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The Economic Cost of the Carbon Tax

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Abstract

The choice of the optimal environmental policy is an important question in the current climate change context. While the carbon tax was the preferred policy of economists in the 1970s and 1980s, governments have implemented both quantity-based policies, such as emissions trading schemes, and price-based policies, such as fossil fuel taxes and renewable energy subsidies. The implementation of a general carbon tax on greenhouse gas emissions is currently not very common, and a low carbon price is generally retained. However, with the development of the EU Carbon Border Adjustment Mechanism, the Fit for 55 package and the need to achieve a low-carbon economy by 2050 if we are to keep the temperature anomaly below 1.5°C, the issue of carbon taxes is back on the agenda and the old debate of price vs. quantity regulation is reopened.

In this article, we extend the input-output analysis by introducing pass-through mechanisms to define a new cost-push price model that accounts for the cascading price effects of a carbon tax through the supply chain. We can then calculate the government revenue from a carbon tax, the net cost to the economy, and the impact on inflation. Implementing a global tax of \$100/tCO2e generates revenue of 2.82% of world GDP, but it also implies a net cost of 2.18% and inflation of 4.08% in terms of the producer price index (PPI) and 3.53% in terms of the consumer price index (CPI). In addition to these macroeconomic effects, we also analyze the microeconomic effects of the carbon tax. In particular, we analyze the impact on issuers' earnings, distributive implications, and social issues related to the carbon tax. We find that the implementation of a carbon tax is not as efficient as economic theory tells us it should be, which justifies the reluctance of governments to implement such a regulatory policy today.

Keywords: Climate change, carbon pricing, decarbonization policy instrument, carbon tax, emissions trading scheme, net-zero emissions, negative externality, input-output analysis, social welfare.

JEL classification: Q5, H2, E3.

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1 Introduction

Tackling the climate crisis requires significant reductions in greenhouse gas (GHG) emissions from human activities. By imposing costs on society, including land-use changes, productivity losses and physical damage, carbon emissions are considered negative externalities that need to be mitigated. Ambitious plans to curb emissions have all recognized the fundamental role of carbon pricing mechanisms in achieving the goal of the Paris Agreement, namely limiting global warming to below the 2°C threshold. According to the World Bank[1], as of 2023, there are 73 carbon pricing initiatives in place around the world, cumulatively covering more than 20% of global GHG emissions. While carbon pricing can take different forms, such as a carbon tax, an emissions trading scheme (ETS), or a carbon credit mechanism, they all adhere to the "*polluter pays*" principle. This principle requires that large emitters of greenhouse gases pay higher taxes or face higher costs as a result of their emissions.

Generally, the appropriate choice of the optimal environmental policy results from a cost-benefit analysis. The theoretical basis of the debate on the most effective instrument for the transition is influenced by the concept of price versus quantity as introduced by Weitzman (1974). The implementation of a price rather than a quantity instrument in an uncertain framework requires the specification of cost and benefit functions. When the marginal cost of reducing emissions tends to increase and the benefits of avoided emissions are relatively flat, the carbon price is often preferred (Hepburn, 2006). Because the intensity of climate damage is a function of the amount of carbon accumulated in the atmosphere, the marginal benefit of reducing emissions is relatively flat. In addition, the marginal cost depends on the progress of current policies and may increase over time. Under such assumptions, Newell and Pizer (2003) showed that a price-based instrument is more efficient than a quantity-based one. Similarly, Hoel and Karp (2002) reached the same conclusion, but argued that quotas become increasingly favorable with longer policy horizons. More recently, Karp and Traeger (2018) adapted the Weitzman framework by incorporating the uncertainty of technological change. This could reduce future abatement costs, favoring the adoption of a quantity instrument. Finally, Roberts and Spence (1976) showed that a hybrid instrument combining the two approaches, such as quota allocation with price bounds, could lead to greater efficiency. The relative effectiveness of each instrument is dynamic and closely related to their respective characteristics (Tang *et al.*, 2019; Stavins, 2022). Thus, economists remain divided, with no consensus on the superior instrument for adoption in the current context.

The primary goal of environmental policy is to mitigate the negative externalities associated with the production or consumption of goods, which often result from fluctuations in supply and demand. In the context of environmental regulation, the cap-and-trade mechanism seeks to limit the quantity of emissions by focusing on the supply side. Conversely, a carbon tax seeks to impose an additional cost on producers, creating a price signal that alters the relative prices of goods and services, thereby influencing demand. While the theoretical framework for these instruments is well established, questions remain about their effectiveness in practice. Numerous meta-analyses have been conducted to assess the empirical effectiveness of implementing either a carbon tax or an emissions trading scheme. Among other things, the results support that a carbon tax is better than an ETS at effectively curbing emissions, although the overall reductions in GHG emissions are very limited in all cases (Haites, 2018; Green, 2021). However, in the case of the Kyoto Protocol, we observe that a cap-and-trade system can accomplish the task. For example, during the first commitment period (2008-2012), the emissions of the European Union were reduced by 19% compared to the base year 1990 (Roncalli, 2024). And the new climate policy of the European Union is largely based on quantity instruments through the Fit for 55 package.

[1] https://carbonpricingdashboard.worldbank.org/map_data.

The empirical validity of these instruments is also questionable from a cost-sharing perspective. Restrictive policies can have side effects and negative spillovers, depending on the scenario considered. For example, if a producer is taxed for emitting carbon dioxide, it has several options. First, it can absorb the full cost of the tax and not pass it on to consumers in the price of its products. Second, it can pass on the full cost of the carbon tax to consumers by increasing the price of the product to compensate for the cost of the carbon tax. Third, it can share a portion of the carbon tax burden with consumers. This pass-through rate depends on various factors, such as market structure (*i.e.*, monopolistic, oligopolistic, or atomistic) and price-demand and price-supply elasticities (Sautel *et al.*, 2022; Desnos *et al.*, 2023). For instance, economists assume that the pass-through rate for energy products can be close to 100%, meaning that a carbon tax will generally be borne by final consumers due to the highly inelastic demand for energy products. As a result, the tax is passed down the supply chain to downstream suppliers and ultimately to the end consumer. In this context, large companies with a dominant position in the supply chain hierarchy can pass on their costs in prices while financially benefiting from this price stimulus (Weber and Wasner, 2023). Furthermore, the implementation of a regional carbon tax (*e.g.*, at the level of the European Union) is more likely than a global and uniform carbon price. However, it may lead to macroeconomic imbalances and relative welfare losses (Pisani-Ferry and Mahfouz, 2023). This would ultimately generate carbon leakage, competitive distortions and distributive implications (Peñasco *et al.*, 2021). Consequently, the European Union has introduced the Carbon Border Adjustment Mechanism (CBAM) to address the risk of competitive distortions by imposing tariffs on the carbon content of imported products. The goal of the CBAM is to ensure the integrity of the EU ETS and its new reform, which is part of the EU Fit for 55 climate policy package. The success of the EU ETS reform will depend on the effectiveness of the CBAM.

In this paper, we focus specifically on the cost analysis of the carbon tax. To do so, we extend the input-output analysis by introducing pass-through mechanisms to define a new cost-push price model that accounts for the cascading price effects of a carbon tax through the supply chain. We can then calculate the government revenue from a carbon tax, the net cost to the economy, and the impact on inflation. Implementing a global tax of $\$100/\text{tCO}_2\text{e}$ generates revenue of 2.82% of world GDP, but it also implies a net cost of 2.18% and inflation of 4.08% in terms of the producer price index (PPI) and 3.53% in terms of the consumer price index (CPI). In addition to these macroeconomic effects, we also analyze the microeconomic effects of the carbon tax. In particular, we analyze the impact on issuers' earnings, distributive implications, and social issues related to the carbon tax. We find that the implementation of a carbon tax is not as efficient as economic theory tells us it should be, which justifies the reluctance of governments to implement such a regulatory policy today.

The paper is organized as follows. In Section Two, we define input-output analysis and show how the cost-push price model can be extended to account for pass-through mechanisms. We can then measure the impact of a carbon tax in terms of economic costs borne by the producer and the downstream supply chain, government revenues, and inflation. In Section Three, we use the Exiobase multi-regional EEIO table to analyze the impact of a global carbon tax of $\$100/\text{tCO}_2\text{e}$ on GDP, PPI, and CPI. These results are complemented by also considering the regional implementation of a carbon tax. Section Four is devoted to a microeconomic analysis of the carbon tax. Using the cost-push price model, we model the demand function and the relationship between the price-demand elasticity and the pass-through rate. We can then calculate the earnings shock at the sector and issuer level. We also illustrate how the carbon tax has several distributive implications and a social impact among households. Finally, Section Five provides some concluding remarks.

2 Carbon tax modeling and input-output analysis

2.1 Input-output analysis

The input-output model was first introduced by Leontief (1936, 1941). It quantifies the interdependencies between different sectors in a single or multi-regional economy, based on the product flows between sectors (Miller and Blair, 2009). The underlying idea is to model the linkages between sectors and to describe the relationships from each of the producer/seller sectors to each of the purchaser/buyer sectors.

2.1.1 The demand-pull quantity model

Following Miller and Blair (2009), we consider n different sectors and we note $Z_{i,j}$ the value of transactions from sector i to sector j. We can interpret $Z_{i,j}$ in different ways:

1. It is the output that sector i sells to sector j;
2. It is the input of sector i required by sector j for its production (or output).

Let y_i be the final demand for products sold by sector i. This final demand is made up of the external sales to households, government purchases, and demand resulting from investment capacity and foreign trade. Then, the total production x_i of sector i is equal to:

$$\underbrace{x_i}_{\text{Supply}} = \underbrace{\sum\nolimits_{j=1}^{n} Z_{i,j} + y_i}_{\text{Demand}} \tag{1}$$

In this equation, x_i and $\sum_{j=1}^{n} Z_{i,j} + y_i$ are the supply and demand related to products of sector i, and $z_i = \sum_{j=1}^{n} Z_{i,j}$ represents intermediate demand. The interdependence relation between sectors is usually expressed as a ratio between $Z_{i,j}$ and x_j:

$$A_{i,j} = \frac{Z_{i,j}}{x_j}$$

Let $A = \left(A_{i,j}\right) = Z \operatorname{diag}(x)^{-1}$ be the input-output matrix of the technical coefficients $A_{i,j}$. In a matrix form, we have $x = Z\mathbf{1}_n + y$ and $Z \equiv A \operatorname{diag}(x) = A \odot x^\top$, and we deduce that:

$$x = Ax + y$$

where $x = (x_1, \ldots, x_n)$ and $y = (y_1, \ldots, y_n)$. Assuming that final demand is exogenous, technical coefficients are fixed and output is endogenous, we obtain:

$$x = (I_n - A)^{-1} y \tag{2}$$

$\boldsymbol{\mathcal{L}} = (I_n - A)^{-1}$ is known as the Leontief inverse (or multiplier) matrix and represents the amount of total output from sector i that is required by sector j to satisfy its final demand. Equation (2) describes a *demand-pull quantity* model. This model is used to evaluate the impact of a change in final demand on the economy, assuming that the structure of technical coefficients is constant. Let Δy be the variation vector. We obtain $\Delta x = \boldsymbol{\mathcal{L}} \Delta y$.

