Cascading Effects of Carbon Price through the Value Chain: Impact on Firm's Valuation

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[1]The opinions expressed in this presentation are those of the authors and are not meant to represent the opinions or official positions of Amundi Asset Management.

Context and literature

→ Explicit need of climate-related risk **stress-testing methodology** required by the ESMA (2022)

An already rich literature on the topic:

- Climate **stress-testing frameworks and methodologies**: e.g. Alogoskoufis et al. (2021), Battiston et al. (2017), and Jung et al. (2021)
- 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) develop a sector-level stress-testing method based on the **Leontief (1970) price model** approach

To answer this need we propose one that

- Accounts for **worldwide supply-chain interactions** and,
- Integrates **firm level carbon intensity metric** for carbon price shock (Bouchet & Le Guenedal, 2020)

Carbon price scenario

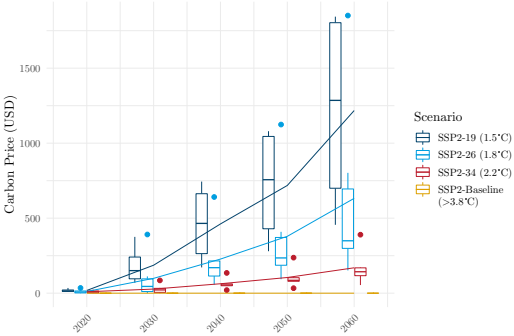


Figure: Long-term carbon price evolution in the different SSP scenarios in IIASA database

Carbon price scenario (USD per ton of CO_{2eq})

We consider 3 scenarios corresponding broadly to the average suggested price for the scenario x date

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

to illustrate the framework.

But

The methodology is **compatible** with regional tax rates

Leontief production function

- Aims at **quantifying and representing the interdependencies** between various **sectors** in an economy or different **regional** economies.
- This methodologies builds on Leontief Input output models (Leontief, 1970)
- We consider a **fixed-proportions** production function.

Fixed-proportions

In this framework, each sector j makes use of the inputs from sector i in the fixed proportion:

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

where x_j is the production of the j-th sector and $x_{i,j}$ denotes the quantity sold by the i-th sector to the j-th sector.

WIOD overview

	USA				
	Sectors	(1) Crop and animal production	(2) Forestry and logging	(3) Fishing and aquaculture	...
USA	(1) Crop and animal production	0.159	0.018	0.018	...
	(2) Forestry and logging	0.025	0.041	0.041	...
	...	...	...	... ...	

Table: Illustration of World Input-Output database (WIOD) dataset (normalized in %)

Read : "*to produce 1 dollar of output, the crop and animal production sector in the United-States buys 0.159 cents of products from itself and 0.018 cents of products from the forestry and logging (in the United States)*"

Leontief production function

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:

$$X = AX + Y \quad X \in \mathrm{R}^{n\times 1} \quad A \in \mathrm{R}^{n\times n} \quad Y \in \mathrm{R}^{n\times 1} \tag{2}$$

where:

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

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.

World input output database

General information

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

Value added of the dataset

+ Relationships are directed and quantified
− Static, sector/ country level, too many relationships in ROW

