Carbon footprint and responsiveness trade-offs in supply chain network design

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Outline

- Supply Chain Responsiveness : Introduction, Limitations, Model
- Carbon Footprint, Benefits of Minimizing Carbon Footprint
- Integrating Carbon Minimization Policies and Supply Chain Responsiveness and Case Study
- Numerical Analysis
- Supply Chain Carbon Footprint Cap
- MCFC: market carbon footprint cap
- SCCFT: supply chain carbon footprint tax

Supply Chain Responsiveness: Introduction

Supply chain responsiveness refers to the ability of a supply chain to respond quickly and effectively to changes in demand, supply, or market conditions. It involves the ability to adapt to changing circumstances and to fulfill customer needs and expectations in a timely manner. A responsive supply chain can help a company to reduce lead times, improve customer satisfaction, and increase profitability.

Some key elements of a responsive supply chain include:

1. Agility: The ability to quickly respond to changes in demand or supply, such as by adjusting production schedules, changing shipping routes, or sourcing alternative materials.
2. Flexibility: The ability to adapt to changes in customer requirements or market conditions, such as by offering customized products, adjusting pricing strategies, or changing distribution channels.
3. Visibility: The ability to track and monitor inventory levels, shipments, and other key performance indicators in real-time, enabling quick decision-making and problem-solving.
4. Collaboration: The ability to work closely with suppliers, customers, and other stakeholders to share information and coordinate activities, such as by using collaborative planning and forecasting tools or joint inventory management systems.

Supply Chain Responsiveness : Benefits

1. Improved customer satisfaction: A responsive supply chain can ensure that products are delivered to customers quickly and efficiently, which can help to improve customer satisfaction. Customers are more likely to return to businesses that provide fast and reliable service.

2. Increased efficiency: A responsive supply chain can help businesses to optimize their inventory levels, reduce stockouts, and minimize waste. This can lead to cost savings and increased efficiency in operations.

3. Better risk management: A responsive supply chain can help businesses to identify and mitigate potential risks in the supply chain. For example, real-time monitoring and analytics can help businesses to identify supply chain disruptions and take proactive measures to avoid them.

4. Improved agility: A responsive supply chain can enable businesses to adapt quickly to changing customer demand and market conditions. This can help businesses to stay competitive and responsive to evolving trends in the market.

5. Enhanced collaboration: A responsive supply chain can facilitate collaboration and communication between suppliers, distributors, and customers. This can help to build strong relationships and foster trust between stakeholders in the supply chain.

Supply Chain Responsiveness : Limitations

1. Cost: Building a responsive supply chain can require significant investments in technology, infrastructure, and personnel. These costs can be a barrier to entry for smaller businesses, and may not be feasible for some organizations.

2. Complexity: A responsive supply chain can be more complex than a traditional supply chain, with multiple stakeholders, processes, and technologies involved. Managing this complexity can be challenging and may require significant resources and expertise.

3. Risk: A responsive supply chain can be more vulnerable to disruptions and risks, such as delays in delivery, quality issues, and supply chain failures. These risks can be mitigated through effective risk management strategies, but businesses should be prepared for potential disruptions.

4. Dependence on technology: A responsive supply chain relies heavily on technology, such as real-time monitoring, analytics, and communication tools. Dependence on technology can create vulnerabilities, such as system failures or cyberattacks, that can disrupt the supply chain.

5. Trade-offs: In some cases, achieving supply chain responsiveness may require trade-offs between speed, cost, and quality. For example, fast delivery may come at a higher cost, or high-quality products may take longer to produce. Businesses must weigh these trade-offs carefully to achieve the right balance for their needs.

Carbon Footprint

Carbon footprint refers to the amount of greenhouse gases, particularly carbon dioxide, that are released into the atmosphere due to human activities such as burning fossil fuels, deforestation, and transportation. It is a measure of the impact that human activities have on the environment in terms of climate change.

The term "carbon footprint" is used to describe the total amount of carbon dioxide and other greenhouse gases that are emitted as a result of an individual, organization, or activity. It is usually measured in tons of carbon dioxide equivalents (CO_2e), which takes into account the impact of other greenhouse gases such as methane and nitrous oxide.

Carbon Minimization Policies : Benefits

1. Cost savings: Companies can save money by reducing their energy consumption and implementing sustainable practices. This can include using renewable energy sources, optimizing transportation, and reducing waste. By doing so, they can reduce their operational costs and increase their profitability.
2. Reputation and brand image: Consumers are becoming increasingly aware of the environmental impact of companies, and many are choosing to support those that are committed to sustainability. By minimizing their carbon footprint, companies can improve their reputation and brand image, which can lead to increased customer loyalty and sales.
3. Compliance with regulations: Many governments are introducing regulations to limit carbon emissions and promote sustainable practices. By minimizing their carbon footprint, companies can ensure compliance with these regulations and avoid potential penalties or fines.
4. Innovation and competitiveness: Companies that are committed to sustainability are often more innovative and competitive. By implementing sustainable practices, they can develop new products and services that meet the growing demand for environmentally friendly options, which can lead to increased market share and revenue.
5. Contribution to a more sustainable future: Ultimately, minimizing carbon footprint is essential for addressing the global climate crisis and creating a more sustainable future. By taking action to reduce their impact on the environment, companies can make a significant contribution to this goal and help ensure a better world for future generations.