2.1.2 The cost-push price model

Let m be the number of primary inputs (*e.g.*, labor, capital, etc.). Let $V = \left(V_{k,j}\right)$ be the value added matrix where $V_{k,j}$ represents the amount of primary input k required to produce the output of sector j. Since the total input of each sector is equal to its total output, we have $x_j = \sum_{i=1}^{n} Z_{i,j} + \sum_{k=1}^{m} V_{k,j}$. Therefore, $\upsilon_j = \sum_{k=1}^{m} V_{k,j} = x_j - \sum_{i=1}^{n} Z_{i,j}$ represents the other expenditure of sector j or the total primary inputs used in sector j. We have $\upsilon = (\upsilon_1, \ldots, \upsilon_n) = V^\top \mathbf{1}_m$. Let $p = (p_1, \ldots, p_n)$ and $\psi = (\psi_1, \ldots, \psi_m)$ be the vector of sector prices and primary inputs. p_j and ψ_k are then the prices per unit of sector j and primary input k. As in the quantity model, the interdependence relationship between primary inputs and sectors is expressed as the ratio between $V_{k,j}$ and x_j:

$$B_{k,j} = \frac{V_{k,j}}{x_j}$$

We denote the input-output matrix of the technical coefficients by $B = \left(B_{k,j}\right) \equiv V \operatorname{diag}(x)^{-1}$. Following Gutierrez (2008), the value of the output must be equal to the value of its inputs:

$$\underbrace{p_j x_j}_{\text{Value of the output}} = \underbrace{\sum\nolimits_{i=1}^{n} Z_{i,j} p_i + \sum\nolimits_{k=1}^{m} V_{k,j} \psi_k}_{\text{Value of the inputs}}$$

We deduce that:

$$\begin{aligned} p_j &= \sum\nolimits_{i=1}^{n} \frac{Z_{i,j}}{x_j} p_i + \sum\nolimits_{k=1}^{m} \frac{V_{k,j}}{x_j} \psi_k \\ &= \sum\nolimits_{i=1}^{n} A_{i,j} p_i + \sum\nolimits_{k=1}^{m} B_{k,j} \psi_k \end{aligned}$$

In a matrix form, we get $p = A^\top p + B^\top \psi$. $\upsilon = B^\top \psi$ is the vector of value added ratios. Finally, the output prices are equal to:

$$p = \left(I_n - A^\top\right)^{-1} \upsilon \tag{3}$$

$\tilde{\boldsymbol{\mathcal{L}}} = \left(I_n - A^\top\right)^{-1}$ is known as the dual inverse matrix and represents the amount of costs from sector j that are passed on to sector i. Equation (3) describes a *cost-push price* model. By adding the income identity[2], Gutierrez (2008) proposed the following complete version of the full basic input-output model:

$$\left\{ \begin{array}{l} x = \left(I_n - A\right)^{-1} y \\ \upsilon = V^\top \mathbf{1}_m \\ \upsilon = B^\top \psi \\ p = \left(I_n - A^\top\right)^{-1} \upsilon \\ x^\top \upsilon = y^\top p \end{array} \right. \tag{4}$$

It mixes both the quantity and price models. In this system, A, B and V are the model parameters, ψ, υ and y are the exogenous variables, and x and p are the endogenous variables. By changing the model parameters or the exogenous variables, we can measure the impacts Δy and $\Delta \upsilon$ on the quantities and prices in the economy. We obtain:

$$\left\{ \begin{array}{l} \Delta x = \boldsymbol{\mathcal{L}} \Delta y = \left(I_n - A\right)^{-1} \Delta y \\ \Delta p = \tilde{\boldsymbol{\mathcal{L}}} \Delta \upsilon = \left(I_n - A^\top\right)^{-1} \Delta \upsilon \end{array} \right.$$

[2]Since the input-output analysis assumes an equilibrium model, the total value of the revenues $y^\top p$ is equal to the total value of costs $x^\top \upsilon$.

2.2 The impact of a carbon tax in the cost-push price model

To study the impact of taxation on production costs, we need to diffuse the carbon tax in the input-output economic model to account for the cascading effects through the value chain. The diffusion of the carbon tax depends on the assumption of the reaction function of suppliers and pass-through mechanisms.

2.2.1 Basic formula

The absolute amount of the carbon tax for sector j is equal to:

$$T_{\mathrm{direct},j} = \boldsymbol{\tau}_j \boldsymbol{\mathcal{CE}}_{1,j}$$

where $\boldsymbol{\tau}_j$ is the nominal carbon tax expressed in $\$/\mathrm{tCO_2e}$ and $\boldsymbol{\mathcal{CE}}_{1,j}$ is the Scope 1 emissions of the sector. We deduce that the carbon tax rate is equal to:

$$t_{\mathrm{direct},j} = \frac{T_{\mathrm{direct},j}}{x_j} = \frac{\boldsymbol{\tau}_j \boldsymbol{\mathcal{CE}}_{1,j}}{x_j} = \boldsymbol{\tau}_j \boldsymbol{\mathcal{CI}}_{1,j}$$

Note that $t_{\mathrm{direct},j}$ has no unit and is equal to the product of the tax and the Scope 1 carbon intensity. The input-output model implies that:

$$p_j x_j = \sum_{i=1}^{n} Z_{i,j} p_i + \sum_{k=1}^{m} V_{k,j} \psi_k + T_{\mathrm{direct},j}$$

We deduce that:

$$p_j = \sum_{i=1}^{n} A_{i,j} p_i + \sum_{k=1}^{m} B_{k,j} \psi_k + t_{\mathrm{direct},j} = \sum_{i=1}^{n} A_{i,j} p_i + \upsilon_j + t_{\mathrm{direct},j}$$

It follows that:

$$p = \left(I_n - A^\top\right)^{-1} \left(\upsilon + t_{\mathrm{direct}}\right)$$

where $t_{\mathrm{direct}} = \left(t_{\mathrm{direct},1}, \ldots, t_{\mathrm{direct},n}\right)$ is the vector of direct tax rates. We recover the cost-push price model, where the vector υ of value added ratios is replaced by $\upsilon + t_{\mathrm{direct}}$. It follows that the vector of price changes due to the carbon tax is equal to:

$$\Delta p = \left(I_n - A^\top\right)^{-1} t_{\mathrm{direct}} \tag{5}$$

This result is obvious since Equation (3) implies that $\Delta p = \left(I_n - A^\top\right)^{-1} \Delta \upsilon$ and $\Delta \upsilon$ corresponds to the vector t_{direct} of direct tax rates.

The vector of total tax cost is equal to:

$$T_{\mathrm{total}} = x \odot \Delta p = x \odot \left(I_n - A^\top\right)^{-1} t_{\mathrm{direct}} \tag{6}$$

while the direct tax cost is $T_{\mathrm{direct}} = x \odot t_{\mathrm{direct}}$. Since we have $x \succeq \mathbf{0}_n$ and $\left(I_n - A^\top\right)^{-1} \succeq I_n$ and using Hadarmard properties, then we conclude that the total tax cost is greater than the direct tax cost for all the sectors:

$$T_{\mathrm{total},j} \geq T_{\mathrm{direct},j}$$

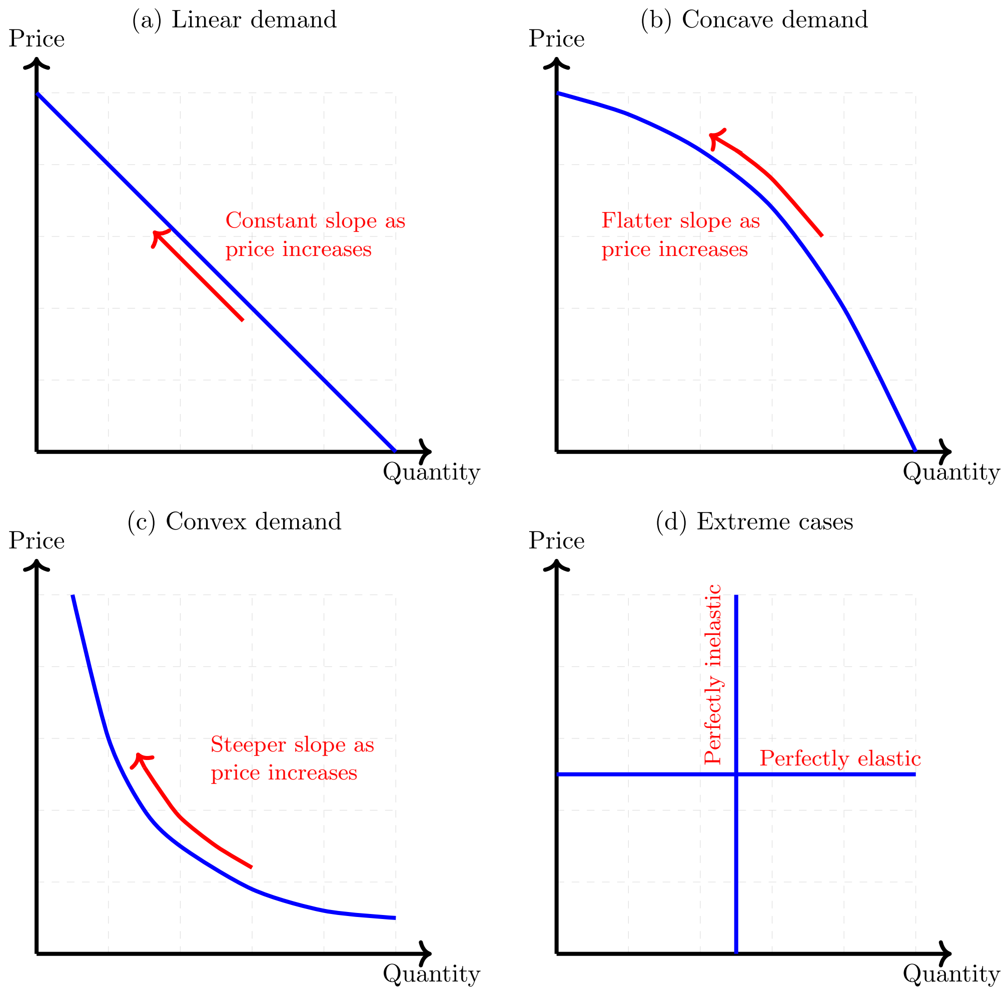
Since the total cost to the economy is equal to $\mathcal{C}_{\mathrm{total}} = \sum_{j=1}^{n} T_{\mathrm{total},j} = x^\top \left(I_n - A^\top\right)^{-1} t_{\mathrm{direct}}$, the tax incidence is then equal to:

$$\mathcal{TI} = \frac{\mathcal{C}_{\mathrm{total}}}{\mathbf{1}_n^\top x} = \frac{x^\top \left(I_n - A^\top\right)^{-1} t_{\mathrm{direct}}}{\mathbf{1}_n^\top x}$$

2.2.2 Definition of the pass-through mechanism

According to RBB Economics (2014), "*cost pass-through describes what happens when a business changes the price of the production or services it sells following a change in the cost of producing them*". Therefore, a pass-through rate is closely related to the supply and demand elasticity. This concept of price adjustment is extremely common in many fields of economics: exchange rates, imperfect competition and Cournot-Bertrand equilibria, product taxation and retail prices, inflation regimes, etc. In other words, pass-through is the ability of a sector or a company to pass costs through its supply chain. In general, this parameter ranges from 0%, where the entire amount is supported by the agent, to 100%, where the entire amount is passed on to customers. As this parameter depends on several factors, such as supply and demand elasticity, international trade exposure, market concentration, product homogeneity, etc., its estimation is not easy, which implies a large uncertainty about the tax incidence in a transition risk framework.

Figure 1: Demand curvature



Source: (RBB Economics, 2014, Figure 2, page 16).

Pass-through strongly depends on the market structure and the supply-demand equilibrium. In Figure 1, we show different demand curves whose slope depends on the consumer response to different price levels. If the slope of the curve is steep, it suggests that an increase in price would lead to a marginal decrease in sales. This scenario represents inelastic demand, where consumer demand is relatively unchanged when the price moves up or down. Conversely, if the demand curve is flatter, an increase in price will result in a significant reduction in the quantity demanded. This situation represents elastic demand, where consumers are highly responsive to price changes. If the demand curve is linear, there is no curvature, which means that the rate of decline in demand remains constant as the price increases (top/left panel in Figure 1). In situations where demand falls more sharply as the price rises, this type of demand is classified as concave to the origin (top/right panel in Figure 1). As prices rise in this scenario, the demand curve becomes increasingly flatter, indicating increased price sensitivity or greater elasticity. In this scenario, firms should absorb part of the cost, implying a relatively low pass-through rate. Finally, if the rate of decline in demand slows with each price increase, this type of demand curve is said to be convex to the origin. In this case, as prices escalate, the remaining demand becomes less sensitive to these price fluctuations (bottom/left panel of the figure). Firms can then pass on the costs and set a relatively high pass-through rate.

From an economic point of view, the specification of the pass-through depends on several factors. In the case of competition, the general formula for the pass-through rate $\boldsymbol{\phi}$ is:

$$\boldsymbol{\phi} = \frac{\mathrm{d}\,p}{\mathrm{d}\,\boldsymbol{\tau}} = \frac{\text{price sensitivity of supply}}{\text{price sensitivity of supply} - \text{price sensitivity of demand}}$$

We deduce that $\boldsymbol{\phi} \in \left[0, 100\%\right]$. In a monopolistic situation, the previous formula becomes:

$$\boldsymbol{\phi} = \frac{1}{2 + \text{elasticity of the slope of inverse demand}}$$

Since the slope elasticity of inverse demand is negative, $\boldsymbol{\phi} \geq 50\%$. We get similar results in oligopolistic situations. In monopolistic and oligopolistic situations, it can also be greater than 100% if demand is highly convex.

