Propagation of Export Shocks: The Great Recession in Japan

Toshihiko Mukoyama[1] Kanato Nakakuni[2] Makoto Nirei[3]

April 2025

[1]Georgetown University
[2]University of Tokyo
[3]University of Tokyo

Background

- Japan experienced a significant decline in GDP during the Great Recession. Japan's real GDP fell by 8.8% from the first quarter of 2008 to the first quarter of 2009.
- Japan had little exposure to US housing finance.
- During the same period, the real value of exports from Japan fell by 36.1%.
- Decline in export demand seems to be a culprit as a major cause of the GDP decline.
- From the viewpoint of the business cycle theory, this instance is a rare event where we can trace the exogenous demand shocks and their propagation.

Question

- How much did the export demand shock contribute to Japan's GDP decline during the Great Recession?
- How did the shock propagate across sectors and regions?

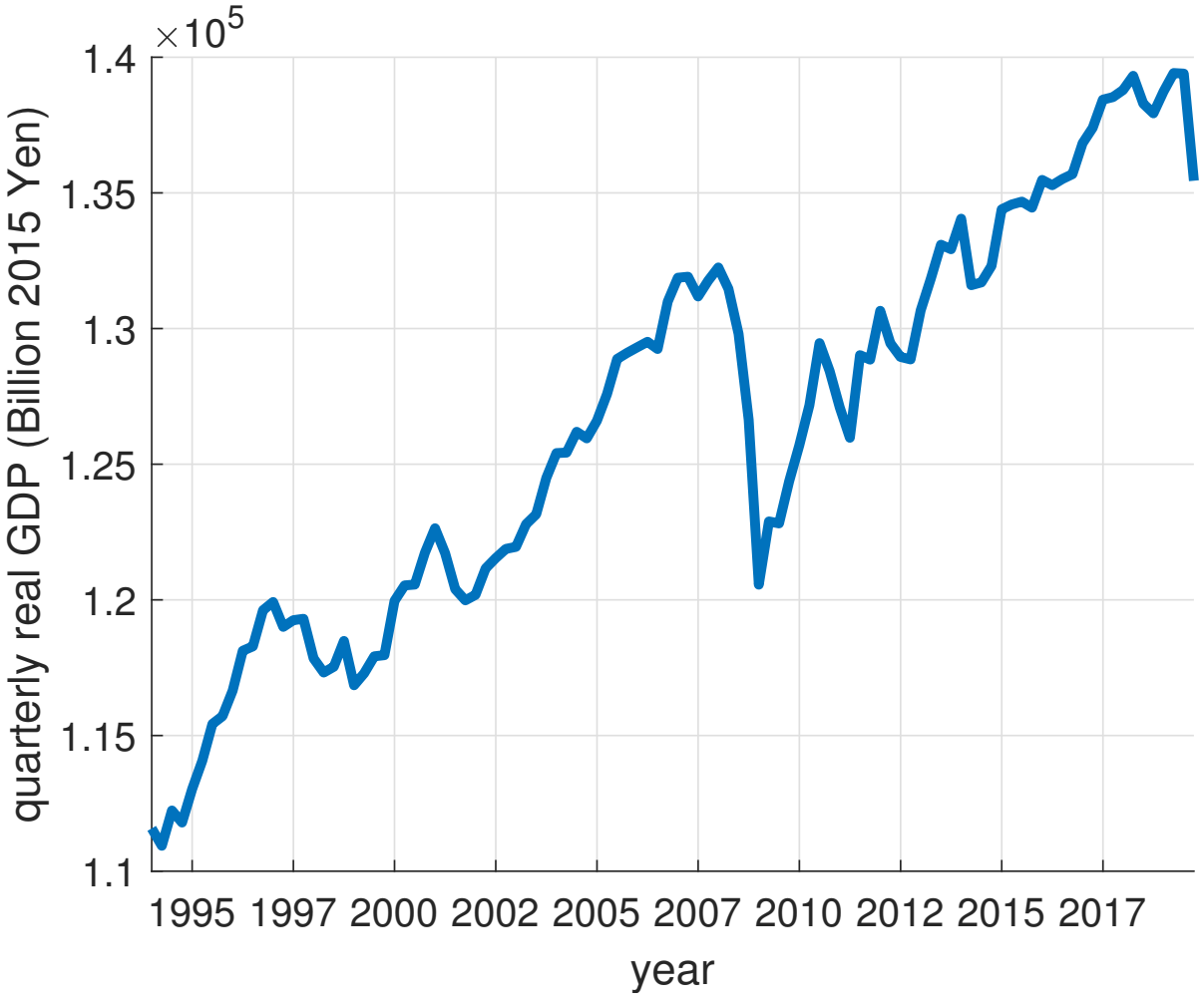
What we do

- Construct the export data, using the customs data, from 9 regions and 26 industries.
- Using the inter-regional input-output (IRIO) table, construct a dynamic general equilibrium model to analyze the propagation of export shocks from one region to other regions.
  - The model provides an "RBC-like" framework that incorporates export demand shock.
  - We can keep track of the propagation process, which is typically a "black box" in the RBC literature.
  - The monopolistic-competition-based model allows us to evaluate the effect of price stickiness.

Literature

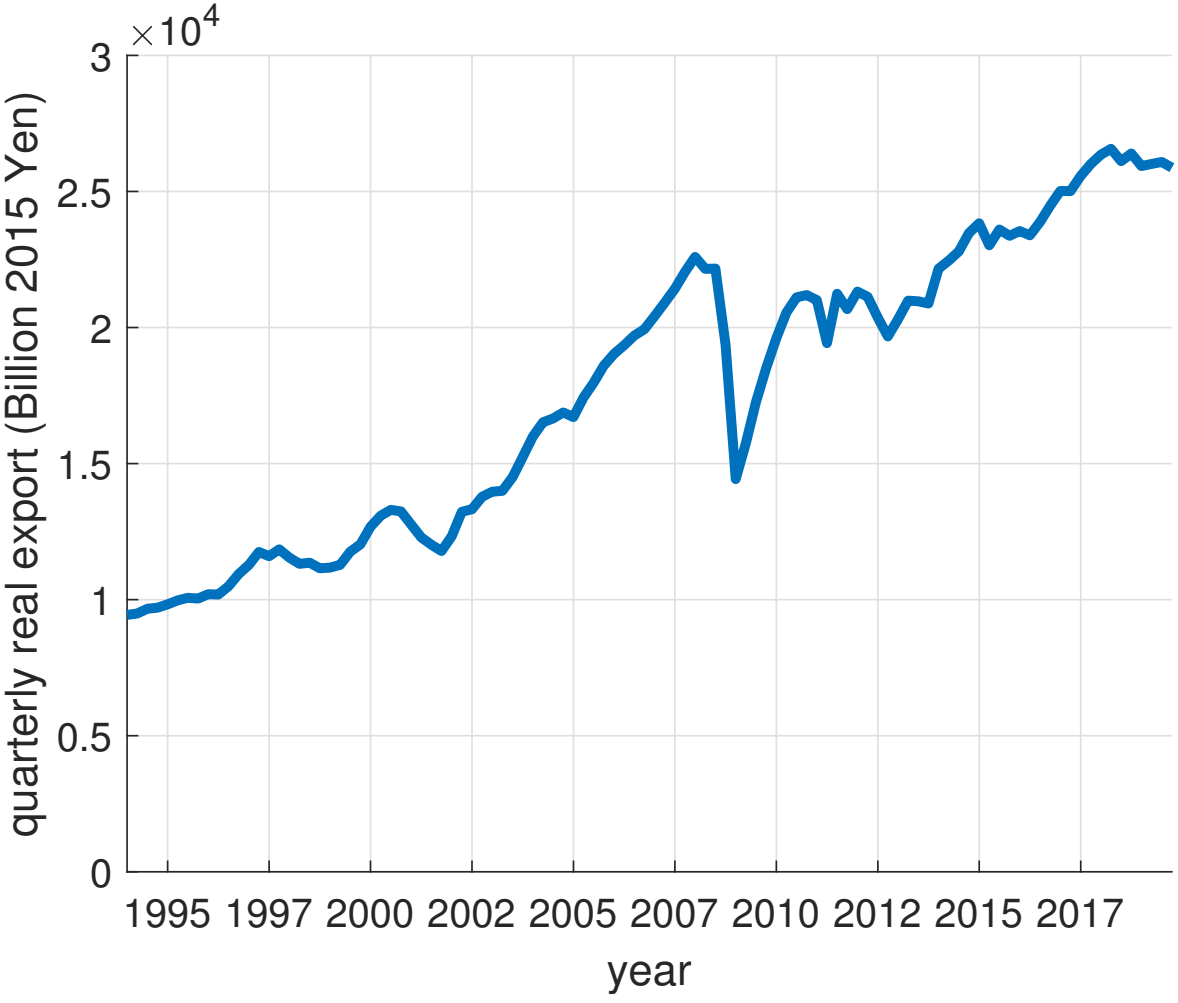
- Sectoral business cycles: Long and Plosser 1987 AER; Dupor 1999 JME; Horvath 2000 JME
- Production network model: Acemoglu et al. 2012 EMA; Baqaee and Farhi 2019 EMA
- Demand shocks in input-output network: Bartelsman et al. 1994 AER; Guiso et al. 2017 JER
- Great recession and trade ("Great Trade Collapse"): Alessandria et al. 2011; Amiti and Weinstein 2011 QJE; Eaton et al. 2016 AER
- Global propagation through input-output network: Ho et al. 2022; Huo et al. 2023; Boeckelmann et al. 2024
- Export shocks in firm-to-firm network: Huneeus 2020; Dhyne et al. 2022
- Regional propagation through input-output network: Caliendo et al. 2018 REStud; Becko et al. 2024

