Input Linkages and the Transmission of Shocks: Firm-Level Evidence from the 2011 Tōhoku Earthquake

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Motivation

- **Question 1:** What is the role of trade and multinational production (MP) in business cycle comovement?
  - Fact 1: Trade and MP large and growing
  - Fact 2: High degree of business cycle synchronization among OECD countries

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  - Fact 1: Trade and MP large and growing
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- **Question 2:** Do imported input linkages matter for spillovers?
  - Transmission is governed critically by the production elasticity of substitution

$$x_t = \left[(1-\mu)^{\frac{1}{\psi}} F_{D,t}(\cdot)^{\frac{\psi-1}{\psi}} + \mu^{\frac{1}{\psi}} IM_t^{\frac{\psi-1}{\psi}} \right]^{\frac{\psi}{\psi-1}}$$

Outline and Preview of Results

- **What we do:**
  - Evaluate the effect of shocks to imported inputs on production
  - Use new firm-level data: multinational status and input trade
  - Natural experiment: March 2011 Tōhoku Earthquake

- **Results:**
  - Most directly impacted firms: JPN multinationals
    - Reduced form result: elasticity of roughly zero
  - Structural estimates of production function:
    - Elasticity of 0.2 between Japanese and other material inputs; 0.03 between materials and capital/labor

- **Implications:**
  - Calibrated IRBC model with complementarity of multinational input trade ↑ value-added comovement by as much as 18 p.p.

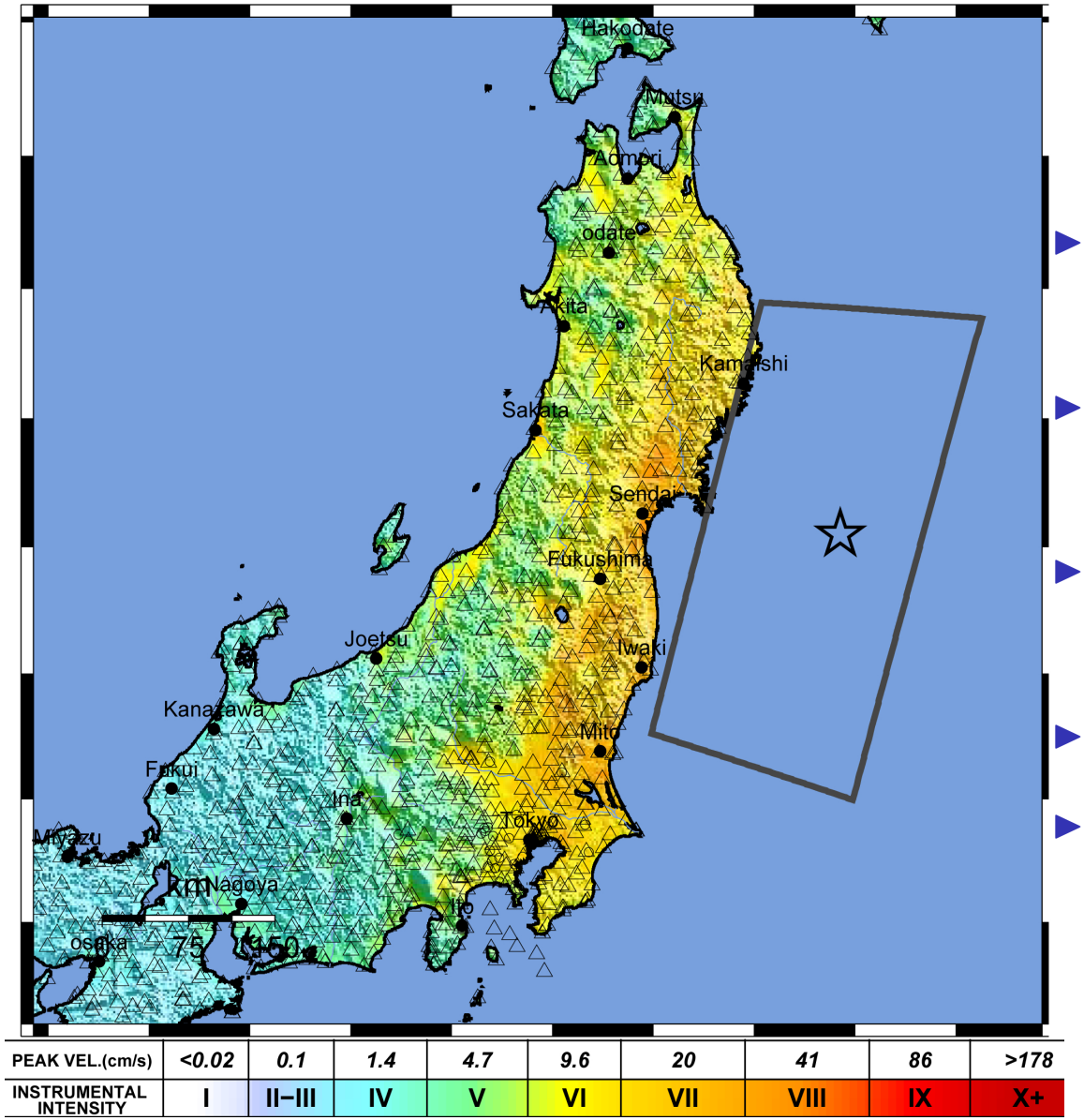
Related Literature

- Global Organization of the Firm (Horizontal vs Vertical FDI)
  - Ramondo, Rappoport and Ruhl (2011), Hanson, Mataloni and Slaughter (2005)
  - Keller and Yeaple (2013), Desai, Foley and Hines (2004)

- Multinationals/Vertical Integration and Business Cycle Comovement
  - Arkolakis and Ramanarayanan (2009), Kose and Yi (2001), di Giovanni and Levchenko (2010), Johnson (2014), Bems and Johnson (2014)
  - Burstein, Kurz and Tesar (2008), Peek and Rosengren (1997, 2000), Kleinert, Martin and Toubal (2012), Cravino and Levchenko (2014)

- Effects of Trade/MP on volatility/productivity
  - di Giovanni and Levchenko (2012), di Giovanni, Levchenko and Mèjean (2013)
  - Koren and Tenreyro (2013), Kurz and Senses (2013), Caselli et al (2014)