2.2.3 Introduction of the pass-through mechanism

To introduce the pass-through mechanism into the input-output model, we need to use a preliminary result related to the mathematical concept of a Neumann series. It is a mathematical series of the form $S := \sum_{k=0}^{\infty} T^k$ where T is a bounded linear operator and $T^k = T^{k-1} \circ T = T \circ T^{k-1}$. If the Neumann series converges in the operator norm, then $\mathrm{Id} - T$ is invertible and its inverse is the Neumann series:

$$(\mathrm{Id} - T)^{-1} = S = \sum_{k=0}^{\infty} T^k$$

where Id is the identity operator. The matrix $\tilde{\boldsymbol{\mathcal{L}}}$ admits the following Neumann series:

$$\begin{aligned} \tilde{\boldsymbol{\mathcal{L}}} &= \left(I_n - A^\top\right)^{-1} \\ &= I_n + A^\top + \left(A^\top\right)^2 + \left(A^\top\right)^3 + \ldots \\ &= \sum_{k=0}^{\infty} \left(A^\top\right)^k \end{aligned} \tag{7}$$

Roncalli (2024) show that the Neumann series $\sum_{k=0}^{\infty}\left(A^{\top}\right)^{k}$ converges to a finite matrix, which implies that the multiplier matrix $\tilde{\boldsymbol{\mathcal{L}}}$ is nonsingular. Therefore, the cost-push price model implies:

$$\Delta p=\tilde{\boldsymbol{\mathcal{L}}}\Delta \upsilon=\sum_{k=0}^{\infty}\left(A^{\top}\right)^{k}\Delta \upsilon=\sum_{k=0}^{\infty}\Delta p_{(k)}$$

where $\Delta p_{(k)}=\left(A^{\top}\right)^{k}\Delta \upsilon$ is the price impact at the k^{th} tier. In fact, $\Delta p_{(k)}$ satisfies the following recurrence relation:

$$\left\{\begin{array}{l}\Delta p_{(k)}=A^{\top}\Delta p_{(k-1)}\\ \Delta p_{(0)}=\Delta \upsilon\end{array}\right.$$

If we consider the price p_j of sector j, we have $\Delta p_{(0),j}=\Delta \upsilon_j$ and:

$$\Delta p_{(k),j}=\sum_{i=1}^{n}A_{i,j}\Delta p_{(k-1),i}$$

This representation helps to better understand the cascading effect of the carbon tax. In the zeroth round, it induces an additional cost $\Delta \upsilon_j$, which is fully passed on to the price p_j of the sector. The new price is then $p_j+\Delta p_{(0),j}=p_j+\Delta \upsilon_j$. In the first round, sector j faces new additional costs due to the price increase of intermediate consumption. We have $\Delta p_{(1),j}=\sum_{i=1}^{n}A_{i,j}\Delta p_{(0),i}=\sum_{i=1}^{n}A_{i,j}\Delta \upsilon_i$. The iteration process continues and we have $\Delta p_{(2),j}=\sum_{i=1}^{n}A_{i,j}\Delta p_{(1),i}=\sum_{i=1}^{n}\sum_{k=1}^{n}A_{i,j}A_{k,i}\Delta \upsilon_k$ at the second round.

Now let us introduce the pass-through mechanism. By definition, we have $\Delta p_{(0),j}=\boldsymbol{\phi}_j\Delta \upsilon_j$ where $\boldsymbol{\phi}_j$ denotes the pass-through rate of sector j. In the first round, we have:

$$\Delta p_{(1),j}=\sum_{i=1}^{n}A_{i,j}\left(\boldsymbol{\phi}_i\Delta p_{(0),i}\right)=\sum_{i=1}^{n}A_{i,j}\left(\boldsymbol{\phi}_i\Delta \upsilon_i\right)$$

More generally, the recurrence relation is:

$$\Delta p_{(k),j}=\sum_{i=1}^{n}A_{i,j}\boldsymbol{\phi}_i\Delta p_{(k-1),i}$$

Let $\boldsymbol{\phi}=\left(\boldsymbol{\phi}_1,\ldots,\boldsymbol{\phi}_n\right)$ and $\Phi=\operatorname{diag}\left(\boldsymbol{\phi}\right)$ be the pass-through vector and matrix. The recurrence matrix form is:

$$\left\{\begin{array}{l}\Delta p_{(k)}=A^{\top}\Phi\Delta p_{(k-1)}\\ \Delta p_{(0)}=\Phi\Delta \upsilon\end{array}\right.$$

We deduce that:

$$\begin{aligned}\Delta p &= \sum_{k=0}^{\infty}\left(A^{\top}\Phi\right)^{k}\Phi\Delta \upsilon\\ &= \left(I_n-A^{\top}\Phi\right)^{-1}\Phi\Delta \upsilon\\ &= \tilde{\boldsymbol{\mathcal{L}}}\left(\boldsymbol{\phi}\right)\Delta \upsilon \qquad (8)\end{aligned}$$

where $\tilde{\boldsymbol{\mathcal{L}}}\left(\boldsymbol{\phi}\right)=\left(I_n-A^{\top}\Phi\right)^{-1}\Phi$.

Since A is a substochastic matrix and Φ is a positive diagonal matrix, we verify that $\boldsymbol{\phi}'\succeq\boldsymbol{\phi}\Rightarrow\tilde{\boldsymbol{\mathcal{L}}}\left(\boldsymbol{\phi}'\right)\succeq\tilde{\boldsymbol{\mathcal{L}}}\left(\boldsymbol{\phi}\right)$. The lower bound is then reached when $\boldsymbol{\phi}=\mathbf{0}_n$ while the upper bound is reached when $\boldsymbol{\phi}=\mathbf{1}_n$.

2.2.4 Application to the carbon tax

Applying the previous analysis to the carbon tax, we have $\Delta \upsilon = t_{\text{direct}}$. We deduce that:

$$\Delta p = \tilde{\boldsymbol{\mathcal{L}}}(\phi)\, t_{\text{direct}} = \left(I_n - A^\top \Phi\right)^{-1} \Phi t_{\text{direct}} \tag{9}$$

A comparison of Equations (5) and (9) shows that the original cost-push price model assumes a pass-through rate of 100%. This means that each economic agent can increase its value added by the value of the carbon tax. If this is not the case, the impact on prices is smaller. In particular, if the pass-through rate is equal to zero, we check that $\Delta p = \mathbf{0}_n$. More generally, we have $\mathbf{0}_n \leq \Delta p \leq \left(I_n - A^\top\right)^{-1} t_{\text{direct}}$.

The definition of a price index is:

$$\mathcal{PI} = \sum_{j=1}^{n} \alpha_j p_j = \alpha^\top p$$

where $\alpha = (\alpha_1, \ldots, \alpha_n)$ is the weights of the basket of items. We deduce that the inflation rate due to the carbon tax between two dates t_0 and t_1 is:

$$\pi = \frac{\mathcal{PI}(t_1) - \mathcal{PI}(t_0)}{\mathcal{PI}(t_0)} = \frac{\alpha^\top \Delta p}{\alpha^\top p} = \frac{\alpha^\top \tilde{\boldsymbol{\mathcal{L}}}(\phi)\, t_{\text{direct}}}{\alpha^\top p}$$

We can simplify this formula because $p = \left(I_n - A^\top\right)^{-1} \upsilon(t_0) = \mathbf{1}_n$ and $\mathbf{1}_n^\top \alpha = 1$. Finally, we have:

$$\pi = \alpha^\top \tilde{\boldsymbol{\mathcal{L}}}(\phi)\, t_{\text{direct}} \tag{10}$$

In general, we define two price indices: the producer price index (PPI) where the basket weights are proportional to the output ($\alpha_j \propto x_j$) and the consumer price index (CPI) where the basket weights are proportional to the final demand ($\alpha_j \propto y_j$). Therefore we obtain:

$$\text{PPI} = \frac{x^\top \tilde{\boldsymbol{\mathcal{L}}}(\phi)\, t_{\text{direct}}}{\mathbf{1}_n^\top x} = \frac{x^\top \left(I_n - A^\top \Phi\right)^{-1} \Phi t_{\text{direct}}}{\mathbf{1}_n^\top x}$$

and:

$$\text{CPI} = \frac{y^\top \tilde{\boldsymbol{\mathcal{L}}}(\phi)\, t_{\text{direct}}}{\mathbf{1}_n^\top y} = \frac{y^\top \left(I_n - A^\top \Phi\right)^{-1} \Phi t_{\text{direct}}}{\mathbf{1}_n^\top y}$$

Similarly, the concept of total tax cost needs to be redefined, as part of the cost is borne by producers and part by consumers. On the consumer side, we need to understand the downstream part of the value chain. We have:

$$\begin{aligned} T_{\text{producer}} &= x \odot (I_n - \Phi)\, t_{\text{direct}} \\ &= x \odot (\mathbf{1}_n - \boldsymbol{\phi}) \odot t_{\text{direct}} \\ &= (\mathbf{1}_n - \boldsymbol{\phi}) \odot T_{\text{direct}} \end{aligned}$$

and:

$$T_{\text{consumer}} = T_{\text{downstream}} = x \odot \tilde{\boldsymbol{\mathcal{L}}}(\phi)\, t_{\text{direct}}$$

We deduce that:

$$\begin{aligned} T_{\text{total}} &= T_{\text{producer}} + T_{\text{consumer}} \\ &= x \odot \left(I_n - \Phi + \tilde{\boldsymbol{\mathcal{L}}}(\phi)\right) t_{\text{direct}} \end{aligned}$$

We also consider a second decomposition between the direct costs of the carbon tax and the indirect costs due to the pass-through mechanism:

$$\begin{cases} T_{\text{direct}} = x \odot t_{\text{direct}} \\ T_{\text{indirect}} = T_{\text{total}} - T_{\text{direct}} = x \odot \left(\tilde{\boldsymbol{\mathcal{L}}} \left(\boldsymbol{\phi} \right) - \Phi \right) t_{\text{direct}} \end{cases}$$

By definition, government revenue is equal to the direct cost of the carbon tax:

$$T_{\text{government}} = T_{\text{direct}} = x \odot t_{\text{direct}}$$

2.2.5 An example

We consider the basic economy given below:

	To				Final Demand	Total Output	Carbon Emissions
	Energy	Materials	Industrials	Services			
From		Z			y	x	$\boldsymbol{\mathcal{CE}}$
Energy	500	800	1 600	1 250	850	5 000	500
Materials	500	400	1 600	625	875	4 000	200
Industrials	250	800	2 400	1 250	3 300	8 000	200
Services	100	200	800	4 375	7 025	12 500	125
Labour	3 000	800	1 000	3 000			
Capital	650	1 000	600	2 000			
Income	5 000	4 000	8 000	12 000			

This basic economy has four sectors: energy, materials, industrials and services. In this economy, businesses in the energy sector buy \$500 of goods and services from other businesses in the energy sector, \$500 of goods and services from the materials sector, \$250 of goods and services from the industrials sector, and \$100 of goods and services from the services sector. The final demand for goods and services produced in the energy sector is equal to \$850, while the total output of this sector is equal to \$5 000. The value added is made up of two items: labour and capital. The energy sector has a labour consumption of \$3 000 and a total output of \$5 000. By construction, the income of the sector is equal to the output of the sector. We deduce that the capital item (capital interest and net profit) is equal to \$650. The carbon emissions, expressed in kgCO_2e, are as follows: 500 for the energy sector, 200 for the materials sector, 200 for the industrials sector and 125 for the services sector. We deduce that the vector of Scope 1 carbon intensities (expressed in $\text{tCO}_2\text{e}/\$\text{ mn}$) is equal to:

$$\boldsymbol{\mathcal{CI}}_1 = \operatorname{diag}(x)^{-1} \boldsymbol{\mathcal{CE}}_1 = \begin{pmatrix} 500/5\,000 \\ 200/4\,000 \\ 200/8\,000 \\ 125/12\,500 \end{pmatrix} \times 10^3 = \begin{pmatrix} 100 \\ 50 \\ 25 \\ 10 \end{pmatrix}$$

We now introduce a differentiated carbon tax: $\boldsymbol{\tau}_1 = \$200/\text{tCO}_2\text{e}$ and $\boldsymbol{\tau}_2 = \boldsymbol{\tau}_3 = \boldsymbol{\tau}_4 = \$100/\text{tCO}_2\text{e}$. The direct tax costs are 100, 20, 20 and 12.5 million dollars for Energy, Materials, Industrials and Services respectively. We deduce that the vector of carbon tax rates is $t_{\text{direct}} = \left(2.00\%, 0.50\%, 0.25\%, 0.10\%\right)$. Let us assume that pass-through rates are uniform ($\boldsymbol{\phi}_1 = \boldsymbol{\phi}_2 = \boldsymbol{\phi}_3 = \boldsymbol{\phi}_4$). The evolution of the total cost is shown in Figure 2. When $\boldsymbol{\phi}_j = 0\%$, $\mathcal{C}_{\text{total}}$ is equal to \$152.50 mn and is the lower bound. The upper bound is reached when $\boldsymbol{\phi}_j = 100\%$ and we get $\mathcal{C}_{\text{total}} = \$430.79$ mn. We have also shown the contribution of each sector by distinguishing between direct and indirect costs. Figure 3 corresponds to the case where the Energy sector passes on the direct costs to the other sectors.