Real GDP



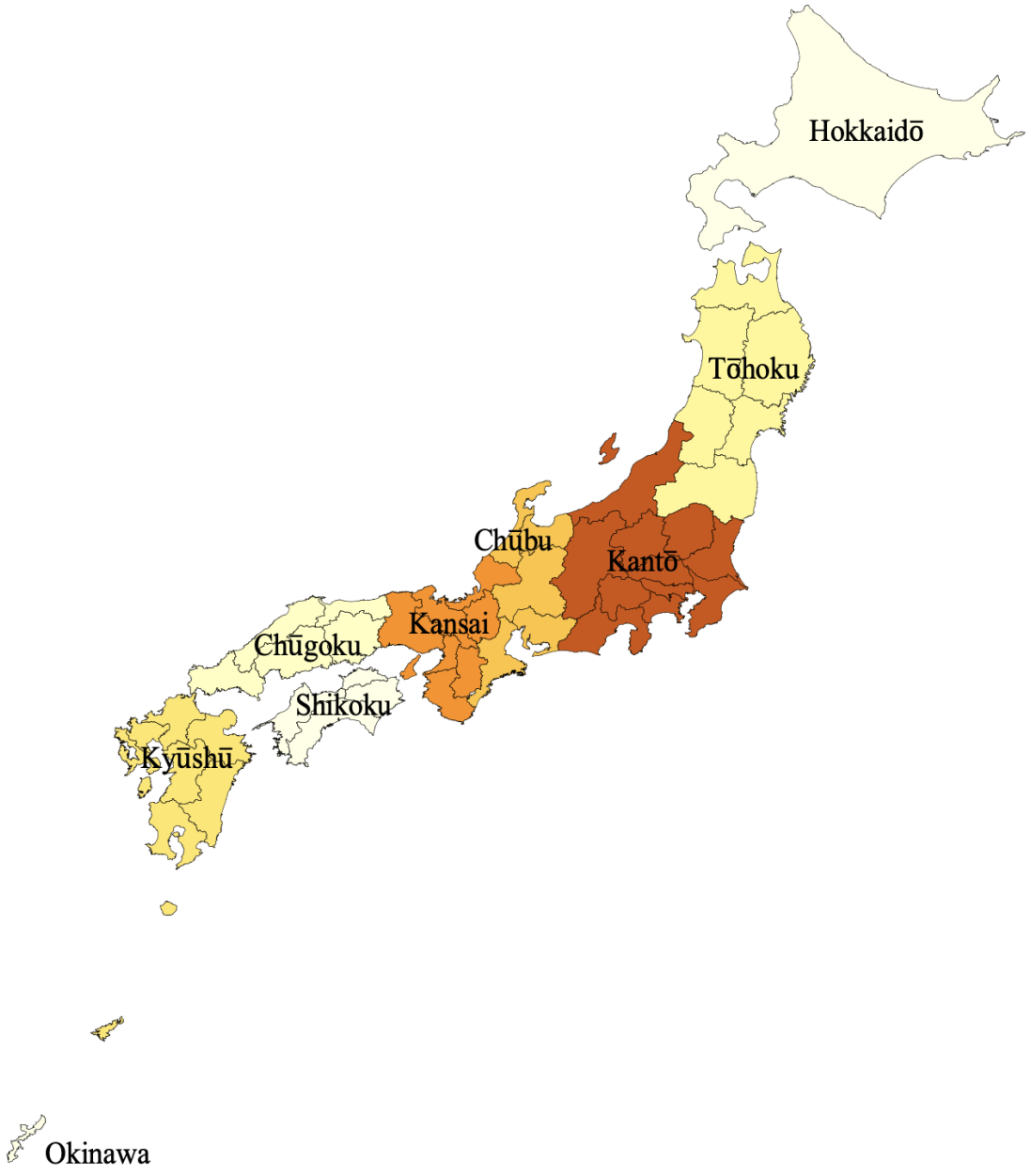
- Source: FRED

Exports

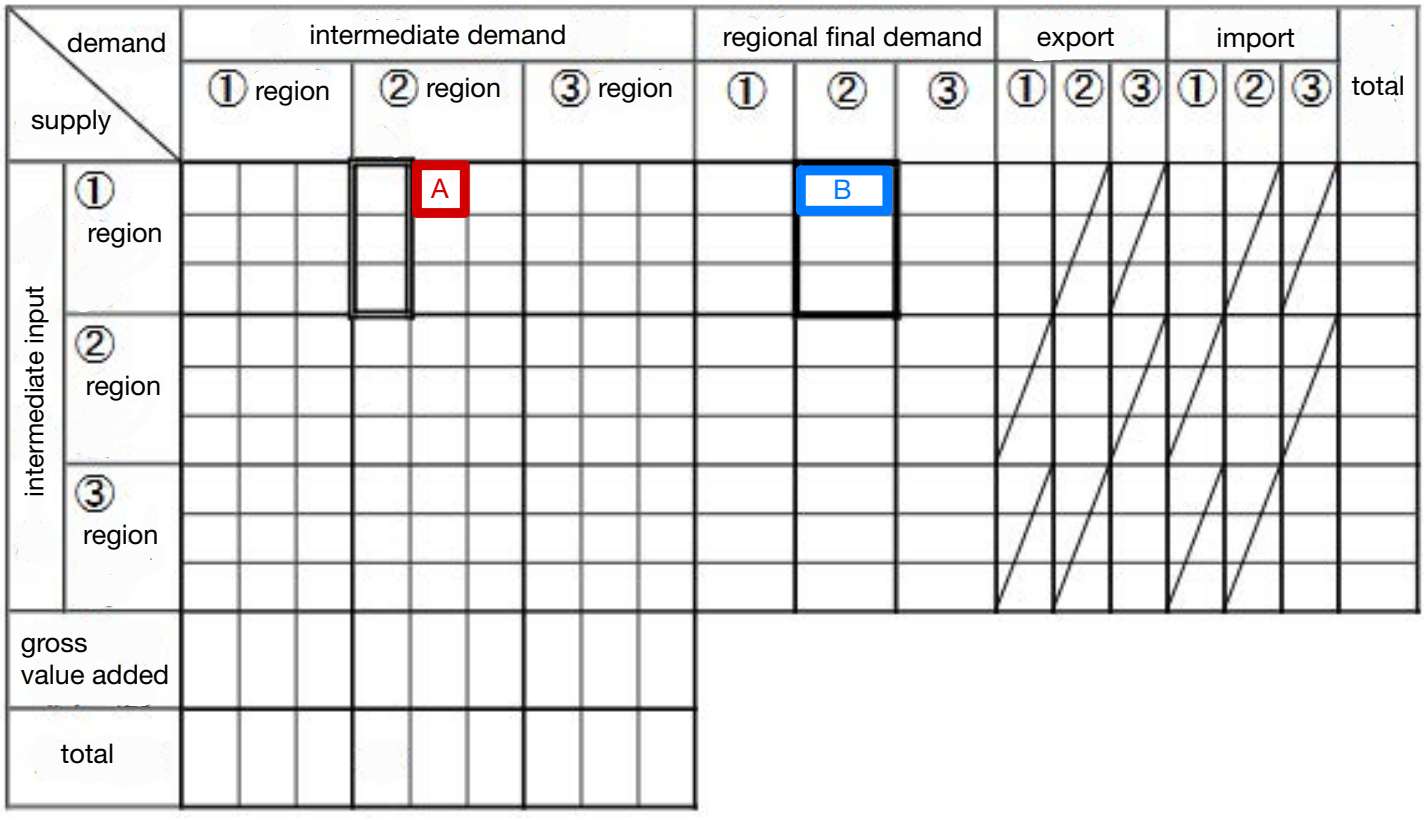


- Source: FRED

Nine regions

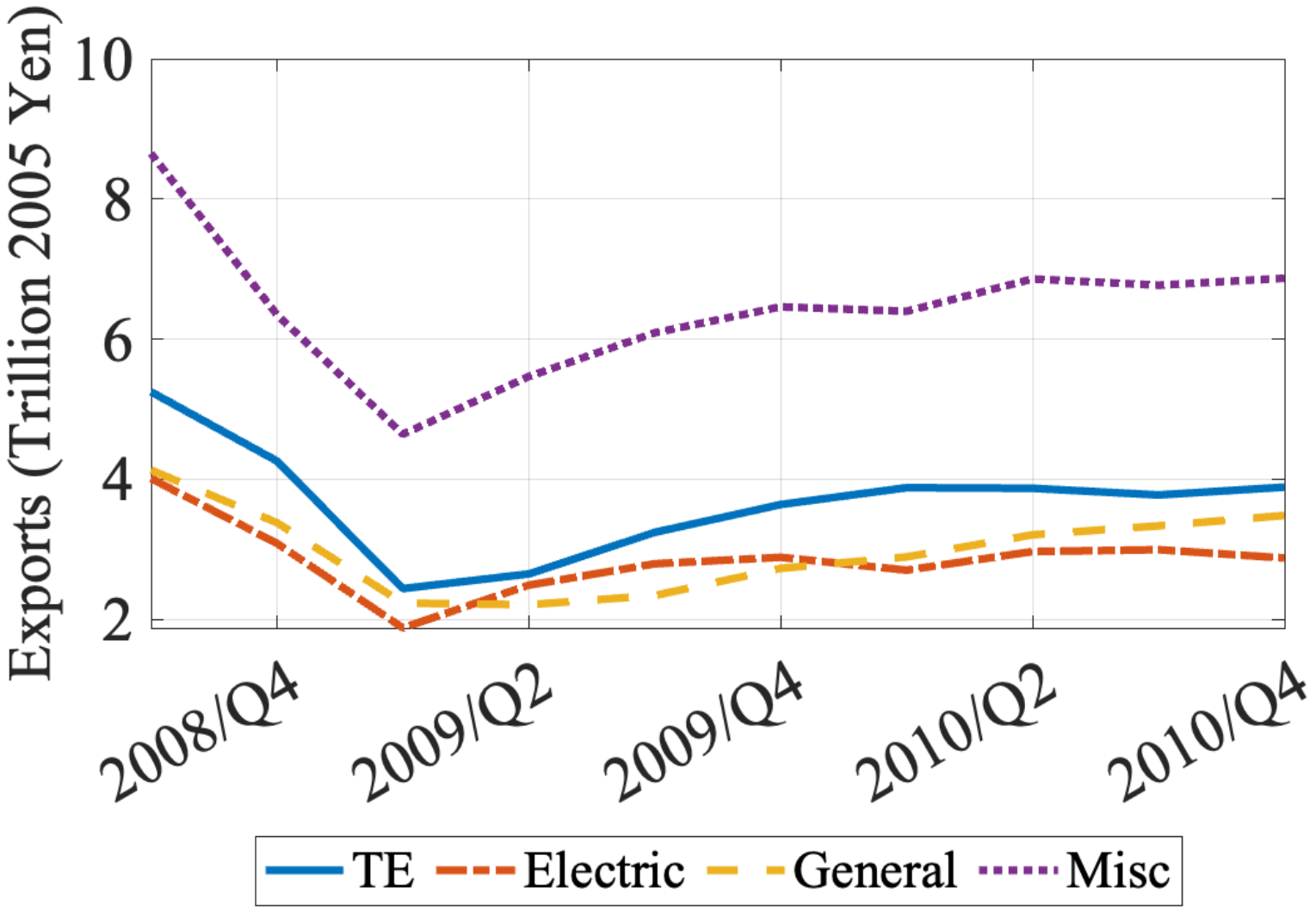


Inter-regional input-output table