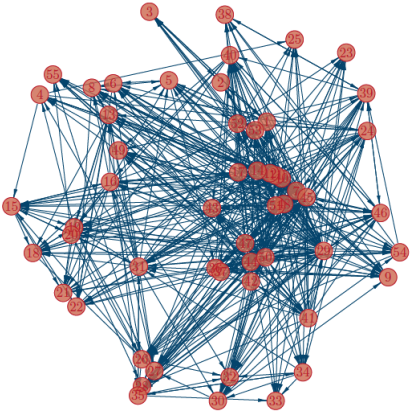
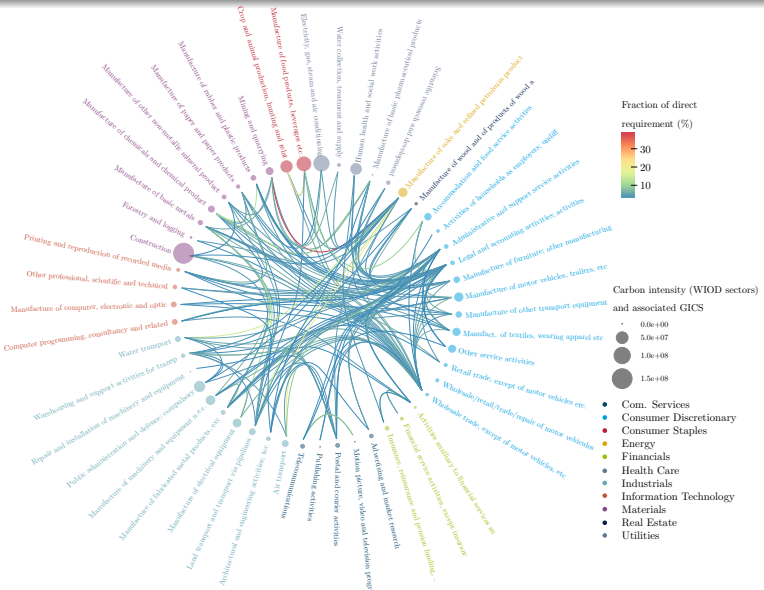


Figure: Force-directed (Kamada Kawai) graph representation of the sector Input-Output relationships (WIOD table) in the United States.

Directed graphs (e.g. Kamada Kawai drawing algorithm)

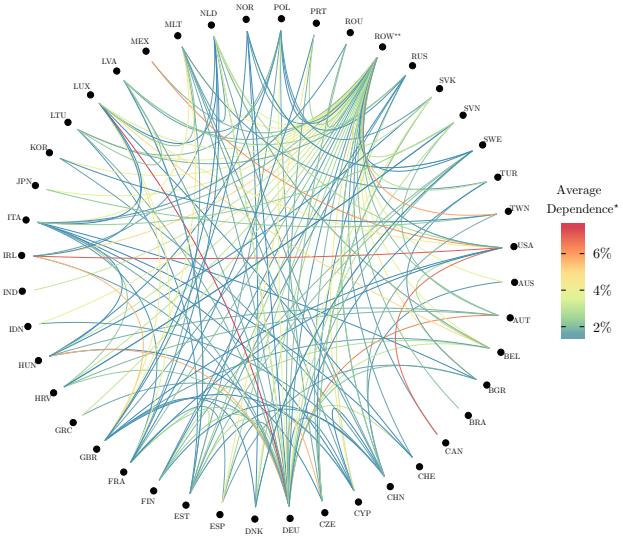
+ Identify communities (or cluster) likely to be homogeneously impacted by shocks (**Consumer discretionary** high centrality)
+ Picture the direction of relationships (insensitive → less intensive?)
- Require binary input: this chart was built taking in consideration only relations exceeding 1%.
- can be hard to read with to many agents



Chord Representation USA (internal)

Mapping to GICS and average sector intensity

- Most relationships are relatively weak
- One particular strong connection Mining Quarry → refine petrolum product etc
- Consumer discretionary high centrality



Chord Representation summed over countries

- We strong relationships:
  - USA/CAN, USA/MEX or USA/IRL
  - in Europe DEU/LUX, germany has high centrality
- The ROW is very central, too many relationships are not well assigned

Environemental externalities

Upstream emissions

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

$$M = (I - A^T)^{-1} \times G \tag{4}$$

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

Carbon price rate

The amount paid per dollar of output in each sector follows:

$$\mathcal{E} = \varphi \times M \tag{5}$$

where φ is the carbon price in USD/tCO_{2e}, the coefficient ε_i represents the mean carbon cost of a dollar unit of production from the sector i.