2011 Tōhoku Earthquake

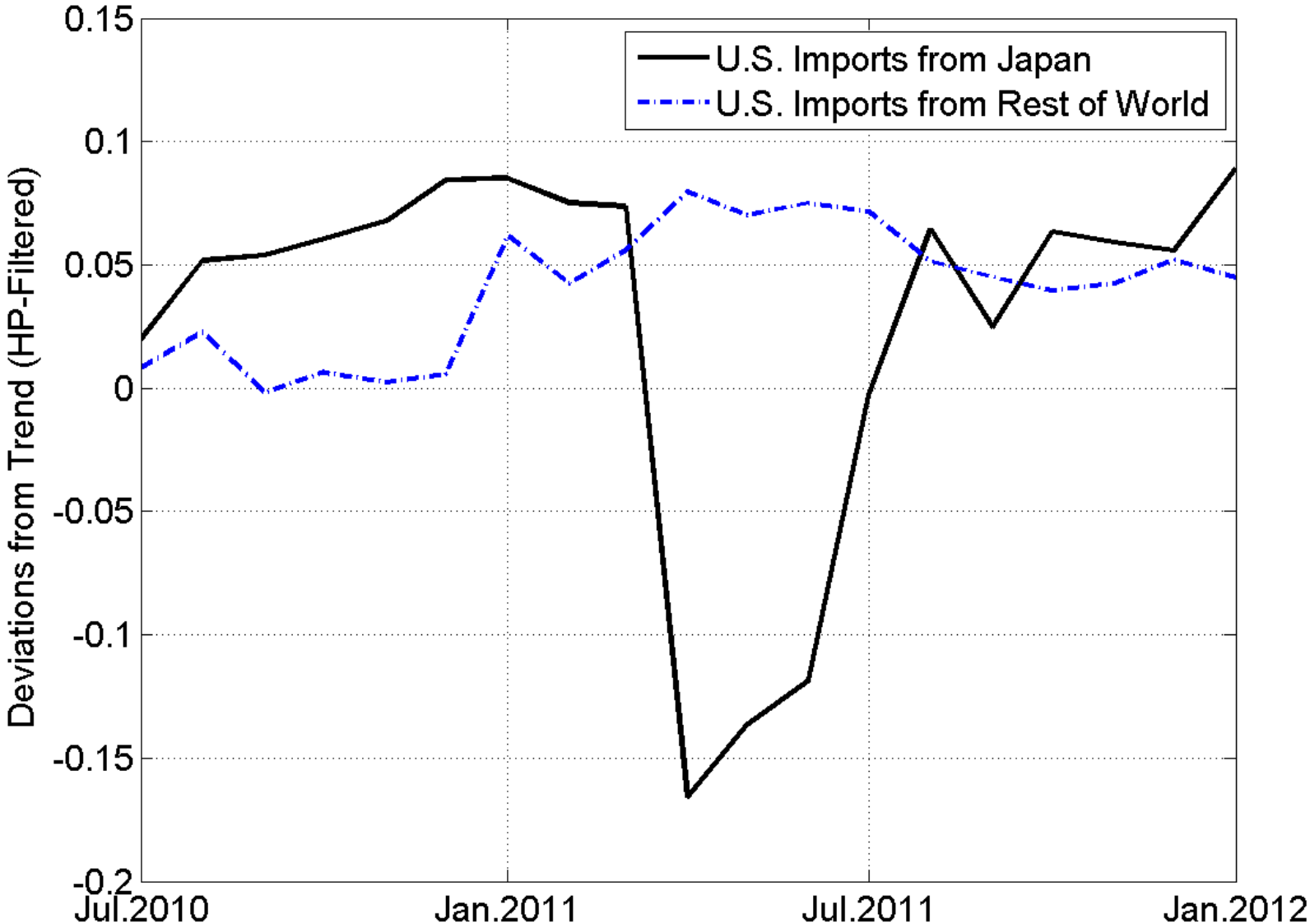


Source: USGS

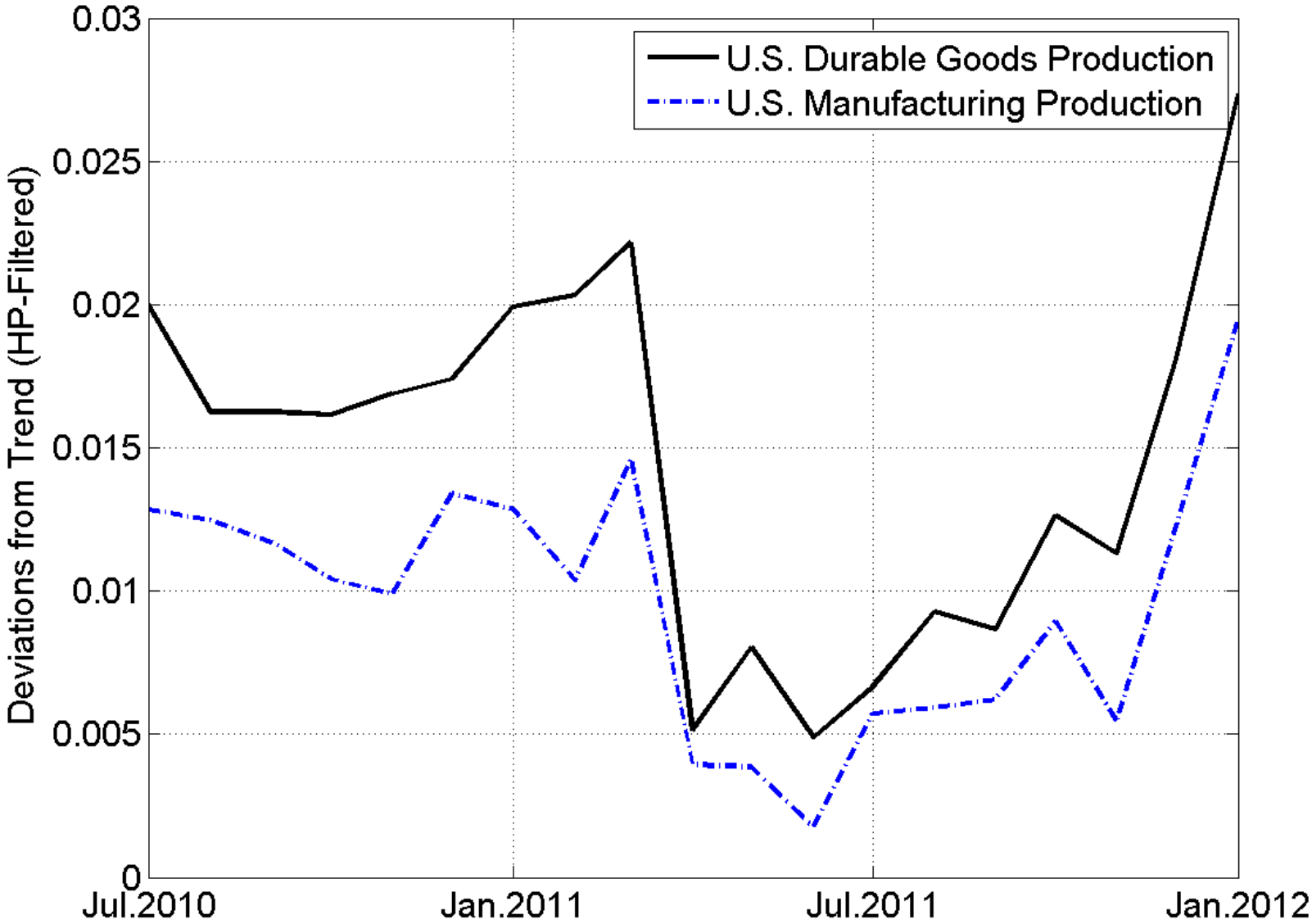
- Earthquake measured 9.0 M_w
- Tsunami: Wave Heights Exceeding 7m
- 1% of Physical Capital Damaged or Destroyed
- Significant death toll
- Widespread power outages

Large Drop in Japanese Industrial Production

U.S. Imports from Japan Fall



Dip in U.S. Industrial Production



Outline

1. The 2011 Tōhoku event in context
   - Background and aggregate impacts

2. Firm-level analysis
   - Empirical evidence for transmission mechanisms

3. Structural model of input linkages
   - Key assumptions
   - Estimation
   - Identification

4. Implications

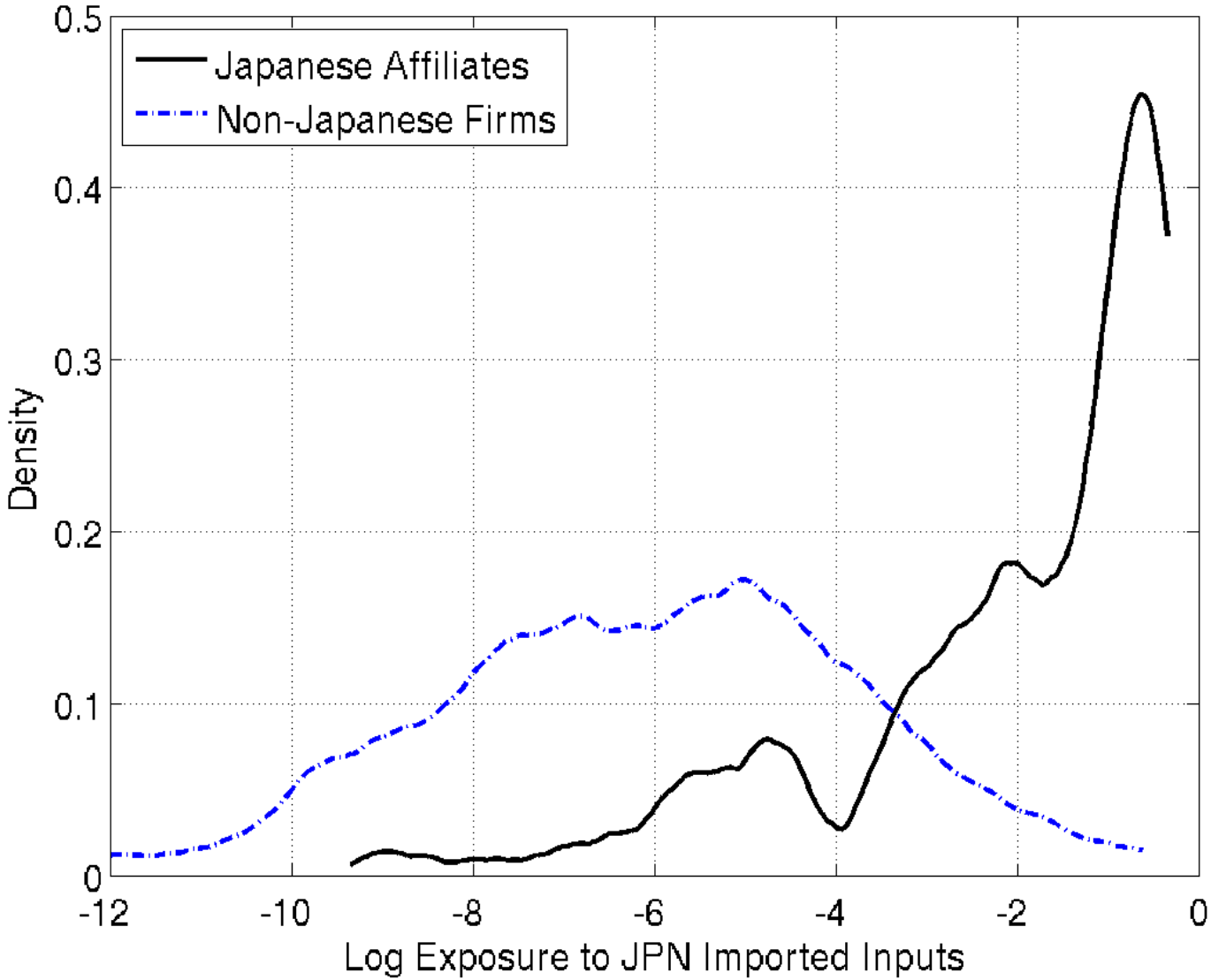
Census Data: Description

- Longitudinal Business Database: restricted to manufacturing firms
  - Annual employment/payroll (quarterly values taken from BR)
- LFTTD: trade in goods by source/destination
- Census of Manufacturers (CM): inventories and sales (2007)

- Two novel extensions to these data resources
  1. Multinational indicators from international corporate directories: LexisNexis and Uniworld

     ▸ Multinationals in Census ▸ Matching Procedure
  2. Separation of firm-level imports by expected use: CM Products Trailer File: ▸ Details

Firm-Level Exposure to Japan



Ownership vs Exposure

Event study specification: Treatment Effects

Goal: The average treatment effect of being Japanese affiliate

- Use other multinationals as control group
- Propensity score reweighting Details

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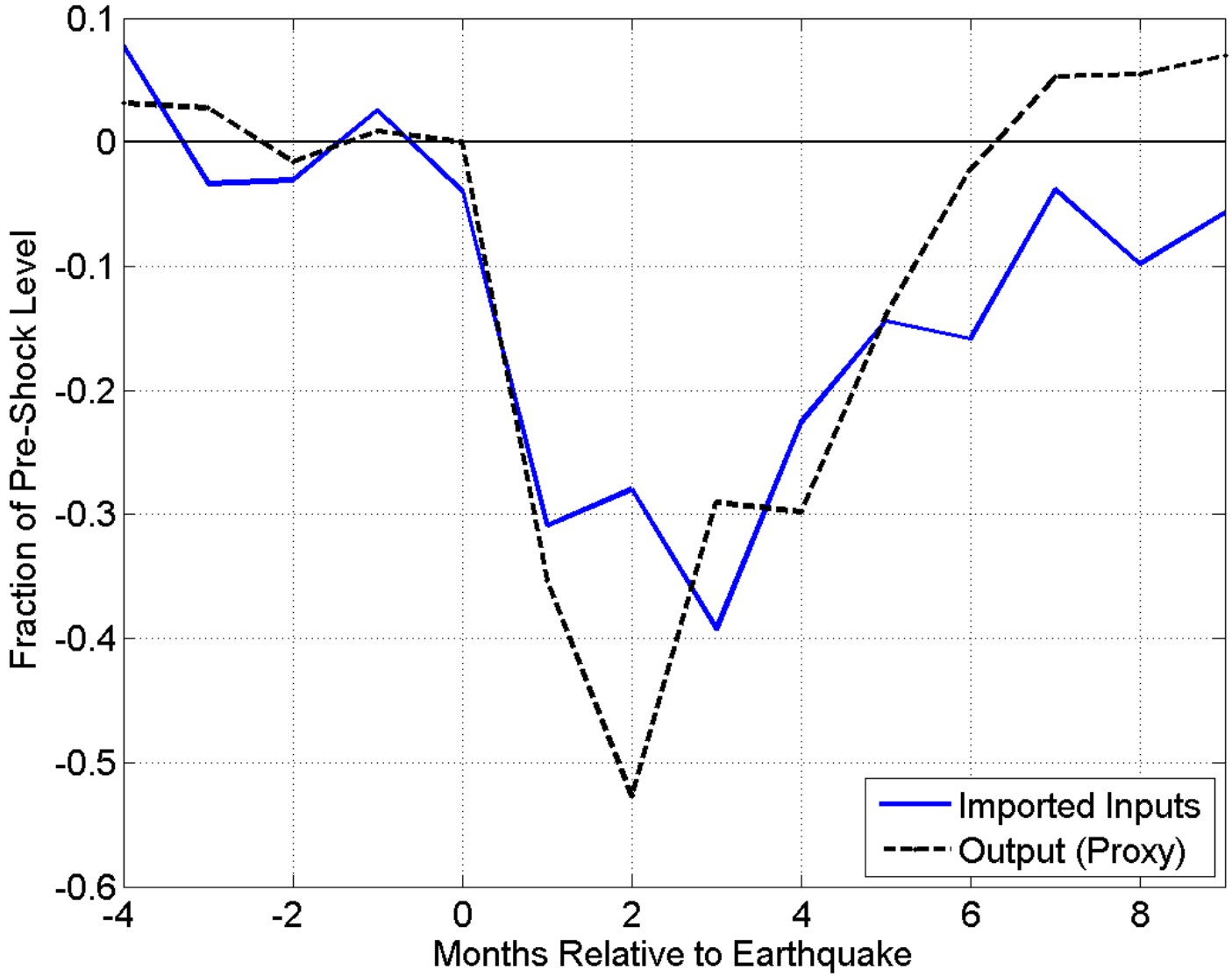
$$V_{i,t}^{M} = \alpha_i + \sum_{p=-14}^{9} \gamma_p E_p + \sum_{p=-14}^{9} \beta_p E_p \text{JPN}_{i,p} + u_{i,t}$$

- $V_{i,t}^{M}$: int. imports of firm i in month t (after removing linear, firm-specific trend through Feb. 2011);
- E_p: indicator for month relative to Tōhoku event (March 2011);
- $\text{JPN}_{i,p}$: indicator for Japanese-owned firm.