Figure 2: Producer and consumer cost contributions (uniform pass-through rate)

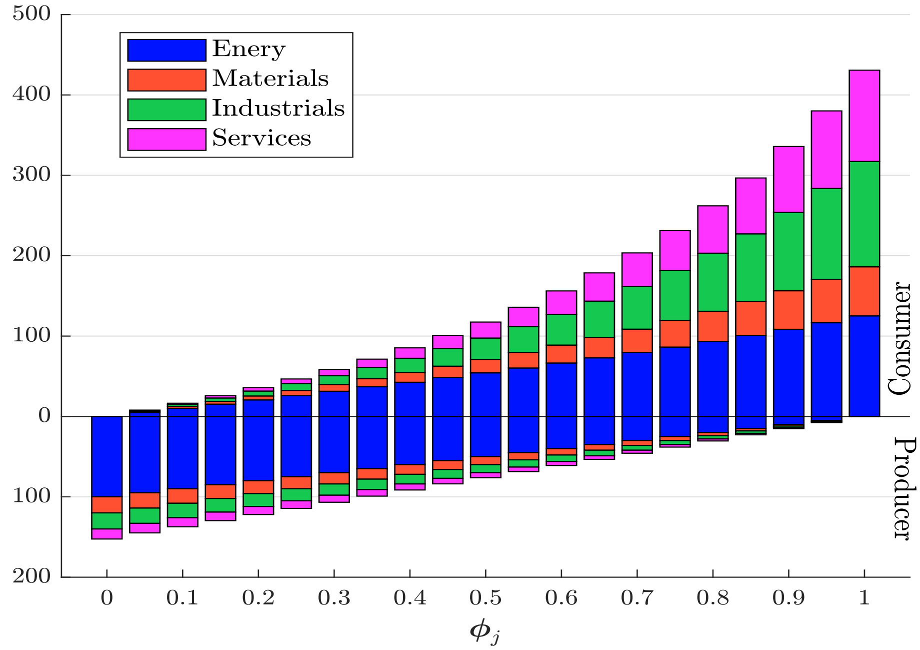
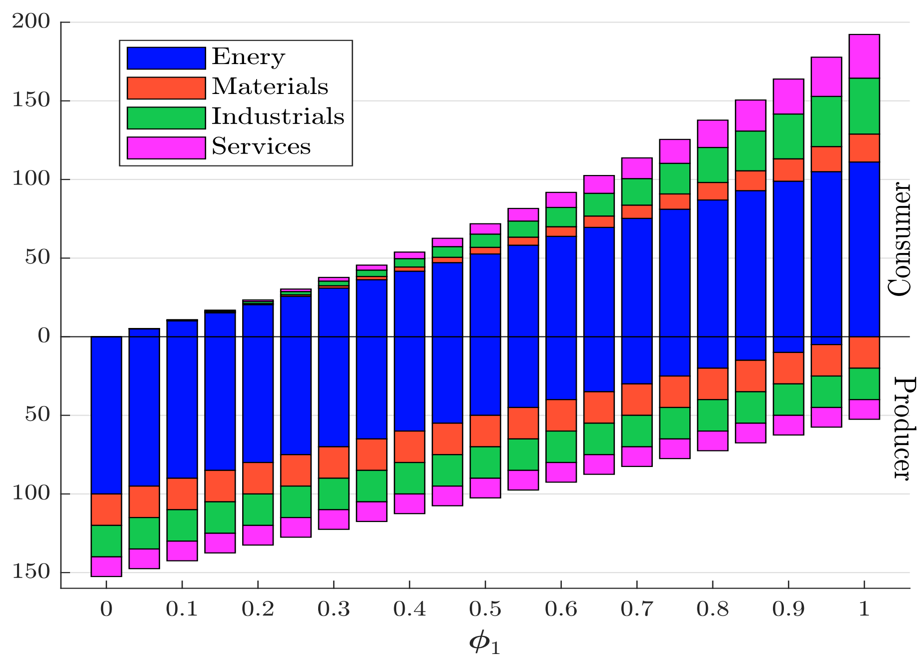


Figure 3: Producer and consumer cost contributions ($\phi_2 = \phi_3 = \phi_4 = 0\%$)



2.3 Definition of the net cost of carbon tax implementation

In Appendix A.1 on page 35, we show that the net economic cost is equal to:

$$\mathcal{C}_{\mathrm{net}} = \omega_{\mathrm{net}}^{\top} \left(\boldsymbol{\tau} \odot \boldsymbol{\mathcal{CI}}_1\right) \tag{11}$$

where $\boldsymbol{\tau}$ is the $n \times 1$ vector of carbon taxes, $\boldsymbol{\mathcal{CI}}_1$ is the $n \times 1$ vector of carbon intensities and ω_{total} is the $n \times 1$ vector defined by:

$$\omega_{\mathrm{net}} = \left(\tilde{\boldsymbol{\mathcal{L}}} \left(\boldsymbol{\phi}\right) - \Phi\right)^{\top} x$$

Several factors determine the net cost to the economy:

1. The carbon footprint of the economy, represented by the carbon intensity $\boldsymbol{\mathcal{CI}}_1$;
2. The tax size $\boldsymbol{\tau}$ which depends on the nominal values and the tax base;
3. The pass-through mechanism $\boldsymbol{\phi}$;
4. The downstreamness of the supply chain, measured by the dual Leontief matrix $\tilde{\boldsymbol{\mathcal{L}}}$.

Below we analyze each of these factors to understand their impact on net economic cost.

Another expression of $\mathcal{C}_{\mathrm{net}}$ is:

$$\mathcal{C}_{\mathrm{net}} = \sum_{j=1}^{n} T_{\mathrm{net},j}$$

where:

$$T_{\mathrm{net},j} = \omega_{\mathrm{net},j} \boldsymbol{\tau}_j \boldsymbol{\mathcal{CI}}_{1,j}$$

Each sector has a positive contribution because[3] $\omega_{\mathrm{net},j} \geq 0$. The contribution $T_{\mathrm{net},j}$ of sector j is the product of three terms: the weight $\omega_{\mathrm{net},j}$, the tax $\boldsymbol{\tau}_j$, and the Scope 1 carbon intensity $\boldsymbol{\mathcal{CI}}_{1,j}$. It is then an increasing linear function of the Scope 1 carbon intensity of sector j. If a sector's carbon intensity is zero, that sector does not generate a net cost on the economy. We get similar results for the tax. The net cost will therefore be higher if the tax is applied to the most polluting sectors in terms of carbon intensity. This result is not obvious because the objective of the carbon tax is to penalize the most polluting sectors and not the other actors in the economy. The problem is that the government only captures the direct costs of the sector: $T_{\mathrm{direct},j} = x_j \boldsymbol{\tau}_j \boldsymbol{\mathcal{CI}}_{1,j} = R_{\mathrm{government},j}$. It can use the product of the tax to promote green technologies, but the economy has to pay a price, which is equal to $T_{\mathrm{net},j} = \omega_{\mathrm{net},j} \boldsymbol{\tau}_j \boldsymbol{\mathcal{CI}}_{1,j}$.

The last term is related to the dual Leontief matrix $\tilde{\boldsymbol{\mathcal{L}}} \left(\boldsymbol{\phi}\right)$, which depends on the matrix of technical coefficients and the vector of pass-through rates. In fact, we can show that the net cost is an increasing function of $\boldsymbol{\phi}$:

$$\boldsymbol{\phi}' \succeq \boldsymbol{\phi} \Rightarrow \mathcal{C}_{\mathrm{net}} \left(\boldsymbol{\phi}'\right) \geq \mathcal{C}_{\mathrm{net}} \left(\boldsymbol{\phi}\right)$$

The lower bound is reached when $\boldsymbol{\phi} = \mathbf{0}_n$, while the upper bound is reached when $\boldsymbol{\phi} = \mathbf{1}_n$:

$$0 \leq \mathcal{C}_{\mathrm{net}} \left(\boldsymbol{\phi}\right) \leq \mathcal{C}_{\mathrm{net}}^{+}$$

where:

$$\mathcal{C}_{\mathrm{net}}^{+} = x^{\top} \left(\left(I_n - A^{\top}\right)^{-1} - I_n\right) t_{\mathrm{direct}}$$

[3] The proof is given in Appendix A.2 on page 35.

Assuming a uniform tax and uniform pass-through rate, Desnos *et al.* (2023) suggest the following approximation:

$$\mathcal{C}_{\text{net}}\left(\boldsymbol{\phi}\right) \approx m_{(1-\infty)}\boldsymbol{\phi}^3\mathcal{R}_{\text{government}}$$

where $\mathcal{R}_{\text{government}} = \mathcal{C}_{\text{direct}}$ are the government revenues and $m_{(1-\infty)}$ is the multiplication factor between indirect and direct carbon emissions:

$$m_{(1-\infty)} = \frac{\boldsymbol{\mathcal{CE}}_{\text{indirect}}}{\boldsymbol{\mathcal{CE}}_{\text{direct}}} = \frac{\boldsymbol{\mathcal{CE}}_{(1-\infty)}}{\boldsymbol{\mathcal{CE}}_{1}}$$

This means that the effect of $\boldsymbol{\phi}$ is cubic. If $\boldsymbol{\phi}$ is less than 50%, the impact is moderate since $0.5^3 = 12.5\%$. If $\boldsymbol{\phi}$ is greater than 75%, any change in the pass-through rate will significantly modify the magnitude of the net cost. In this case, the impact of the pass-through can be important.

The last factor is the impact of the supply chain. In fact, we have:

$$\tilde{\boldsymbol{\mathcal{L}}}\left(\boldsymbol{\phi}\right) - \Phi = \sum_{k=1}^{\infty}\left(A^{\top}\right)^{k}\Phi^{k+1}$$

The effect of Φ has been already discussed above, and thanks to the cubic approximation we can consider the impact of the supply chain through the matrix A of technical coefficients. The previous calculation shows that the impact on the net cost depends on the sparsity of A. Moreover, if the carbon tax is uniform and the pass-through rate is equal to 100% for all sectors, we obtain:

$$\mathcal{C}_{\text{net}} = \boldsymbol{\tau}\cdot\left(\mathbf{1}_n^{\top}\left(\boldsymbol{\mathcal{CE}}_{\text{total}} - \boldsymbol{\mathcal{CE}}_{\text{direct}}\right)\right) = \boldsymbol{\tau}\cdot\left(\mathbf{1}_n^{\top}\boldsymbol{\mathcal{CE}}_{\text{indirect}}\right)$$

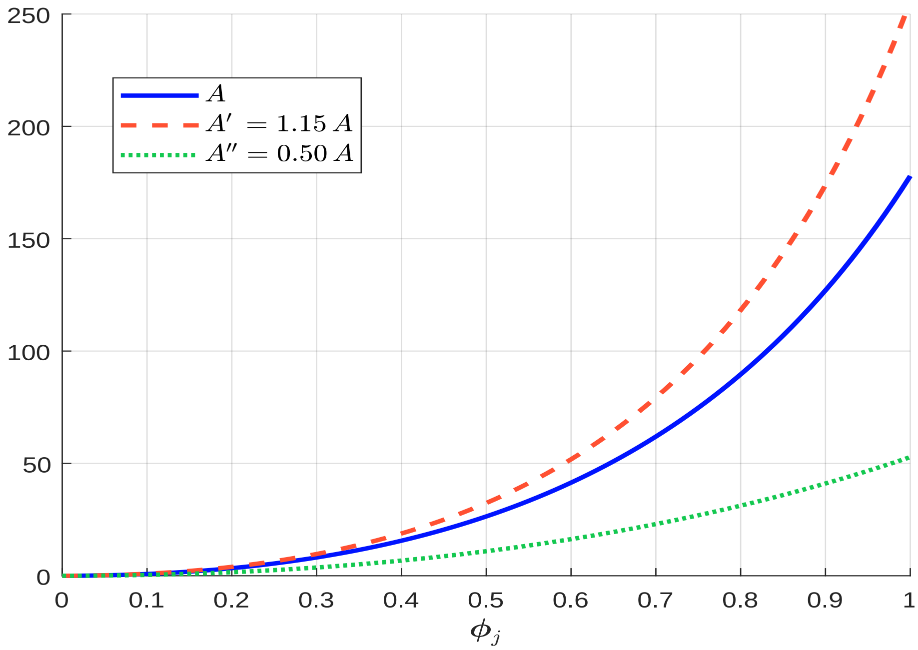
In this case, the net cost is equal to the carbon tax multiplied by the indirect carbon emissions. These results show that the denser the supply chain, the higher the net cost.