Integrating Carbon Minimization Policies And Supply Chain Responsiveness

1. Adopt sustainable transportation: Businesses can switch to more sustainable modes of transportation, such as electric or hybrid vehicles, or use more fuel-efficient vehicles for transportation. This can help to reduce carbon emissions while maintaining supply chain responsiveness.

2. Optimize logistics and warehousing: By optimizing logistics, businesses can minimize transportation distances, reduce the number of trips, and consolidate shipments. This can help to reduce carbon emissions and transportation costs while improving supply chain responsiveness.

3. Implement real-time tracking and monitoring: Real-time tracking and monitoring of shipments can help businesses to identify potential supply chain disruptions and take proactive measures to avoid them. This can help to maintain supply chain responsiveness while reducing the risk of disruptions that can lead to increased carbon emissions.

4. Foster collaboration with suppliers: Collaboration with suppliers can help businesses to identify opportunities for reducing carbon emissions and developing sustainable supply chain practices. This can help to reduce the carbon footprint of the entire supply chain while maintaining responsiveness.

5. Adopt sustainable packaging: Sustainable packaging can help to reduce the carbon footprint of the supply chain. Businesses can use recycled materials, design for easy recycling, and reduce packaging waste to achieve this.

Case Study : Tata Steel

Supply chain responsiveness:

Tata Steel has a global supply chain that spans multiple countries and regions. The company uses a variety of strategies to ensure that its supply chain is responsive to customer demand and market conditions. For example, Tata Steel uses advanced analytics and real-time monitoring to optimize inventory levels and identify potential supply chain disruptions. The company also has a network of suppliers and distributors to ensure that products are delivered quickly and efficiently to its customers.

In addition, Tata Steel has adopted several initiatives to improve its supply chain responsiveness. For example, it has implemented a digital platform called "myTATAsteel" that allows customers to place orders, track shipments, and access product information in real-time. The company has also launched an "e-procurement" portal that allows suppliers to bid for contracts and submit invoices online.

Tata Steel has set ambitious targets to reduce its carbon footprint and transition to a low-carbon economy. The company has adopted a range of initiatives to achieve these targets, including:

1. Energy efficiency: Tata Steel has implemented several initiatives to improve energy efficiency in its operations, such as installing energy-efficient equipment, optimizing processes, and using renewable energy sources. The company has set a target to reduce its specific energy consumption by 3% year-on-year.
2. Carbon capture and storage: Tata Steel is exploring the use of carbon capture and storage (CCS) technologies to capture carbon emissions from its steel-making processes and store them underground. The company has collaborated with several research institutes and universities to develop and test these technologies.
3. Circular economy: Tata Steel has adopted a circular economy approach to reduce its carbon footprint. The company has launched several initiatives to recycle and reuse waste materials from its operations, such as slag and fly ash. This approach helps to reduce the amount of waste generated by the company and minimize its carbon emissions.

Responsiveness Tradeoffs

- A responsive supply chain is essentially an optimization problem as stated below :
- Assumptions -demand in markets is stationary and stochastic, with mean demand rate λ_m

1. Constraint (1)- denoting cost function -total supply chain costs per unit of time .
2. Constraint (2) - ensuring that each market is assigned to one and only one facility and transport mode.
3. Constraint (3) -relates variables Z_f and Y_{mft}.

$$\min_{Y_{mft}, Z_f} \sum_{m,f,t} unitcost^C_{mft} \lambda_m Y_{mft} + \sum_f c^F_f Z_f$$

$$\text{s.t.} \quad \sum_{f,t} Y_{mft} = 1 \quad \forall m$$

$$M^{big} Z_f \geq \sum_{m,t} Y_{mft} \quad \forall f$$

The binary decision variable (Indices)

Y_{mft} -Assign one facility f and one transport mode t to each market m.

Z_f-indicates whether facility f is used for manufacturing or not.

λ_m-mean demand rate.

(cF f)-fixed charges of running facilities

C_{mft} - It is unit cost decomposed into Inventory cost and porcurement cost .

Q_{mft} -The order quantity .

R_{mft} - the reorder point

f τ mftðxÞ (density) -The demand over lead time distribution functions

Fτ mftðxÞ - cumulative demand over lead time

N_{mft} - denotes the average number of shortages per ordering cycle.

τ_{mft}- supply chain lead time for each market .

K_{mft} - Ordering costs

Total Variable cost for supplying one unit

- The total variable cost for supplying one unit, $unitcost^{C}_{mft}$, can be decomposed into inventory cost and procurement cost.
- Inventory costs (holding costs in markets' warehouses and in transit, as well as ordering and shortage costs.
- procurement costs (raw materials, manufacturing including labour and transport).

$$\boxed{\begin{aligned} unitcost^{C}_{mft} = {} & warehousing^{C}_{mft} + in\_transit^{C}_{mft} + ordering^{C}_{mft} + shortage^{C}_{mft} \\ & + raw\_materials^{C}_{f} + manufacturing^{C}_{f} + transport^{C}_{mft} \qquad (4) \end{aligned}}$$

Inventory Costs

- The order quantity Q_{mft} and the reorder point R_{mft} are computed as follows and use these values as inputs in our cost function for possible market–facility–transport combination
- Assumption that demands occurring when the system is out of stock are backordered.
- The demand over lead time distribution functions are denoted f τ mftðxÞ (density) and Fτ mftðxÞ (cumulative) while nmft denotes the average number of shortages per ordering cycle.
- The supply chain lead time is deterministic and depends on manufacturing lead time at a facility (τf), distance between the facility and market locations (dmf) and transport mode speed $(\dot{\tau}_t)$:

τmft = $\tau_f + d_{mf}\dot{\tau}_t.$

$$Q_{mft} = \sqrt{\frac{2\lambda_m(K_{mft} + \pi_m n_{mft})}{h_m}} \quad \forall m, f, t$$

$$\frac{Q_{mft} h_m}{\pi_m \lambda_m} = 1 - F^{\tau}_{mft}(R_{mft}) \quad \forall m, f, t$$

$$n_{mft} = \int_{R_{mft}}^{\infty} (x - R_{mft}) f^{\tau}_{mft}(x)\, dx \quad \forall m, f, t$$

Inventory cost

- Warehousing costs depend on the warehousing cost per unit (hm).
- In-transit costs are proportional to the in-transit carrying cost per unit of product per period (rm) and to the supply chain lead time (τmft).
- Ordering costs (Kmft) cover the administrative costs of ordering one shipment including border-crossing costs.
- Shortage costs are caused by unfulfilled market demand, leading to a penalty cost (πm).

$$h_m = h_m^0 + h_m^e p_m^e.$$

Warehousing costs is distinguish into energy and non energy component which will later allow us to include a carbon tax on energy prices.

$$warehousing_{mft}^C = \frac{h_m}{\lambda_m}\left(\frac{Q_{mft}}{2} + R_{mft} - \lambda_m \tau_{mft}\right) \quad \forall m, f, t$$

$$in\_transit_{mft}^C = r_m \tau_{mft} \quad \forall m, f, t$$

$$ordering_{mft}^C = \frac{K_{mft}}{Q_{mft}} \quad \forall m, f, t$$

$$shortage_{mft}^C = \frac{\pi_m n_{mft}}{Q_{mft}} \quad \forall m, f, t$$

Procurement cost

- we capture three types of costs that is raw material, manufacturing and transport costs.
- Raw material costs include all processes upstream of facilities. The non-energy cost (c r f) and the energy intensity (c re f) of sourcing raw materials (or components) from suppliers
- Manufacturing costs decomposed into labour costs facilities (cf l), as geographical wage differences have played an increasing role in industry location and proportional to energy consumption (cf e) different levels of access to energy resources across regions affect energy prices (pe f)
- Transport costs are proportional to product weight (w) and distance travelled between facilities and markets (dmf).which determine non-energy transport prices **(C_0 t)** and energy intensity **(C_ e t).**

$$raw\_materials_f^C = c_f^r + c_f^{re} p_f^e \quad \forall f$$

$$manufacturing_f^C = c_f^l + c_f^e p_f^e \quad \forall f$$

$$transport_{mft}^C = (\dot{c}_t^0 + \dot{c}_t^e p_t^e)\, w\, d_{mf} \quad \forall m, f, t$$

Emissions from different sources

- Raw materials emissions (ε_r): These are the emissions associated with the production and transportation of the raw materials used in a product. These emissions can include those from mining, harvesting, or extraction of the materials typically calculated on a per unit weight.

- Manufacturing emissions (ε_f): These are the emissions associated with the production process at the manufacturing facility. These emissions can include those from energy use, such as electricity or natural gas production calculated on the basis of per unit production.

- Warehouse emissions (ε_h): These are the emissions associated with storing and managing inventory at a warehouse. They are proportional to inventory level calculated on a per unit weight.

- Transport emissions (ε_t): These are the emissions associated with the transportation of products from the manufacturing facility to the end customer. These emissions can include those from energy use for transportation,such as fuel consumption in trucks or planes, as well as those from the production of the transportation vehicles

Integrating Carbon Footprint Tradeoffs

- Product carbon footprint (PCF) is basically total amount of green house gas emissions produced during the lifecycle of the product .
- Raw materials' emissions (εr f) include emissions from processes upstream of facilities in the supply chain,
- Manufacturing emissions (εf) focus on the facility. Emissions at warehouses (εh m) are proportional to inventory levels
- Transport emissions (ε_ t) are proportional to product weight and distance. Hence, we get the following emission terms

$$warehousing^{\varepsilon}_{mft} = \frac{\varepsilon^h_m}{\lambda_m}\left(\frac{Q_{mft}}{2} + R_{mft} - \lambda_m \tau_{mft}\right) \quad \forall m, f, t$$

$$raw\_materials^{\varepsilon}_f = \varepsilon^r_f \quad \forall f$$

$$manufacturing^{\varepsilon}_f = \varepsilon_f \quad \forall f$$

$$transport^{\varepsilon}_{mft} = \dot{\varepsilon}_t \, w \, d_{mf} \quad \forall m, f, t$$

$$PCF_m(Y_{mft}) = \sum_f \sum_t \left(raw\_materials^{\varepsilon}_f + warehousing^{\varepsilon}_{mft} + manufacturing^{\varepsilon}_f + transport^{\varepsilon}_{mft} \right) Y_{mft}$$

SCCFC: supply chain carbon footprint cap

- A cap, called supply chain carbon footprint cap (SCCFC), is imposed on the sum of all carbon footprints for all units of product sold in all markets .
- The goal of SCCFC is to reduce the negative impact of supply chains on the environment and mitigate the effects of climate change.
- The most cost-effective reductions can be achieved, as it is possible to balance emissions caused by different markets compensation of emissions across markets is no longer possible.

$$\boxed{\sum_m \lambda_m PCF_m(Y_{mft}) \le SCCFC}$$

MCFC: market carbon footprint cap

- A cap, called the market carbon footprint cap (MCFC), is imposed on the sum of carbon footprints for all units of product sold in a particular market.

