Navigating the Waves of Global Shipping: Drivers and Aggregate Implications

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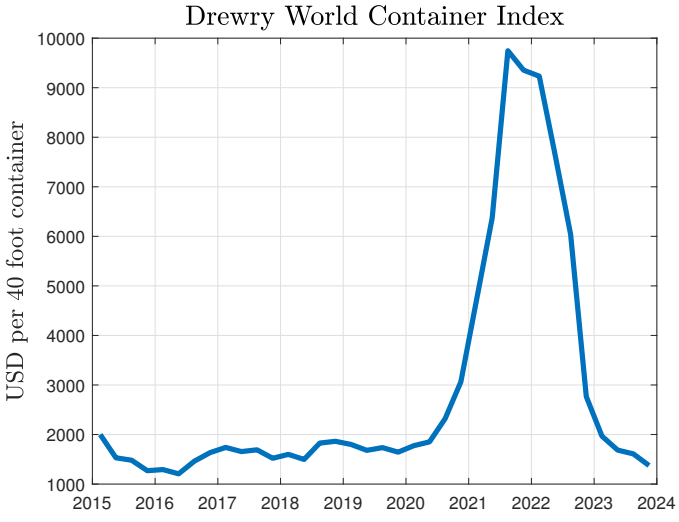
Shipping Price Dynamics



$\Rightarrow$ Unprecedented spike of shipping costs!

Questions:

1. What accounts for these unprecedented dynamics?
2. What are the implications?

Shipping Price Dynamics (cont.)

Standard models typically abstract from shipping market dynamics...

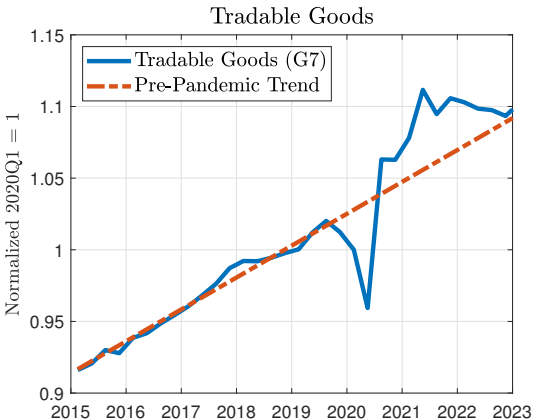
- Trade models with agg. dynamics: Shipping subject to iceberg costs, but perfectly elastic shipping supply
- Models with market for shipping services typically abstract from aggregate dynamics

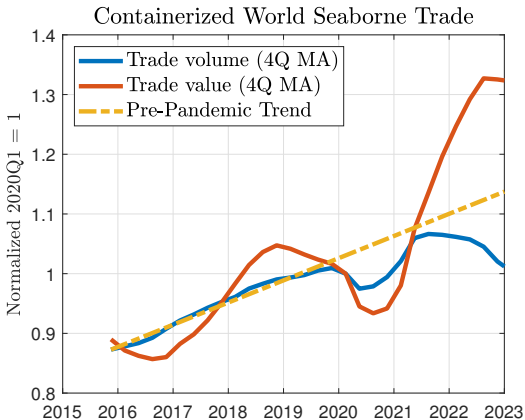
This paper:

1. Novel evidence on the determinants of shipping costs and the dynamics of international shipping supply
2. Study drivers and aggregate implications of shipping dynamics using quantitative model

Let's start by taking a look at indicators of shipping demand and supply...

Shipping Demand and Supply





- Demand for tradable goods above trend since mid-2020: ⇑ Demand for shipping services
- Yet, real volumes shipped below trend since the start of COVID-19: ⇓ Supply of shipping services

  ⇒ Higher shipping costs

This Paper

Questions:

1. What accounts for the unprecedented dynamics of international shipping costs?
2. To what extent have these dynamics affected aggregate outcomes?

How we answer these questions:

- Document salient features of international shipping dynamics
- Set up multi-country model of trade with market for shipping services consistent with salient features
- Quantify sources of unprecedented increase of international shipping costs
- Investigate aggregate implications: Contrast vs. standard model without market for shipping services

Shipping Price Dynamics During Normal Times

⇒ But international shipping costs also very volatile during "normal" times

We then ask:

1. Can our model account for these?
2. Implications for aggregate dynamics?

Salient Features of Shipping Dynamics

Data and Approach

We begin by documenting salient features of shipping dynamics. . .