Good and service price structure

The idea of Leontief Price structure Model is

⇒ To decompose the price of goods and services offered by each sector

We can write the value added as:

$$v_j = \frac{V_j}{x_j} = p_j - \sum p_i a_{ij} \quad \text{where} \tag{6}$$

- p_i is the unit prices of sector i
- $\sum p_i a_{ij}$ is the input cost of a unit of j
- V_j added value (noted v_j per unit production)

Leontief price model relationship

Following Mardones (2020) Mardones and Mena, 2020 we use under the matrix form:

$$P = A^T P + V \quad \text{and then:} \quad P = \left[(I - A)^{-1}\right]^T V \tag{7}$$

Good and service price structure

Baseline price structure

When there is no carbon price (baseline)

$$p_i = (1+\tau_i)\left[\sum_{j=1}^{n} p_j a_{ij} + \underbrace{v_i}_{v_i = wl_i + rk_i}\right] \text{, in matrix form: } \quad P = (I - (A_\tau)^T)^{-1} V \tag{8}$$

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:

$$(A_\tau)^T \equiv \begin{pmatrix} a_{11} + (1 - \frac{1}{(1+\tau_1)}) & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} + (1 - \frac{1}{(1+\tau_n)}) \end{pmatrix} \tag{9}$$

Price structure under carbon restriction

Carbon shock price structure

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

$$p_i^\varepsilon = (1+\epsilon_i)(1+\tau_i)\left[\sum_{j=1}^{n} p_j^\varepsilon a_{ij} + v_i\right] \quad \text{or in matrix form,} \quad P(\varepsilon) = \left[(I - A_\tau^\varepsilon)^{-1}\right]^T V \tag{10}$$

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).

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

Sector/country impact ratio

Price shock vector

Assuming constant sector value added V we can write:

$$P = (I - (A_\tau)^T)^{-1} V \quad \text{and} \quad P(\varepsilon) = \left[(I - A_\tau^\varepsilon)^{-1}\right]^T V \tag{12}$$

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

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

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

Firm-level estimation

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.

Firm-level estimation

We then calculate an adapted carbon pricing rate vector ε^k at the issuer level:

$$\mathcal{E}^k = \varphi \times m^k \tag{16}$$

Then, the shock at the issuer level can be approximated with:

$$P(\varepsilon^k) = \left[(I - A_\tau^{\varepsilon^k})^{-1} \right]^T \times (I - A_\tau^T) \times P \tag{17}$$

$$\mathcal{R}_i^k(\varepsilon^k) = \frac{x_i^{\varepsilon^k}}{x_i} = \frac{p_i}{p_i^{\mathcal{E}^k}} \quad \text{and} \quad ES^k = \frac{\mathrm{EBITDA}^k(0) - \mathrm{EBITDA}^k(\varphi)}{\mathrm{EBITDA}^k(0)} = 1 - \mathcal{R}_i^k(\varepsilon^k) \tag{18}$$

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.

Financial data

1. **Financial data** Firm-level Earnings before Interest, Taxes and Depreciation (EBITDA) are provided by FactSet.
2. **Emission data** We use two types of emission data:
   - **Sector-level GHG emissions**: Sector-level average intensities of GHG emissions (Scope 1) are provided by Exiobase 3. (see (Stadler et al., 2018) for more detail). It covers 43 countries and 5 rest of the World regions split up between 163 sectors.
   - **Issuer-level GHG emission:** Data are provided by Trucost. We retrieve Scope 1 emissions intensity for all firms in our investment universe.

Financial data and carbon intensities are retrieved as of December 2019. Based on the data available, 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).

Impact ratio of firms

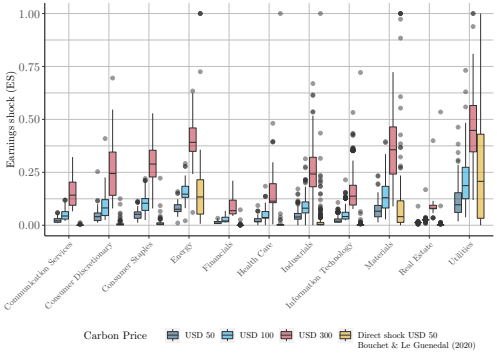


Figure: Earnings shock due to the introduction of a carbon price of USD 50, 100 and 300 per tCO_{2eq} on firms belonging to the MSCI World Index, by sector

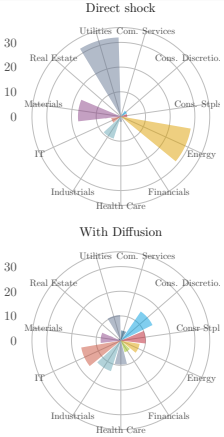


Figure: Relative contributions of GICS sectors earning shocks (USD 50)