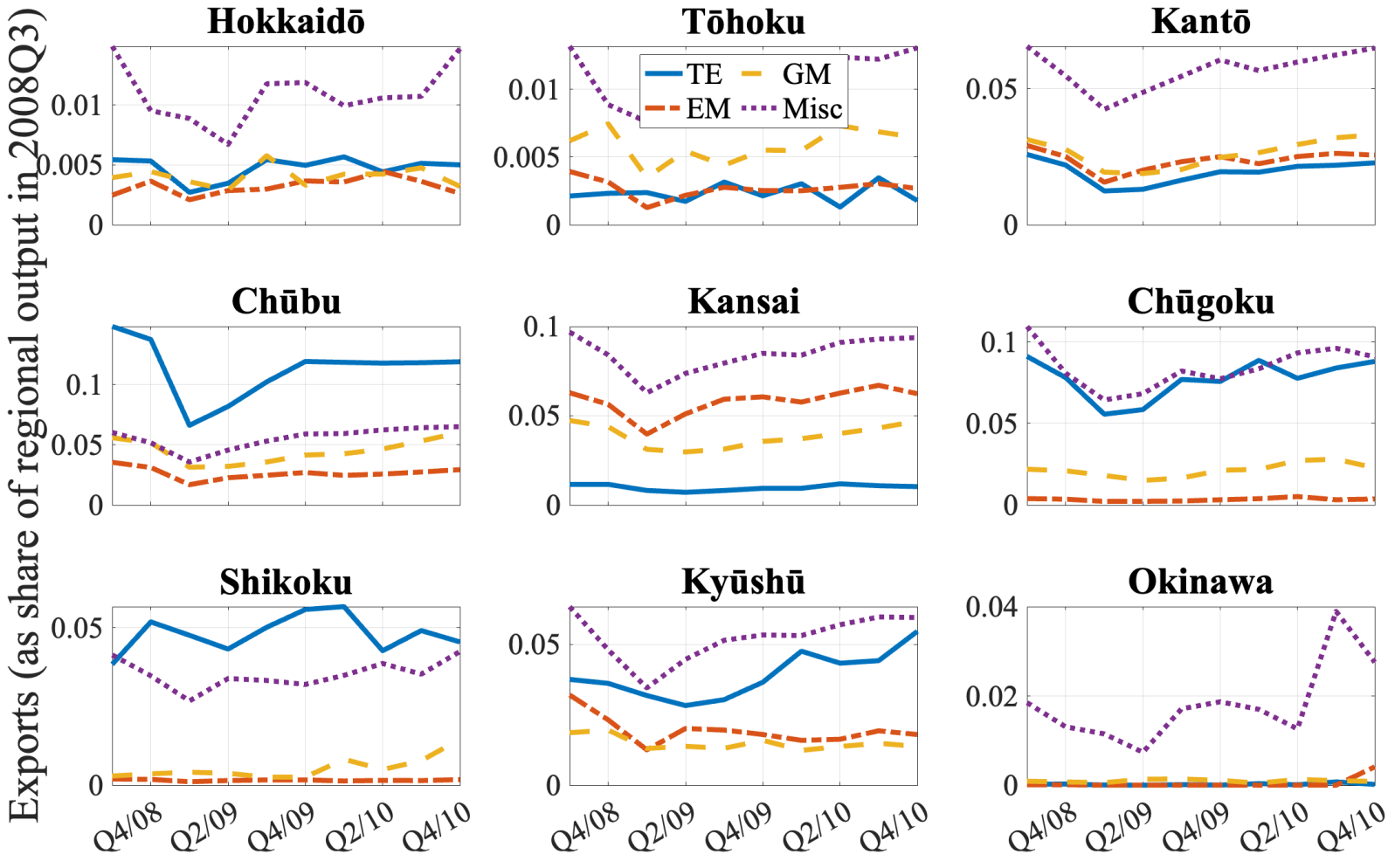


- A is the value of region-1 industry-1 product used as an input in region-2 industry-2 production.
- B is the value of region-1 industry-1 product demanded by the consumers in region-2.