Goals:

- Identify potentially critical ingredients to model
- Characterize key moments of the data to discipline quantification

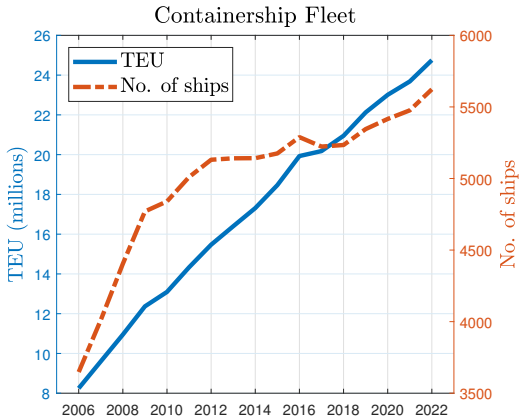
Data:

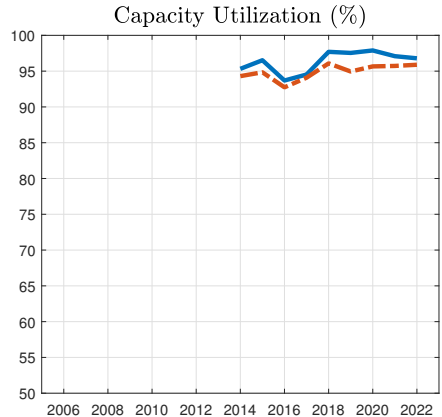
- Focus on containership trade
- Shipping costs from Drewry + Shipping supply from Clarkson's *Shipping Intelligence Network*

How we look at it:

1. Shipping supply
2. Interaction with shipping demand and prices
3. Shipping investment

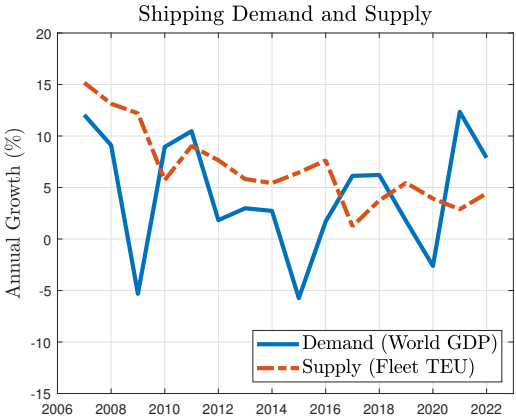
Shipping Supply





- Shipping supply: Significant and steady growth of world containership fleet/capacity
- Shipping utilization: High and steady capacity utilization

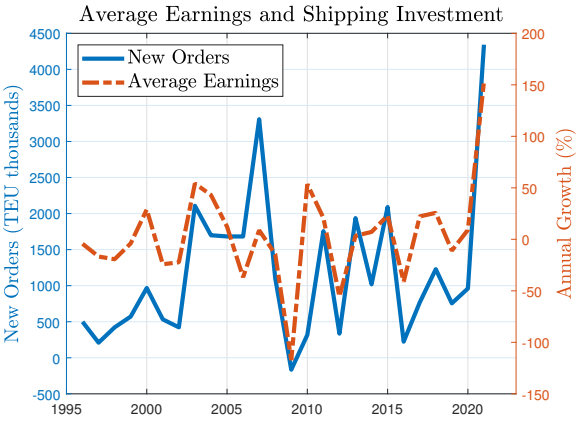
Shipping Demand, Shipping Supply, and Prices

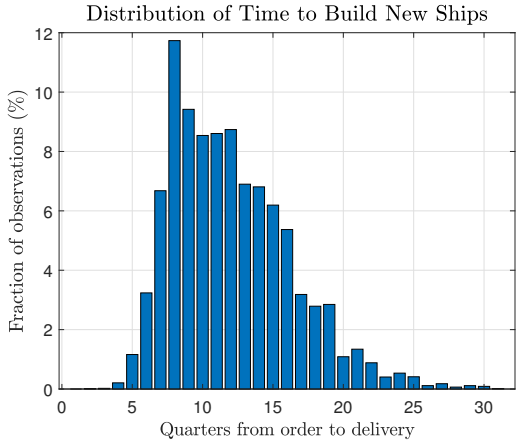


- Shipping demand more volatile than shipping supply
- Excess demand for shipping highly correlated with shipping prices

$\Rightarrow$ Inelastic demand for shipping + rigid short-run shipping supply, key factor in response of shipping costs?

Higher Prices ⇒ Higher Investment ⇒ Higher Capacity, Eventually





- When prices are higher and earnings increase ⇒ Higher orders for new ships
- But supply takes time to adjust: Producing new ships takes 2–4 years on average!