U.S. Affiliates of Japanese Multinationals



Alternative Specification

Standard Errors

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Model

Production Function

$$x_{it} = \phi_i \left[\mu_i^{\frac{1}{\zeta}} \left[(k_{it})^{\alpha} (l_{it})^{1-\alpha} \right]^{\frac{\zeta-1}{\zeta}} + (1-\mu_i)^{\frac{1}{\zeta}} M_{it}^{\frac{\zeta-1}{\zeta}} \right]^{\frac{\zeta}{\zeta-1}}$$

where

$$M_{it} = \left(\nu_i^{\frac{1}{\omega}} \left(m_{it}^{-J} \right)^{\frac{\omega-1}{\omega}} + (1-\nu_i)^{\frac{1}{\omega}} \left(m_{it}^{J} \right)^{\frac{\omega-1}{\omega}} \right)^{\frac{\omega}{\omega-1}}$$

- m_{it}^{J}: Japanese intermediate inputs with weight $(1-\nu_i)$
- m_{it}^{-J}: non-Japanese intermediate inputs with weight ν_i
- ω: elasticity of substitution between intermediates
- ζ: elasticity of substitution between intermediates and capital-labor aggregate

Model

Assumptions

- Two six month periods
  - Pre-Tsunami: firm optimizing, FOCs hold
  - Post-Tsunami: Delivery of Japanese inputs possibly exogenous, can't use FOCs for estimation
- Post-Tsunami, the capital stock is fixed
- The production function always holds

Structural Estimation

- Back out ν_i and μ_i from FOCs with data from pre-Tsunami period, and the ϕ_i from data on production
- Estimate the production function directly with these values and data for post-Tsunami period for elasticities

Estimation

Our output proxy is defined such that:

$$\kappa_i = \frac{V_{it-1}^{NA}}{p_{it-1}x_{it-1}}$$

We assume that post-Tsunami:

$$\begin{aligned}\ln V_{it}^{NA} &= \ln \kappa_i p_{it} x_{it} + u_{it} \\ &= \ln(\kappa_i \phi_i) + \ln\left(\left[\mu_i^{\frac{1}{\zeta}}\left(p_{it}^x K_{it}^{\alpha} L_{it}^{1-\alpha}\right)^{\frac{\zeta-1}{\zeta}} + (1-\mu_i)^{\frac{1}{\zeta}}\left(p_{it}^x\right)^{\frac{\zeta-1}{\zeta}}\left(M_{it}\right)^{\frac{\zeta-1}{\zeta}}\right]^{\frac{\zeta}{\zeta-1}}\right) + u_{i,t}\end{aligned}$$

where u_{it} is a normal error, and $E\left[u_{it}|X_i\right] = 0$.

Under this exogeneity assumption, the above equation can be estimated via maximum likelihood

Estimation Results

Elasticity Estimates

	Japanese Multinationals	Non-Japanese Multinationals
ω	0.201	0.624
(elast. m^J & m^{-J})	(0.133)	(0.164)
ζ	0.032	0.038
(elast. M & k, l)	(0.279)	(0.142)
Number of Firms	105	304

Source: CMF, LFTTD, DCA, and UBP

Bootstrapped Standard Errors

Estimation Results

Sample Details

	Japanese Multinationals	Non-Japanese Multinationals
Number of Firms	105	304
Share of Total Trade		
JPN int imports	0.60	0.23
Non-JPN int imports	0.02	0.66
N.A. exports	0.08	0.47

Source: CMF, LFTTD, DCA, and UBP

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Other Results, Robustness, and Implications

Other Results / Robustness

- Mis-measurement of Firm Production Details
- Inventories Details
- Price Movements Details
- Domestic Inputs Details
- Strategic Interaction Details
- Geographic Heterogeneity Details

Implications

- External Validity
- Results from calibrated IRBC model

External Validity

Other foreign affiliates exhibit similar importing behavior:

- 12 percent of cost due to imported inputs from source country
- 45 percent of imports from source country
- Large majority is intra-firm

A low elasticity for imported inputs by foreign affiliates is not that surprising:

- 70 percent of input trade is intra-firm (specialized products embodying firm-specific knowledge)
- Affiliate trade is highly complex: import $\approx$ 230 unique (HS10) products each month

Implications for IRBC Models

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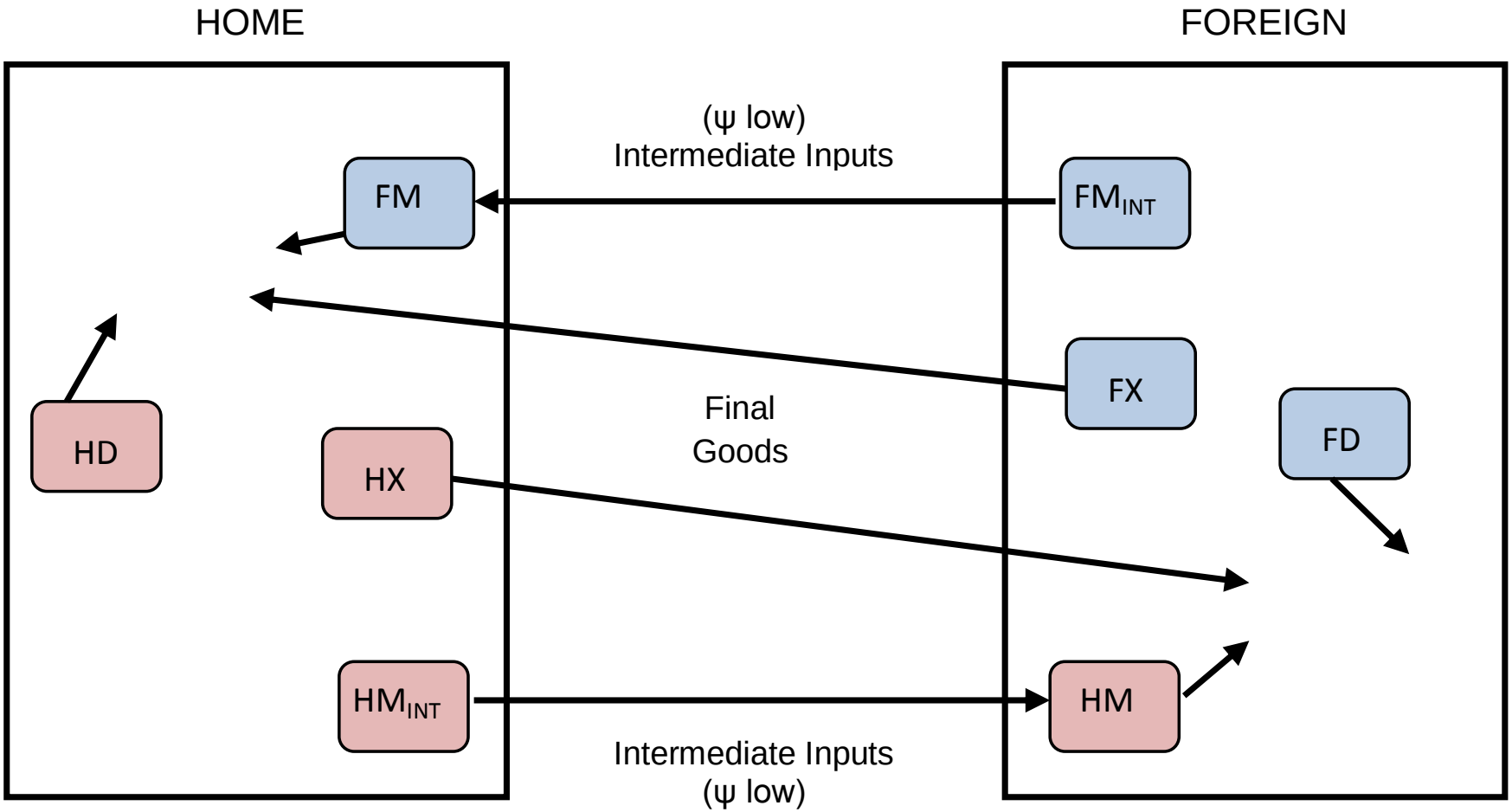

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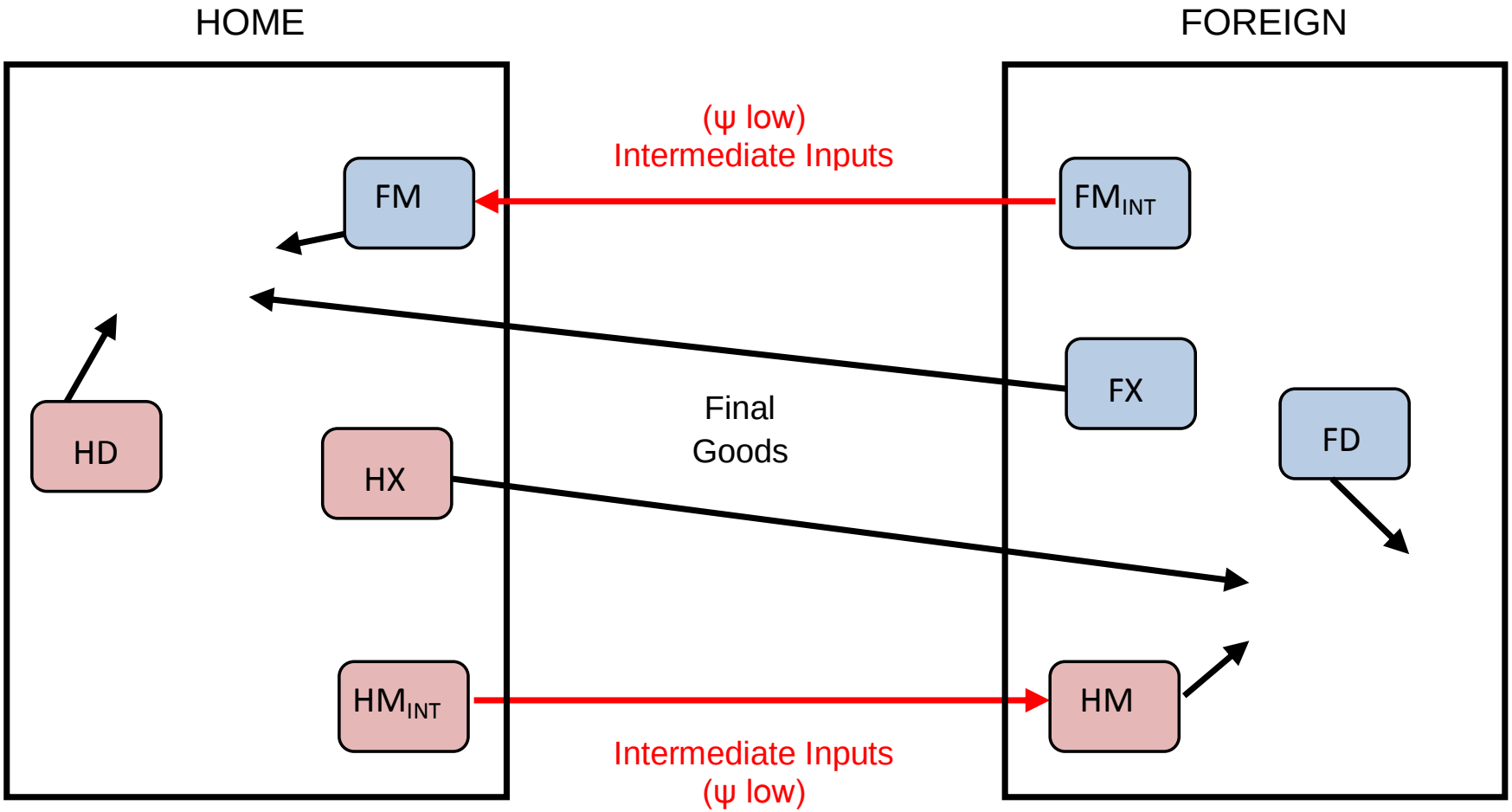