SCCFC

- More constraining markets
- Each market's emissions are not constrained: the cap is set at the global supply chain level.

MCFC

- Markets may source from various channels but each market has to satisfy a given cap.

$$\lambda_m PCF_m(Y_{mft}) \leq MCFC_m \quad \forall m$$

SCCFT: supply chain carbon footprint tax

- The supply chain carbon footprint tax (SCCFT) case, which consists of imposing a common tax for all emissions in the whole supply chain.
- We explicitly take energy consumption costs into account . To account for the taxes, the energy prices at facilities for transport and in markets (pe f , pe t and pe m) are modified to adjusted prices (p~ e f , p~ e t and p~ e m), by adding a supplementary term
- we multiply the taxes on carbon emissions (pε f , pε t and pε m, in €/kgCO2) by conversion factors relating carbon emissions and energy consumption (eε f , eε t and eε m in kgCO2/kg fuel) to get this additional term.

$$\boxed{\tilde{p}_f^e = p_f^e + e_f^\varepsilon p_f^\varepsilon \quad \forall f;}$$

$$\boxed{\tilde{p}_t^e = p_f^e + e_t^\varepsilon p_t^\varepsilon \quad \forall t;}$$

$$\boxed{\tilde{p}_m^e = p_m^e + e_m^\varepsilon p_m^\varepsilon \quad \forall m}$$

Modified adjusted prices

Numerical Analysis

Description of Setting

- Creating two stylised supply chains from the apparel sector.
- Innovative product is latest trend top and functional product is plain white t shirt.
- Cost of goods sold higher for innovative product.
- Holding costs include opportunity and obsolescence costs.
- Penalty costs are set to be equal to profit margins.
- Demand for innovative product and demand over lead time follow log normal distribution.
- A hypothetical global firm with markets located in western regions is used for illustration.
- The geographical setting, the distances, the 50 market locations and the 50 potential facility locations are illustrated in Fig. 1 given on the right.

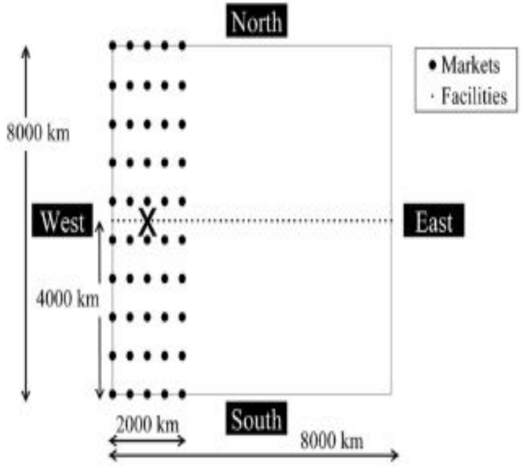


Fig. 1. Geographical locations of markets (large dots) and potential facilities (small dots).

Description of Setting Contd.

- East–west wage differences are modelled by assuming that labour unit costs progressively decrease with facility longitudes from 1.5 €/unit in the most western facility location to 0.5 €/unit in the most eastern one.
- Manufacturing energy intensity, by contrast, increases from west to east, from 0.2 to 0.4 kg of fuel per unit.
- Four transport modes are considered. From slowest to fastest, from cheapest to most expensive, and from least to most polluting, they are sea, rail, road and air transport. Classic average speeds per mode of 25, 45, 60 and 250 km/h are used.
- Transport emission factors (ε_t) from Defra (2010) are used.
- For raw material and manufacturing emissions, fuel-based approaches to estimating greenhouse gas emissions are well established (IPCC, 2006).
- Fuel oil is the sole energy source and its emission factor is 3.7655 kgCO2/kg fuel to convert from energy to emissions and vice versa.
- The price of fuel oil is set at 1.5 €/kg.

Numerical Analysis : Base Case

Innovative Product

- Latest Trend Top
- Uncertain demand ($CV_m = 1.5$)
- A large profit margin (40%)
- Low competition
- Cost of goods sold = €4.5
- Selling price = €7.5
- Holding costs = 50%
- Penalty Costs = €3

Functional Product

- Plain white t shirt
- Relatively certain demand ($CV_m = 0.2$).
- Small profit margin (5%)
- High competition.
- Cost of goods sold = €4
- Selling price = €4.21
- Holding costs = 20%
- Penalty Costs = €0.21

Numerical Analysis : Base Case

- Appling our model for both functional and innovative products, considering only costs but no carbon policy is our Base Case.
- It is more costly to run a supply chain for an innovative product than for a functional product
- The main reason is the high degree of supply chain responsiveness required by the innovative product

Effects of a supply chain carbon footprint cap (SCCFC)