Discussion: From Data to Model

Key takaways:

1. Excess demand is highly correlated with shipping prices

   $\Rightarrow$ Modeling market for shipping services as critical for shipping prices

2. Shipping supply typically operates at capacity

   $\Rightarrow$ Model: Limited potential to adjust supply along intensive margin, need to build new ships

3. Shipping capacity responds sluggishly to fluctuations in shipping costs

   $\Rightarrow$ Model: Shipping investments take time + Adjustment costs

Model

Model: Setup

- Two countries: Home, foreign $\Rightarrow$ Symmetric countries, focus presentation on home
- Commodity space:
  - In each country, two types of domestic varieties: tradable, non-tradable
  - In each country, intermediate input bundle between domestic and foreign tradable varieties
  - In each country, consumption-capital bundle of domestic and foreign tradable varieties + domestic non-tradable
- International trade:
  - Goods: Tradable varieties
  - Financial assets: 1-period bond
- Shipping technology:
  - Shipping varieties across countries requires hiring shipping services
  - Shipping services are supplied by a **global shipping firm**

Model: Households

Preferences

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \frac{\left[c_t^{\mu}(1-n_t)^{1-\mu}\right]^{1-\gamma}}{1-\gamma}$$

Income

- Unit endowment of time, allocated between leisure and work n_t
- Own producers of domestic varieties + domestic bundles
- Own fraction ψ of the global shipping firm

Consumption-savings: Two savings technologies

- Financial: 1-period risk free bond subject to quadratic bond-holding costs
- Physical: Productive capital subject to quadratic investment costs

Model: Household's Problem

$$\max \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \frac{\left[c_t^{\mu}(1-n_t)^{1-\mu}\right]^{1-\gamma}}{1-\gamma}$$

subject to

$$p_t c_t + p_t i_t + \frac{p_t b_{t+1}}{1+r_t} + p_t \frac{\Phi_b}{2}\left(b_{t+1} - \overline{b}\right)^2 = w_t n_t + r_{Kt} k_t + p_t b_t + \Pi_t + \psi\Theta_t \quad \forall t = 0, ...\infty$$

$$k_{t+1} + \frac{\Phi_k}{2}\left(i_t - \delta\overline{k}\right)^2 = (1-\delta)k_t + i_t \quad \forall t = 0, ...\infty$$

k_0 and b_0 given

Model: Tradable and Non-Tradable Varieties

Tradable varieties

- Produced with capital, labor, and intermediate inputs: $y_{Tt} = z_t a_T \left(k_{Tt}^{\theta} n_{Tt}^{1-\theta}\right)^{\varphi} m_{Tt}^{1-\varphi}$
- Sold domestically and internationally under perfect competition
- Used for consumption, investment, and intermediate input

Non-tradable varieties

- Produced with labor: $y_{Nt} = z_t a_N n_{Nt}$
- Sold domestically under perfect competition
- Used for consumption and investment

Model: Global Shipping Firm

- Start of period t, firm owns shipping capacity g_t
- Each unit of shipping capacity allows the firm to:
  - Ship a unit of the home tradable variety to the foreign country
  - Or to ship a unit of the foreign tradable variety to the home country

    $\Rightarrow$ Shipments depart and arrive in the same time period
- Global shipping firm sells global shipping services to importers of tradable varieties
  - Importers need to pay shipping cost h_t per unit of tradable variety purchased internationally
  - Perfect competition, shipping cost h_t ensures demand $=$ supply of shipping services

Model: Global Shipping Firm Investment and Problem

- Global shipping firm accumulates shipping capacity endogenously
  - Scaling up shipping capacity is time-intensive: Investment i_{gt} in t, shipping capacity increases by $a_g i_{gt}$ in $t + \ell$
  - Investments in shipping capacity are also subject to quadratic investment costs
  - Composition of investments and adj. costs: ψ from home, $1 - \psi$ from foreign
  - Discounting λ_t, proportional to ownership shares

Firm's problem:

$$\max \mathbb{E}_0 \sum_{t=0}^{\infty} \lambda_t \left\{ h_t g_t - \left[p_t \psi + (1-\psi) p_t^*\right] i_{gt} - \left[p_t \psi + (1-\psi) p_t^*\right] \frac{\Phi_g}{2} \left(i_{gt} - \frac{\delta_g}{a_g} \overline{g} \right)^2 \right\}$$

subject to

$$g_{t+1} = (1 - \delta_g) g_t + a_g i_{gt-\ell+1}$$

$$g_{t+1} \geq 0$$

g_0 given

Model: Aggregation of Varieties into Final and Intermediate Bundles

Intermediate input bundle:

$$m_t = \left[\zeta {m_t^h}^{\frac{\mu-1}{\mu}} + (1-\zeta) {m_t^f}^{\frac{\mu-1}{\mu}} \right]^{\frac{\mu}{\mu-1}}$$

Consumption-capital bundle:

$$y_{Tt} = \left[{y_{Tt}^h}^{\frac{\rho-1}{\rho}} + {y_{Tt}^f}^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}}$$

$$y_t = \left[\chi {y_{Tt}}^{\frac{\eta-1}{\eta}} + (1-\chi) {y_{Nt}}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}$$

To import one unit of foreign variety m_t^f or y_{Tt}^f, need to pay:

- h_t in shipping costs
- τ in iceberg costs

Model: Equilibrium

A **competitive equilibrium** of the world economy consists of:

- Prices, wages
- Allocations

such that the following hold in each country:

- Solve problem of each of the agents
- Clear domestic markets: Labor, varieties, intermediate input bundle, consumption-capital bundle

and such that:

- **Solve problem of global shipping firm**
- **Clear global shipping market:** $y_{Tt}^{f} + m_{t}^{f} + y_{Tt}^{h*} + m_{t}^{h*} = g_{t}$

How Shipping Supply Affects Imports, Shipping Costs, and Aggregate Outcomes

How Shipping Supply Affects Imports, Shipping Costs, and Aggregate Outcomes

Let's take a look at the total demand for imports...

$$\text{Imports}_t = \underbrace{\left(\frac{\tau p^f_{Tt} + h_t}{p_{Tt}}\right)^{-\rho} y_{Tt}}_{\text{Consumption-capital}} + \underbrace{\left(\frac{\tau p^f_{mt} + h_t}{p_{mt}}\right)^{-\mu} m_t}_{\text{Intermediate inputs}}$$

Consider an increase in the demand for tradables, y_{Tt}:

- Shipping capacity fixed in short-run $\Rightarrow$ **Demand for imports $>$ Shipping capacity**
- **Shipping costs increase** to make imports demand consistent with shipping capacity
- Remark #1: If $\rho > \mu$, share of intermediates in total imports increases
- Remark #2: Imports of intermediates increase less than under flexible shipping supply $\Rightarrow$ Impact on output
- Remark #3: Shipping price response is decreasing in the level of shipping costs

How Shipping Costs Affect Investments in Shipping Capacity

Euler equation:

$$\underbrace{\mathbb{E}_t\left\{\frac{\beta\lambda_{t+1}}{\lambda_t}\left[p_{t+1}\psi+(1-\psi)p^*_{t+1}\right](1-\delta_q)\right\}}_{\text{Undepreciated value of shipping capacity}}+\underbrace{\mathbb{E}_t\left[\frac{\beta^\ell\lambda_{t+\ell}}{\lambda_t}\left(A_q h_{t+\ell}\right)\right]}_{\text{Returns from selling shipping services}}=\underbrace{p_t\psi+(1-\psi)p^*_t}_{\text{Investment cost}}$$

An increase of international shipping costs $h_{t+\ell}$ in ℓ periods...

- Increases the returns to investing in shipping capacity today

But transitory shocks today with limited effect on shipping costs ℓ periods from now...

- Have no impact on investments in shipping capacity today
- Thus, shipping investments respond to shocks today only if sufficiently persistent

Quantitative Analysis

Shipping Disruptions in the Aftermath of COVID-19

Quantification

Questions:

1. What accounts for the unprecedented dynamics of international shipping costs?
2. To what extent have these dynamics affected aggregate outcomes?

Experiment:

- Economy is in steady-state before pandemic hits
- Unexpected transitory shocks
- Perfect foresight

Parametrization approach:

- One period = One quarter
- Symmetric countries estimated to match U.S. data
  1. Predetermined parameters
  2. Parameters chosen to match moments prior to COVID-19
  3. Shocks + Parameters chosen to match dynamics following shocks

Quantification: Predetermined Parameters

Parameter	Value	Description
β	0.99	Discount factor
$1/\gamma$	0.5	Intertemporal elasticity of substitution
μ	0.34	Consumption share in household utility
δ	0.025	Capital depreciation rate
ρ	1.50	Consumption-capital bundle: Trade elasticity
ν	1	Intermediate input bundle: Trade elasticity
η	1	Elasticity between tradable and non-tradable goods
δ_g	0.029	Shipping capacity depreciation rate
ℓ	6	Shipping production lag
χ	0.31	Share of tradables in final goods
θ	0.36	Capital share in gross output of tradables
φ	0.577	Share of intermediates in gross output of tradables
a_N	1	Productivity of non-tradable goods
a_T	1	Productivity of tradable varieties
ψ	0.50	Share of shipping firm owned by home country
Φ_b	0	Bond-holding cost

Quantification: Parameters Estimated to Pre-Shock Steady-State

Trade costs:

Parameter	Value	Description
τ	6.02	Iceberg trade cost
ζ	0.31	CES weight on domestic intermediates
a_g	0.11	Shipping investment productivity

Moment	Data	Model
Tradables: Imports / Absorption	0.146	0.146
Intermediates: Imports / Absorption	0.263	0.263
Shipping costs / Imports	0.043	0.043

$\Rightarrow$ Shipping costs estimated from CIF/FOB for US containership freight (US Census 2019)

Shocks and Targets

Model post-pandemic dynamics as driven by 2 shocks:

1. Demand for tradables: Weight of tradable goods in consumption-capital
2. Shipping supply: Share of shipping capacity that can be used

   [Source: Global seaborne trade from Clarkson's + Voyage times from Flexport]

Remarks:

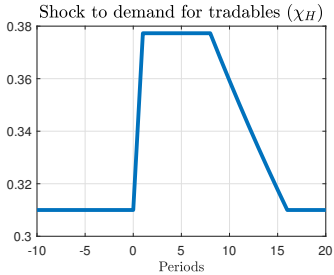
- One value per shock, duration = 2 years — revert back to steady-state gradually over 2 years
- Target empirical dynamics from 2020Q3 onwards relative to pre-2020 trend

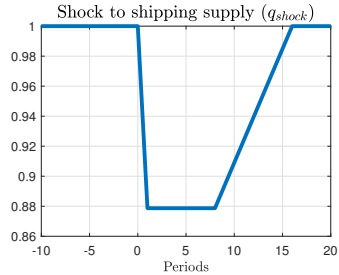
Quantification: Parameters Estimated to Dynamics Following Shocks

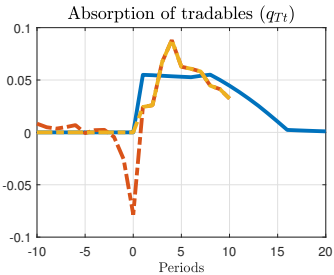
Parameter	Value	Description
ε_χ	0.20	Global shock to demand for tradables
ε_q	-0.12	Global shock to shipping supply
ϕ_k	37.44	Capital adjustment cost
ϕ	699.66	Shipping adjustment cost

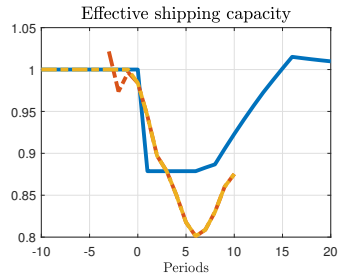
Moment	Target value	Model
Real tradable GDP, avg. log-change 2020Q3-2022Q2	0.054	0.054
Effective shipping supply, avg. log-change 2021-2022	-0.128	-0.128
Real investment, avg. log-change 2020Q3-2021Q2	-0.042	-0.042
Shipping investment/Shipping fleet, avg. change 2020Q3-2021Q2	0.037	0.037

Quantification: Shocks and Targets

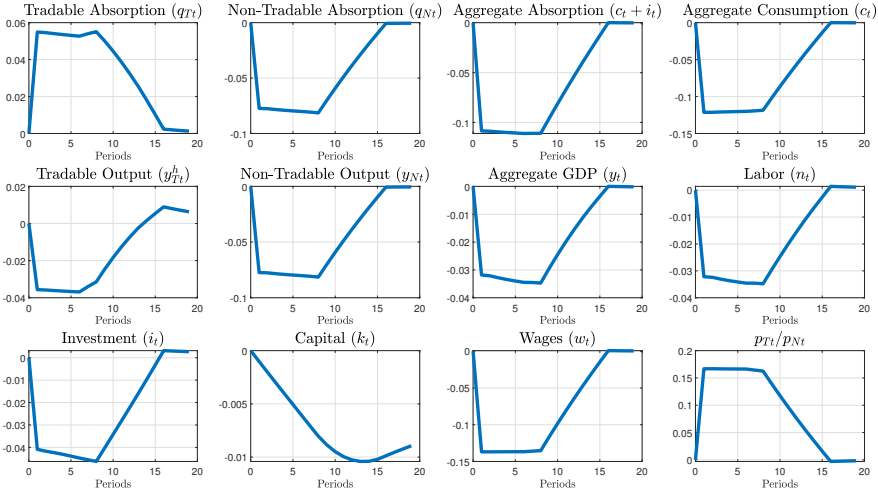








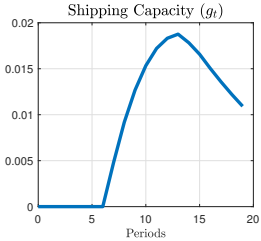
Q1: Aggregate Dynamics Following Shocks?

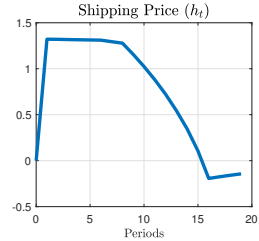


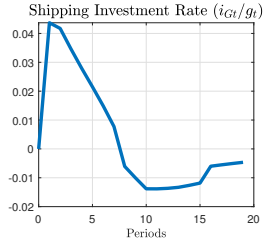
⇒ Sectoral reallocation: Higher demand for tradables, lower for non-tradables

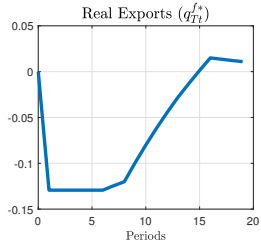
⇒ Contractionary: Hard to scale up tradables in short-run + lower shipping capacity

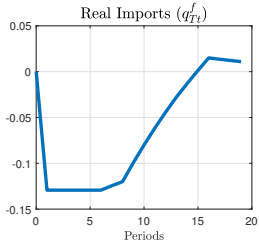
Q2: Shipping and Trade Dynamics?