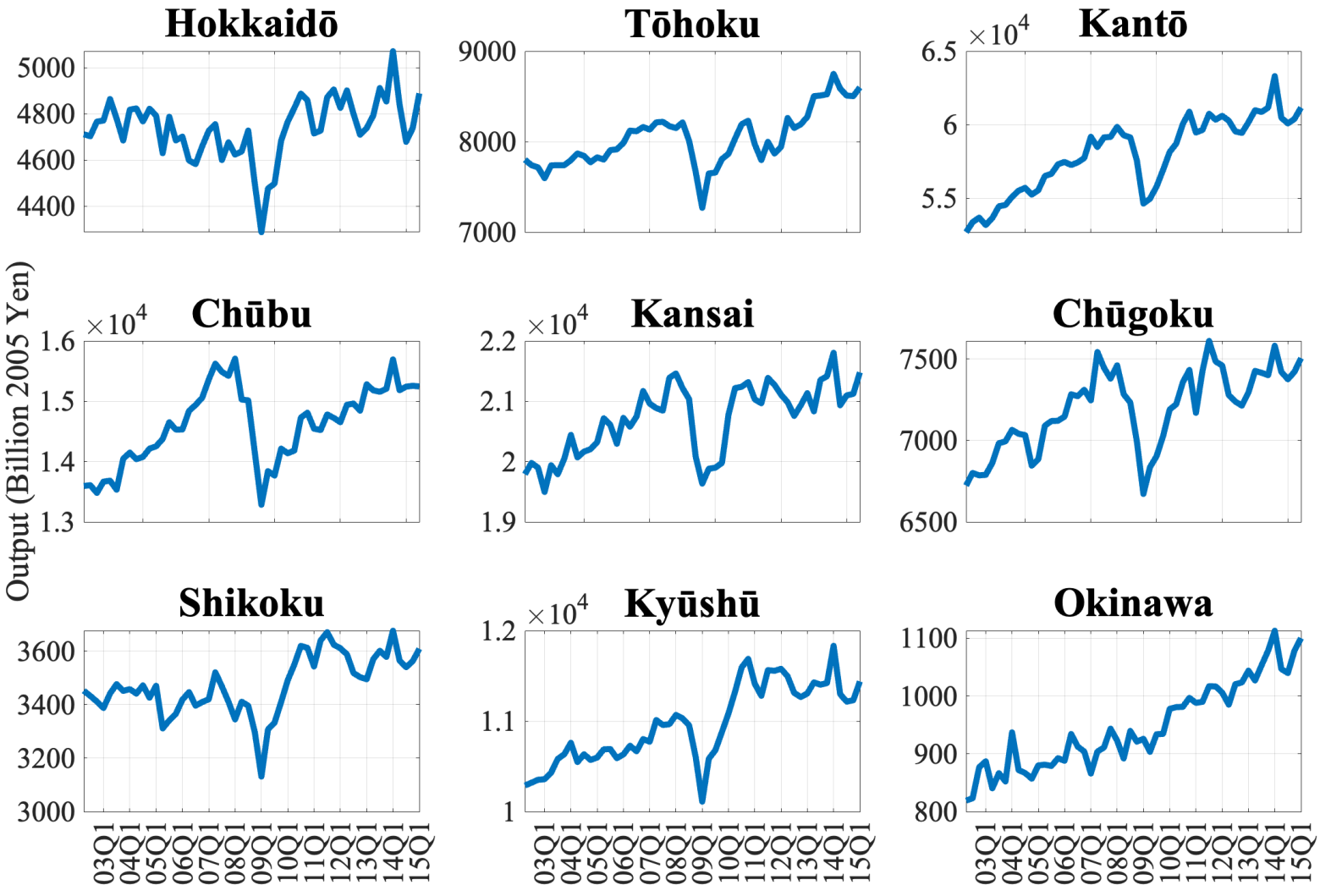
Exports


Exports (Trillion 2005 Yen)
10
8
6
4
2
2008/Q4
2009/Q2
2009/Q4
2010/Q2
2010/Q4
TE
Electric
General
Misc

Regional exports (scaled to regional GDP in the initial date)



Regional output



Model

- Dynamic input-output model with multiple regions.
- Representative consumer in each region.
- Monopolistic producer in each industry-region.
- Export (and import). The entire country is a small open economy.

Consumers

There are S products (industries) and I regions. The representative consumer (a price taker) at region i maximizes

$$\sum_{t=0}^{\infty} \frac{1}{(1+\rho)^t} \left[\frac{(C_{i,t})^{1-\sigma_c} - 1}{1-\sigma_c} - \chi_i \frac{(N_{i,t})^{1+\zeta}}{1+\zeta} \right]$$

subject to

$$P_{i,t}^c C_{i,t} + P_{i,t}^x X_{i,t} \leq \int_0^S w_{si,t} n_{si,t} ds + r_{i,t} K_{i,t} + \Pi_{i,t} + B_{i,t}$$

and

$$K_{i,t+1} = (1-\delta) K_{i,t} + X_{i,t}$$

No inter-regional movements of capital, labor, and ownership.

$B_{i,t}$ is an international transfer accompanying trade deficits and exogenous to regions.

Consumers

where

$$C_{i,t} = \left[\int_0^S \int_0^I (\xi^i_{sjc})^{\frac{1}{\sigma}} (c^i_{sj,t})^{\frac{\sigma-1}{\sigma}} dj ds + \int_0^S (\xi^i_{sfc})^{\frac{1}{\sigma}} (c^i_{sf,t})^{\frac{\sigma-1}{\sigma}} ds \right]^{\frac{\sigma}{\sigma-1}},$$

$$X_{i,t} = \left[\int_0^S \int_0^I (\xi^i_{sjx})^{\frac{1}{\sigma}} (x^i_{sj,t})^{\frac{\sigma-1}{\sigma}} dj ds + \int_0^S (\xi^i_{sfx})^{\frac{1}{\sigma}} (x^i_{sf,t})^{\frac{\sigma-1}{\sigma}} ds \right]^{\frac{\sigma}{\sigma-1}},$$

and

$$N_{i,t} = \left[\int_0^S (n_{si,t})^{\frac{\tau+1}{\tau}} ds \right]^{\frac{\tau}{\tau+1}}.$$

Consumers

Solutions:

- Intertemporal optimization:

$$\left(\frac{C_{i,t}}{C_{i,t+1}}\right)^{-\sigma_c} = \frac{1}{1+\rho}\left(1+\frac{r_{i,t+1}}{P^x_{i,t+1}}-\delta\right)$$

- Labor supply:

$$\frac{w_{si,t}}{P^c_{i,t}} = \chi_i (C_{i,t})^{\sigma_c} (N_{i,t})^{\zeta} \left(\frac{n_{si,t}}{N_{i,t}}\right)^{\frac{1}{\tau}}.$$

Consumers

Solutions:

- Domestic goods demand:

$$c^i_{sj,t} = \left(\frac{p_{sj,t}}{P^c_{i,t}}\right)^{-\sigma} \xi^i_{sjc} C_{i,t}$$

- Foreign goods (import) demand:

$$c^i_{sf,t} = \left(\frac{p_{sf,t}}{P^c_{i,t}}\right)^{-\sigma} \xi^i_{sfc} C_{i,t}$$

- Investment goods demand:

$$x^i_{sj,t} = \left(\frac{p_{sj,t}}{P^x_{i,t}}\right)^{-\sigma} \xi^i_{sjx} X_{i,t}$$

Consumers

Solutions:

- Price index for consumption:

$$P_{i,t}^{c} \equiv \left[\int_0^S \int_0^I \xi_{sjc}^{i} (p_{sj,t})^{1-\sigma} dj ds + \int_0^S \xi_{sfc}^{i} (p_{sf,t})^{1-\sigma} ds \right]^{\frac{1}{1-\sigma}}$$

- Price index for investment:

$$P_{i,t}^{x} \equiv \left[\int_0^S \int_0^I \xi_{sjx}^{i} (p_{sj,t})^{1-\sigma} dj ds + \int_0^S \xi_{sfx}^{i} (p_{sf,t})^{1-\sigma} ds \right]^{\frac{1}{1-\sigma}}$$

Production

In region i, good h is produced by

$$y_{hi,t} = A_{hi}(M_{hi,t})^{\alpha}(N_{hi,t})^{\beta}(K_{hi,t})^{1-\alpha-\beta},$$

where

$$M_{hi,t} = \left[\int_0^S \int_0^I (\gamma_{sj}^{hi})^{\frac{1}{\sigma}} (m_{sj,t}^{hi})^{\frac{\sigma-1}{\sigma}} djds + \int_0^S (\gamma_{sf}^{hi})^{\frac{1}{\sigma}} (m_{sf,t}^{hi})^{\frac{\sigma-1}{\sigma}} ds\right]^{\frac{\sigma}{\sigma-1}}.$$

m_{sj}^{hi} is the intermediate good s from region j used in production of good h in region i.

Inverse demand for intermediate goods:

$$m_{sj,t}^{hi} = \left(\frac{p_{sj,t}}{P_{hi,t}^{m}}\right)^{-\sigma} \gamma_{sj}^{hi} M_{hi,t},$$

where

$$P_{hi,t}^{m} \equiv \left[\int_0^S \int_0^I \gamma_{sj}^{hi}(p_{sj,t})^{1-\sigma} djds + \int_0^S \gamma_{sf}^{hi}(p_{sf,t})^{1-\sigma} djds\right]^{\frac{1}{1-\sigma}}.$$

Production

- The total demand for the good (s, j) is, by adding the consumption demand, investment demand, and the intermediate good demand,

$$y_{sj,t} = \int_0^I (c^i_{sj,t} + x^i_{sj,t})di + \int_0^S \int_0^I m^{hi}_{sj,t} didh + y^f_{sj,t}$$

  where $y^f_{sj,t}$ represents the foreign (export) demand.

- Assume that the foreign demand takes the form

$$y^f_{sj,t} = \omega^f_{sj,t}(p_{sj,t})^{-\sigma}(\bar{P}_t)^{\sigma}.$$

  $\omega^f_{sj,t}$ is the parameter that governs the export shock and $\bar{P}_t$ is the price level in the foreign country.

