The Evolution of Shippers Batch Size Decisions : a Micro-econometric Analysis over Three Decades

El-Mehdi Aboulkacem, François Combes, Martin Koning, Univ Gustave Eiffel, IFSTTAR

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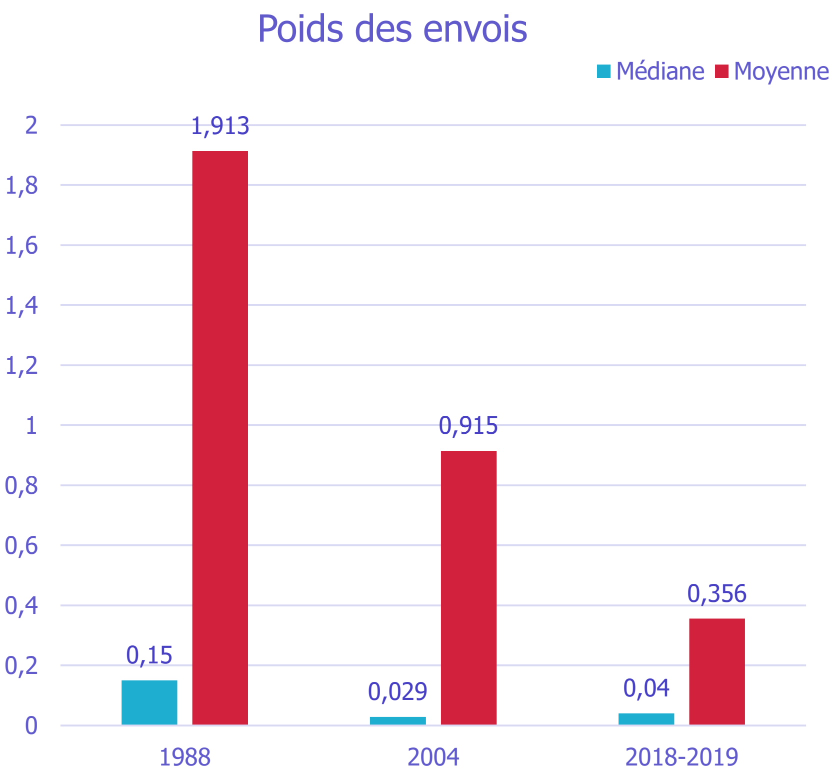
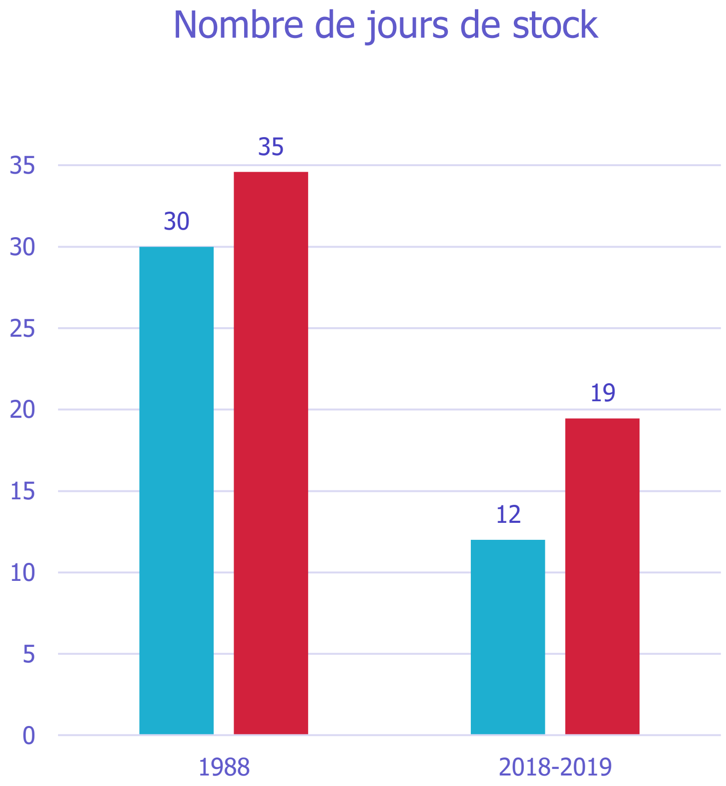
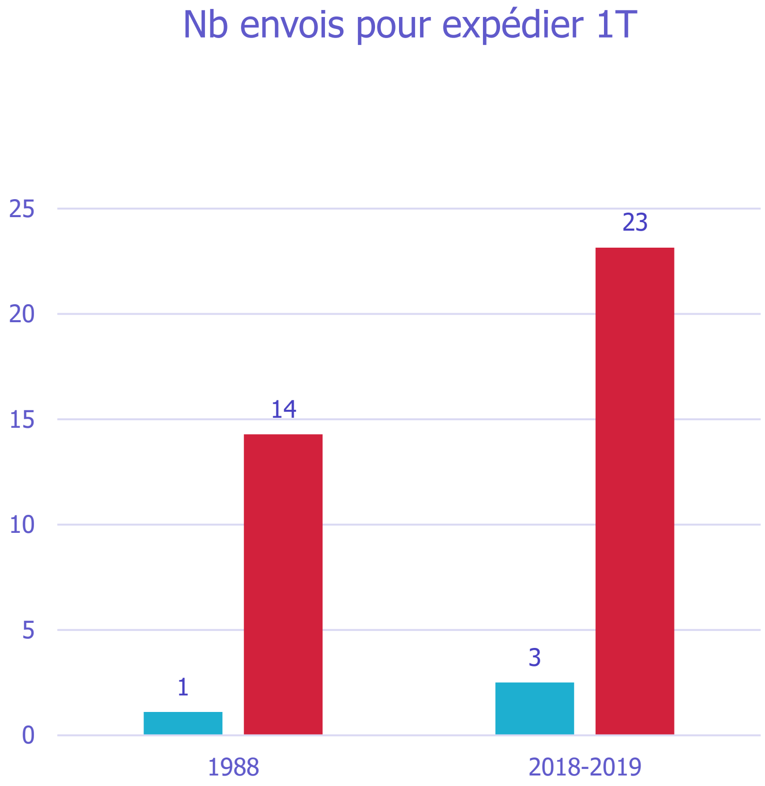
Université
Gustave Eiffel

