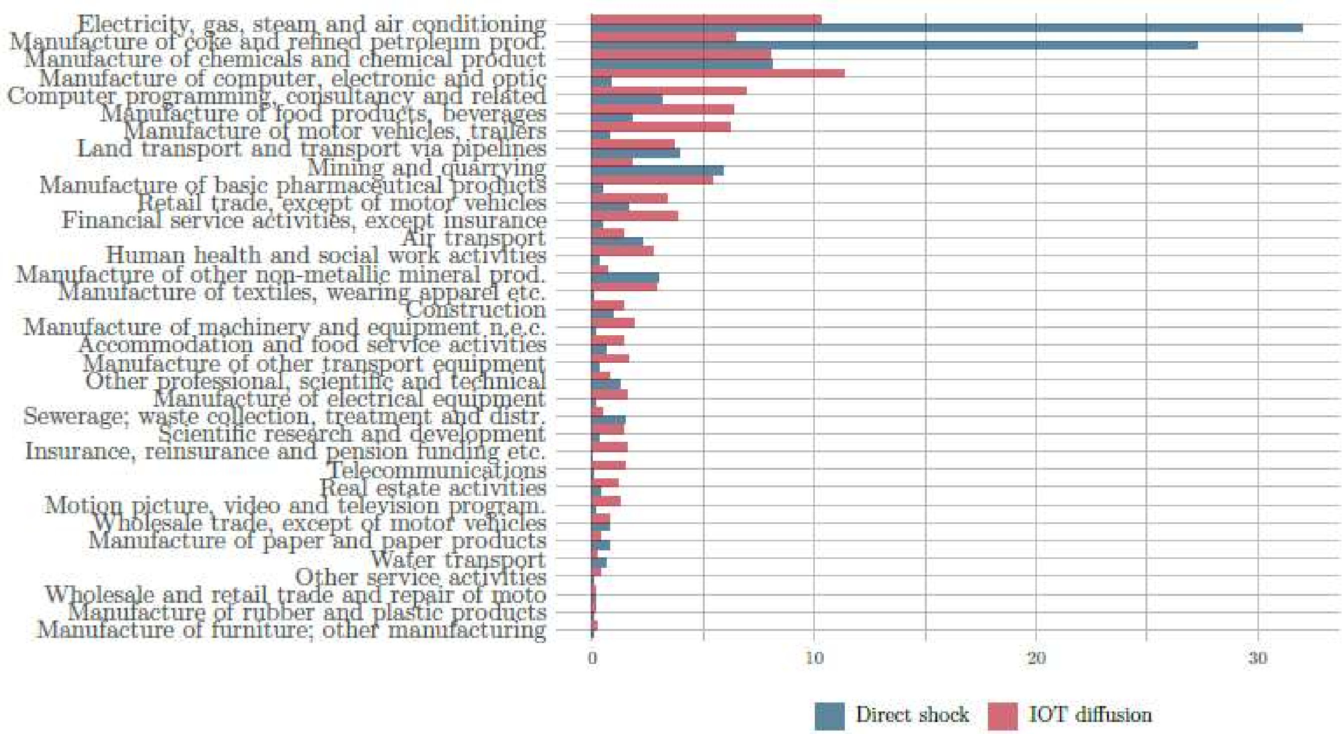


Source: Factset, Exiobase, Trucost, authors' calculations

Impact on Sectors

– Relative Contributions of WIOD sectors earnings' shocks

(b) 35 largest relative contributions of WIOD sectors earning shocks



Source: Factset, Exiobase, Trucost, authors' calculations

Impact on Index Composition

- **Sector composition of the MSCI World after a carbon price introduction**
  - reduces the weight of Utilities, Energy and Materials by 18.8%, 8.6% and 4.7% in relative terms.
  - Finance and Real Estate benefit because of their relatively low direct carbon intensity and limited indirect emissions (+3.3% and 2.5%)

		USD 50		USD 100		USD 300	
	MSCI World*(%)	weight (%)	relative change	weight (%)	relative change	weight (%)	relative change
Communication Services	7.4	7.5	1.6%	7.6	3.0%	7.9	7.6%
Consumer Discretionary	12.9	12.8	-0.8%	12.6	-1.9%	11.9	-7.5%
Consumer Staples	6.9	6.8	-1.8%	6.7	-3.9%	6.0	-13.2%
Energy	3.1	2.8	-8.6%	2.6	-16.9%	1.6	-49.8%
Financials	13.0	13.5	3.3%	13.9	6.7%	15.9	21.6%
Health Care	12.7	12.9	1.5%	13.1	3.0%	13.7	8.4%
Industrials	10.0	9.9	-1.3%	9.7	-3.0%	8.9	-10.9%
Information Technology	24.4	25.0	2.2%	25.5	4.3%	27.5	12.5%
Materials	4.0	3.8	-4.7%	3.6	-9.3%	2.9	-26.6%
Real Estate	2.8	2.9	2.5%	2.9	5.0%	3.2	15.4%
Utilities	2.8	2.3	-18.8%	1.8	-34.5%	0.4	-84.6%

Source: Factset, Exiobase, Trucost, authors' calculations

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Conclusion

- **Our paper proposes a simple stress testing exercises at their portfolio level**
- **Carbon Price Impact:**
  - Carbon intensive sectors, such as Utilities, Energy and Materials could suffer earnings shocks between 7% and 12%, with the introduction of a carbon price at USD 50
  - Less intensive sectors such as Information Technology, Consumer Discretionary and Consumer staples could also incur non negligible shocks, close to 3-4%.
- **Even low carbon-intensive sectors could be substantially impacted by the introduction of a carbon price, because of its cascading effect on firms' supply chains**
- **Introducing a USD 50 carbon price would reduce the weight of the Utilities, Energy and Materials, while Financials and Real Estate would benefit the most**

Limitations

- **Input-Output tables provide static information about flows between sectors**
  - No longer valid in a context of a rapidly evolving environment, such as climate change
- **Firms are assigned to one unique sector, which might bias the estimates for highly diversified firms**
- **The Input-Output tables describe broad supply chain relationships between sectors**
  - there might be considerable dispersion at the firm level within a given sector
- **A global carbon price imposed on all sectors and countries uniformly**
  - Carbon pricing initiatives are local, and taxes or allowance prices can be fixed at a sector level.
- **Cost pass-through assumed =1, the entire cost passed to customers**
  - In practice, firms may choose to absorb part of this cost by reducing their margins

DISCLAIMER

The data used to carry out this study come from the processing of record keeping and account keeping of AMUNDI ESR employee and pension savings accounts. These data have been analyzed anonymously for scientific, statistical or historical research purposes.

MENTIONS LÉGALES

Amundi Asset Management

Société Anonyme au capital social de 1 086 262 605 euros
Société de Gestion de Portefeuille agréée par l'AMF sous le n° GP 04000036
Siège social : 90, boulevard Pasteur - 75015 Paris - France
Adresse postale : 90, boulevard Pasteur CS21564 - 75730 Paris Cedex 15 - France
Tél. +33 (0)1 76 33 30 30
Siren : 437 574 452 RCS Paris - Siret : 43757445200029 - Code APE : 6630 Z - N° Identification TVA : FR58437574452

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