Production

- The monopolist in (s, j) industry maximizes profit in two steps: (i) finding the right combination of intermediate goods, capital, and labor per unit of output; (ii) finding the right quantity to produce.
- The first step (competitive in factor markets):

$$\min_{M_{sj,t}, N_{sj,t}, K_{sj,t}} \quad P^m_{sj,t} M_{sj,t} + w_{sj,t} N_{sj,t} + r_{j,t} K_{sj,t}$$

subject to

$$1 = A_{sj} (M_{sj,t})^{\alpha} (N_{sj,t})^{\beta} (K_{sj,t})^{1-\alpha-\beta}.$$

The solution yields the unit cost λ^{sj}:

$$\lambda_{sj,t} = \frac{(P^m_{sj,t})^{\alpha} (w_{sj,t})^{\beta} (r_{j,t})^{1-\alpha-\beta}}{A_{sj} \alpha^{\alpha} \beta^{\beta} (1-\alpha-\beta)^{1-\alpha-\beta}}$$

Production

- Let

$$D_{sj,t} \equiv \left(\int_0^I \left((P_{i,t}^c)^\sigma \xi_{sjc}^i C_{i,t} + (P_{i,t}^x)^\sigma \xi_{sjx}^i X_{i,t} \right) di + \int_0^S \int_0^I (P_{hi,t}^m)^\sigma \gamma_{sj}^{hi} M_{hi,t} di dh \right) + \omega_{sj,t}^f \bar{P}_t^\sigma$$

- The second step (monopolist in the product market):

$$\max_{p_{sj,t}} (p_{sj,t} - \lambda_{sj,t})(p_{sj,t})^{-\sigma} D_{sj,t}.$$

The result is the standard constant markup rule:

$$p_{sj,t} = \frac{\sigma}{\sigma - 1} \lambda_{sj,t}.$$

Thus the production of good (s, j) is

$$y_{sj,t} = \left(\frac{\sigma}{\sigma - 1} \lambda_{sj,t} \right)^{-\sigma} D_{sj,t}.$$

Trade imbalance

- We do not allow borrowing and lending across regions.
- We admit international trade imbalances (Dekle et al. 2007)
- The current account deficit at the national level is

$$\int_0^I B_{i,t} di = \int_0^S \int_0^I p_{sf,t} \left(c^i_{sf,t} + x^i_{sf,t} + \int_0^S m^{hi}_{sf,t} dh \right) dids - \int_0^S \int_0^I p_{si,t} y^f_{si,t} dids$$

where $B_{i,t}$ is distributed to region i as an international transfer.

Static symmetric model

- Before getting into the quantitative model, we consider a simpler version.
- Consider a static economy without capital (and the production is $y = AM^{\alpha}N^{1-\alpha}$).
- Assume $S = I = 1$.
- All firms are symmetric (ξ's are all 1 and $\gamma_{sf}^{hi} = \gamma_f$ for $\forall h, i, s$).
- All regions are symmetric $A^{hi} = (\alpha^{\alpha}(1-\alpha)^{1-\alpha})^{-1}$ for $\forall h, i$.
- Trade balances: $B_i = 0$ for $\forall i$.
- This model can be characterized analytically.

Static symmetric model

On the production side, the economy has the property

- M and N are linear in y.
- w/p is constant.

Note that from the definition of the price index, we can write

$$\frac{p}{P} = \left(1 + \left(\frac{p}{p_f}\right)^{\sigma-1}\right)^{\frac{1}{\sigma-1}} = \Gamma(p),$$

$$\frac{p}{P_m} = \left(1 + \gamma_f \left(\frac{p}{p_f}\right)^{\sigma-1}\right)^{\frac{1}{\sigma-1}} = \Gamma_m(p),$$

where $\Gamma(p)$ and $\Gamma_m(p)$ are increasing in p. Given the imported goods price p_f, the increase in the domestic good price is translated to the discrepancy between PPI (p) and CPI (P).

Static symmetric model

- On the demand side, first note from the consumer's budget constraint,
$$C = \xi_c \frac{p}{P} y,$$
where $\xi_c \equiv (1 - \alpha(\sigma - 1)/\sigma)$. Here, C can change even when y is the same because of the relative price change.
- The demand equation
$$y = p^{-\sigma} \left(P^{\sigma} C + P_m^{\sigma} M + \omega^f \right)$$
can be rewritten as (replacing M and C)
$$\left(1 - \xi_c \Gamma(p)^{1-\sigma} - (1 - \xi_c)\Gamma_m(p)^{1-\sigma}\right) p^{\sigma} y = \omega^f.$$
The left-hand side is increasing in p, and thus, this equation can be drawn as a downward-sloping demand curve. More importantly, the demand curve shifts rightward with ω^f.

Static symmetric model

- On the supply side, starting from the labor supply equation:

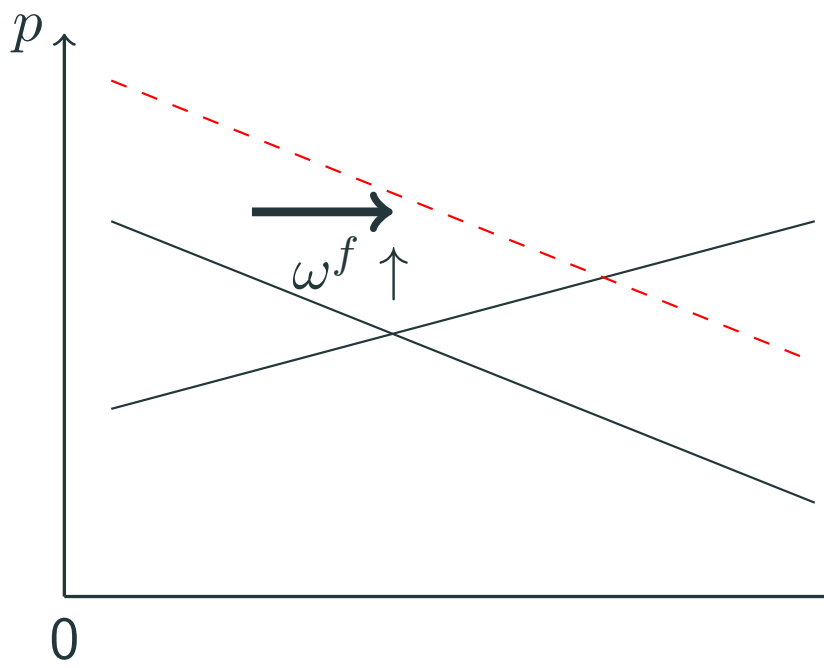
$$\frac{w}{P} = \chi C^{\sigma_c} N^{\zeta}.$$

  Note that $w/P \propto \Gamma(p)^{1-\alpha}\Gamma_m(p)^{\alpha}$ increases with p, which has a positive effect on labor supply N (substitution effect), whereas a high C has a negative effect on labor supply (wealth effect).
- Using the linear relationship between N and y, the relationship between C and y, and w/p being constant, we can derive the supply curve

$$\Gamma(p)^{1-\sigma_c}\Gamma_m(p)^{\frac{\alpha(1+\zeta)}{1-\alpha}} = const \cdot y^{\zeta+\sigma_c}.$$

  This relationship is upward sloping if the wealth effect is not too strong, that is, $\sigma_c \leq 1$.

Comparative statics



Supply:

$$y^{\sigma_c+\zeta} = \frac{\Gamma(p)^{1-\sigma_c}\Gamma_m(p)^{\frac{\alpha(1+\zeta)}{1-\alpha}}}{\chi\xi_c^{\sigma_c}(1-\alpha)^{\zeta}\left(\frac{\sigma}{\sigma-1}\right)^{\frac{1+\alpha\zeta}{1-\alpha}}}$$

Demand:

$$y = \frac{\omega^f}{(1-(\mu_c\Gamma(p)^{1-\sigma}+(1-\mu_c)\Gamma_m(p)^{1-\sigma}))p^{\sigma}}$$

Demand and supply for domestically produced goods. ($\Gamma(p)$ and $\Gamma_m(p)$ are increasing functions and satisfy $\Gamma(p) = p/P$ and $\Gamma_m(p) = p/P_m$ in equilibrium.)

Comparative statics

- Suppose that the supply curve is upward sloping (i.e., $\sigma_c \leq 1$).
- When ω^f goes up, only the demand curve shifts, and in the new equilibrium, both y and p go up.
- p going up means both P and p/P go up. w/P goes up.
- y going up means M, N, and C all go up. C goes up because of both (i) y going up (more production) and (ii) p/P going up (terms of trade improvement).