We consider the example given on page 16 and assume a uniform carbon tax of $\$100/\text{tCO}_2\text{e}$. In Figure 4, we show the evolution of the net cost $\mathcal{C}_{\text{net}}$ with respect to the pass-through rate. We get cubic behavior, as expected. Now let us densify the matrix of technical coefficients. For instance, if we look at the matrix $A' = 1.15\cdot A$ instead of A, we get the red dashed line. The net cost has increased because the supply chain is denser. On the contrary, the net cost decreases when we consider a sparser supply chain (we obtain the green dotted line if $A'' = 0.50\cdot A$).

3 Macroeconomic incidence of the carbon tax

The empirical validity of a carbon tax requires careful consideration of the economic costs to countries. These costs are estimated using the Exiobase 3 EEIO model for the year 2022. Exiobase is a multi-regional EEIO model that includes 43 countries (representing 95% of world GDP) and a rest-of-the-world (ROW) group. Approximately 163 industries are listed according to the NACE classification. The costs generated by the carbon tax are linked not only to direct emissions, but also to indirect emissions distributed throughout the value chain. The uneven distribution of costs among producers is exacerbated by the pass-through mechanism. We consider the classification made by Desnos *et al.* (2023), which groups industries into four clusters with respect to price-demand elasticity: highly elastic, high elastic, medium elastic, and low elastic. For each cluster, we assign a value of the pass-through parameter of 20%, 40%, 70%, and 95%, respectively. It is important to note that a pass-through rate of zero means that the entire burden of the tax falls on producers, with no

Figure 4: Net economic cost $\mathcal{C}_{\text{net}}$



ability to offset it by raising selling prices. Conversely, when the pass-through rate is at its maximum, the firm no longer bears the cost of the tax because it is indirectly incorporated into prices. In this case, the tax burden falls entirely on consumers, who do not adjust their demand.

3.1 Impact on GDP

3.1.1 GDP impact in a global carbon tax framework

In Table 1, we report on the results considering a uniform global carbon tax of \$100/tCO_2e. Several metrics (*i.e.*, total, direct, indirect, producer, and downstream costs) are provided to disentangle the macroeconomic incidence of a global carbon tax, as well as the expected revenues generated by the carbon tax. The cost and revenue results are expressed as a percentage of GDP[4]. At the global level, the implementation of a uniform carbon tax affects GDP by 5.01% and generates revenue of 2.82%. The net cost would then be 2.18% of world GDP. While the government revenue is exactly the direct cost of the carbon tax, the net cost is the indirect cost of the carbon tax due to the pass-through mechanism. If we split the total cost between what is paid by the producer and what is paid by the downstream supply chain, including the final consumer, we find that out of the 5.01% of the total cost, only 0.93% is paid by the producers, while 4.08% is paid by the value chain and consumers. This means that only 20% of the carbon tax is effectively borne by the producers themselves.

When we break down the analysis to the regional level, we see some economic disparities between countries. Overall, twelve regions have total costs above the average level. Russia is the most affected country with total costs of 12.79% of GDP. It is followed by India (11.38%), Indonesia (7.85%), and China (7.47%). Looking at the split between direct and indirect costs, we find that they are relatively stable across countries. However, a small group

[4]This means that we normalize these figures by the total output $\mathbf{1}_n^\top x$.

Table 1: Economic impact of a global carbon tax ($100/tCO$_2$e, Exiobase 2022)

Region	Cost						Revenue
	$\mathcal{C}_{\text{total}}$	$\mathcal{C}_{\text{direct}}$	$\mathcal{C}_{\text{indirect}}$	$\mathcal{C}_{\text{producer}}$	$\mathcal{C}_{\text{downstream}}$	$\mathcal{C}_{\text{net}}$	$\mathcal{R}_{\text{government}}$
World	5.01%	2.82%	2.18%	0.93%	4.08%	2.18%	2.82%
AUS	4.63%	2.93%	1.70%	0.81%	3.82%	1.70%	2.93%
AUT	2.08%	0.91%	1.17%	0.30%	1.77%	1.17%	0.91%
BEL	1.77%	0.94%	0.82%	0.44%	1.33%	0.82%	0.94%
BGR	7.07%	3.94%	3.12%	0.89%	6.18%	3.12%	3.94%
BRA	5.22%	3.78%	1.44%	2.01%	3.21%	1.44%	3.78%
CAN	3.74%	2.25%	1.49%	0.57%	3.17%	1.49%	2.25%
CHE	0.75%	0.30%	0.45%	0.16%	0.59%	0.45%	0.30%
CHN	7.47%	3.44%	4.03%	1.21%	6.26%	4.03%	3.44%
CYP	5.05%	3.94%	1.11%	2.49%	2.56%	1.11%	3.94%
CZE	4.47%	2.13%	2.34%	0.44%	4.03%	2.34%	2.13%
DEU	1.99%	1.10%	0.89%	0.35%	1.64%	0.89%	1.10%
DNK	1.47%	0.98%	0.49%	0.54%	0.93%	0.49%	0.98%
ESP	2.25%	1.15%	1.11%	0.41%	1.84%	1.11%	1.15%
FIN	2.80%	1.36%	1.44%	0.36%	2.44%	1.44%	1.36%
FRA	1.39%	0.79%	0.60%	0.35%	1.04%	0.60%	0.79%
GBR	1.53%	0.88%	0.65%	0.33%	1.20%	0.65%	0.88%
GRC	6.39%	4.61%	1.78%	2.52%	3.87%	1.78%	4.61%
HRV	3.57%	2.18%	1.38%	0.89%	2.67%	1.38%	2.18%
HUN	3.41%	1.83%	1.58%	0.61%	2.80%	1.58%	1.83%
IDN	7.85%	5.53%	2.31%	2.08%	5.77%	2.31%	5.53%
IND	11.38%	6.83%	4.55%	2.28%	9.11%	4.55%	6.83%
IRL	1.47%	0.95%	0.52%	0.57%	0.89%	0.52%	0.95%
ITA	2.22%	0.93%	1.29%	0.28%	1.93%	1.29%	0.93%
JPN	2.85%	1.38%	1.47%	0.32%	2.53%	1.47%	1.38%
KOR	4.23%	1.61%	2.61%	0.38%	3.85%	2.61%	1.61%
LTU	4.06%	2.41%	1.65%	1.00%	3.06%	1.65%	2.41%
LUX	1.15%	0.51%	0.64%	0.35%	0.80%	0.64%	0.51%
LVA	3.43%	2.15%	1.28%	1.07%	2.36%	1.28%	2.15%
MEX	5.59%	3.60%	1.99%	1.02%	4.57%	1.99%	3.60%
MLT	1.82%	0.64%	1.18%	0.17%	1.65%	1.18%	0.64%
NLD	2.25%	1.14%	1.12%	0.51%	1.74%	1.12%	1.14%
NOR	1.81%	1.31%	0.51%	0.58%	1.23%	0.51%	1.31%
POL	5.84%	3.44%	2.40%	0.98%	4.86%	2.40%	3.44%
PRT	3.77%	2.13%	1.64%	0.70%	3.07%	1.64%	2.13%
ROU	4.10%	2.19%	1.91%	0.69%	3.42%	1.91%	2.19%
RUS	12.79%	8.55%	4.24%	1.44%	11.34%	4.24%	8.55%
SVK	3.29%	1.62%	1.66%	0.42%	2.87%	1.66%	1.62%
SVN	2.79%	1.51%	1.28%	0.47%	2.32%	1.28%	1.51%
SWE	1.21%	0.59%	0.62%	0.21%	1.00%	0.62%	0.59%
TUR	5.78%	3.73%	2.05%	1.39%	4.39%	2.05%	3.73%
TWN	5.16%	2.21%	2.95%	0.75%	4.41%	2.95%	2.21%
USA	2.17%	1.40%	0.78%	0.34%	1.83%	0.78%	1.40%
ROW	7.55%	5.14%	2.40%	1.87%	5.68%	2.40%	5.14%

of countries, including Malta, Switzerland, Italy, and Austria, bear slightly more indirect than direct costs. While several factors could explain the relative impact of the carbon tax on GDP, these countries appear to be relatively more exposed to the pass-through rate of foreign sectors. As they are at the bottom of the global supply chain, their dependence makes them more vulnerable to cascading price effects. Given this pass-through mechanism, these countries pay the cost of emitting abroad. This cost could be represented by the tax revenue shortfall, which is systematically lower than the net cost of the carbon tax for these countries. Conversely, countries with higher direct than indirect costs are less affected by their trade dependence. This is the case, for example, for Russia, Canada, Brazil, Australia, India, and the United States. In this context, a degree of energy independence allows these countries to avoid the worst economic effects of the tax.

Following the decomposition between producer and downstream costs, we find that some countries contribute to the amplification of the pass-through mechanism at the global level. This is particularly the case for South Korea, Malta, Japan, Russia and the Czech Republic, where less than 10% of the carbon tax is borne by producers.

3.1.2 GDP impact in a regional carbon tax framework

Although climate change is a global phenomenon whose effects know no borders, it is unlikely that common measures such as an international carbon pricing system will see the light of day. However, the need for an urgent response to climate risks cannot wait for a global coalition. On the one hand, many regions of the world, especially those with historical responsibility for climate change, are mobilizing to curb emissions trends. On the other hand, the proliferation of different ambitions, targets and instruments is rarely coordinated, raising questions about effectiveness at the macroeconomic level.

In this context, we analyze the economic repercussions of the implementation of individual climate policies. Using the tax framework developed in this study, we analyze an individual carbon tax in Europe, the United States, and China. For each scenario, we apply the carbon tax to the sectors that make up the economy without considering a carbon border adjustment mechanism. Under these circumstances, we observe that the implementation of a carbon tax within EU member states will primarily affect European economies (Table 2). Without a CBAM, countries outside Europe will not suffer from the implementation of the European tax. More than 95% of the total costs fall on the countries of the European Union. More specifically, the results highlight that the fifteen countries most affected by the tax are not the continent's major economies, but rather the more fragile states of Central and Eastern Europe (*e.g.*, Bulgaria, Romania, Croatia, Latvia, Lithuania, Czech Republic or Poland). This observation refers to the density of trade relations within the EU itself. In most cases, these countries trade within the EU area.

In Tables 3 and 4, we report on estimates for a US and a Chinese carbon tax, respectively. As in the case of the EU tax, the economic incidence of the carbon tax is almost entirely borne by the domestic economy. For the US, the total cost is less than 2% of GDP, while for China this figure reaches 6.89%. The two main trading partners of the United States, namely Canada and Mexico, will be indirectly affected by the tax by up to \$5.5 bn and \$3.7 bn, respectively, which is less than 0.2% of their respective GDP. Despite the limited cascading effect of the domestic carbon tax, the estimates illustrate the distorting effects of an isolated climate policy. Finally, if we compare the macroeconomic impacts on a global scale, we see that the impact of an American or Chinese tax on world GDP is larger than that of a European tax. A Chinese carbon tax could induce a significant cost of 1.66% on the global economy, which is more than four times the total impact of a European tax.