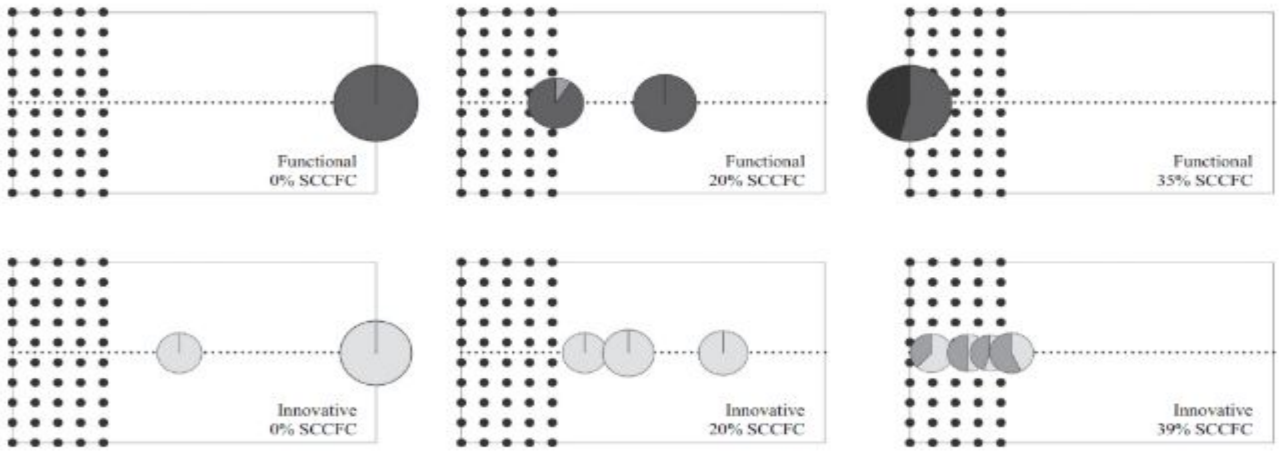
Table 2
Summary of metrics for both product types.

	Functional			Innovative		
	Base case	−20%	−35%	Base case	−20%	−39%
SC carbon footprint (tCO_2)	11.6	9.3	7.5	15.3	12.2	9.3
Total costs (k€)	18.2	+9%	+17%	21	+0.5%	+5%
Lead time[a] (days)	33	−35%	−16%	6	−20%	+24%
Distance[a] (km)	7445	−55%	−65%	6227	−39%	−63%
Stock cover[a] (days)	15	−11%	−5%	28	−15%	+18%
Type II service level[a] (%)	95	+2%	+1%	96	+1%	−1%
Sea freight (%)			46%			
Rail freight (%)	100%	98%	54%			
Road freight (%)		2%				35%
Air freight (%)				100%	100%	65%

[a] Average metrics across all markets.

- SCCFC policy limits the overall emissions necessary to supply all markets

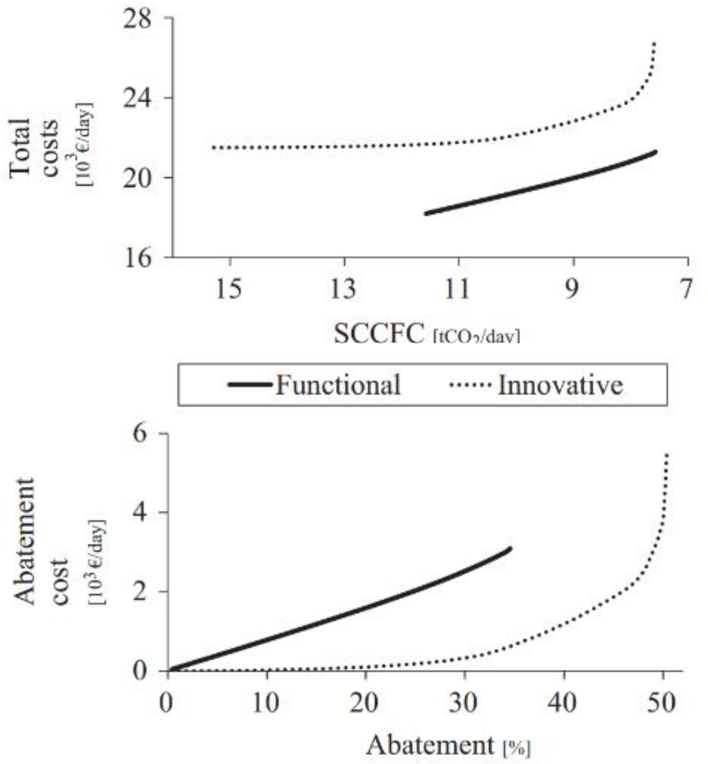
Facility Location and SCCFC Strictness Correlation



- In the base case most of the facilities are in the east and uses fastest mode of transportation for the innovative products and slowest for the functional products.
- When we started applying the emission caps then facilities started moving closer to market and transportation mode started shifting towards a slower mode.

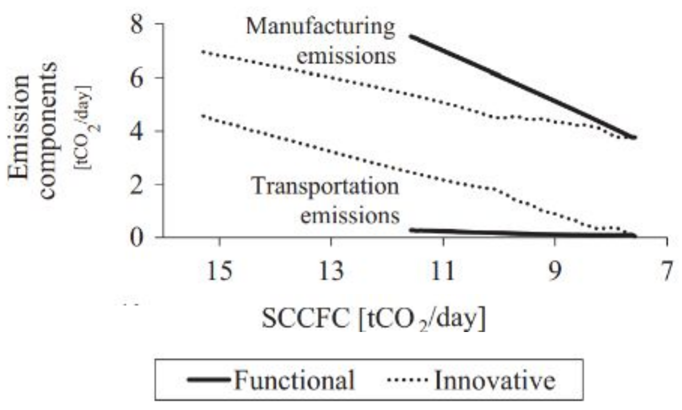
Effects of a supply chain carbon footprint cap (SCCFC)