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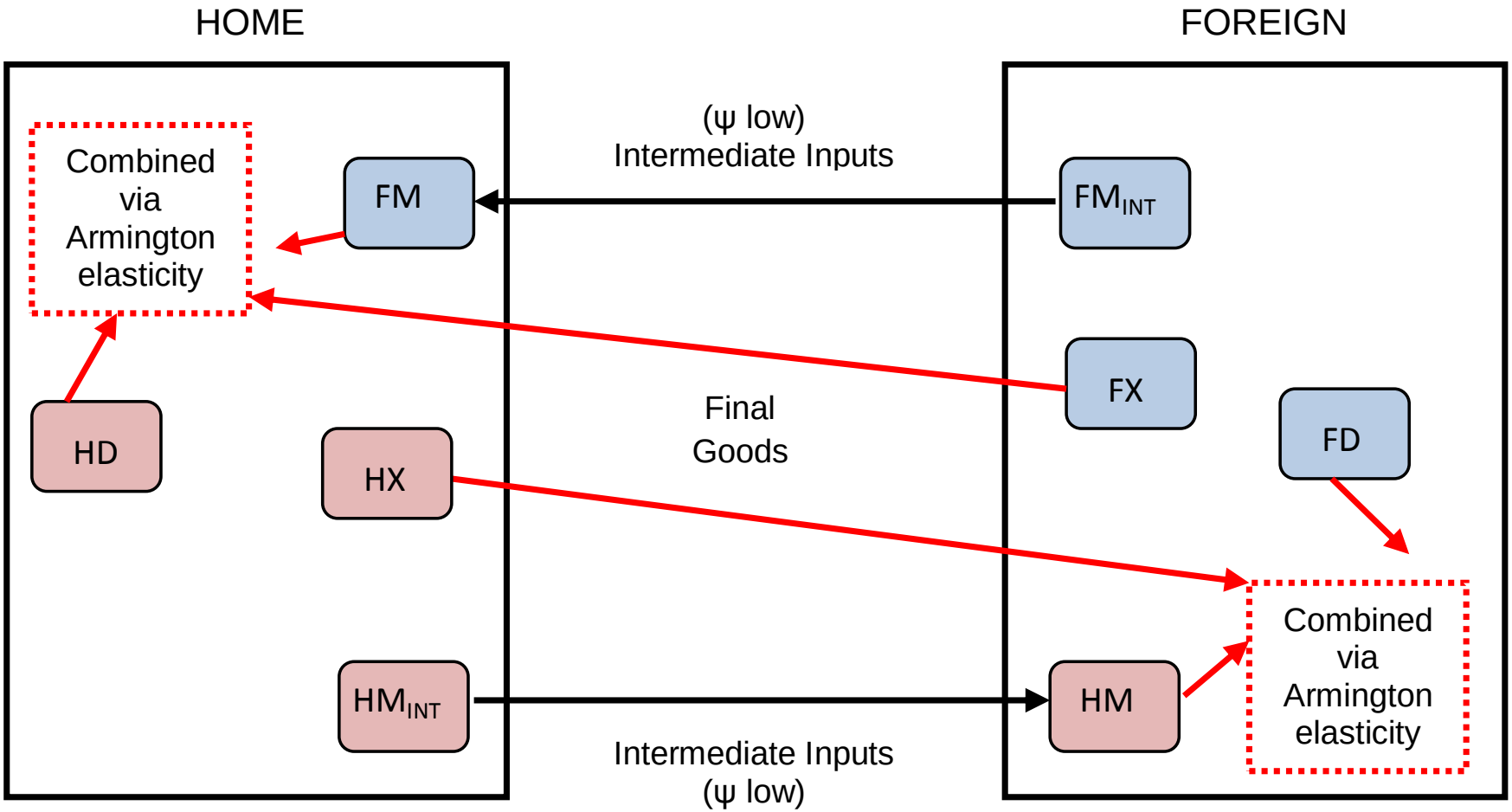

Model Moments

Model Moment	Data	Baseline	No M.P.
Contemporaneous Correlation of:			
GDP^H, GDP^F	0.59	0.20	0.02
C^H, C^F	0.23	0.34	0.38
EX^H, EX^F	0.63	0.53	0.11
EX^H_{INT}, EX^F_{INT}	?	0.64	—
TB^H, GDP^H	-0.17	0.65	0.73

Impulse Responses

Conclusion and Discussion

Summary and Key Findings:

- We estimate the elasticity of substitution for imported inputs
- Natural experiment to overcome classic identification problem
- Evidence for the transmission of the shock to the U.S. via the rigid supply chains of multinational firms

Implications:

- Complementarities in cross-country inputs an important "real" source of cross-border spillovers
- Potential for the propagation of shocks to upstream/ downstream firms
- Policies affecting supply linkages must be announced sufficiently prior to implementation to prevent disruptions

Country	Correlation of Country Real GDP with: U.S. GDP		World GDP	
	1980-1995	1995-2010	1980-1995	1995-2010
United States	1.00	1.00	0.28	0.71
Australia	0.62	0.49	0.10	0.31
Austria	-0.07	0.75	0.45	0.65
Belgium	0.23	0.78	0.52	0.70
Canada	0.81	0.84	0.13	0.64
Denmark	0.34	0.80	0.11	0.72
Finland	0.26	0.82	0.11	0.75
France	-0.07	0.80	0.46	0.74
Germany	-0.12	0.72	0.48	0.77
Italy	0.29	0.65	0.48	0.69
Japan	0.07	0.71	0.50	0.68
Korea, Rep.	0.02	0.17	-0.02	0.39
Netherlands	0.60	0.73	0.48	0.77
Norway	0.49	0.43	0.29	0.49
Spain	-0.02	0.66	0.46	0.67
Sweden	0.41	0.86	0.22	0.67
Switzerland	0.40	0.74	0.41	0.76
United Kingdom	0.47	0.80	-0.11	0.64
Median	**0.29**	**0.74**	**0.35**	**0.68**

Source: International Financial Statistics, IMF.

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Mapping $\frac{dlnx}{dlnM^J}$ into ψ

We measure ψ using $\frac{dlnx}{dlnM^J}$:

$$\frac{dlnx_t}{dlnM_t^J} = \frac{\mu^{\frac{1}{\psi}} \left(\frac{M_t^J}{F_D(\cdot)}\right)^{\frac{\psi-1}{\psi}}}{\left((1-\mu)^{\frac{1}{\psi}} + \mu^{\frac{1}{\psi}} \left[\frac{M_t^J}{F_D(\cdot)}\right]^{\frac{\psi-1}{\psi}}\right)}$$

Assuming i) constant relative input prices, ii) an aggregate input bundle M^J that reflects an optimal mix of subcomponents, and iii) M^J is (weakly) scarce, then $\frac{dlnx}{dlnM^J}$ is a monotone function of ψ:

$$\frac{\partial \frac{dlnx_t}{dlnM_t^J}}{\partial \psi} < 0 \qquad \text{and} \qquad \lim_{\psi \to 0^+} \frac{dlnx_t}{dlnM_t^J} = 1$$

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Data on Multinational Firms

1. BEA Surveys
   - Only multinational firms, not linked to universe of other firms in the U.S. (Hence, no comparison groups)
   - Linking across years is problematic
   - Yeaple (2009), Ramondo, Rappaport, Ruhl (2011), Helpman, Melitz, Yeaple (2003)
2. Identification via Foreign Trade Transactions (LFTTD)
   - Unable to distinguish U.S.-based vs Foreign-based multinational firms
   - Ignores ownership levels (threshold is fixed at 6-10%)
   - Rules out non-trading multinationals by assumption
   - Bernard, Jensen, Redding, Schott (2010), Bernard, Jensen, Schott (2006, 2009)
3. Others
   - Alfaro and Charlton (2009), Doms and Jensen (1998), Rowland and Tesar (2004), Bernard and Jensen (2007), Fort (2012)

International Directories of Corporate Activity

Utilize directories of international corporate structure to supplement existing firm-level datasets

1. LexisNexis Directory of Corporate Affiliations
   - Annual (1994-2011) information on public/private firms: roughly 70,000 parent firms in 2007.
   - Contains both U.S. based and Foreign-based parent firms, including all affiliates, regardless of location.
   - Disadvantages: Inclusion criteria has revenue threshold ($>$ 10 million 1994-2002; $>$ 1 million 2003-2011)
2. Uniworld Business Publications
   - Two Directories: 1) Directory of Foreign Firms Operating in the U.S. and 2) American Firms Operating in Foreign Countries
   - Triennial (1989-1995); Biennial (1995-2012)

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Classifying Firm-Level Trade

- CMF-Products Data: product-level shipments by establishment
- **Step 1:** Construct set of "final goods" products for a given industry. Let:
  - X_{pj} total shipments of product p in industry j
  - X_j total shipments in industry j
  - Then $S_{pj} = \frac{X_{pj}}{X_j}$ is share of industry output by product p
  - Final goods for industry j are any p where $S_{pj} \geq W$

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  - Final goods for industry j are any p where $S_{pj} \geq W$
- **Step 2:** Classify a firm i's imports (M_{ij}) (non-Census years):

$$\left.\begin{aligned} M_{ij}^{int} &= \sum_{p \notin P_j} M_{ipj} \\ M_{ij}^{fin} &= \sum_{p \in P_j} M_{ipj} \end{aligned}\right\} \quad \text{where} \quad P_j = \{p \mid S_{pj} \geq W\}.$$

Classifying Firm-Level Trade: Example

NAICS Industry 333120: Construction Machinery Manufacturing

- Final Product: Product 333120 Construction Machine Manuf.
  - Share of total Production in Industry 333120 is 0.81.
  - Consists of Power Cranes, Shovels, Excavators, Coal Haulers, Mixers, Pavers, Tractor Shovel Loaders, Construction Wheel and Crawler Tractors, Motor Graders

- All others classified as intermediates. These *could* include:
  - 333612 - Mechanical Speed Changers, Gears
  - 336350 - Transmissions and Parts
  - 333996 - Fluid Power Pumps
  - 332912 - Fluid Power Valves
  - 333924 - Portable Loading Docks
  - 333513 - Die-Casting Machines (Punching, Shearing, Bending, etc)
  - 333613 - Power Transmission Equipment (Plain Bearings, Clutches, Couplings, Joints, Drive Chains)

Classifying Firm-Level Trade: Results

Sensitivity to Threshold Value W:

	Threshold Values		
	$W = 0$	$W = 0.1$	$W = 0.2$
Number of Final Good Products per Industry			
Median	19	1	1
Mean	25	1.52	1.14
Min	1	1	0
Max	154	6	3
Implied Share of Intermediate Inputs			
Imports	60.9	63.90	63.97
Exports	52.0	54.96	55.04

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Probabilistic Record Linking to U.S. Census Bureau Business Register

- No common firm or establishment identifier requires matching based on name and address information
- Due to misspellings, alternate name and address conventions, etc, one must allow for non-exact matches.