Impact ratio of firms

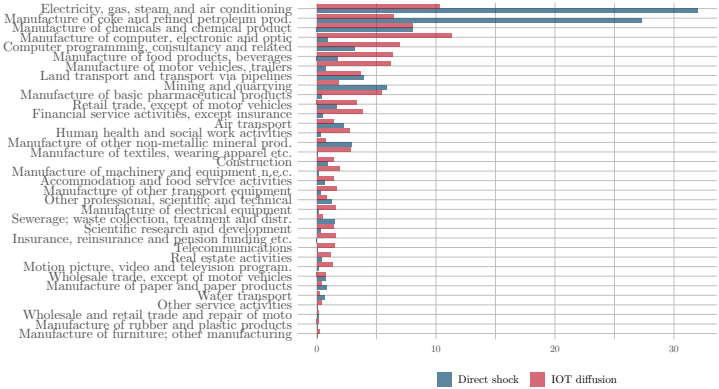


Figure: Earnings shock due to the introduction of a carbon price of USD 50, 100 and 300 per tCO_{2eq} on firms belonging to the MSCI World Index, by sector

Sensitivity analysis

The sensitivity of the firms' issuer direct intensity ($\mathcal{CI}_1$) and indirect emissions

$$ES = a + \beta_{\text{direct}}\mathcal{CI}_1 + \beta_{\text{indirect}}\left(m_{i,c} - g_{i,c}\right)$$

where

- $m_{i,c}$ denotes upstream direct and indirect intensities at the WIOD sector i and country c level.
- To account only for indirect upstream emissions, we subtract the average sector intensity $g_{i,c}$ to the $m_{i,c}$ (containing both direct and indirect emission by construction).

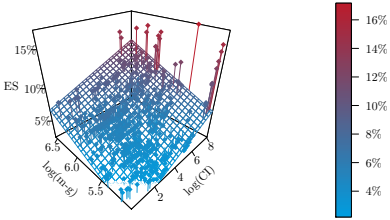


Figure: Firms' earnings shock due to the introduction of a carbon price of USD 50, depending on their idiosyncratic carbon intensity and indirect upstream sector×country emission intensities, MSCI World

Impact on index composition

Impact on firm value

Let us assume that the firms' value (EV_k) is proportional to its earnings (Bouchet & Le Guenedal, 2020):

$$\mathrm{EV}_k(t) = r_k \times \mathrm{EBITDA}^k(t) \tag{19}$$

where r_k is a (stable) corporate-specific ratio. Thus,

$$\frac{(\mathrm{EV}_k(\varphi) - \mathrm{EV}_k(0))}{\mathrm{EV}_k(0)} = \frac{(\mathrm{EBITDA}^k(\varphi) - \mathrm{EBITDA}^k(0)) \times r_k}{\mathrm{EBITDA}^k(0) \times r_k} = -ES^k \tag{20}$$

The enterprise value represents the total asset summing over the free-float market capitalization (Equity) and total debt:

$$EV_k = E_k + D_k \quad \text{Assuming that the debt remains constant we have:} \tag{21}$$

$$\Delta EV_k(\varphi) = \Delta E_k(\varphi) \tag{22}$$

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

Table: Sector composition of the MSCI World under a carbon price shock

		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%

* The original MSCI World index composition has been rebased to account for missing data on firms' carbon emissions. We cover 96% of the original index.

Limits and conclusion

Limits of the IO

- Fixed proportions
- Unlabeled relationships (ROW)...
- at a sector/country level only (no company level dispersion)
- Mapping issues (for companies with diverse activities for example)

Modeling assumption

- Price elasticity equal to 1 (should be specific to products)
- Global carbon price
- Cost pass-though equal to 1 (full price reflected to costumer)
- Simplified channeling to the firm value

Improvement of information quality

Supply-chain data propose little information on the nature/strength of connections

Model adaptability

Most these assumptions modeling choices can be relaxed / improved to provide better assessment

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