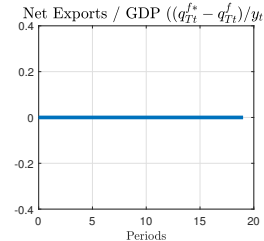








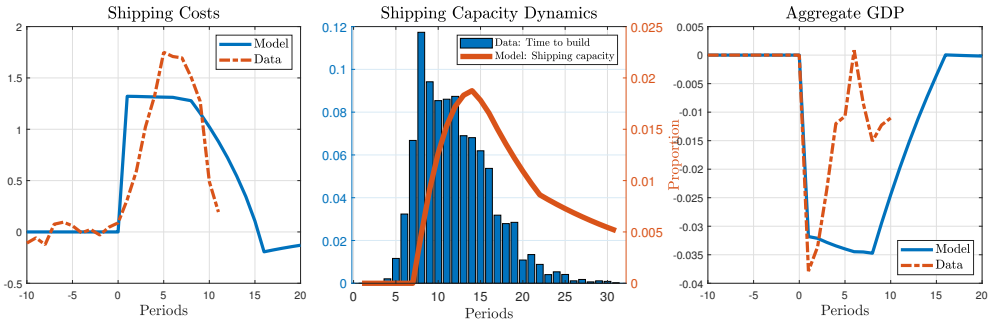




⇒ Shipping prices: Significant and persistent increase

⇒ Trigger spike in shipping investments, but capacity takes time to adjust

Q3: Shipping and Aggregate Dynamics, Model vs. Data?



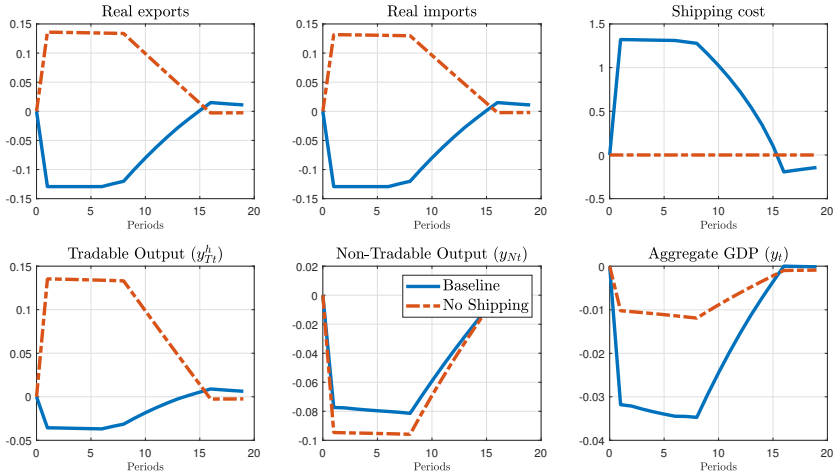
⇒ Shipping prices: Model accounts for 75.5% of the peak increase observed in the data

⇒ Adjustment of shipping capacity also consistent with the data

⇒ Similar decline of GDP on impact, but faster reversal

Q4: Aggregate Implications of Inelastic Shipping Capacity?

Contrast baseline vs. model without shipping market:



⇒ Significant decline of tradable output and GDP due to shipping disruptions

Overview of Results

1. Aggregate dynamics following shocks?

   $\Rightarrow$ Sectoral reallocation of demand + Supply contraction

2. Shipping and trade dynamics?

   $\Rightarrow$ Persistent increase of shipping prices + Sluggish supply adjustment

3. Shipping dynamics, model vs. data?

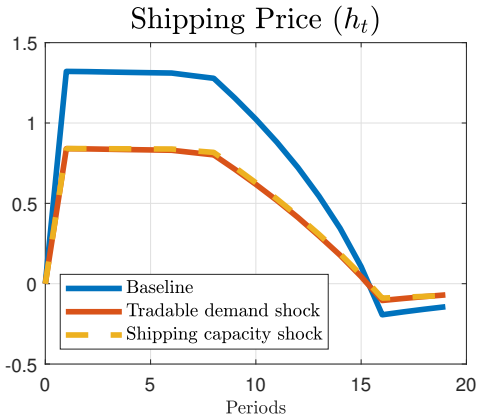
   $\Rightarrow$ Shipping prices and capacity consistent with data