Utilize a multi-variable weighted bigram matching algorithm

- Assigns score based on the percentage of bigram matches between two potential records in corresponding datasets
- Use name, street address, city, state, and zip code
- In general, only accept matches with $> 95\%$ matching score
- Supplement with "Clerical Review" to maintain high degree of accuracy and coverage ▸ Details ▸ Back

Details on Probabilistic Record Linking

Table A1. Match Statistics: 2007

	# of Establishments	Matched to B.R.	Percent Matched
Total	112,346	81,656	0.73
U.S. Multinationals	22,500	16,396	0.73
Foreign Multinationals	10,331	7,555	0.73

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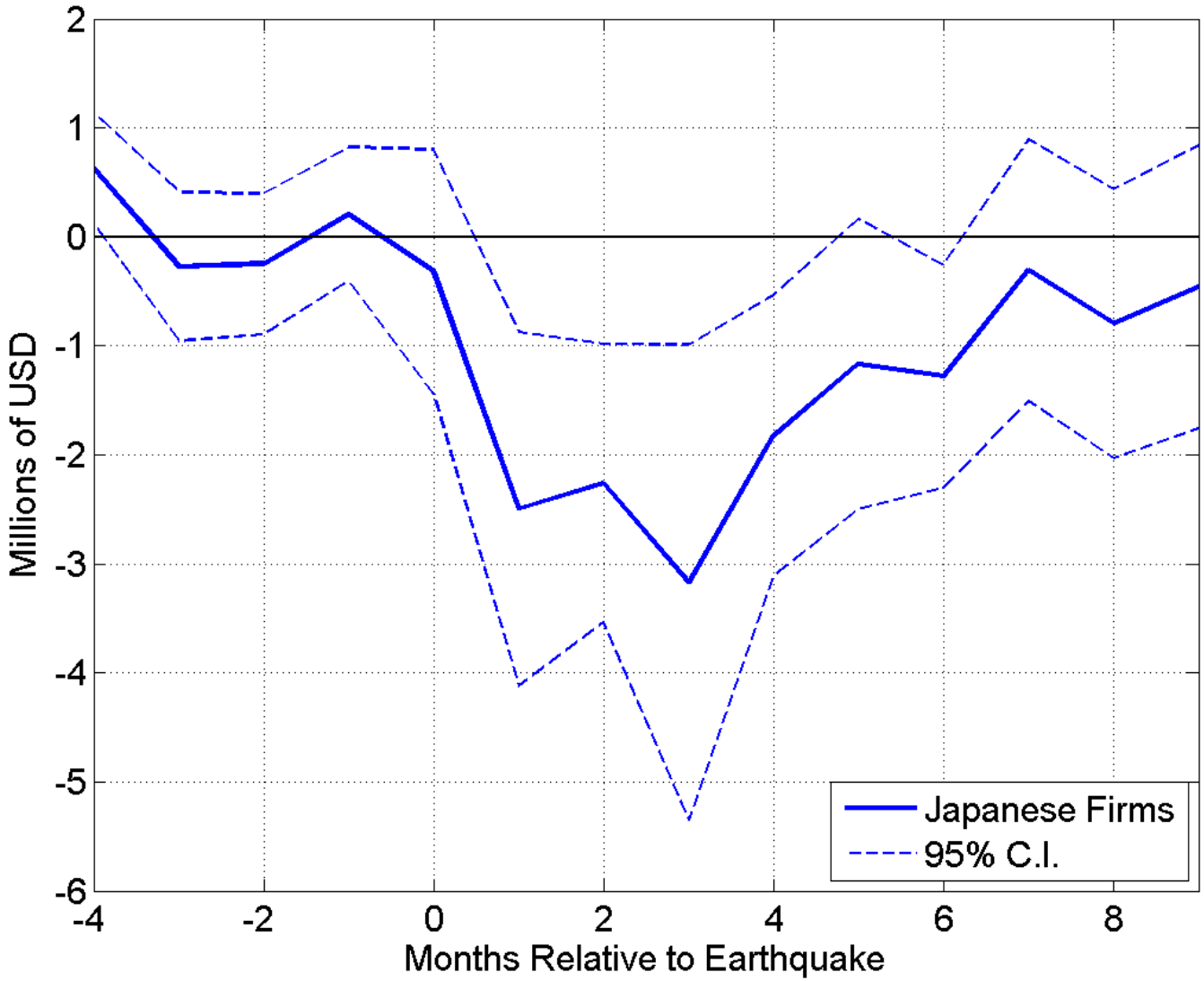
Imported Intermediates of JPN Affiliates



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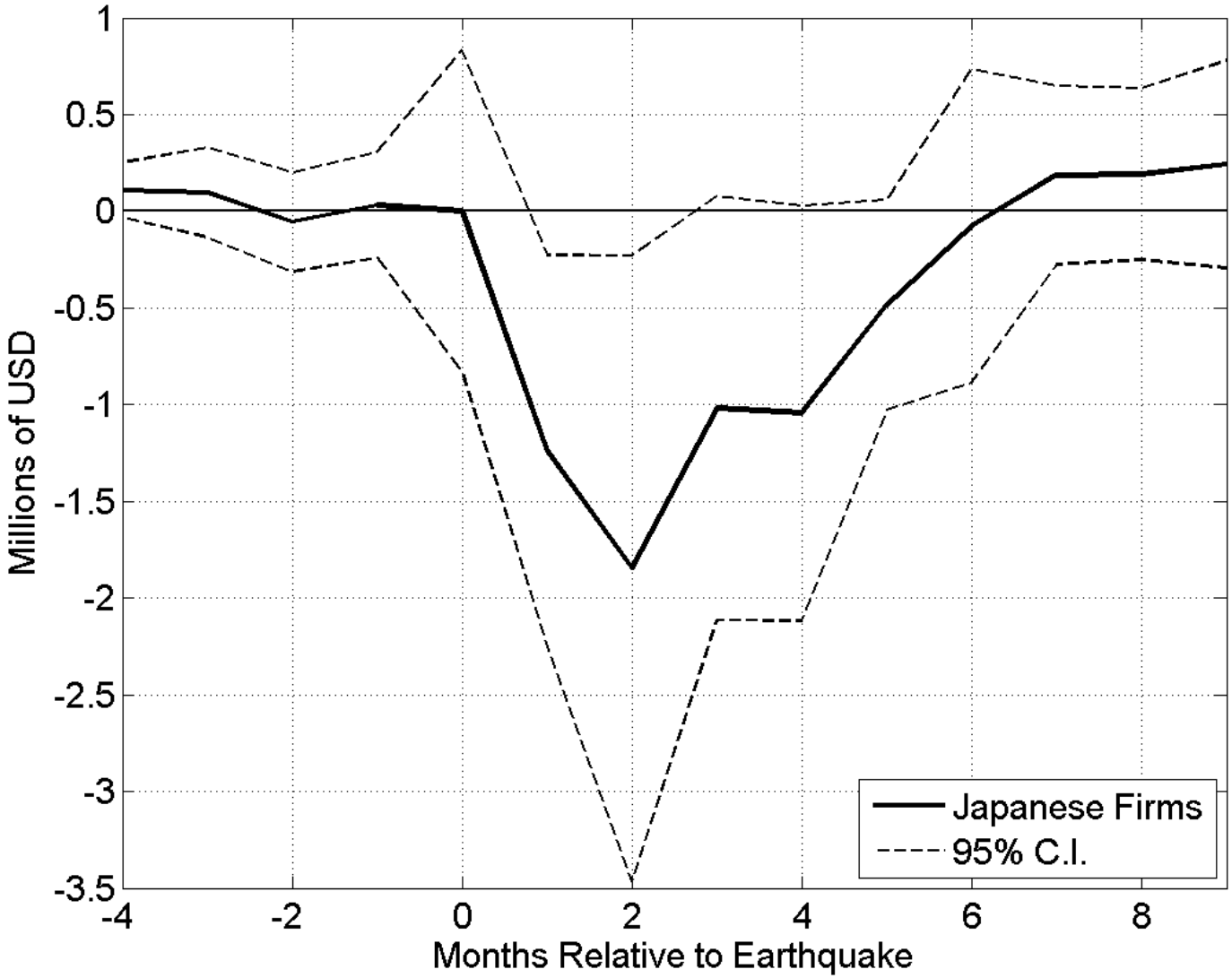
Output (Proxy) of JPN Affiliates



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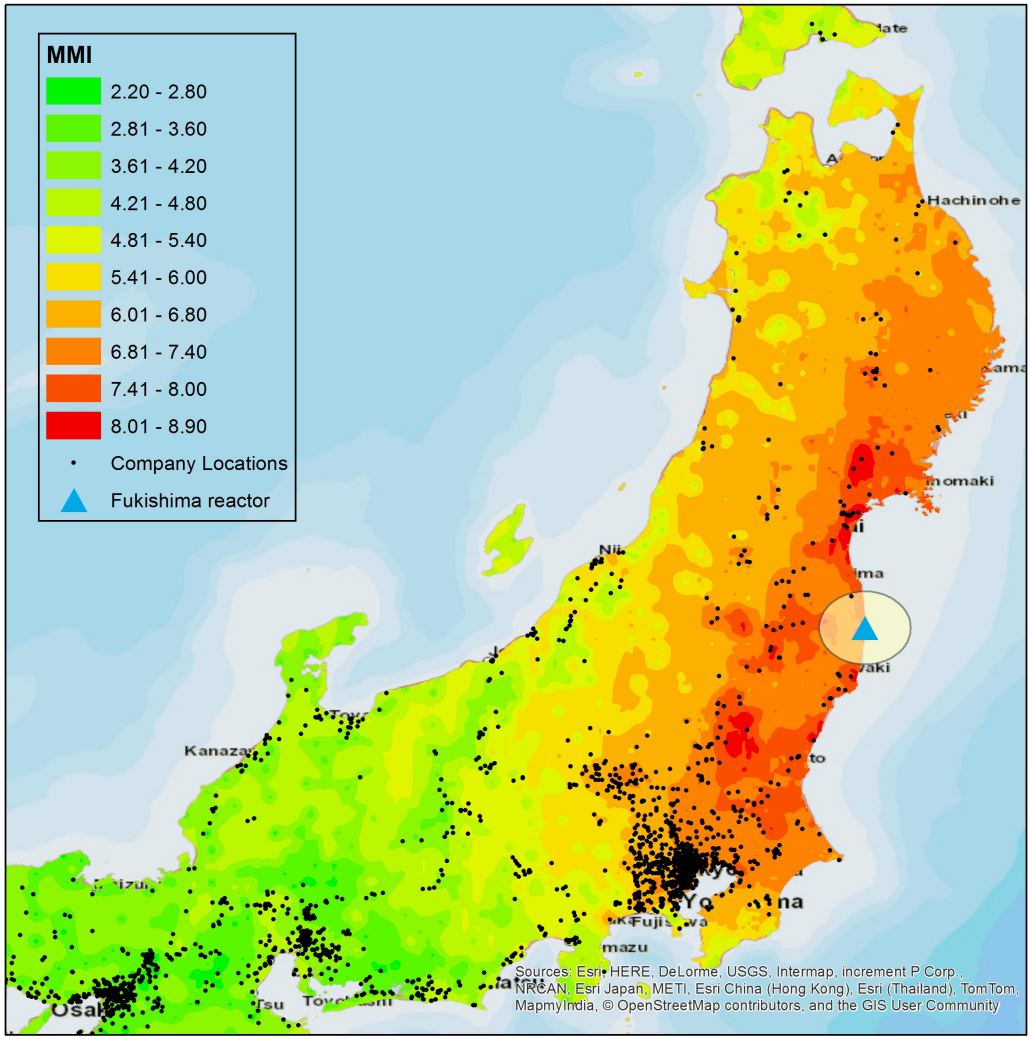
Modified Mercalli Index



Source: USGS and LexisNexis/Uniworld

Pairing with GIS Information

- DCA Data: Geocode JPN addresses of any firm with U.S. operations
- Pair with earthquake intensity measure (inverse distance-weighted avg within 10km radius)
- Firm-level averages in Japan, mapped to U.S. locations

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Transmission of Shock: Which Firms?

Which Firms Were Affected?

- Define disruption to output (proxy) as:
  - $X_{ik}^{D} = 1$ | N.A. exports 20% below trend for Apr-Aug 2011

Evaluating Probability of Disruption (Probit)

$$Pr(X_{ik}^{D} = 1) = \Phi\left[\beta_1 \text{JPN}_{ik} + \beta_2 Exposed_{ik} + \beta_3 MMI_{ik} + \gamma_k\right]$$

- $\text{JPN}_{ik} = 1$ if firm is a Japanese affiliate
- $Exposed_{ik} = 1$ if firm has 2010 "cost" share ≥ 0.05
- $MMI_{ik} = 1$ if average of JPN affiliates experience ≥ 4.5 MMI

Transmission of Shock: Which Firms?

	JIMP Disrupted ($J_{ik}^D = 1$)			
	(1)	(2)	(3)	(4)
Japan	0.707***		0.310***	0.686***
	(0.092)		(0.115)	(0.150)
Exposed		0.814***	0.636***	0.991***
		(0.088)	(0.110)	(0.144)
JPN*Exp				-0.848***
				(0.222)
MMI	0.346***	0.389***	0.341***	0.306***
	(0.069)	(0.067)	(0.069)	(0.070)
Ports	0.248	0.217	0.168	0.174
	(0.211)	(0.212)	(0.213)	(0.213)
Industry F.E.	Yes	Yes	Yes	Yes
Observations	2451	2451	2451	2451

*** p< 0.01, **p< 0.05, * p< 0.1

Transmission of Shock: Which Firms?