Table 2: Economic impact of a EU carbon tax ($100/tCO_2e, Exiobase 2022)

Region	Cost						Revenue
	$\mathcal{C}_{\text{total}}$	$\mathcal{C}_{\text{direct}}$	$\mathcal{C}_{\text{indirect}}$	$\mathcal{C}_{\text{producer}}$	$\mathcal{C}_{\text{downstream}}$	$\mathcal{C}_{\text{net}}$	$\mathcal{R}_{\text{government}}$
World	0.36%	0.22%	0.14%	0.07%	0.28%	0.14%	0.22%
BGR	6.30%	3.94%	2.35%	0.89%	5.41%	2.35%	3.94%
GRC	5.64%	4.61%	1.03%	2.52%	3.12%	1.03%	4.61%
POL	5.21%	3.44%	1.77%	0.98%	4.24%	1.77%	3.44%
CYP	4.86%	3.94%	0.92%	2.49%	2.37%	0.92%	3.94%
CZE	3.90%	2.13%	1.76%	0.44%	3.46%	1.76%	2.13%
ROU	3.60%	2.19%	1.41%	0.69%	2.91%	1.41%	2.19%
PRT	3.28%	2.13%	1.15%	0.70%	2.58%	1.15%	2.13%
LTU	3.22%	2.41%	0.82%	1.00%	2.22%	0.82%	2.41%
LVA	3.11%	2.15%	0.96%	1.07%	2.05%	0.96%	2.15%
HRV	2.88%	2.18%	0.70%	0.89%	1.99%	0.70%	2.18%
SVK	2.72%	1.62%	1.09%	0.42%	2.30%	1.09%	1.62%
HUN	2.70%	1.83%	0.87%	0.61%	2.08%	0.87%	1.83%
SVN	2.38%	1.51%	0.87%	0.47%	1.91%	0.87%	1.51%
FIN	2.27%	1.36%	0.91%	0.36%	1.91%	0.91%	1.36%
ESP	1.82%	1.15%	0.68%	0.41%	1.41%	0.68%	1.15%

Table 3: Economic impact of a US carbon tax ($100/tCO_2e, Exiobase 2022)

Region	Cost						Revenue
	$\mathcal{C}_{\text{total}}$	$\mathcal{C}_{\text{direct}}$	$\mathcal{C}_{\text{indirect}}$	$\mathcal{C}_{\text{producer}}$	$\mathcal{C}_{\text{downstream}}$	$\mathcal{C}_{\text{net}}$	$\mathcal{R}_{\text{government}}$
World	0.44%	0.29%	0.14%	0.07%	0.37%	0.14%	0.29%
USA	1.96%	1.40%	0.57%	0.34%	1.62%	0.57%	1.40%
CAN	0.18%	0.00%	0.18%	0.00%	0.18%	0.18%	0.00%
MEX	0.18%	0.00%	0.18%	0.00%	0.18%	0.18%	0.00%
KOR	0.07%	0.00%	0.07%	0.00%	0.07%	0.07%	0.00%
IRL	0.06%	0.00%	0.06%	0.00%	0.06%	0.06%	0.00%
BRA	0.05%	0.00%	0.05%	0.00%	0.05%	0.05%	0.00%
TWN	0.04%	0.00%	0.04%	0.00%	0.04%	0.04%	0.00%
ROW	0.04%	0.00%	0.04%	0.00%	0.04%	0.04%	0.00%
IND	0.04%	0.00%	0.04%	0.00%	0.04%	0.04%	0.00%
NLD	0.03%	0.00%	0.03%	0.00%	0.03%	0.03%	0.00%
GBR	0.03%	0.00%	0.03%	0.00%	0.03%	0.03%	0.00%
NOR	0.02%	0.00%	0.02%	0.00%	0.02%	0.02%	0.00%
BEL	0.02%	0.00%	0.02%	0.00%	0.02%	0.02%	0.00%
JPN	0.02%	0.00%	0.02%	0.00%	0.02%	0.02%	0.00%
CHN	0.02%	0.00%	0.02%	0.00%	0.02%	0.02%	0.00%

Table 4: Economic impact of a carbon tax in China ($100/tCO$_2$e, Exiobase 2022)

Region	Cost						Revenue
	$\mathcal{C}_{\text{total}}$	$\mathcal{C}_{\text{direct}}$	$\mathcal{C}_{\text{indirect}}$	$\mathcal{C}_{\text{producer}}$	$\mathcal{C}_{\text{downstream}}$	$\mathcal{C}_{\text{net}}$	$\mathcal{R}_{\text{government}}$
World	1.66%	0.81%	0.85%	0.29%	1.38%	0.85%	0.81%
CHN	6.89%	3.44%	3.45%	1.21%	5.68%	3.45%	3.44%
ROW	0.13%	0.00%	0.13%	0.00%	0.13%	0.13%	0.00%
KOR	0.12%	0.00%	0.12%	0.00%	0.12%	0.12%	0.00%
MEX	0.06%	0.00%	0.06%	0.00%	0.06%	0.06%	0.00%
IND	0.05%	0.00%	0.05%	0.00%	0.05%	0.05%	0.00%
IDN	0.05%	0.00%	0.05%	0.00%	0.05%	0.05%	0.00%
JPN	0.04%	0.00%	0.04%	0.00%	0.04%	0.04%	0.00%
POL	0.04%	0.00%	0.04%	0.00%	0.04%	0.04%	0.00%
CZE	0.04%	0.00%	0.04%	0.00%	0.04%	0.04%	0.00%
HUN	0.04%	0.00%	0.04%	0.00%	0.04%	0.04%	0.00%
TUR	0.04%	0.00%	0.04%	0.00%	0.04%	0.04%	0.00%
CAN	0.03%	0.00%	0.03%	0.00%	0.03%	0.03%	0.00%
BEL	0.03%	0.00%	0.03%	0.00%	0.03%	0.03%	0.00%
SVK	0.03%	0.00%	0.03%	0.00%	0.03%	0.03%	0.00%
AUS	0.03%	0.00%	0.03%	0.00%	0.03%	0.03%	0.00%

3.2 Impact on inflation

To measure the impact of the carbon tax on inflation, we split the analysis between the Producer Price Index (PPI) and the Consumer Price Index (CPI). While the PPI provides information on inflationary pressures within the supply chain, the CPI is relevant for measuring the impact of price changes on living standards. Although there are large gaps between the two indicators, the PPI mechanically leads the CPI. The discrepancy between the two indicators lies in the way weights are assigned within the price index. In the case of the PPI, the index includes weights based on the country's production structure. Conversely, for the CPI, the basket of goods and services reflects the distribution of final demand. Therefore, the differences between these two indicators for the same country are based on how domestic demand relates to domestic production. For example, it is possible that a country's value chain could be more affected than consumption if the final demand for goods and services affected by taxation represents only a small part of the consumption basket. This scenario reinforces the snowball effect induced by the pass-through mechanism until it reaches the bottom of the value chain. Conversely, if a relatively important part of final demand is directed to foreign supply, the impact on consumer prices may exceed that of the domestic value chain. To understand the differences in inflation across countries, it's necessary to add the influence of direct emissions and the value chain impact to the previous weighting effect. As with the GDP impact, inflation is affected by both direct and indirect emissions. In other words, countries with high carbon footprints and high dependence on foreign production are relatively more affected than countries with low emissions and less dependence.

3.2.1 Inflationary pressure on the supply chain

In Table 5, we present the PPI values for the fifteen most affected countries, categorized according to different tax structures. With a uniform global tax of $100/tCO$_2$e, cost-push inflation reaches 4.08% worldwide. When the basket weights are proportional to output, we faithfully recover the country rankings from the economic impact. Russia emerges as the hardest hit country from a producer perspective, with a PPI of 11.3%. It is closely followed by India (9.11%), China (6.26%), Bulgaria (6.18%) and Indonesia (5.77%). In the light of the previous detailed results (see Table 1), we can better understand the sources of producer inflation. For example, Russia's inflation rate is mostly influenced by direct emissions, despite having one of the lowest value chain impacts in the world. Conversely, China faces relatively greater penalties from value chain impacts than from direct emissions. Bulgaria experiences inflationary pressure from both effects to a similar degree.

Table 5: Producer price index (π_{ppi}) estimates (\$100/tCO_2e, Exiobase 2022)

Rank	Global tax		EU tax		US tax		China tax	
	World	4.08%	World	0.28%	World	0.37%	World	1.38%
1	RUS	11.34%	BGR	5.41%	USA	1.62%	CHN	5.68%
2	IND	9.11%	POL	4.24%	CAN	0.18%	ROW	0.13%
3	CHN	6.26%	CZE	3.46%	MEX	0.18%	KOR	0.12%
4	BGR	6.18%	GRC	3.12%	KOR	0.07%	MEX	0.06%
5	IDN	5.77%	ROU	2.91%	IRL	0.06%	IND	0.05%
6	ROW	5.68%	PRT	2.58%	BRA	0.05%	IDN	0.05%
7	POL	4.86%	CYP	2.37%	TWN	0.04%	JPN	0.04%
8	MEX	4.57%	SVK	2.30%	ROW	0.04%	POL	0.04%
9	TWN	4.41%	LTU	2.22%	IND	0.04%	CZE	0.04%
10	TUR	4.39%	HUN	2.08%	NLD	0.03%	HUN	0.04%
11	CZE	4.03%	LVA	2.05%	GBR	0.03%	TUR	0.04%
12	GRC	3.87%	HRV	1.99%	NOR	0.02%	CAN	0.03%
13	KOR	3.85%	SVN	1.91%	BEL	0.02%	BEL	0.03%
14	AUS	3.82%	FIN	1.91%	JPN	0.02%	SVK	0.03%
15	ROU	3.42%	AUT	1.50%	CHN	0.02%	AUS	0.03%

Disaggregating the carbon tax frameworks, we find that inflationary pressures are marginal at the global level. For a European carbon tax, producer inflation is concentrated in European economies, especially in Central and Eastern European countries. Carbon-intensive producers are at the top of the list. The US carbon tax mainly affects the US economy itself. The cascading effect of producer inflation is contained within the borders of the United States-Mexico-Canada Agreement (USMCA). Despite being implemented in only one economy, a Chinese or American carbon tax has a greater impact on global PPI than the European carbon tax. Nevertheless, we confirm that the inflationary shock to output would be significantly higher in the case of a Chinese carbon tax (1.38%). The global value chain is thus more concentrated around this economy in terms of production and, by extension, GHG emissions, which amplifies the inflationary impact on producers.

3.2.2 Inflationary pressure on the consumer basket

In Table 6, we report the CPI estimates for the fifteen most affected countries. Escalating producer prices in response to a global and uniform carbon tax lead to a 3.53% increase in consumer prices worldwide. This time, Indonesia is the hardest hit country in the world, with a consumer price index of 6.75%. Close behind are China with a CPI of 6.35%, France (6.29%), India (5.98%) and Russia (5.72%). Although the top five list is roughly the same as the previous one, France appears in third place. While previous estimates didn't mention France as being particularly affected by the global carbon tax, either directly or indirectly, final demand is particularly affected. There is a pronounced effect related to the weights of goods in the consumption basket. Final demand could be skewed towards carbon-intensive products, which are likely to come from foreign economies where producers have significant pricing power. This foreign preference in final demand thus inflates the French CPI. In contrast to France, Russian consumption is less affected by the global carbon tax. While the Russian value chain is particularly penalized by the tax due to the high carbon intensity of production, final demand is moderately affected due to a more diversified consumption allocation. On the other hand, countries that are highly dependent on Russian energy supplies, such as China and India, would be significantly affected by the price effects.

Table 6: Consumer price index (π_{cpi}) estimates (\$100/tCO_2e, Exiobase 2022)

Rank	Global tax		EU tax		US tax		China tax	
	World	3.53%	World	0.48%	World	0.27%	World	1.15%
1	IDN	6.75%	FRA	5.95%	USA	1.06%	CHN	5.88%
2	CHN	6.35%	CZE	4.07%	MEX	0.16%	ROW	0.16%
3	FRA	6.29%	HRV	3.83%	CAN	0.16%	KOR	0.08%
4	IND	5.98%	GRC	3.59%	IRL	0.05%	AUS	0.07%
5	RUS	5.72%	POL	3.49%	BRA	0.04%	IND	0.07%
6	CZE	4.63%	CYP	3.32%	GBR	0.04%	CAN	0.07%
7	HRV	4.42%	BGR	3.16%	ROW	0.04%	MEX	0.06%
8	GRC	4.35%	SVK	2.80%	KOR	0.03%	TUR	0.05%
9	POL	4.14%	MLT	2.69%	IND	0.03%	IDN	0.04%
10	BGR	3.89%	PRT	2.58%	NOR	0.03%	BRA	0.04%
11	ROW	3.82%	LUX	2.30%	NLD	0.03%	JPN	0.04%
12	TWN	3.73%	HUN	2.20%	LUX	0.03%	BEL	0.04%
13	CYP	3.57%	LTU	2.11%	TWN	0.02%	RUS	0.04%
14	MLT	3.38%	NLD	2.11%	BEL	0.02%	GRC	0.04%
15	SVK	3.36%	SVN	1.90%	TUR	0.02%	POL	0.04%

Overall, we find that changes in the CPI are relatively weaker than changes in the PPI after the carbon tax is introduced. This would suggest that the impact on production is relatively stronger than on consumption. However, we have previously argued that the producer does not absorb much of the tax, but rather uses its position in the value chain to raise final prices. The main reason for this relationship lies in the demand component. It is likely that final demand for sectors with very high carbon intensity (*e.g.*, steel production, mining, extraction, etc.) represents a lower share of consumption than for sectors with low carbon intensity (*e.g.*, health services, real estate, agriculture). The trickle-down effect of price pressure is limited in the CPI because weighted shares do not amplify the pass-through effect as in the PPI. On the other hand, we observe that this relationship is reversed when the tax is implemented within European borders. This time, the impact on the global CPI is relatively larger, by 0.2 percentage points, than on the PPI. The price contagion in the value chain is passed on to the final consumer, whose demand is predominantly oriented towards domestic products. Similarly, a Chinese carbon tax would put slightly more inflationary pressure on Chinese consumers than on Chinese producers. Nevertheless, a Chinese carbon tax would put more pressure on the global value chain than on global consumption. This is also the case for the US tax, which puts the Chinese and US economies at the crossroads of inflation. Finally, there is an inverse relationship between PPI and CPI for the major U.S. trading partners. The impact of producer price increases is greater in Canada than in Mexico, while Mexican final demand is more sensitive to a US carbon tax than is Canadian.