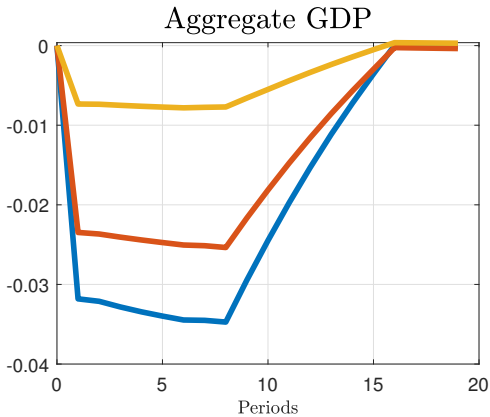
4. Aggregate implications of inelastic shipping capacity?

   $\Rightarrow$ Significant decline of tradable output and GDP due to shipping disruptions

Let's examine what channels/ingredients are critical in accounting for these findings...

Relative Importance of Demand vs. Supply Shocks?

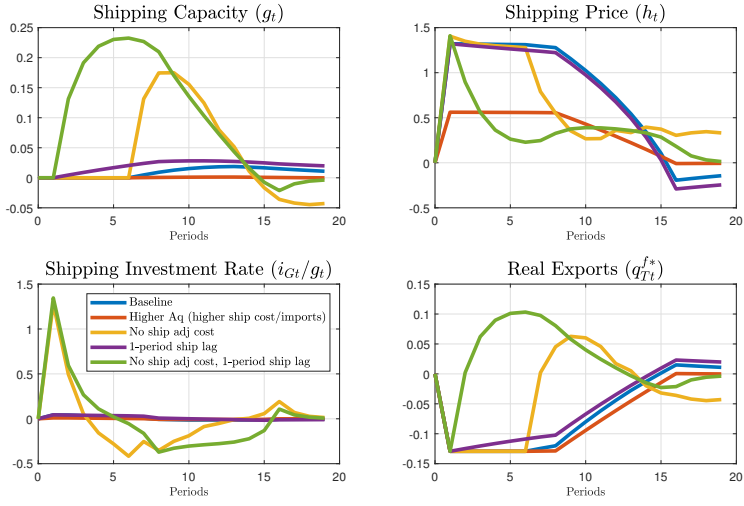




$\Rightarrow$ Higher shipping prices: $\approx 1/2$ tradable demand, $\approx 1/2$ shipping capacity

$\Rightarrow$ Lower aggregate GDP: Primarily driven by demand reallocation toward shipping-intensive sector

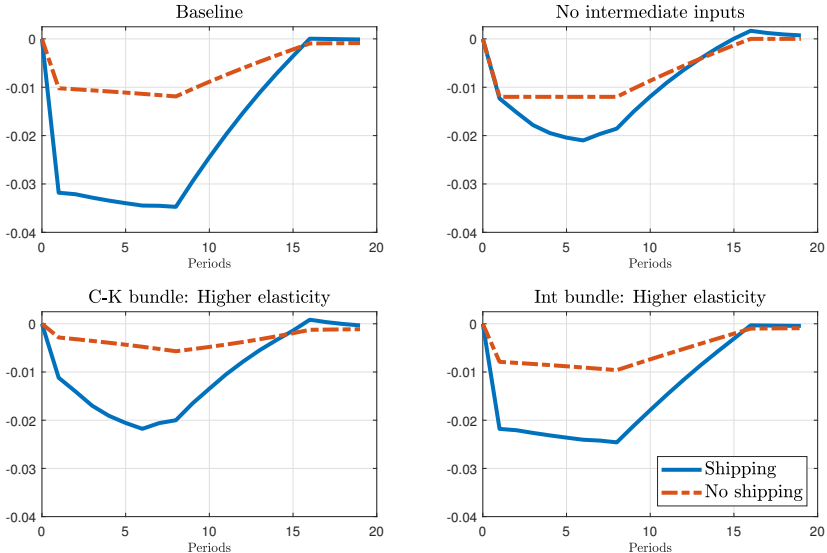
What Accounts for Shipping Dynamics?



$\Rightarrow$ Shipping price level: Shipping investment productivity (i.e., shipping cost / imports)

$\Rightarrow$ Shipping price dynamics: Shipping production lag + Adjustment cost

What Accounts for Aggregate Implications?