Main mechanism

- Export demand parameter ω_f goes up $\rightarrow$
- The price of domestic goods, relative to the price of import goods, goes up $\rightarrow$
- The consumer's income (and real wages) goes up (acts similarly to productivity shock) $\rightarrow$
- Depending on substitution effect and wealth effect, labor supply may go up or down $\rightarrow$
- Depending on whether labor supply goes up or down, domestic production may go up or down $\rightarrow$
- Import always goes up (both substitution effect and income effect) if trade balances. If labor supply goes up, all Y, C, and N move together with the export shock. (We will use $\sigma_c = 1$ in the quantitative model.)

Accommodating heterogeneity

Analytical solution is possible for the case $\sigma_c = 1$ (log utility) with heterogeneous input-outputs. Let $q_{sj} := p_{sj}^{\sigma-1}$, $Q_{sj} := (P_{sj}^m)^{\sigma-1}$, $Y_{sj} := p_{sj} y_{sj}$, $Y_i^0 := Y^i$, $Q_i^0 := (P_i^c)^{\sigma-1}$.

$$d \ln \boldsymbol{Y} = \operatorname{diag}(qY)^{-1} \cdot \Bigg[\underbrace{\operatorname{diag}(\omega^f)(\bar{P})^\sigma d \ln \boldsymbol{\omega^f} + \Gamma^0 \operatorname{diag}\left(\frac{1}{1 - \alpha(\sigma-1)/\sigma + b_I}\right) d\boldsymbol{b}_I}_{\text{direct exogenous effects}} + \underbrace{G d \ln \boldsymbol{Y}}_{M \text{ effect}} + \underbrace{\Gamma^0 d \ln \boldsymbol{Y}^0}_{C \text{ effect}} + \underbrace{G d \ln \boldsymbol{Q} + \Gamma^0 d \ln \boldsymbol{Q}^0 - \operatorname{diag}(qY) d \ln \boldsymbol{q}}_{\text{Price effects}} \Bigg]$$

Quantitative model: calibration

- Calibrate the baseline economy in 2008Q3, that is, just before the export shock hits.
- The consumption share and the investment share, which dictate $\{\xi^i_{sjc}\}_{i,sj}$ and $\{\xi^i_{sjx}\}_{i,sj}$, is taken from the inter-regional input-output table in 2005 (IRIO2005).
- The cost share of each intermediate good (s,j) for the producer of good h at region i is governed by $\{\gamma^{hi}_{sj}\}_{hi,sj}$; this also follows IRIO2005.
- $\{\omega^f_{sj}\}_{sj}$ (export demand parameters) are set so that the GDP share of export goods (s,j) matches IRIO2005.
- Productivity $A_{sj} = A_s \times A_j$, A_s is from the JIP database (also the cost share parameter $\{\alpha_s\}$). A_j is from the wage data in the Monthly Labor Force Survey.
- Disutility of labor, χ_i, is calibrated to replicate the regional variation of the employed population in 2008Q3.

Experiment

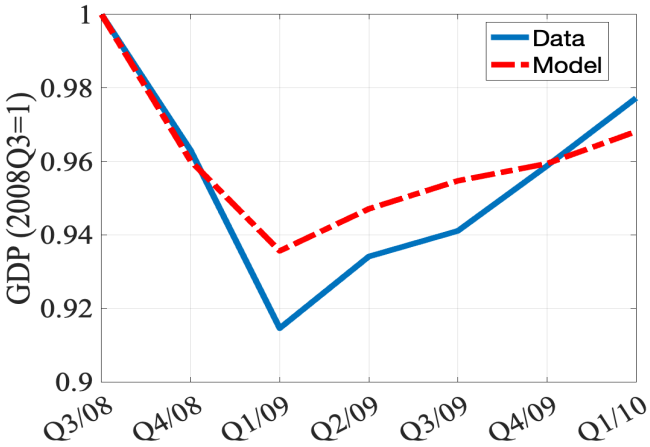
- Determine $\omega^f_{si,t}$ so that

$$\frac{p_{si,t}y^f_{si,t}}{p_{si,t=0}y^f_{si,t=0}} = \frac{\text{export value of } si \text{ in } t \text{ in data}}{\text{export value of } si \text{ in } t=0 \text{ in data}}.$$

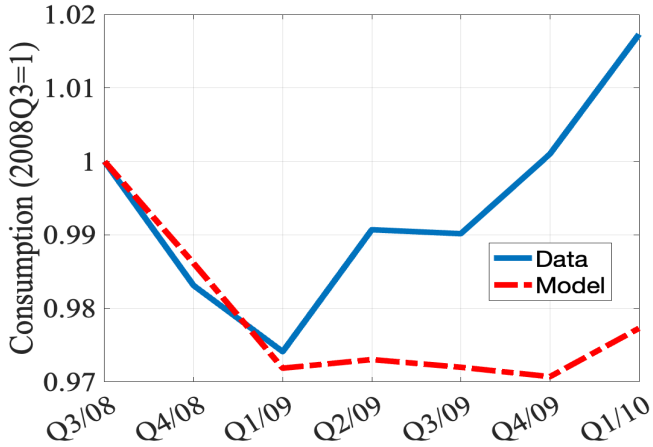
  ($t = 0$ means 2008Q3)
- Starting from the 2008Q3 steady state, the economy follows the perfect-foresight dynamics (an "MIT shock" construction).
- $\omega^f_{si,t}$ stays constant after 2010Q1.