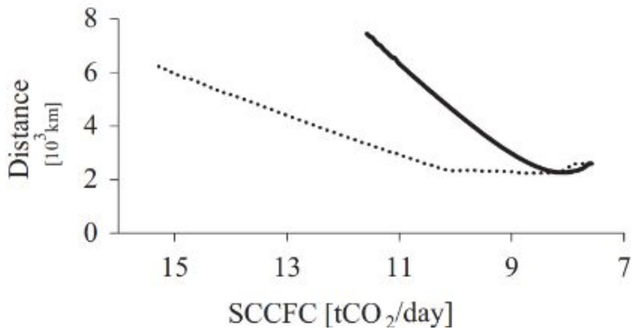
1. Effect on total costs and potential for supply chain carbon



- We observe that for a range of caps (down to 11.6 tCO2/day), the chain supplying the functional product is unaffected as the base case is already less polluting.
- For both product types, the most stringent feasible cap is around 7.6 tCO2/day.
- For the innovative product an emission reduction target of up to 50% is feasible, whereas for the functional product, only a 35% reduction can be achieved.
- For a wide range of emission reductions, equivalent carbon abatement (in percent) is cheaper for the innovative product than for the functional product.

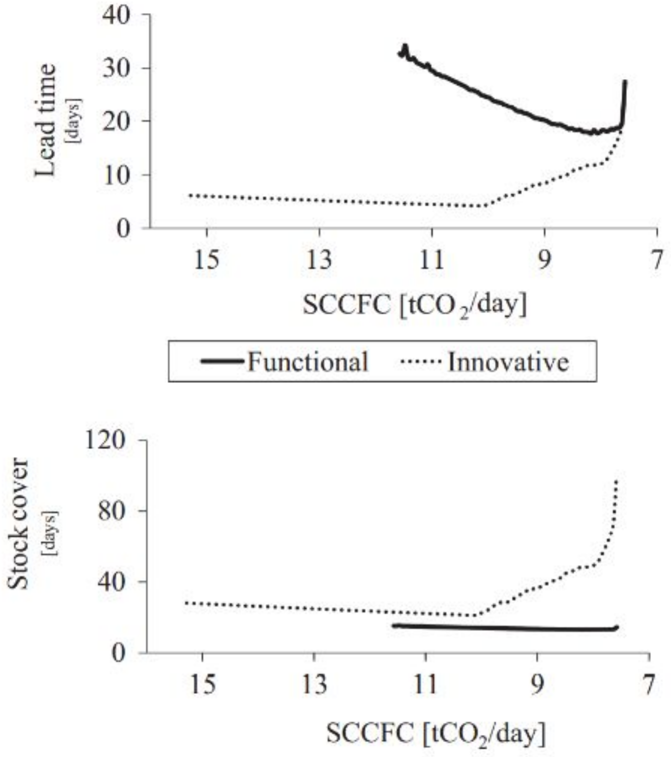
2. Effects of SCCFC on the supply chain network





- The magnitude of emissions from different processes varies considerably by product type.
- For the functional product, manufacturing emissions are clearly dominant, as slow and less polluting transport modes are used for all caps.
- For the innovative product, manufacturing and transport emissions have comparable magnitudes in the base case and then progressively converge to similar values as for the functional product
- For both products manufacturing is progressively shifted to locations closer to the target markets, this occurs at different rates.
- For the functional product, the slope of the distance curve is more significant. This is due to the dominance of manufacturing emissions for this product.

2. Effects of SCCFC on the supply chain network



- For the functional product, lead time decreases progressively for most feasible emission caps – with reductions of up to 15 days.
- Lead time curve of innovative product changes slope over time due to changes in transport mix, starting with 100% air freight and gradually adding road, rail and sea freight as caps become stricter.
- The different degrees of demand uncertainty result in stock covers that are lower for the functional product than for the innovative one.
- Since shorter lead times imply lower uncertainty of demand over lead time, we observe that stock covers evolve in close relation to lead times.
- Service levels are initially higher for the innovative product, but this is inverted once it becomes too costly to hold larger inventories to compensate for longer lead times.