3 Stylized facts







- Quantitative illustration of a deep-rooted trend
  - **Very well known among logisticians and researchers**
  - **Not very well documented and measured**

Context

- The stylized facts feed the numerous environmental issues related to freight and logistics : GHG emissions – soil artificialisation – noise pollution etc…
- Research mainly focuses on transport and neglects warehousing
- Figures showing the weight of warehousing in GHG
  - **WEF 2009 : warehousing is responsible of 13% of logistics related GHG**
  - **British Department of Energy and Climate Change 2013 : Warehouses related GHG are equivalent to 27% of the GHG emanating from heavy trucks**
- Public policies : the standards imposed on trucks are well known, whereas the regulations on warehouses' energy consumption are recent, fuzzy, and hard to apply
- A holistic view needs to be adopted. **Otherwise** :
  - **Fragmentary understanding of the mechanisms underlying the supply and demand for transport and logistics services**
  - **Recommending regulations and public policies targeting one dimension of the problem at a time**
  - **=> Positive impact on the target components but adverse elsewhere**

Inventory size Vs Shipment frequency

- Transport and warehousing are strongly connected
- “Inventory size Vs transport operations frequency” is an important trade-off firms face
- Bigger inventories means higher inventory costs but fewer transport operations and lower transport costs; whereas smaller inventories lead to the opposite
- The optimal shipment size is a central output of this trade-off
- Investigating its determinants is key for identifying effective levers for acting on goods transport vehicles flows and on warehousing practices

Temporal and geographical parameters : important but neglected

- Baumol and Vinod (1970) – Economic Order Quantity Model : firms optimal shipment size decisions result from a complex trade-off which determinants are : **shipment costs, shipment time, warehousing cost, and capital costs**

- The cost items for producing transport, warehousing, and capital costs evolve according to the economic context, the geographical and regulatory constraints, and the technological developments

=> The demands for transport and logistics services are very likely to evolve structurally over time
=> Durable changes in vehicles flows and logistical practices
=> Harmful consequences on society in terms of ecology and life quality

But

- **No papers exploring the evolution of firms shipment size decisions over time**
- **The impacts of geography and environmental regulations are almost never discussed**

Objective

Fill the existing gap

- Two strands of analysis : analytical and empirical

Analytical framework

Analytical Framework

- Extension of EOQ model by Baumol and Vinod (1970) with **two important features:**