National level responses

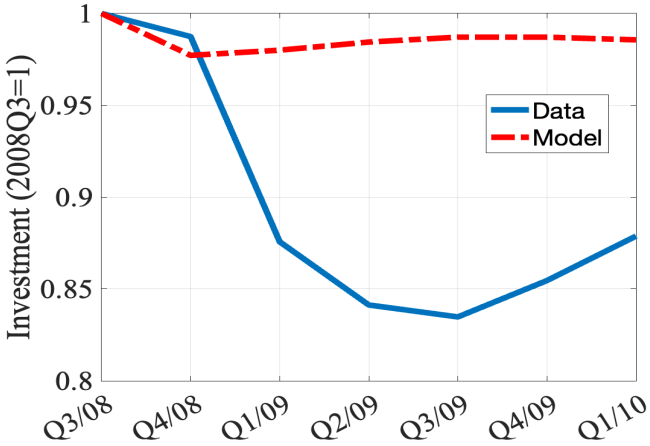
(a) Output



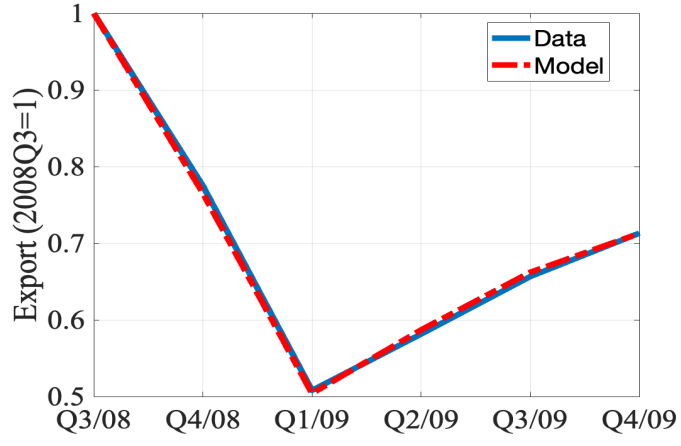
(b) Consumption



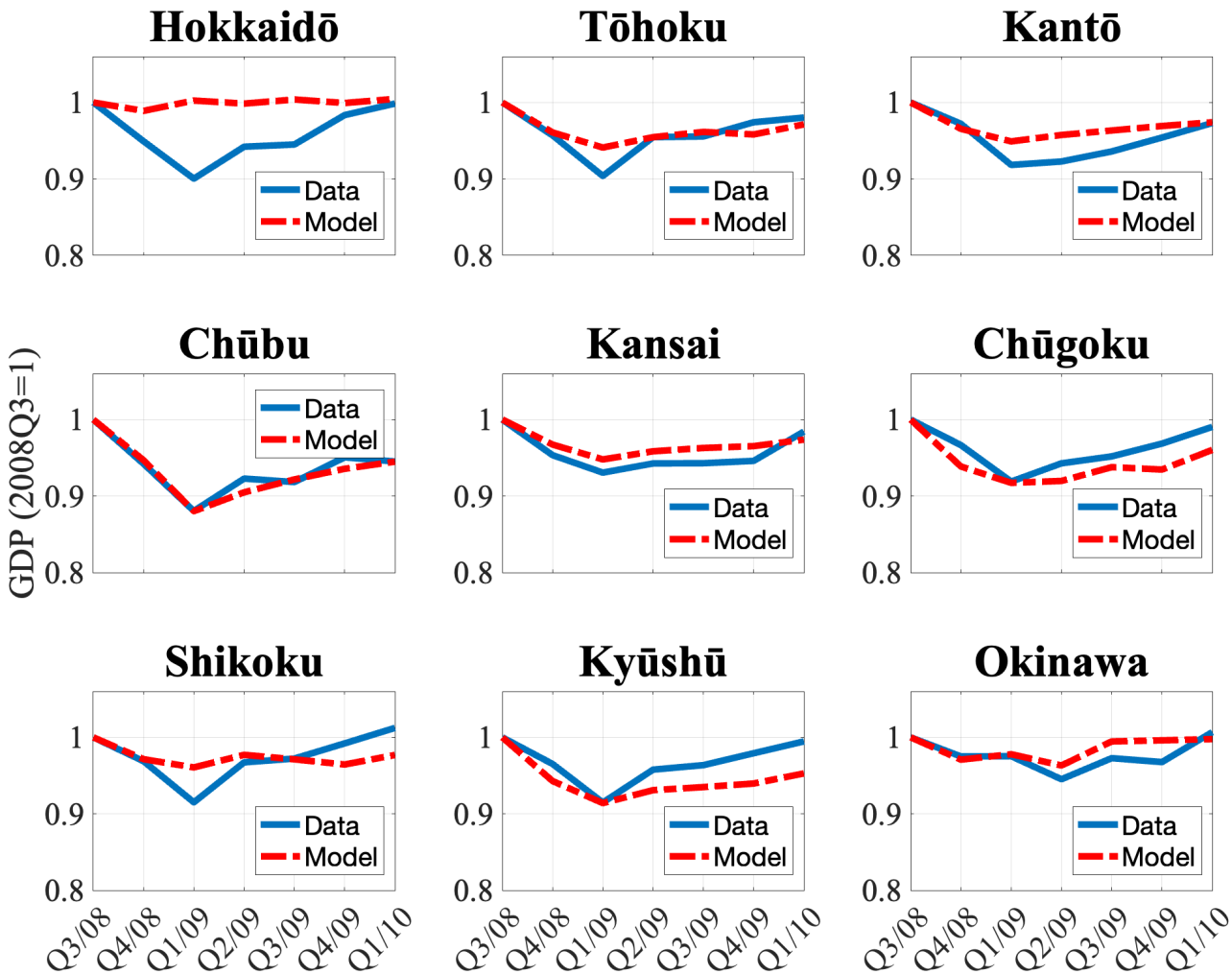
(c) Investment



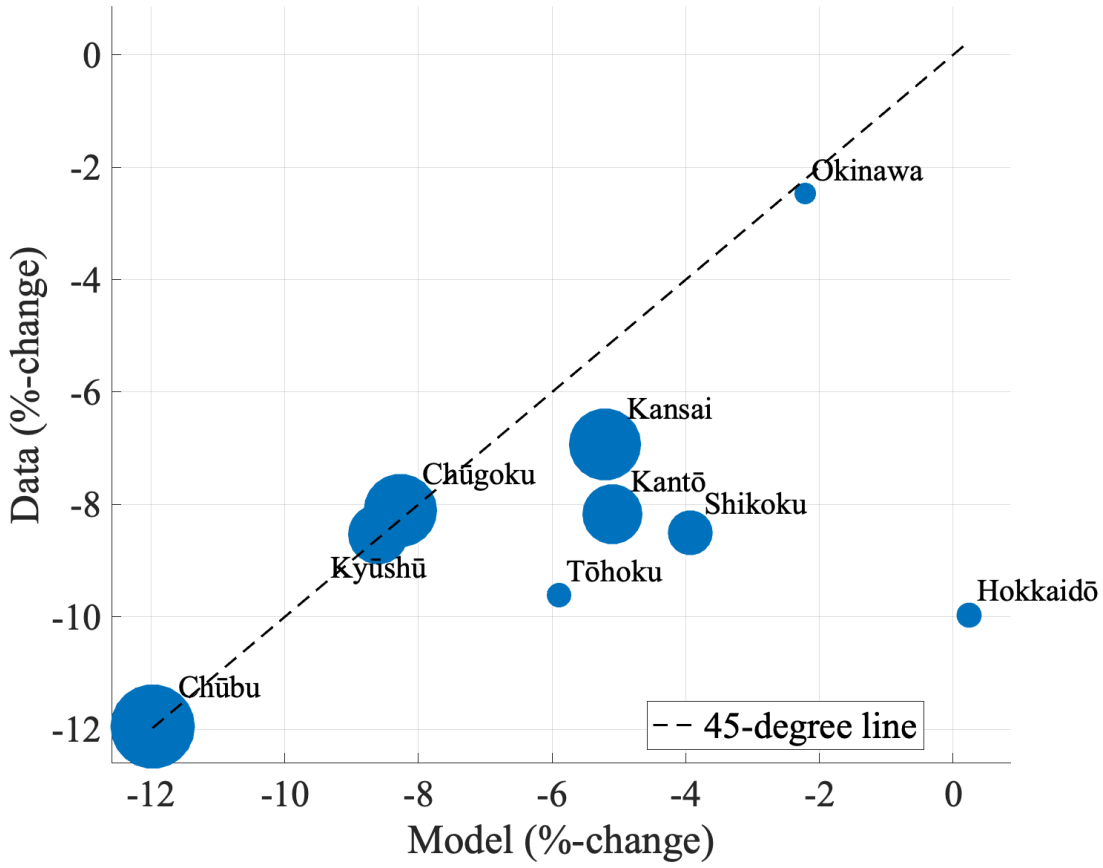
(d) Export



Regional responses



Regional responses



- % change between 2008Q3 and 2009Q1
- The size of the bubble represents export/GDP

Decomposition

- How do export shocks propagate across regions?
- We consider a counterfactual experiment where we feed the export shock to just one sector in one region. Then, we decompose the output change in each region to different channels.

Procedure

- Four demand factors:

$$y_{sj,t} = \int_0^I (c^i_{sj,t} + x^i_{sj,t})di + \int_0^S \int_0^I m^{hi}_{sj,t} didh + y^f_{sj,t}$$

- Domestic consumption and investment demands:

$$c^i_{sj,t} = \xi^i_{sjc} \left(\frac{p_{sj,t}}{P^i_t} \right)^{-\sigma} C^i_t$$

$$x^i_{sj,t} = \xi^i_{sjx} \left(\frac{p_{sj,t}}{P^i_t} \right)^{-\sigma} X^i_t$$

- Domestic intermediate demand (from (h, i)):

$$m^{hi}_{sj,t} = \gamma^{hi}_{sj,t} \left(\frac{p_{sj,t}}{P^{hi}_t} \right)^{-\sigma} M^{hi}_t$$

- Foreign demand:

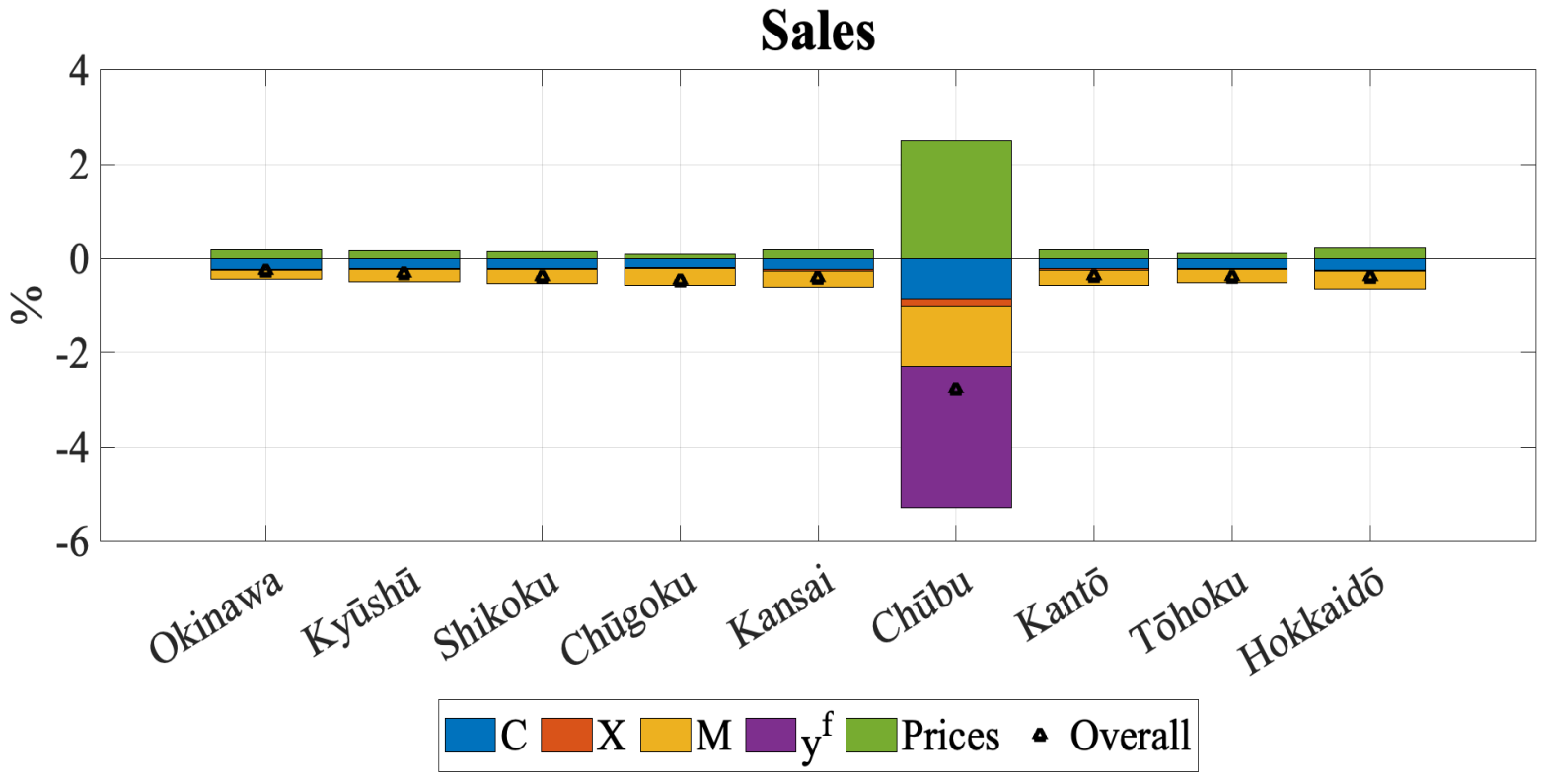
$$y^f_{sj,t} = \omega_{sj,t} \left(\frac{p_{sj,t}}{\bar{P}} \right)^{-\sigma}$$