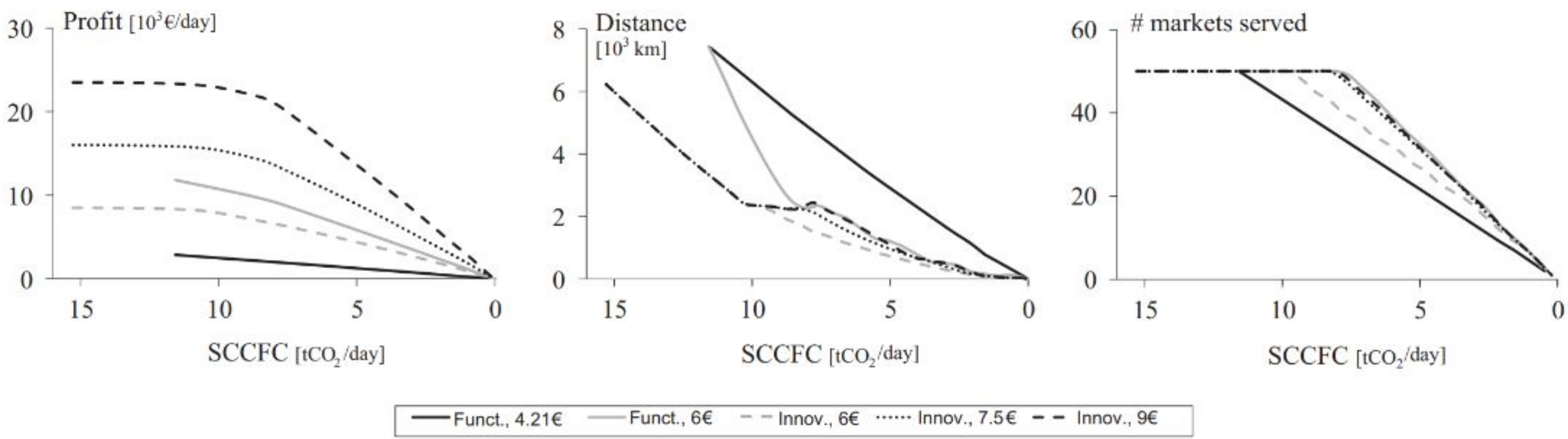
3. Profit maximisation and market selection

- In previous model we were minimizing total costs while serving all markets and complying with a carbon footprint policy.
- However, as emission policies increase costs, some markets may become unprofitable, and, therefore, the company may decide to exit them.
- To consider this case, we reformulate our model to a profit maximization problem, where the company is allowed to exit any market.

$$\max_{Y_{mft}, Z_f} \sum_{m,f,t} (sellingprice_m - unitcost^C_{mft}) \lambda_m Y_{mft} - \sum_f c^F_f Z_f$$

$$\text{s.t.} \quad \sum_{f,t} Y_{mft} \leq 1 \quad \forall m$$

3. Profit maximisation and market selection



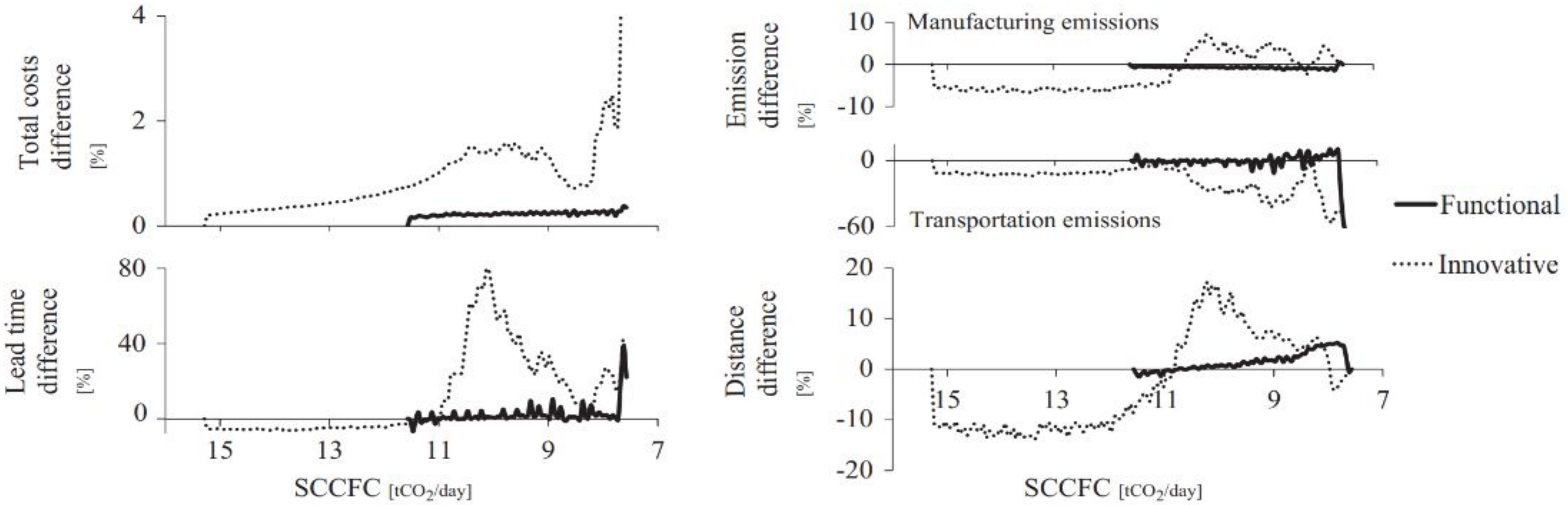
- In the base case, all 50 markets are served for all the products. When SCCFC becomes more stringent, company starts exiting some markets because they become unprofitable.
- The cap at which markets are exited depends on each product (profit margin).
- The average distance drops as the most distant markets are exited first, and profits further decrease as less markets are served. Ultimately, the zero emission SCCFC can be attained theoretically, with zero markets being served.

4. Market vs. supply chain carbon footprint cap

- MCFC policy is more constraining than SCCFC policy, as compensation of emissions across different markets is not allowed.
- In the base model (without carbon policy), we observe that the variability or dispersion of carbon footprints across all markets is more for innovative products than functional ones.
- This suggests that MCFC policy will have significant implications on innovative products compared to functional ones.
- To compare both policies, we are imposing the same total supply chain carbon abatement cap.