1. Transport production process considered in detailed way so that the important production cost items such as energy, the driver and the vehicle are explicitly considered

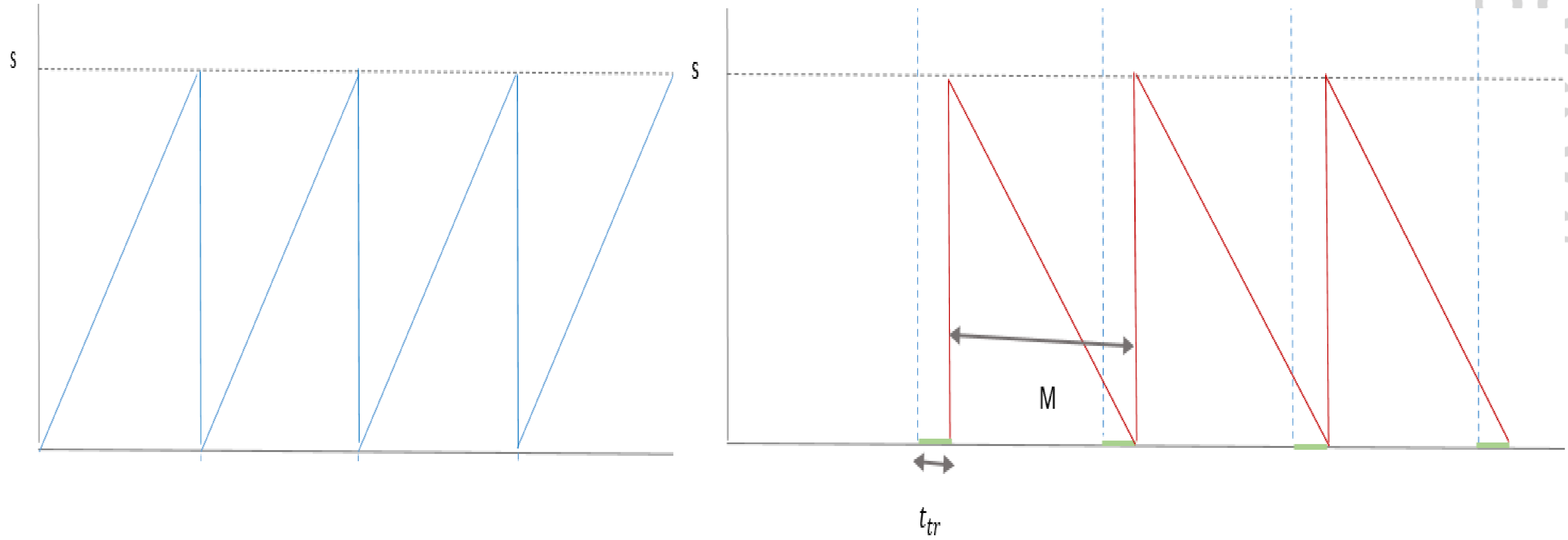
2. Warehousing costs formulated with a level of detail allowing to consider the costs depending on storage duration, warehouses locations etc…

⇒ The model emphasizes the roles played by the cost items evolving over time

=>Considering warehouses locations allows to take account of several geographical parameters and constraints as these are reflected in storage prices

Analytical framework

- We consider a shipper sending annually Q tons from area A to area B via regular shipments of constant size
  - **Area A warehouse fills up at a steady rate** q_{or}
  - **When inventory reaches a level s the goods are sent to B**
  - **There, merchandise is stored and the goods are picked at a steady rate** $\boldsymbol{q} = q_{dest} = q_{or}$



- This logistical process requires human, material and financial resources
  => Total Logistical Cost (TLC) that shippers seek to minimize

The annual TLC depends on the shipments' size s
  => Optimal s needs to be determined

TLC = Inventory costs + Transport costs

TLC in the literature

$$C_n(q_n) = \frac{Q_n}{q_n}F_n + Q_n c_n(q_n) + \frac{q_n}{2}(w_n + rv_n)$$

The individual components of the TLC are given by:

- Q_n: Constant and continuous flow of goods regarding individual n per period (ton/year).
- q_n: Shipment size per transport of individual n to satisfy the total demand Q_n (ton/shipment).
- F_n: Fixed costs per shipment for individual n independent of the shipment size q_n (€/shipment).
- $c_n(q_n)$: Variable transport costs for individual n dependent on the shipment size q_n (€/ton).
- w_n: Warehousing costs per unit of commodity per year for individual n (€/ton).
- r: Interest rate valuing the bounded capital in form of inventory holding costs
- v_n: Value density of the transported commodities (€/ton)

Inventory cost

Inventory costs can be grouped into 3 categories

1. Cost that depends on time but not on the quantity of goods stored : purchasing or renting storage space, taxes, insurances, security, etc... Noted f_x

2. A handling cost entailed each time goods are received or picked for expedition etc... Noted h_x

3. Cost that depends on time and on the quantity of goods stored : capital cost including opportunity cost, goods depreciation, etc... Noted ξ

Annual Inventory Cost :

$$C_{inv} = (f_{or} + f_{dest} + \xi\mu)\frac{Q}{q}s + (h_{or} + h_{dest})Q$$

Transport costs

- Only shipments transported by road are considered
  - **Data shows that the large majority of transport operations are operated by road**
  - **Even if the main transport mode used is rail, freighter or airplane, the goods make a significant part of their journey on the road**

Transport cost

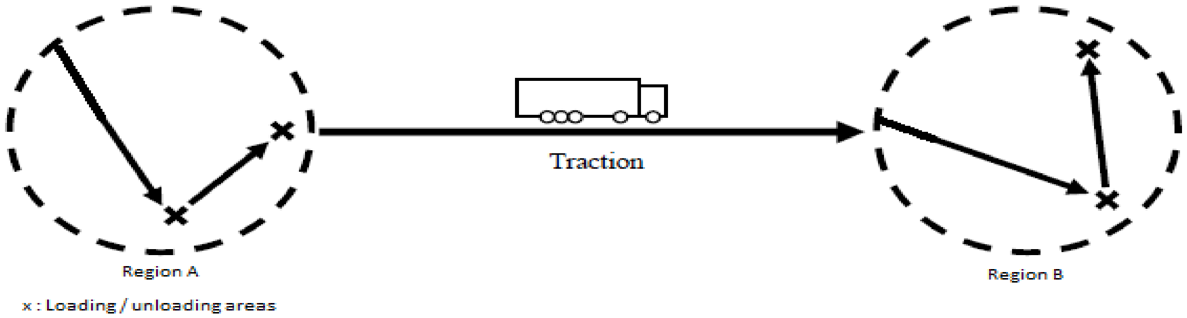
- Transport operation :
  - **Traction along highway of length D where the trucks average speed is v**
  - **Approach movement is operated to reach loading and unloading zones. The approach distance is d_a and the approach speed is v_a**
  - **loading and unloading duration is t_l**

- Transport operation cost items can be grouped into two categories :

1. Costs depending on distance such as fuel, maintenance, tolls etc... Noted c_d
2. Costs depending duration such as driver's related costs etc… Noted c_h

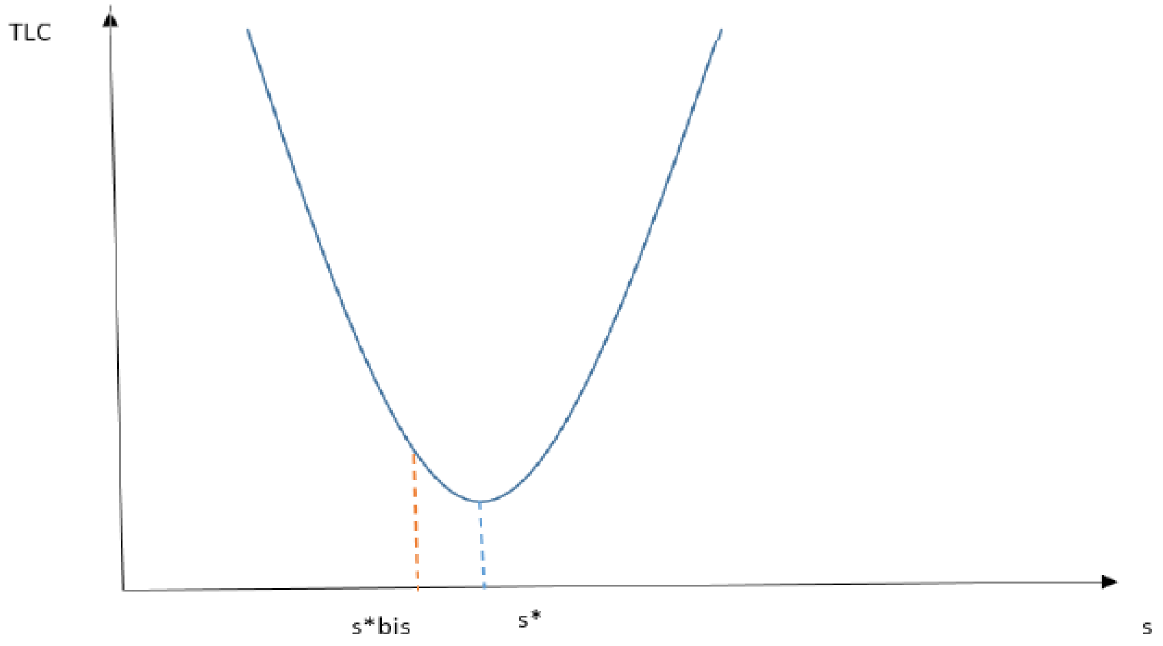
A transport operation Cost :