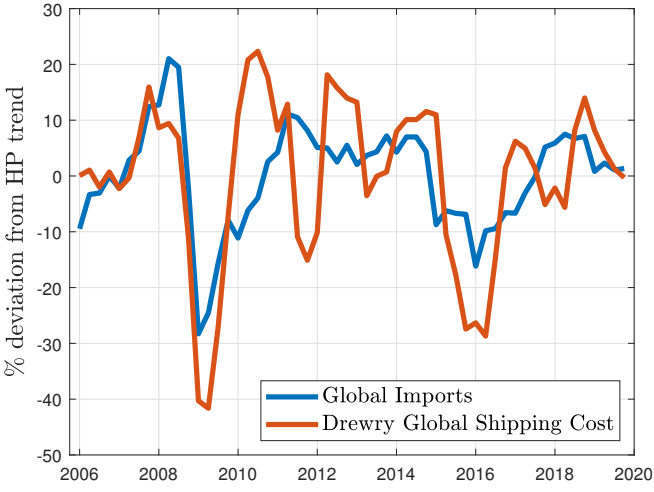


⇒ Critical channels: Input-output linkages, complementarity between home and foreign intermediates

Quantitative Analysis

Shipping Capacity and Business Cycle Dynamics

Shipping Price Dynamics During Normal Times



$\Rightarrow$ But international shipping costs also very volatile during "normal" times

We then ask:

1. Can our model account for these?
2. Implications for aggregate dynamics?

How we answer these questions:

- Two BC shocks: productivity, trade costs
- Recalibrate adj. costs
- Examine shipping fluctuations + Implications for business cycles

Q∅: How Well Accounts for Business Cycle Fluctuations?

Aggregates

	Std. dev.	*Std. dev. relative to GDP*	
	Real GDP	Consumption	Investment
Data	**1.92**	0.75	3.27
Baseline	**1.92**	0.77	3.87

International Trade

	Std. dev. relative to GDP		*Corr. with GDP*	
	Imports	Tradable Abs.	Imports	Tradable Abs.
Data	3.08	**2.67**	0.61	0.77
Baseline	1.74	**2.65**	0.12	0.38

⇒ **Productivity shock + Capital adj. costs: Aggregate business cycle dynamics**

⇒ **Iceberg trade cost shock: International trade fluctuations**

Q1: Shipping Price Fluctuations?

	$\frac{\text{Std. dev.}h}{\text{Std. dev. GDP}}$	corr(h,GDP)
Data	7.56	0.21
Baseline	36.00	0.55
No shipping	—	—

$\Rightarrow$ **Pro-cyclical and volatile! But...**

1. **Higher volatility than data:** Abstract from other margins of adjustment that may mitigate price pressures
   - e.g., Imperfect capacity utilization, other shipping modes, etc.

2. **More pro-cyclical than data:** US data $\neq$ global output, other sources of shocks, etc.

Q2: Implications for Business Cycle Fluctuations?

	Std. dev.	*Std. dev. relative to GDP*	
	Real GDP	Consumption	Investment
Data	1.92	0.75	3.27
Baseline	1.92	0.77	3.87
No shipping	2.28	0.83	4.57

⇒ **In contrast to post-COVID, we find shipping supply rigidities mitigate volatility**

Q2: Implications for Business Cycle Fluctuations?

	Std. dev.	*Std. dev. relative to GDP*	
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Why? Consider business cycle shocks...

- Higher demand for tradables **during expansions**
- Given rigid shipping capacity, tradables increase less than in a model without shipping
- Aggregate output **increases less** than in a model without shipping

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Now consider the COVID shocks...

- Higher demand for tradables **during contraction**: Lower NT, higher T
- Given rigid/lower shipping capacity, tradables increase less than in a model without shipping
- Aggregate output **decreases more** than in a model without shipping

Q3: What Accounts for the Implications of Shipping?

One channel: Degree of cross-country shock correlation

	− correlation	No correlation	+ correlation
$\text{corr}(z, z^*)$	-0.99	0.00	0.99
Std. dev. h relative to GDP	3.46	36.00	54.05

Std. dev. real GDP	− correlation	No correlation	+ correlation
Baseline	2.03	1.92	1.80
No shipping	2.09	2.28	2.46
No shipping / Baseline	2.96%	18.75%	36.67%

⇒ **With correlated shocks, expansions put higher pressure on shipping capacity — and vice-versa**

⇒ **Shipping capacity mitigates global shocks, making local shocks look relatively larger**

Concluding Remarks

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We document novel features of the dynamics of global shipping

- Shipping price dynamics and determinants
- Shipping supply adjustment

  $\Rightarrow$ Given this evidence, we ask...

Q1: What accounts for the dynamics of international shipping costs?

- Fluctuations in demand for tradables + Inelastic short-run shipping supply $\Rightarrow$ Excess demand fluctuations
- Can account for shipping cost dynamics post-COVID + at business cycle frequencies

Q2: How do the dynamics of global shipping affect aggregate macro fluctuations?

- Post COVID-19: Economic contraction is amplified due to limited shipping capacity
- Business cycles: Agg. fluctuations mitigated, shipping rigidities limit trade adj. in short-run
- Input-output linkages are critical for these effects

Appendix

Quantification: Aggregate Implications