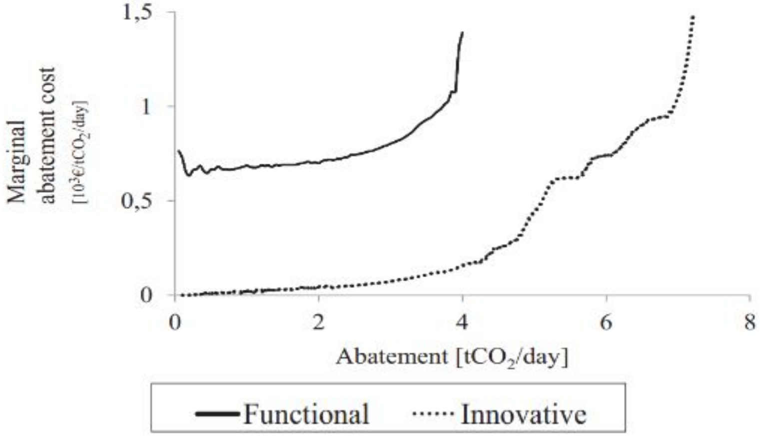
$$\sum_{m} MCFC_m = SCCFC$$

4. Market vs. supply chain carbon footprint cap



- All curves for the functional product oscillate around zero, whereas for the innovative product there are larger differences between the two policies.
- Lead time and distance differences become important for innovative products.
- The total cost is higher for innovative products, but the difference is relatively small.
- MCFC and SSCFC policies will cost the same for both products, but there will be significant network design implications for the innovative products.

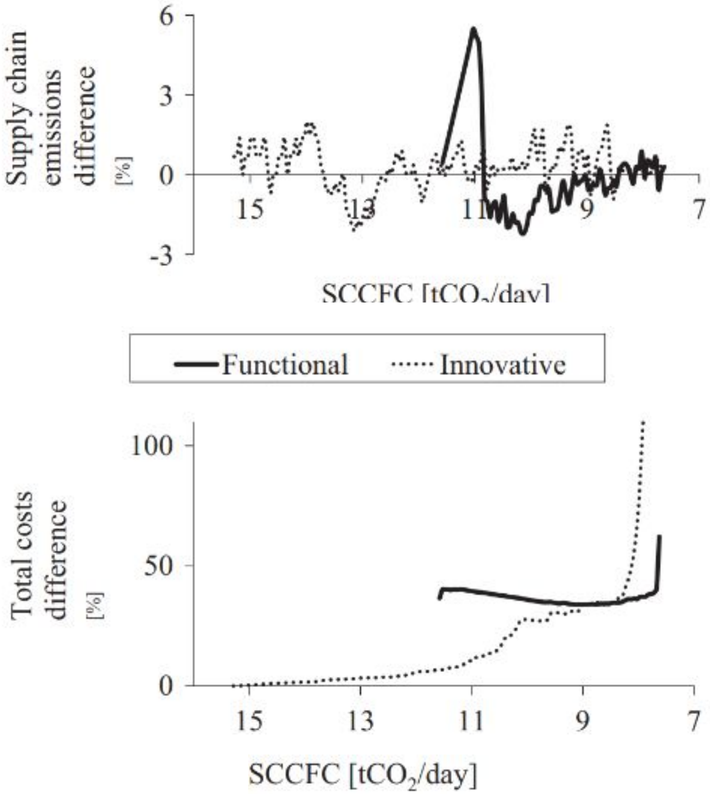
5. Supply chain carbon footprint cap and tax equivalence



- The marginal abatement cost (MAC) curve links a firm's emission level and the cost of additional units of pollution reduction, i.e., it is the change in abatement cost per unit change in abatement.
- If a tax is set equal to a firm's MAC curve for a level of abatement & firm tries to minimize its costs, the tax will induce the firm to achieve that level of abatement, which could otherwise be achieved by imposing a cap

- However, for levels of abatement with higher MAC than the tax, it will be cheaper for the company to pay the tax than to abate further.
- Using SCCFC model, we can derive the levels of supply chain carbon footprint tax (SCCFT) that should a priori induce a desired level of carbon abatement, and the marginal abatement cost (MAC) curves give us an indication on these levels for a given company with a given context.
- Supply chain carbon tax has a selective effect on product types.

5. Supply chain carbon footprint cap and tax equivalence



- Percentage difference in supply chain emissions between SCCFT and SCCFC is relatively low for most levels of abatement.
- Total supply chain costs are considerably higher in SCCFT compared to SCCFC policy.
- In the case of a tax set to reach the same level of abatement, the company will pay these same costs plus the tax for the remaining carbon it will still be emitting.
- The network design remains relatively similar for both SCCFC & SCCFT policies.

Conclusion

- Product's characteristics, and the degree of innovativeness in particular, strongly affects the supply chain network design, the cost and potential for carbon abatement, as well as the levers used to decrease emissions.
- Analyses with increasingly stringent supply chain carbon footprint caps (SCCFC) revealed non-monotonic evolutions of transport mixes, lead times, distances and stock covers, which confirms the need of using mathematical models.
- MCFC becomes relatively more constraining than an SCCFC as the dispersion in the carbon footprints of products sold across markets increases. Moreover, we observe that meeting an MCFC is not much more expensive but can have an important impact on the network design.
- Comparable levels of abatement can be achieved with both SCCFC and SCCFT policies. Although the optimal network design for these two policies remains similar, total costs are higher when there is a tax on supply chain carbon emissions rather than a cap.

Thank You