$$C_{tr} = 2d_a\left(c_d + \frac{c_h}{v_a}\right) + 2c_h t_l + \frac{c_d + \frac{c_h}{v}}{K} sD + \left(c_d + \frac{c_h}{v}\right)\zeta D$$



Optimal shipment size

$$s^* = \sqrt{\frac{\left(2d_a\left(c_d + \frac{c_h}{v_a}\right) + 2c_h t_l + \left(c_d + \frac{c_h}{v}\right)\zeta D\right)Q}{(f_{or} + f_{dest} + \xi\mu)}}$$



Optimal shipment size

$$s^* = \sqrt{\frac{\left(2d_a\left(c_d + \frac{c_h}{v_a}\right) + 2c_h t_l + \left(c_d + \frac{c_h}{v}\right)\zeta D\right)Q}{(f_{or} + f_{dest} + \xi\mu)}}$$

- This equation gives an overview of the **impact of economic parameters, geographic constraints and public policies on shippers decisions regarding transport and warehousing demand**, and on the **overall flow of transport vehicles and warehousing needs**

Numerical example

- Consider two shippers sending two different types of goods, from the same origin to the same destination.
  - **Shipper 1 : computer devises worth one million Euros per ton**
  - **Shipper 2: fruits and vegetables worth 2000 Euros per ton**
  - **Both shippers send : 10 million euros of goods : Shipper 1 = 10 T - Shipper 2 = 5000 tons**

	Shipper 1 : Computer devices	Shipper 2 : fruits and vegetables
Distance D	300 km[19]	
Average speed in highway : v	70km/h	
Approach distance : d_a	10 km[20]	
Approach speed : v_a	25 km/h	
Cost per unit of distance : c_d	0.51 €/km (Fuel : 0.43€/km)	
Cost per unit of time : c_h	30 €/h (Driver : 22€/h)	
Empty run rate : ζ	0.23	
(un)Loading duration : t_l	1h	3h
Storage space cost : f_{or} and f_{dest}	0.12 €/h	0.06 €/h
depreciation rate ξ_1	0.005 %/h	0.2 %/h
Capital opportunity cost ξ_2	0.002 %/h (10% per year)	

- By considering reasonable assumptions
  Shipper 1 : $s_1 = 0.06\,Tons$ and $N_1 = 179\,shipments$ => 18 shipments per ton
  Shipper 2 : $s_2 = 6\,Tons$ and $N_1 = 827\,shipments$ => 0.17 shipment per tons

Examples of cost item impacts

Cost items changes	Shipper 1 : Computer devices		Shipper 2 : fruits and vegetables	
	ds	dN	ds	dN
50% increase in energy cost	+ 6%	-6%	+4%	-4%
50% decrease in energy cost	-6%	+7%	-5%	+5%
50% increase in driver cost	+12%	-11%	+13%	-12%
50% decrease in driver cost	-14%	+16%	-16%	+18%
Doubling storage cost	0%	0%	-1.5%	+1.5%
Eliminating storage cost	+0.01%	-0.01%	+1.5%	-1.5%
Multiplying storage cost by 10	-2%	+2	-11%	+13%
50% increase in distance D and 80% decrease in storage costs	+10%	-9%	+9%	-8%
Doubling the capital cost	-12%	+13%	-0.5%	+0.5%
Eliminating capital cost	+18%	-15%	+0.5%	-0.5%
50% increase in approach distance	+5%	-5%	+4%	-4%
50% decrease in approach distance	-5.5%	+6%	-4%	+4%