	NAEXP Disrupted ($X_{ik}^{D} = 1$)			
	(1)	(2)	(3)	(4)
Japan	0.443***		0.352***	0.347**
	(0.092)		(0.117)	(0.152)
Exposed		0.351***	0.145	0.140
		(0.089)	(0.112)	(0.149)
JPN*Exp				-0.008
				(0.228)
MMI	-0.176***	-0.121*	-0.178***	-0.178***
	(0.068)	(0.065)	(0.068)	(0.068)
Ports	-0.174	-0.144	-0.197	
	(0.224)	(0.225)	(0.226)	
Industry F.E.	Yes	Yes	Yes	Yes
Observations	2451	2451	2451	2451

*** p< 0.01, **p< 0.05, * p< 0.1

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Inverse Propensity Score Re-Weighting

Use size (pre-shock) and industry to balance out control group

	Japanese Firms	Other Multinationals	Balancing Tests t	$p > \|t\|$
Average (in thousands USD)				
N.A. Exports	3,505	3,413	0.38	0.706
share intra-firm	72.0	52.2		
Intermediate	8,076	7,597	0.87	0.384
Input Imports				
share from Japan	70.0	3.5		
share intra-firm	86.0	21.7		
Industry (Avg)	–	–	0.009	0.965

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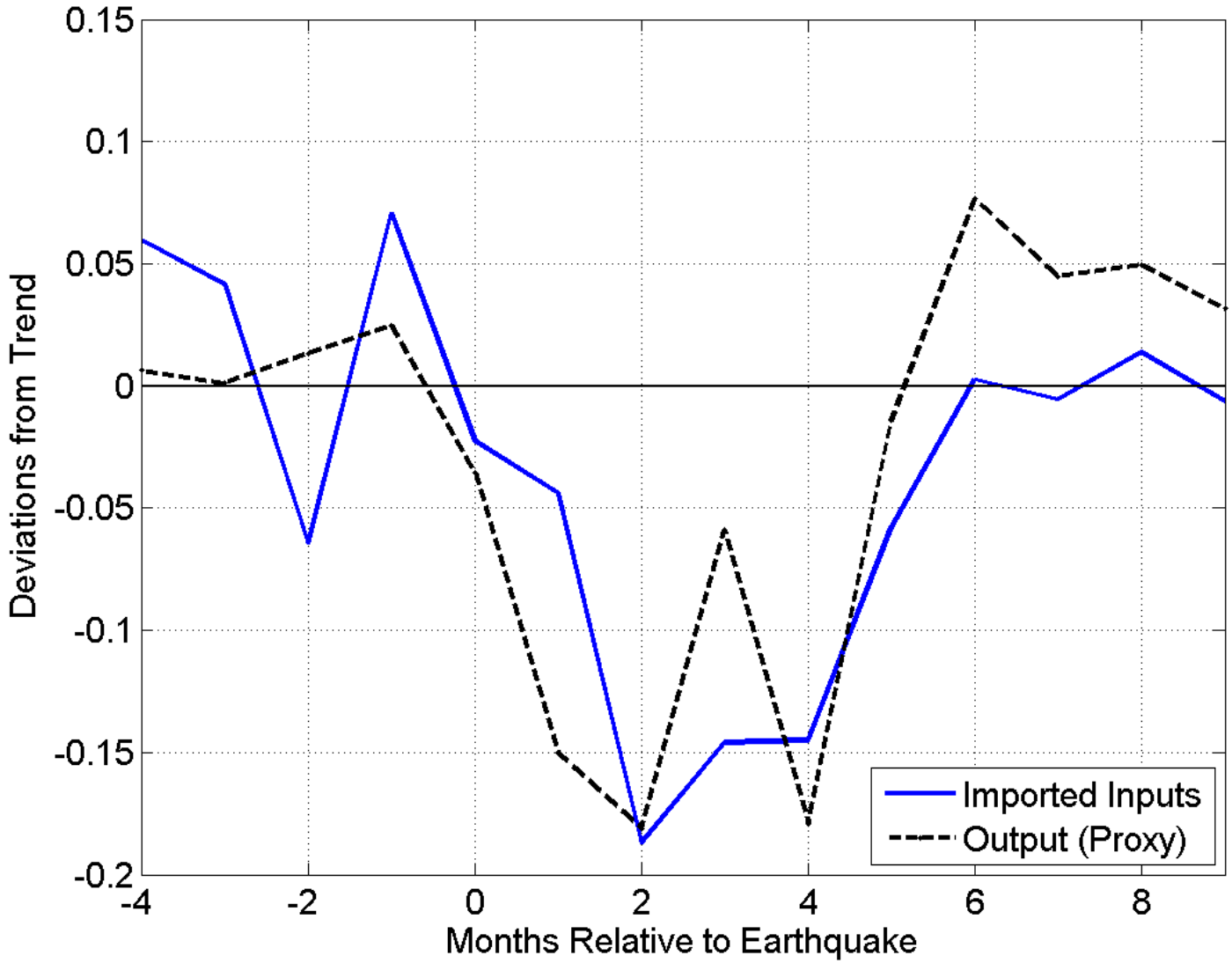
Alternative Specification



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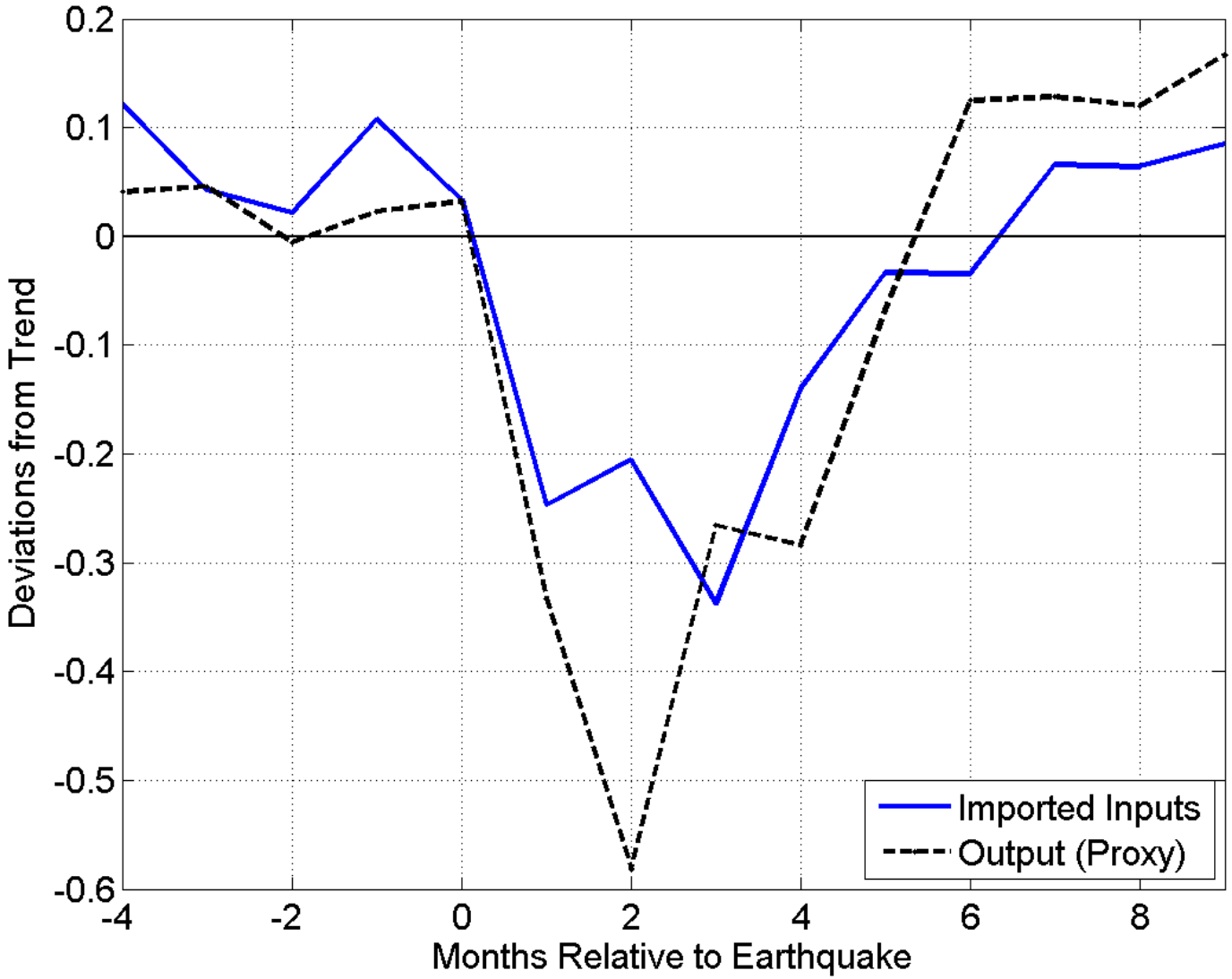

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Composition of Japanese Imports by Japanese Multinationals

	Japanese Multinationals
Share Intermediate	53.8
of which	
share Related-Party	85.7

Source: CMF, LFTTD, DCA. The data are for year 2007

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Effects on Domestic Labor Inputs

$$\Delta \text{emp}_{j,t} = \sum_{i=-3}^{3} \gamma_i E_i + \sum_{i=-3}^{3} \beta_i E_i D_{j,i} + u_{j,t}$$

where:

- $\Delta \text{emp}_{j,t} \equiv ln(\text{emp}_{j,t}/\text{emp}_{j,t-4})$: employment (payroll)
- E_i: corresponds to each calendar month
- $D_{j,t}$: equals one if firm is owned by Japanese parent company.

Result: No β_i significant surrounding Tōhoku event. No quantitatively meaningful movements.

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Prices

$$\mathrm{m}_{p,j,t} = \alpha_{pj} + \sum_{i=-19}^{9} \gamma_i E_i + \sum_{i=-19}^{9} \beta_i E_i D_{j,i} + u_{j,t}$$

where:

- $\mathrm{m}_{p,j,t} = log\mathrm{M}_{p,j,t}$: unit values of product p, firm j, month t
- α_{pj} are firmXproduct fixed-effects,
- E_i: corresponds to each calendar month
- $D_{j,t}$: equals one if firm is owned by Japanese parent company.

Result: No β_i significant surrounding Tōhoku event. No quantitatively meaningful movements.