4 Microeconomic impact of the carbon tax

The analysis of the economic costs of the carbon tax is not limited to the macroeconomic perspective. In particular, the underlying microeconomic mechanisms draw our attention. First, the impact of the carbon tax is unlikely to be sector neutral, as the carbon intensity of industries is highly heterogeneous. As a result, the tax burden may be more or less concentrated on certain industries that may abuse their market power. By considering a sectoral approach, we can refine the cost distribution across sectors given their respective revenue shocks. Second, an overwhelming issue in the environmental transition is related to its social welfare implications. Again, the impact of the carbon tax is unlikely to be socially neutral. Given the results on inflation, the increase in consumer prices affects households in different ways, since their consumption structure is inextricably linked to their standard of living (Semet, 2024). Thus, different degrees of tax progressivity are expected compared to static estimates of consumer price inflation.

4.1 Impact on earnings

4.1.1 Methodology

We use the model developed by Desnos *et al.* (2023). Using the cost-push price model and the accounting identity formula for the income of sector j, they showed that the introduction of the tax implies a variation in the value added V_j for sector j, which has the following expression:

$$\Delta V_j = \underbrace{x_j \Delta p_j}_{\text{Price impact}} + \underbrace{\left(x_j - x_j^-\right) p_j^-}_{\text{Final demand impact}} - \underbrace{\left(x_j - x_j^-\right) \sum_{i=1}^{n} A_{i,j} p_i^-}_{\text{Intermediate demand impact}} - \underbrace{x_j \sum_{i=1}^{n} A_{i,j} \Delta p_i}_{\text{Production cost impact}} - \underbrace{\left(1 - \phi_j\right) T_{\text{direct},j}}_{\text{Direct impact}}$$

where x_j^-, and p_j^- are the output and price of sector j before the introduction of the tax. The variation in value added has five components. The first component $x_j \Delta p_j$ is the price effect, which is generally a positive factor. The second and third components $\left(x_j - x_j^-\right) p_j^-$ and $\left(x_j - x_j^-\right) \sum_{i=1}^{n} A_{i,j} p_i^-$ measure the impact of final and intermediate demand. These two terms are generally negative because $x_j \leq x_j^-$. The fourth component $x_j \sum_{i=1}^{n} A_{i,j} \Delta p_i$ is the increase in production costs, while the last term is the direct impact on producers. Assuming that the earnings' shock is proportional to the variation in value added, we get:

$$\mathbb{S}_j := \frac{\text{Ebitda}_j - \text{Ebitda}_j^-}{\text{Ebitda}_j^-} = \frac{\Delta V_j}{V_j^-}$$

To use the previous model, we need to calibrate the slope b_j of the demand function[5]. Since we have $\Delta y_j = -b_j \Delta p_j$, we deduce that:

$$b_j = -\frac{\Delta y_j}{\Delta p_j} = -\boldsymbol{\varepsilon}_j \frac{y_j^-}{p_j^-} = -\boldsymbol{\varepsilon}_j y_j^-$$

[5] In fact, we need to calculate $\Delta x = x - x^- = \boldsymbol{\mathcal{L}} \Delta y$, so we need to calculate Δy.

where ε_j is the price elasticity of demand. Using the relationship between the elasticity ε_j and the pass-through rate ϕ_j:

$$\varepsilon_j = 1 - \frac{1}{\phi_j}$$

the slope of the demand function is then equal to:

$$b_j = -\left(1 - \frac{1}{\phi_j}\right) y_j^- = \frac{1 - \phi_j}{\phi_j} y_j^-$$

The previous approach can be extended at the issuer level by decomposing the earnings-at-risk between the earnings shock due to the global value chain and the specific direct impact of the carbon tax. In this case, we consider the carbon intensity of the issuer instead of the carbon intensity of the sector.

4.1.2 Results

Let us first focus on the impact of a carbon tax on corporate profits. In Table 7, we report on the earnings' shock[6] in percentage terms according to the eleven sectors that make up the Global Industry Classification Standard (GICS). We consider different values of the pass-through parameter ranging from 0% to 100%. The results suggest that when less than 50% of the carbon tax is passed on to downstream agents, the earnings' shock is systematically negative. At the aggregate level, the earnings' shock for the MSCI World Index at a 25% pass-through rate is −4.41%. While Utilities, Energy and Materials bear the bulk of the tax burden (−57.82%, −20.35% and −12.79%), Communication Services (−0.41%) and Information Technology (−0.58%) are barely affected.

Table 7: Earnings' shock estimates in % (global tax, \$100/tCO_2e, Exiobase 2022, MSCI World index, May 2023)

ϕ	0%	25%	50%	75%	90%	95%	100%
Communication Services	−0.06	−0.41	−0.42	−0.29	−0.10	−0.00	0.11
Consumer Discretionary	−1.62	−2.23	−1.94	−1.23	−0.32	0.13	0.69
Consumer Staples	−0.99	−3.37	−3.49	−1.73	0.65	1.75	3.04
Energy	−14.64	−20.35	−14.97	−1.93	36.39	52.95	71.72
Financials	−0.80	−1.24	−1.00	−0.59	−0.18	−0.00	0.20
Health Care	−0.17	−0.76	−0.91	−0.71	−0.29	−0.08	0.19
Industrials	−3.86	−3.49	−1.66	0.71	2.65	3.44	4.34
Information Technology	−0.13	−0.58	−0.58	−0.40	−0.09	0.07	0.27
Materials	−18.40	−12.79	−3.90	6.20	13.30	15.92	18.73
Real Estate	−0.60	−0.96	−0.88	−0.55	−0.18	−0.01	0.18
Utilities	−72.08	−57.82	−25.40	9.02	30.89	38.44	46.13
MSCI World index	−4.30	−4.41	−2.65	−0.06	3.29	4.69	6.26

When $\phi = 75\%$, the earnings' shock becomes positive for some sectors. This is especially the case for the most affected sectors, namely Utilities (+9.02%), Materials (+6.20%) and Industrials (+0.71%). As the pass-through rate gets closer to one, this phenomenon of positive returns gains momentum. For example, the MSCI World Index shows positive earnings of about +3.29% at a pass-through rate of 90%. Only six sectors are still negatively impacted, namely Communication Services (−0.10%), Consumer Discretionary (−0.32%),

[6] Remember that the earnings' shock is proportional to the variation in value added.

Financials (−0.18%), Health Care (−0.29%), Information Technology (−0.09%), and Real Estate (−0.18%). In the most extreme scenario, where the pass-through rate reaches 100%, the earnings' shock is positive for all sectors, boosting the MSCI World by +6.26%. Again, Energy, Utilities and Materials have very large positive earnings shocks (+71.72%, +46.13% and +18.73%). These sectors make profit from the environmental tax thanks to their natural but advantageous position in the value chain. In fact, while they pass on their direct costs throughout the global value chain, they do not face profit pressures from other sectors because they are at the top of the value chain. The large profit gap between sectors is the result of each sector's upstream value chain (the cost of production) and its downstream value chain (how much can be passed on to the end consumer). A sector at the top of its global value chain receives low costs from its suppliers. Therefore, it can pass on more costs than it receives. Conversely, if a sector is at the bottom of the global value chain, it receives high costs from its suppliers, which acts as a snowball effect. Thus, there is an asymmetry between the costs it can pass on and the costs it receives.

To understand how a carbon tax affects sectors differently, it seems relevant to look closely at upstream and downstream supply chains. Yet the impact of the tax varies not only between sectors, but also within sectors. In Table 8, we analyze this dispersion by reporting the mean $\mu\left(\mathbb{S}_j\right)$, the standard deviation $\sigma\left(\mathbb{S}_i\right)$, and the confidence intervals ranging from 5% to 95% of the earnings shock at the issuer level. According to the pass-through mechanism retained here, energy and utilities companies are, on average, the only beneficiaries (*i.e.*, positive earnings) of the carbon tax. The impact of these sectors on the MSCI World Index is significant, as the index has an average positive earnings of +2.58%, while all sectors record negative earnings. However, these sectors are characterized by a wide dispersion of issuer earnings. For example, at the bottom of the distribution, companies in these sectors are barely affected by the tax, while at the top, issuer earnings are strictly positive. The negative impact of the carbon tax on them is thus very limited. The confidence intervals for Materials issuers are even wider, as the bottom 5% of issuers' earnings are the lowest (−58.51%), while the top 5% of issuers' earnings reach +34.33%. This dispersion may be due to the large product heterogeneity within the materials sector (*e.g.*, chemicals, construction, packaging, or mining), which places sub-sectors at different levels of the value chain.

Table 8: Earnings' shock decomposition in % (global tax, \$100/tCO_2e, Exiobase 2022, MSCI World index, May 2023)

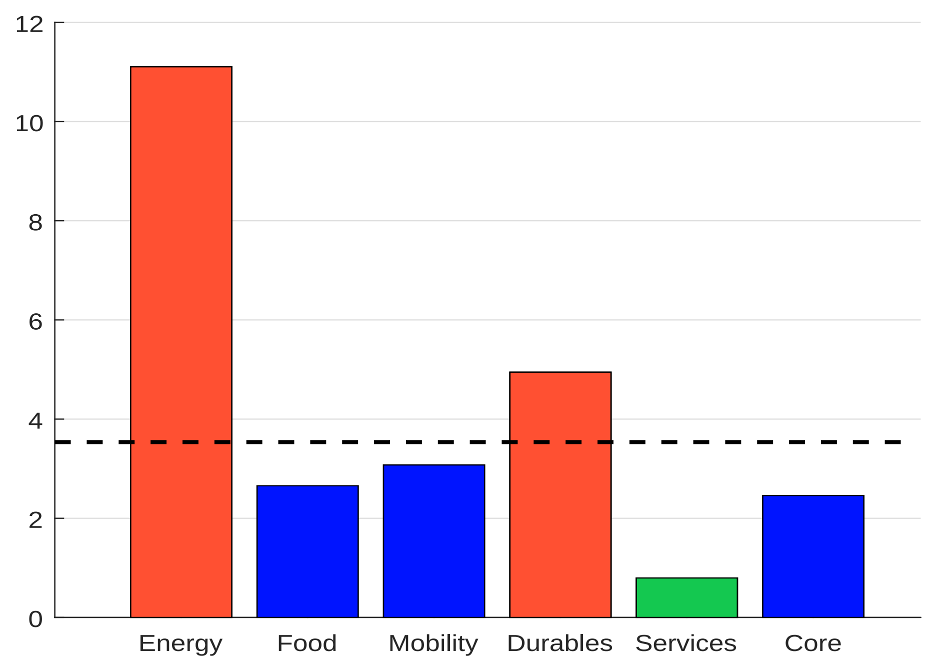
Statistic	$\mu\left(\mathbb{S}_j\right)$	$\sigma\left(\mathbb{S}_i\right)$	$\mathbb{Q}_{5\%}\left(\mathbb{S}_i\right)$	$\mathbb{Q}_{50\%}\left(\mathbb{S}_i\right)$	$\mathbb{Q}_{95\%}\left(\mathbb{S}_i\right)$
Communication Services	−0.33	0.46	−1.45	−0.42	−0.02
Consumer Discretionary	−2.21	13.68	−4.10	−1.26	−0.43
Consumer Staples	−3.97	2.71	−9.21	−4.05	−1.31
Energy	51.41	69.71	−0.74	24.21	35.82
Financials	−0.74	0.42	−0.87	−0.53	−0.17
Health Care	−0.49	0.49	−1.21	−0.70	−0.03
Industrials	−0.17	14.15	−11.37	−1.30	0.32
Information Technology	−0.52	0.91	−2.45	−0.54	−0.24
Materials	−0.51	95.06	−58.51	−5.50	34.33
Real Estate	−0.19	0.68	−0.80	−0.18	−0.04
Utilities	37.98	24.73	−0.80	40.38	94.14
MSCI World index	2.58	32.80	−7.78	−0.68	33.70

In contrast to these case study sectors, the results indicate that issuers in the Consumer Staples and Consumer Discretionary sectors are the most penalized by the carbon tax. On average, they experience a loss of 3.97% and 2.21% of earnings, respectively. Although the dispersion of issuer earnings within the Consumer Discretionary sector is important, none of the issuers report a positive earnings shock. As these sectors are at the bottom of the global value chain, they incur high costs from suppliers that they cannot pass on to other sectors as they face the end consumer directly. Finally, the impact of the carbon tax appears to be relatively homogeneous and small within some sectors, such as Communication Services, Financials, Health Care, Information Technology and Real Estate. This may be due to the fact that these sectors are less dependent on the most affected sectors, as they consist of services rather than goods. The high heterogeneity of the earnings shock both across and within sectors does not contradict the main observation. While the vast majority of winners are located in high-emitting sectors, the sectors most affected are those dealing with final consumption. This result calls into question the effectiveness of a carbon tax, as the tax burden is unevenly spread across vulnerable sectors.