Examples of cost item impacts

50% Decrease of energy related costs :

- Enhancement of vehicle energy efficiency
- Use of renewable energies
- Global economic shock
- Decrease of taxes on energy

=> Shipper 1 : ds = -6% - dN = +7% => + 13 shipments per year
=> Shipper 2 : ds = -6% - dN = +7% => + 58 shipments per year

Multiplying storage costs by 10 :

- Competition for land
- Storage space scarcity
- Enhancement of warehouses energy efficiency related measures

=> Shipper 1 : ds = -2% - dN = +2% => + 4 shipments a year
=> Shipper 2 : ds = -11% - dN = +13% => + 108 shipments a year

Conclusions from the analytical model

- Carrying out public policies impacting shippers’ shipment size decisions, and by construction the flows of goods transport vehicles and warehouses sizes is a difficult balancing act.

- Public authorities cannot act directly on D and Q.
- Public authorities can act on transport, storage and capital related costs, directly or indirectly.

- But acting on transport related costs impacts also storage needs and demand and vice versa
- Environmentally oriented measures may have counter-intuitive consequences

Empirical Exercise

Objectives

- Assess the validity of EOQ model over a long period
- See if the shippers changed their behavior over time
- Explore the reasons
- Quantify the evolution of the determinants impact all the other thinks being equal

Empirical work

- A series of shipment size models with a temporal dimension are estimated

- 3 sets of data collected from French shippers
  - **Surveys conducted in 1988, 2004-2005, and 2016-2019 => Unique data in terms of temporality**
  - **Informs about the shippers characteristics - their latest shipments' weights and values - the distance between the sender and the recipient - the way the merchandise is conditioned - transport constraints – whether transport is operated by the shipper himself or by an external carrier**
  - **Informs about and most importantly, the annual sender-recipient commodity flow**

- Data on shippers is matched with data giving information on **population densities** of the departure and arrival cities at **the period shipments are operated**

Base line model

$$s^* = \sqrt{\frac{\left(2d_a\left(c_d+\frac{c_h}{v_a}\right)+2c_h t_l+\left(c_d+\frac{c_h}{v}\right)\zeta D\right)Q}{(f_{or}+f_{dest}+\xi\mu)}} \Leftrightarrow lns = cste + \frac{1}{2}lnQ + \frac{1}{2}lnD' + \frac{1}{2}ln(f_{or} + f_{dest} + \xi\mu)$$

Where $cste = \frac{1}{2}\ln[2d_a\left(c_d + \frac{c_h}{v_a}\right) + 2c_h t_l]$

- Problem : inventory costs are not available in the data

⇒ Suitable proxies are needed

- In the literature : inventory costs are proxied by the goods value density

- Problem : value density = good proxy for capital opportunity cost not for warehousing costs

⇒ The existing models are present biased estimators

Solution :
Warehousing costs are proxied here by population densities

Base line model

The regressed model :

$$ln(s) = \delta_1 \ln(departure\ city\ pop\ density) + \delta_2 ln(destination\ city\ pop\ density) \\ cste + \alpha_q lnQ + \alpha_v \ln(Value\ density) + +\alpha_D D \\ +\alpha_x X + \ \varepsilon$$

X : vector containing information on conditioning constraints, transport constraints, whether the shipment is single or grouped, and whether it is carried out by the shipper itself or by an external carrier

Regression results

	Estimator
Intercept	2.16246 (***)
Log(Annual Tonnage to recipient)	0.43413 (***)
Log(Value Density)	-0,44498 (***)
Log(Pop density - sender municipality)	-0.04974 (***)
Log(Pop density - recipent municipality)	-0.03496 (***)
Distance	0.00079501(***)
Constraints	
Fragile	-0.18650 (***)
Dangerous product	0.26599 (***)
Refrigeration	-0.60104 (***)
Volumunous	0.43615 (***)
Conditionning	
Bluk	-0.09747 (*)
Container	-0.12944 (.)
Other	-0.79097 (***)
Palette	Ref
Single shipment	0.39642 (***)
Transport by shipper	0.18968 (***)
R^2	0.7198
Adjusted R^2	0.7192
N	6065