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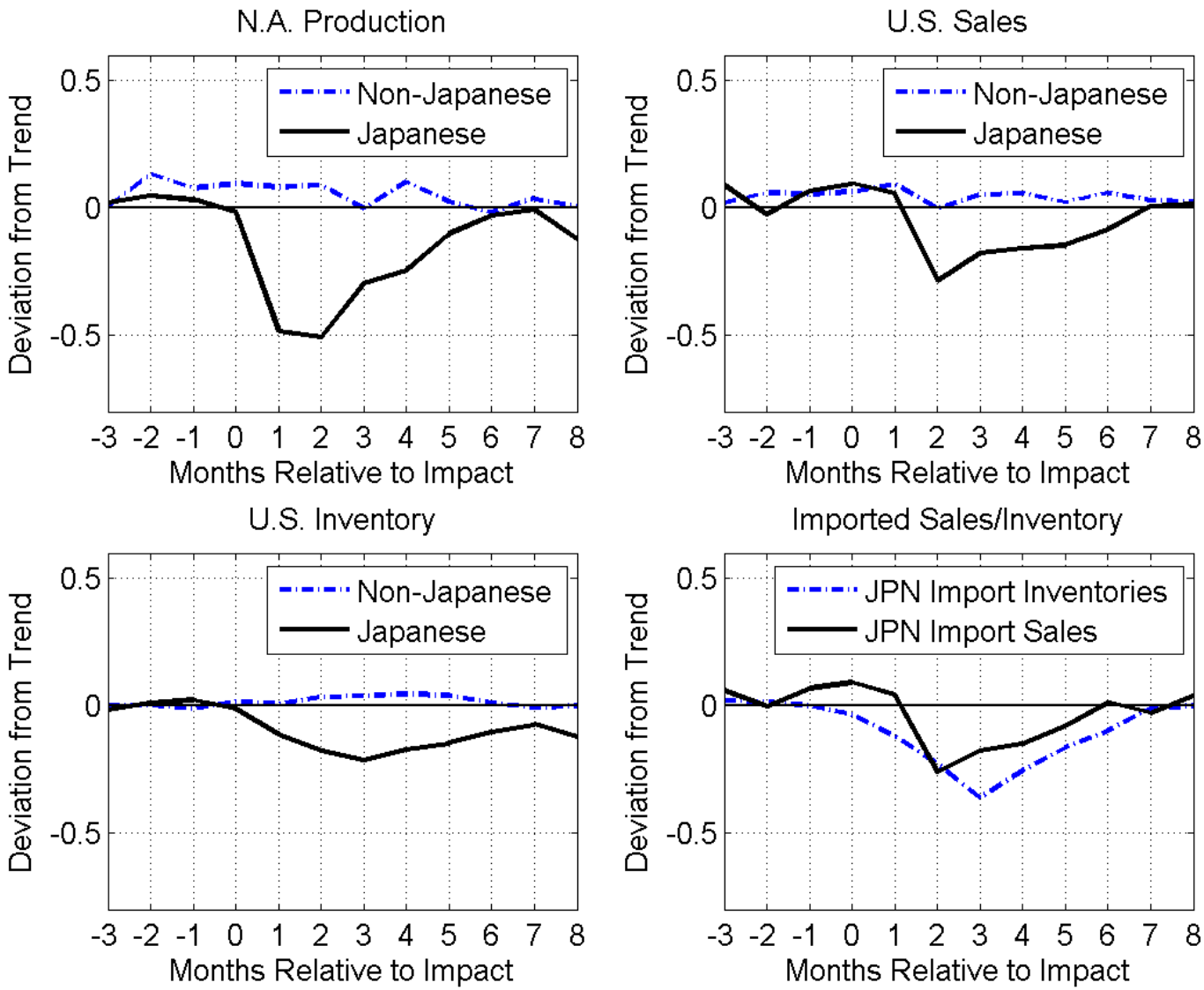
Yen per USD (Index Feb 2011=1)

Strategic Interaction



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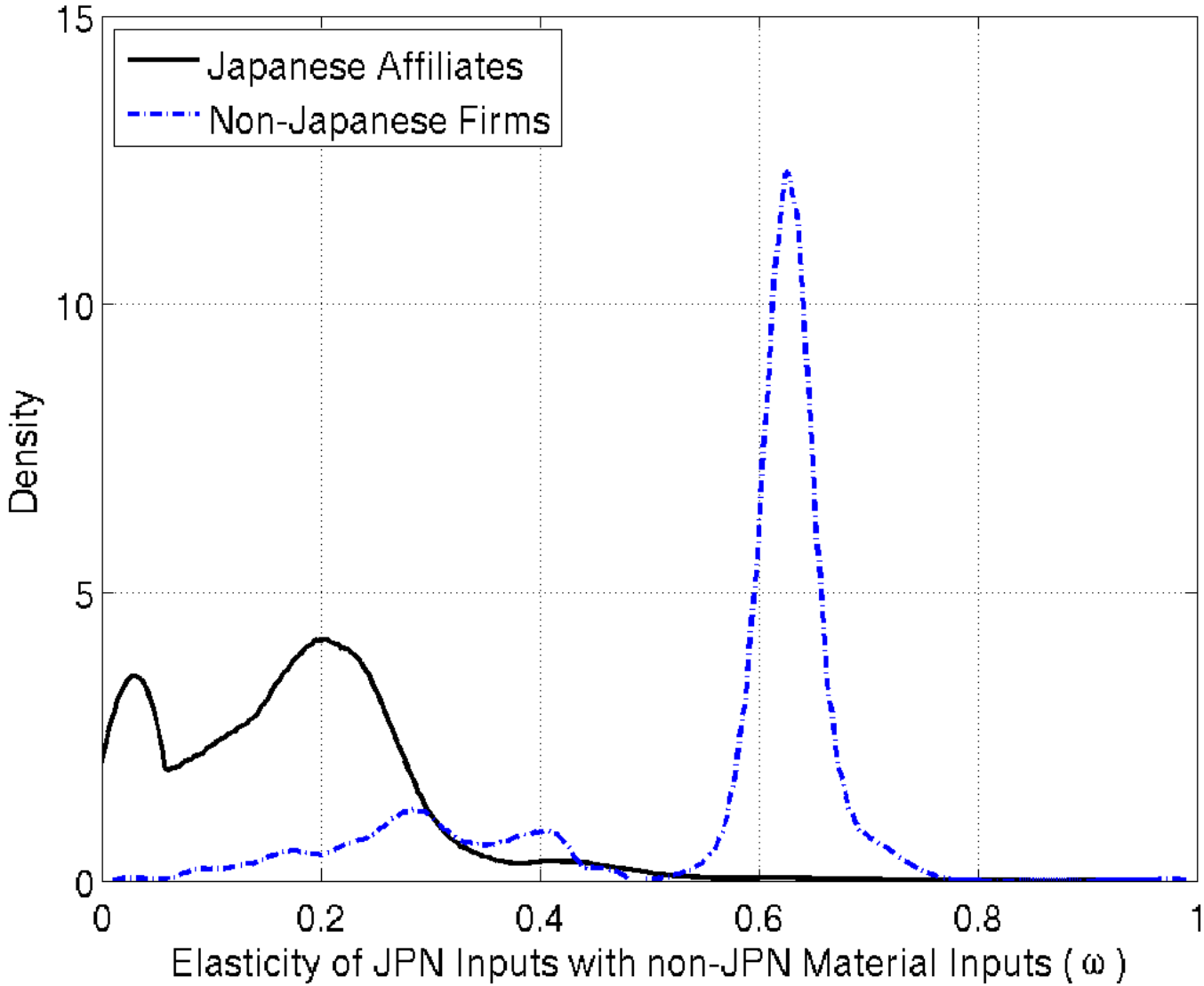
Bootstrapped Standard Errors



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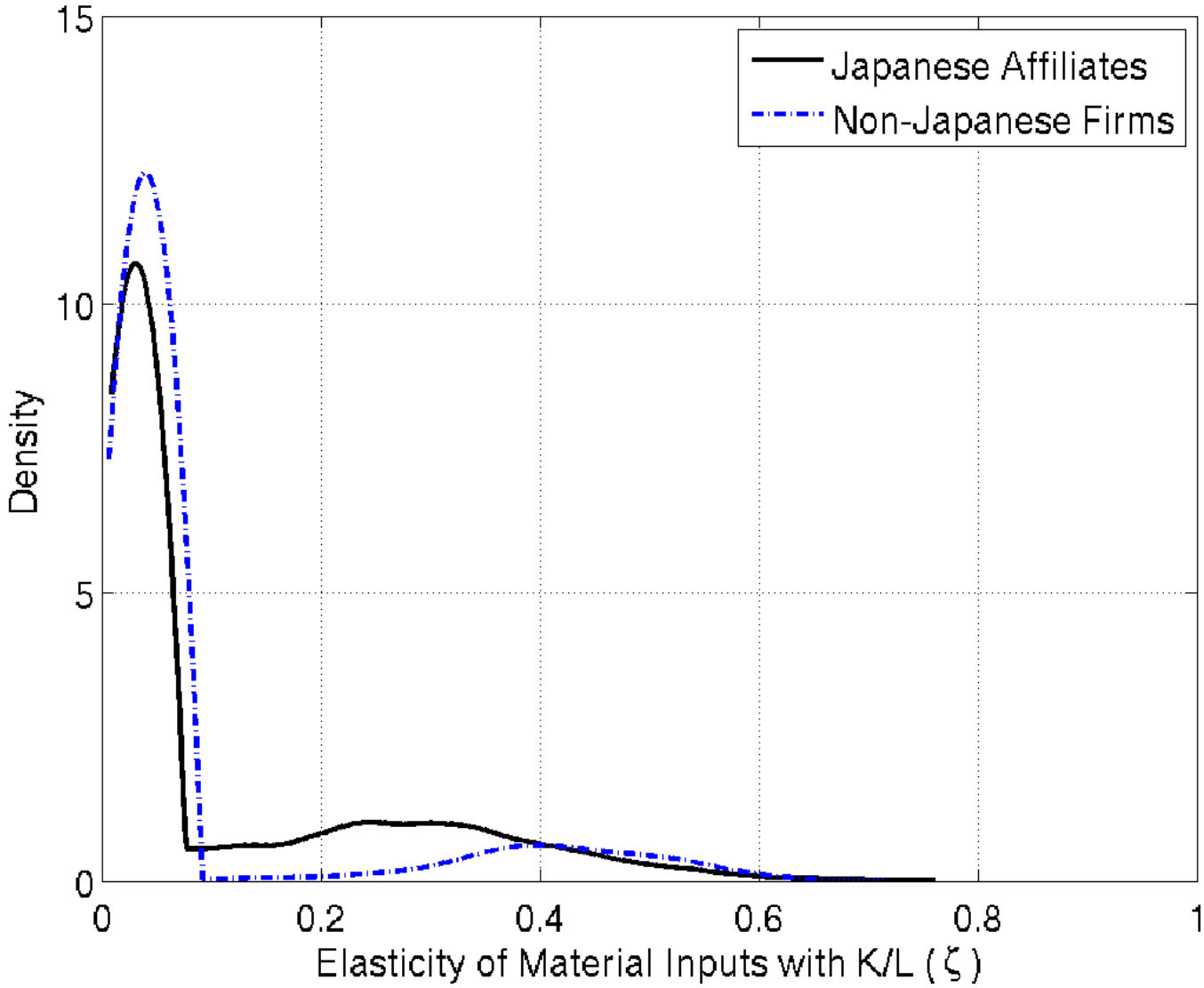
Bootstrapped Standard Errors



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Multiple Products: Example

$$M_t^J = \left[(1-\eta)^{\frac{1}{\chi}} m_1^{\frac{\chi-1}{\chi}} + \eta^{\frac{1}{\chi}} m_2^{\frac{\chi-1}{\chi}} \right]^{\frac{\chi}{\chi-1}}$$

A Simple Example With 2 Inputs

	Input 1 (m_1)	Input 2 (m_2)	Measured Imports ($\widehat{M}^J$)	Effective Imports[1] (M^J)
Before	80	20	100	100
After	70	10	80	68.4
Percent Drop	0.125	0.5	0.2	0.315

[1] Using equation above where $\eta = 0.8$ and $\chi = 0.2$.