4.2 Social impact

In addition to its macroeconomic impact, the carbon tax instrument generates cascading price increases with significant distributive implications. These costs are unevenly spread across the population due to different consumption patterns, which are generally associated with income levels. High-income households typically allocate a smaller share of their expenditures to carbon-intensive goods, such as transportation and energy, while low-income households bear a disproportionate burden because they consume relatively more these products. Vulnerability to price increases also varies geographically. Indeed, inflationary pressures on consumer prices may disproportionately affect certain countries with a high dependence on certain components, increasing existing inequalities.

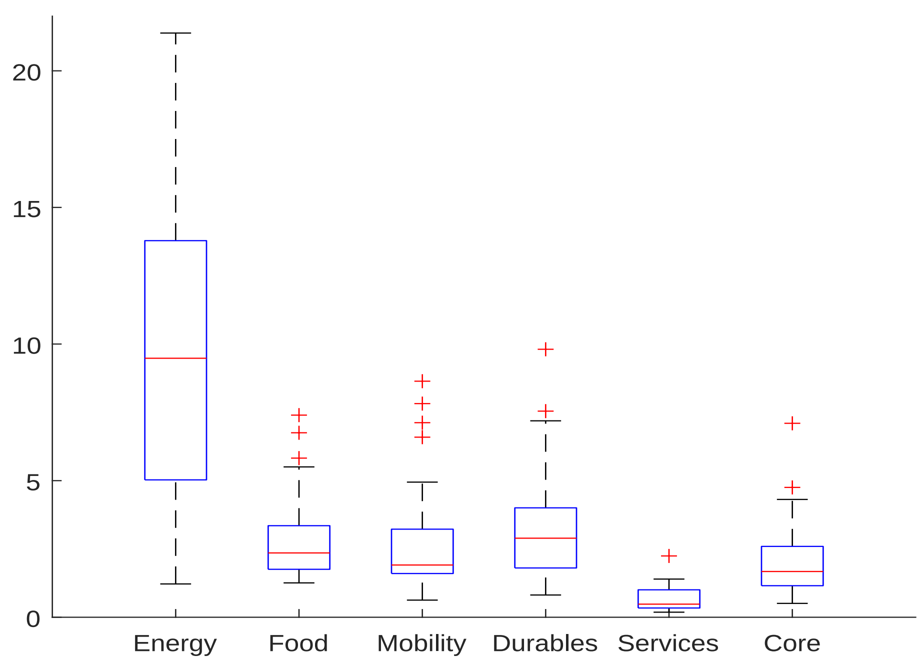
Figure 5: World inflation components in % (global tax, \$100/tCO_2e, Exiobase 2022)



Consistent with its primary objective, the carbon tax primarily targets energy products, resulting in an average relative price increase of 11.11% (see Figure 5). In a global tax scenario assuming minimal risk of carbon leakage, this price increase is expected to drive a shift from expensive fossil fuel-based energy sources to cleaner alternatives such as renewables, which have become comparatively more affordable. This shift would be confirmed by increased demand for cleaner energy sources if consumers exhibit elastic demand for fossil fuels. However, in the short term, this phenomenon may not be certain for energy, as the supply of renewable energy is not sufficient to meet the growing demand. This leads to an unchanged level of consumption by energy-intensive consumers, despite the additional costs incurred. As a result, the consumption level of energy-intensive consumers remains unchanged and contributes to the heterogeneous distribution of carbon footprints. On the other hand, durable goods, including manufactured goods, represent the second most affected consumption category, as industries and materials pass on price increases directly to consumers. This time, the regressive effect of the tax could be reduced. In terms of impact on the CPI, mobility ranks third, followed by food, while services show minimal impact. Notably, the core inflation, excluding energy and food, shows limited variation overall.

As shown in Figure 6, the energy component explains most of the variance in inflation rates across countries. Countries least affected by energy prices, such as Norway, Switzerland or France, typically benefit from a healthy share of renewable energy in their energy mix, including nuclear power. Conversely, countries most affected by energy prices, such as Indonesia, China or India, rely heavily on carbon-intensive energy sources such as coal and oil. These differences in the energy mix increase inflationary pressures on consumers and disproportionately hurt emerging economies. As a result, penalizing carbon-induced growth will ultimately affect consumption in emerging countries. For instance, inflation rates in these countries stand at 4.49% compared to 2.67% in developed countries, exacerbating the unequal distribution of the transition costs.

Figure 6: Box plot of country inflation components in % (global tax, \$100/tCO_2e, Exiobase 2022)



5 Conclusion

In this study, we have analyzed the economic effects of introducing a carbon tax. This policy instrument, often recommended by economists for its ability to address market distortions, is generally considered a critical component of ambitious climate policies. The primary goal of this instrument is to reduce greenhouse gas emissions by exploiting the "*polluter pays*" principle. Through a trickle-down effect, the policy aims to raise the relative prices of climate-damaging products, thereby encouraging a shift in consumer demand towards low-emission alternatives. The tax revenue is seen as additional revenue for the government, which can be used to support the development of clean technologies, improve energy efficiency, and promote the adoption of green alternatives.

If the environmental benefits of such an instrument are unquestionable in the long run, the costs it imposes on the economy should not be overlooked. In this study, we conduct this analysis using a partial equilibrium model based on Exiobase input-output tables for the year 2022. Within the Leontief cost-push framework, we examine the effects of a \$100/tCO_2e carbon tax. These include both macroeconomic effects, such as those on GDP and inflation, and microeconomic effects, which include social impacts and earnings shocks at the issuer level. A key aspect of our empirical model is the synthetic approach used to assess the pass-through mechanism. This parameter represents how cost shifts at the producer level manifest themselves in price dynamics for consumers or downstream markets. In addition, the tax design studied in this article is adapted to test different scenarios. Although a global tax system should be preferred as a first-best solution, country-based carbon taxes seem more likely. Therefore, our analysis includes the effects of a global tax applicable to all countries as well as individual regional taxes (*e.g.*, at the European, American, and Chinese levels).

Implementing a global carbon tax would imply a total cost of 5.01% of world GDP, but this would be partially offset by an increase in tax revenues of about 2.82% of world GDP, bringing the net cost of the tax to 2.18% of world GDP. From another perspective, we find that only 0.93% of the total tax cost is paid directly by producers, while the remaining 4.08% is borne by the downstream of the value chain, especially by final consumers. This suggests that only 20% of the carbon tax is actually paid by the emitter. In addition, the implementation of the tax leads to significant inflationary pressures, depending on the country. At the global level, a uniform carbon tax could increase inflation by 4.08% and 3.53%, respectively, depending on whether the tax is levied on producers or consumers. In regional tax scenarios, whether in Europe, China or the US, we confirm that the impact on growth and inflation is predominantly domestic. For example, more than 95% of the total cost of a EU carbon tax is borne by European members.

The results suggest a clear asymmetry between the liability and cost sharing of the actors involved in global warming. Indeed, the economies most negatively affected by the tax are typically emerging economies, while those least penalized are more developed economies. This argument holds at the microeconomic level, as the most carbon-intensive sectors benefit from the tax to the detriment of less carbon-intensive sectors. For example, energy and utilities issuers are among the biggest beneficiaries of the tax. Due to their dominant position in the global value chain, these large emitters have a strong influence on prices in downstream sectors, particularly in the consumer staples and consumer discretionary sectors.

These results dispel the illusion of an efficient instrument that no longer seems to adhere to the "*polluter pays*" logic, at least in the short run. This highlights the importance of considering whether a price-constraining instrument might be more adaptable in such circumstances than a quantity-regulating approach.

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A Mathematical results

A.1 Mathematical expression of the net cost $\mathcal{C}_{\text{net}}$

We have seen that the total cost to the economy is equal to:

$$\begin{aligned}
\mathcal{C}_{\text{total}} &= \sum_{j=1}^{n} T_{\text{total},j} \\
&= \mathbf{1}_n^\top \left(x \odot \left(I_n - \Phi + \tilde{\boldsymbol{\mathcal{L}}}(\boldsymbol{\phi}) \right) t_{\text{direct}} \right) \\
&= x^\top \left(I_n - \Phi + \tilde{\boldsymbol{\mathcal{L}}}(\boldsymbol{\phi}) \right) t_{\text{direct}}
\end{aligned}$$

Therefore, we get:

$$\mathcal{C}_{\text{total}} = \omega_{\text{total}}^\top \left(\boldsymbol{\tau} \odot \boldsymbol{\mathcal{CI}}_1 \right) \tag{12}$$

where $\boldsymbol{\tau}$ is the $n \times 1$ vector of carbon taxes, $\boldsymbol{\mathcal{CI}}_1$ is the $n \times 1$ vector of carbon intensities and ω_{total} is the $n \times 1$ vector defined by:

$$\omega_{\text{total}} = \left(I_n + \tilde{\boldsymbol{\mathcal{L}}}(\boldsymbol{\phi}) - \Phi \right)^\top x$$

However, the total cost includes the revenue from the carbon tax, which belongs to the government. It is better to consider the net cost, which is the difference between the total cost and the government revenue:

$$\mathcal{C}_{\text{net}} = \mathcal{C}_{\text{total}} - \mathcal{R}_{\text{government}} = \sum_{j=1}^{n} T_{\text{total},j} - \sum_{j=1}^{n} T_{\text{government},j} = \sum_{j=1}^{n} T_{\text{indirect},j}$$

We deduce that the net cost is equal to the indirect cost. We get:

$$\mathcal{C}_{\text{net}} = \omega_{\text{net}}^\top \left(\boldsymbol{\tau} \odot \boldsymbol{\mathcal{CI}}_1 \right) \tag{13}$$

where:

$$\omega_{\text{net}} = \omega_{\text{total}} - x = \left(\tilde{\boldsymbol{\mathcal{L}}}(\boldsymbol{\phi}) - \Phi \right)^\top x$$

A.2 Nonnegative property of ω_{net}

Using the properties of Neumann series (Roncalli, 2024), we deduce that:

$$\begin{aligned}
\tilde{\boldsymbol{\mathcal{L}}}(\boldsymbol{\phi}) - \Phi &= \left(I_n - A^\top \Phi \right)^{-1} \Phi \\
&= \sum_{k=0}^{\infty} \left(A^\top \Phi \right)^k \Phi - \Phi \\
&= \sum_{k=1}^{\infty} \left(A^\top \Phi \right)^k \Phi
\end{aligned}$$

By construction, A and Φ are two nonnegative and stochastic matrices. Using the properties of NN matrices (Desnos *et al.*, 2023; Roncalli, 2024), we conclude that:

$$\tilde{\boldsymbol{\mathcal{L}}}(\boldsymbol{\phi}) - \Phi \succ \mathbf{0}_{n,n}$$

We also assume that $x \succ \mathbf{0}_n$. So we get that ω_{net} is a vector with positive values:

$$\omega_{\text{net}} \succ \mathbf{0}_n$$

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