Procedure

Steps:

1. Compute two economies. (1) baseline (2008Q3) (2) the economy with export shock at 2009Q1, but only one industry and one region (let's say TE industry in Chubu).
2. Consider five factors separately (only change these, keeping the rest as in the baseline):
   - Prices p_{sj} (except for the foreign demand), P^i, and P^{hi} ($\bar{P}$ is fixed because of the small open economy assumption.)
   - Consumption C
   - Investment X
   - Intermediate good M
   - Export y^f

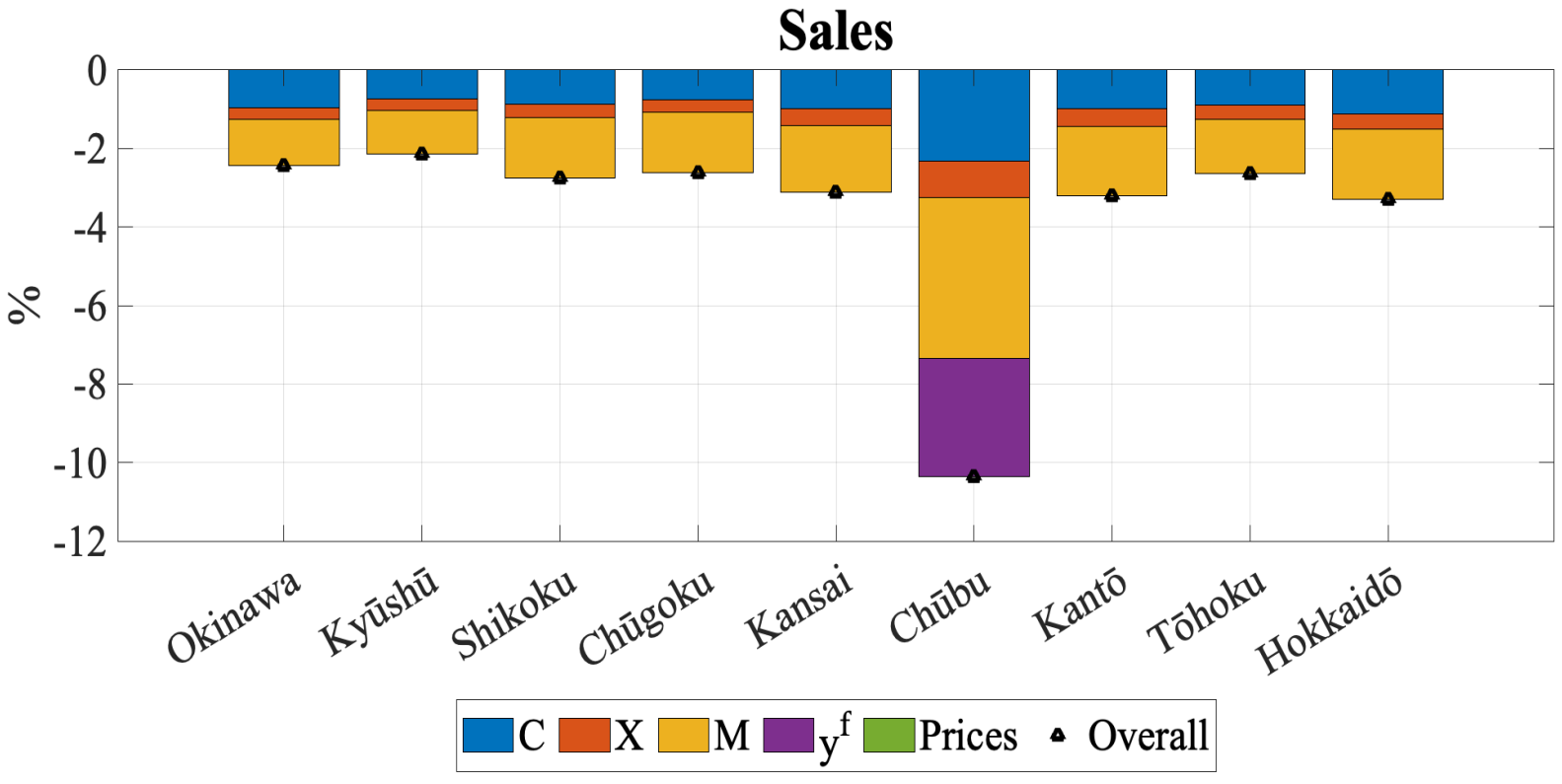
Outcome


Sales
4
2
0
-2
-4
-6
%
Okinawa
Kyūshū
Shikoku
Chūgoku
Kansai
Chūbu
Kantō
Tōhoku
Hokkaidō
C
X
M
y^f
Prices
Overall

Highlight of the propagation mechanism

- In Chūbu, export, M, X, and C all had a negative impact on GDP. Price changes counteract (because the Chūbu goods become cheaper).
- The decline in demand from Chūbu causes M, X, and C in other regions to fall. The price change counteracts.
- Overall, there is a meaningful propagation to other regions. No obvious "gravity" patterns.
- For propagation, both consumption and intermediate-good demand are important (from Chūbu and also the region itself).

The role of fixed prices



The outcome from the fixed-price model

- Suppose that the prices of all goods are fixed at the 2008Q3 level.
- With fixed prices, there are no counteracting price effects.
- The magnitude is quite large; “completely fixed prices” is an extreme assumption.

Conclusion

- We constructed a small open economy with (i) input-output linkage, (ii) inter-regional linkage, and (iii) export demand shocks.
- We quantify the model to Japan during the Great Recession, using the customs data and inter-regional input-output table.
- The model can replicate a substantial decline in output due to the export demand shock.
- For across-regional propagation, both consumption and intermediate-good demand play an important role.
- Price stickiness is quantitatively important.

Extra

#	Industry (our classification)	JIP(2008)	A_s	α_s
1	Agriculture, Forestry, Fisheries	1-6	1.000	0.71
2	Mining and Quarrying of Stone and Gravel	7	0.497	0.72
3	Food and Beverage	8-14	2.596	0.79
4	Textile Mill Products	5	2.078	0.66
5	Pulp, Paper, and Paper Products	18	1.631	0.82
6	Chemical Products	23-29	1.975	0.86
7	Petroleum and Coal Products	30,31	3.149	0.98
8	Ceramic, Stone, and Cray Products	32-35	0.813	0.66
9	Iron and Steel	36,37	3.412	0.90
10	Non-Ferrous Metals	38,39	1.271	0.83
11	Fabricated Metal Products	40,41	2.154	0.63
12	General-Purpose Machinery	42-45	2.879	0.72
13	Electrical Machinery	46-53	3.165	0.75
14	Transportation Equipment	54-56	5.876	0.82
15	Information and Communication Electronics Equipment	57	1.188	0.67
16	Miscellaneous Manufacturing Products	16,17,19-22,58,59	2.092	0.69
17	Construction	60,61,72	15.465	0.77
18	Electricity, Gas, Heat Supply and Water	62-66	4.330	0.81
19	Whole Sale and Retail Trade	67,68	18.296	0.50
20	Finance, Insurance, and Real Estate	69-71	8.289	0.50
21	Transportation	73-77	4.350	0.59
22	Information and Communication	78,79, 90-93	4.308	0.67
23	Education, Medical, Health Care, and Welfare	80-84,98-107	7.578	0.39
24	Services for Businesses	85-88,	5.754	0.60
25	Services for Consumers	89,94-97	4.802	0.57
26	Others	108	1.389	0.98