The results are consistent with theory and expectations

- The estimator related to Q is close to ½
- The order of magnitude of the estimator related to the distance is as expected
- The estimators related to value density is close to -1/2
- The estimators related to population densities are negative and very significant :
- The sum of the estimators related to value density and population densities is lower than -1/2

Significance and negativity of population densities estimators = original and important finding

- It corroborates the idea that the difficulty of holding inventory for shippers increases with population density because of
  - **Higher land costs**
  - **Less availability of storage space**
  - **More severe access constraints for vehicles of large capacity,**
  - **The preference of local public decision-makers to allocate the available space to the residential and tertiary sectors to the detriment of storage spaces.**

=> Including departure and arrival population density in the model allows to better proxy the overall capital

Models with temporal dimension

1. We add to the baseline model two dummies indicating whether the shipment was send in the second (2004 - 2005) or in the third (2016 - 2019) period

2. We add to baseline model period dummies and cross-dummy variables obtained by multiplying the commodity rate, value density, distance, and population densities by periods dummies

Recall that $cste = \frac{1}{2}\ln\left[2d_a\left(c_d + \frac{c_h}{v_a}\right) + 2c_h t_l\right]$ => Cste increases with c_d and c_h

$\Rightarrow$ If controlling for the impact of the evolution of inventory cost, period dummies estimators catch the impact of transport cost items evolution

$\Rightarrow$ If not, they catch the sum of the impacts

Models with temporal dimension

	Estimator	Estimator
Intercept	2.64483(***)	1.61812 (***)
Period 2 (P_2)	-0.62216 (***)	0.50779 (*)
Period 3 (P_3)	-0.19167 (***)	1.88055 (***)
Log(Annual Tonnage to recipient)	0.43806 (***)	0.48115(***)
P_2* Log(Annual Tonnage to recipient)		-0.04093(**)
P_3* Log(Annual Tonnage to recipient)		-0.12187 (***)
Log(Value Density)	-0.45577 (***)	-0.40410 (***)
P_2*Log(Value Density)		-0.04900 (**)
P_3*Log(Value Density)		-0.11341 (***)
Log(Pop density - sender municipality)	-0.03383 (***)	0.00293 (.)
P_2*Log(Pop density - sender municipality)		-0.06342 (*)
P_3*Log(Pop density - sender municipality)		-0.03924 (.)
Log(Pop density - recipent municipality)	-0.03341 (***)	-0.00950(.)
P_2*(Pop density - recipent municipality)		-0.01609 (.)
P_3* (Pop density - recipent municipality)		-0.07032 (**)
Distance	0.00076338(***)	0.00122(***)
P_2* Distance		-0.00053105 (***)
P_3 * Distance		-0.00078689 (***)
Constraints		
Dangerous product	0.29151 (***)	0.28251 (***)
Refrigeration	-0.49966(***)	-0.50408 (***)
Voluminous	0.50978(***)	0.51132 (***)
Conditionning		
Bluk	-0.09713(**)	-0.09699 (*)
Container	-0.21214(**)	-0.24857 (**)
Other	-0.93502 (***)	-0.93496 (***)
Palette	Ref	Ref
Single Shipement	0.37348 (***)	0.36021 (***)
Own account	0.08347 (**)	0.09857 (***)
R^2	0.7297	0.7323
Adjusted R^2	0.7292	0.7312
N	6065	6065

Conclusion

The paper contributes to the literature in three dimensions

1. It provides an analytical extension of the EOQ model where the important cost items related to transport and inventory are detailed, and the impact of the some major constraints such as storage and vehicles capacities are discussed

2. The empirical results show that the shippers' behavior change from a period to another, and which of the two conflicting mechanisms determining firms' shipment size have had the most impact

3. The temporal evolution of the shippers behavior shown by the empirical results assess the need to conduct surveys on shippers batch on more regular basis. Indeed, their behavior evolve over time, and using old dataset for analysis, setting public policy or modeling demand for freight may lead to inappropriate results and recommendations

Thank you