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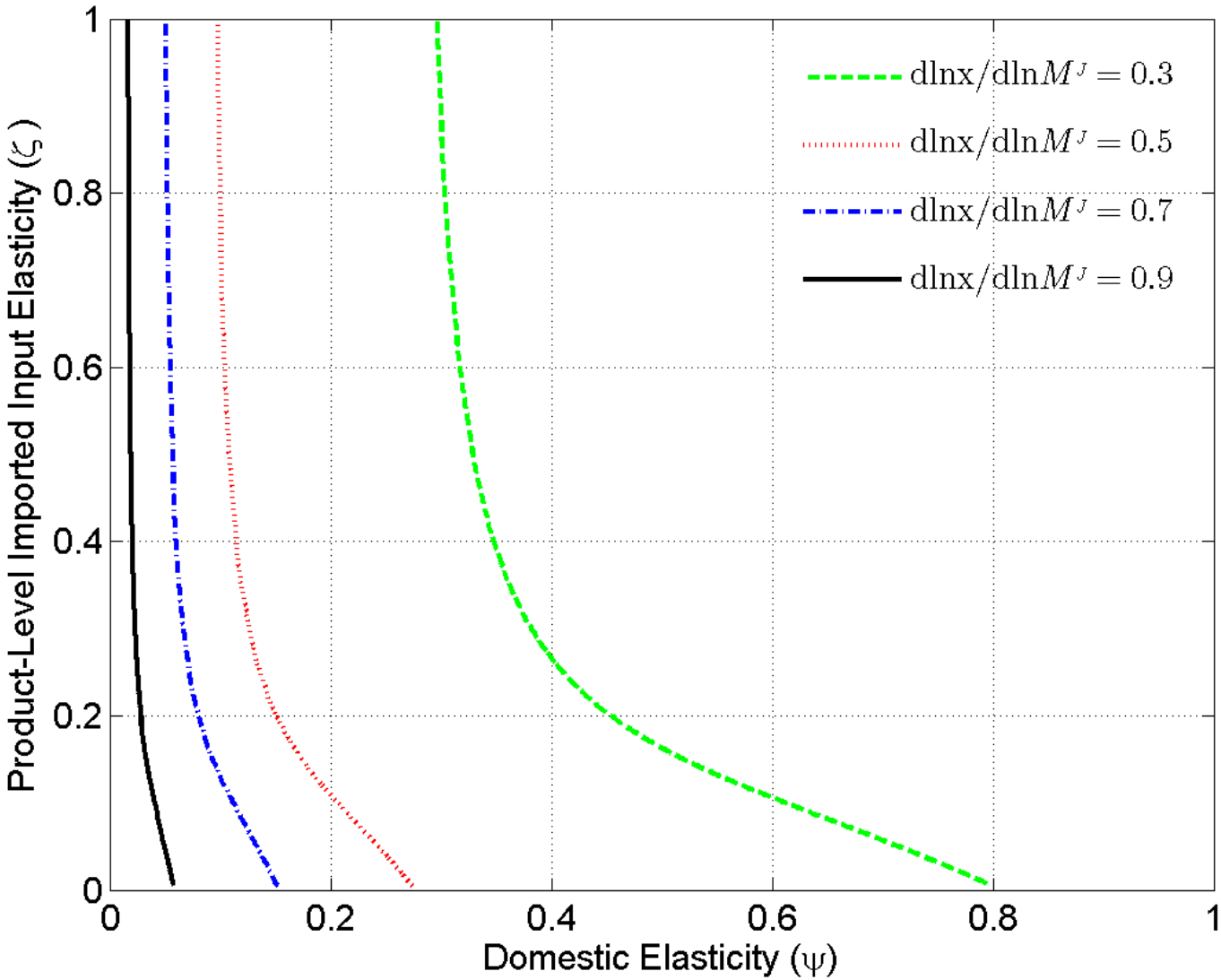
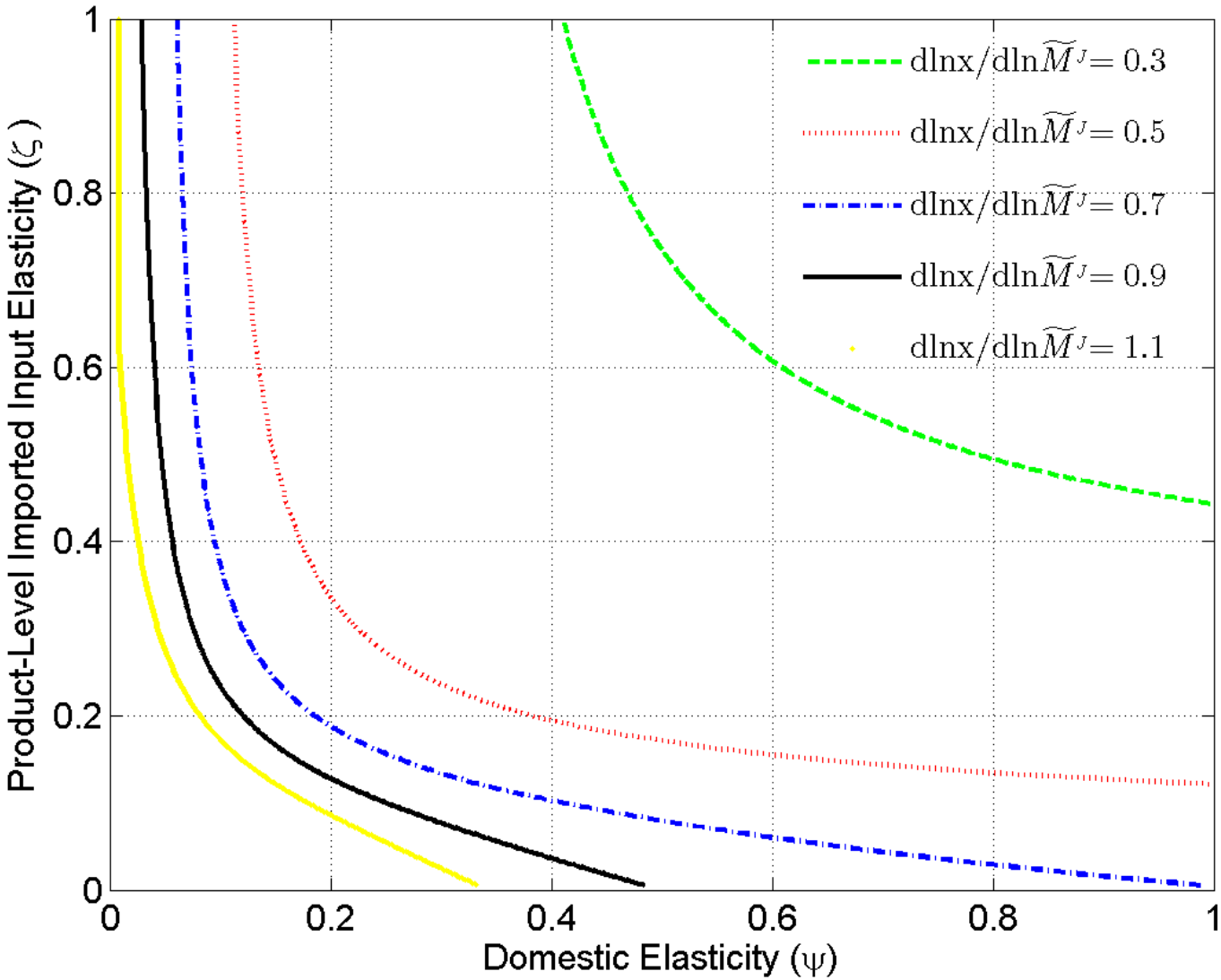
Multiple Products: Example



Multiple Products: Example



Deviations from Optimal Input Allocations

Constructing a firm-level measure of the input mix from Japan:

- Assume that each firm j has an optimal bundle of JPN inputs at time $t = s^*$
- Construct the share of JPN imports for each product code p: $s^j_{p,t}$
- Then we can define the distance from optimal input allocation as:

$$DO^j_t = \sum_{p=1}^{P} \left(|s^j_{p,t} - s^j_{p,s}| \right)$$

- where P is the total number of products.

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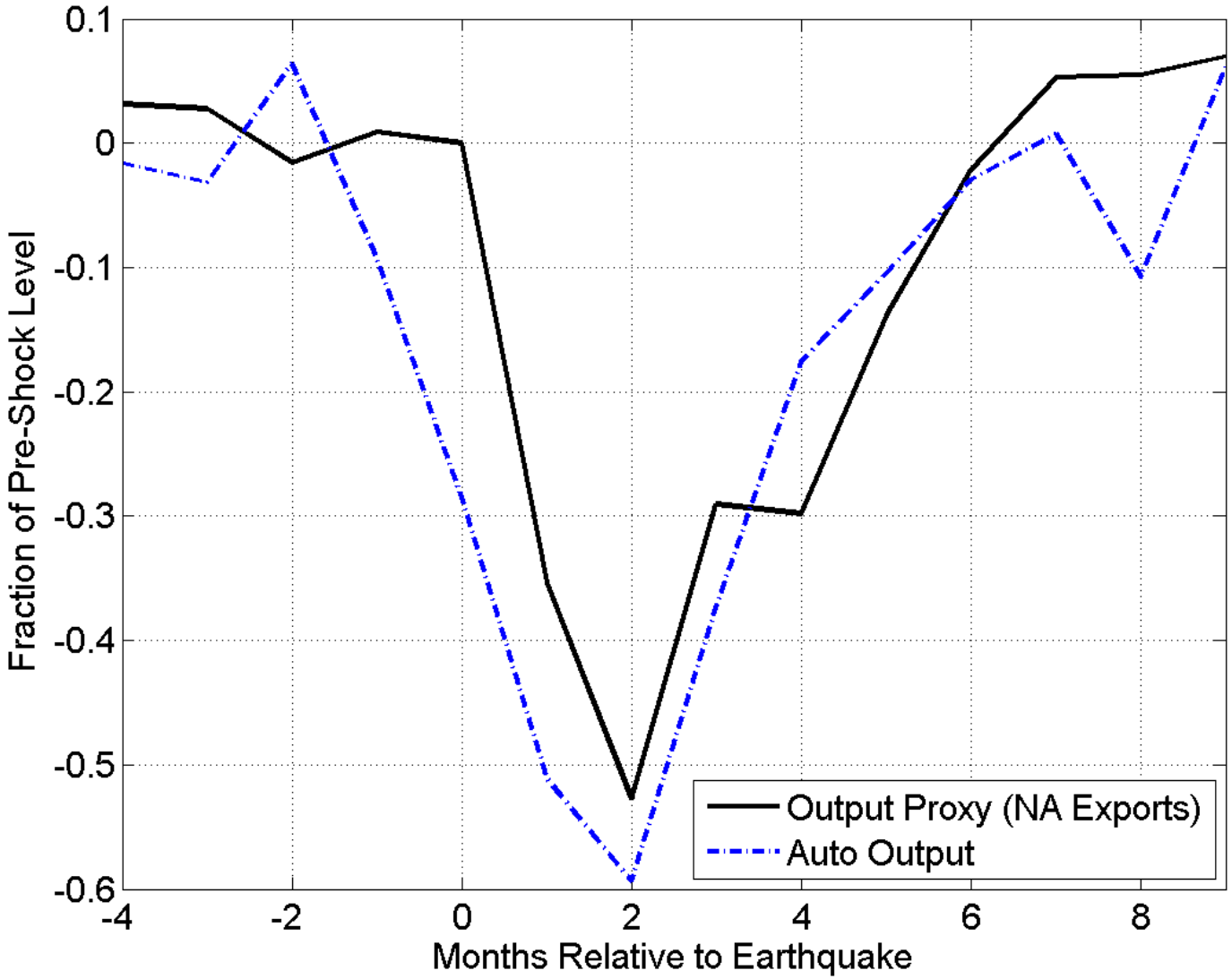
Mis-measurement of Firm Production

Does our proxy accurately capture firm production in the U.S.?

- Automotive sector contains model-line production data at a monthly frequency Ward's Data
- Run identical specification using production data:

$$Q_{i,t} = \alpha_0 + \alpha_i + \sum_{p=-14}^{9} \gamma_p E_p + \sum_{p=-14}^{9} \beta_p E_p \text{JPN}_{i,p} + u_{i,t}$$

Assessing the Proxy for Production



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Intermediate Input Inventories

Why do input inventories not absorb or cushion the shock?

Answer: Very low levels of intermediate input inventories

- for Japanese affiliates: roughly a 3-week supply of material input inventories (2007, Census of Manufacturers)
- consistent with well-known "lean" production philosophy

Potential Puzzle: With such a rigid supply chain, one would expect higher degree of inventory holdings as buffer against disruptions.

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Auto Sector Data: Description

Ward's Automotive Database (2000-2012)

- Monthly North American plant/model line
- Covers universe of assembly operations of finished cars and light trucks
- Includes:
  1. Production (plant and model-line)
  2. Inventories (model-line)
  3. Sales (model-line)
- Inventories and sales include origin of production
- Also: monthly production by model line for Japan

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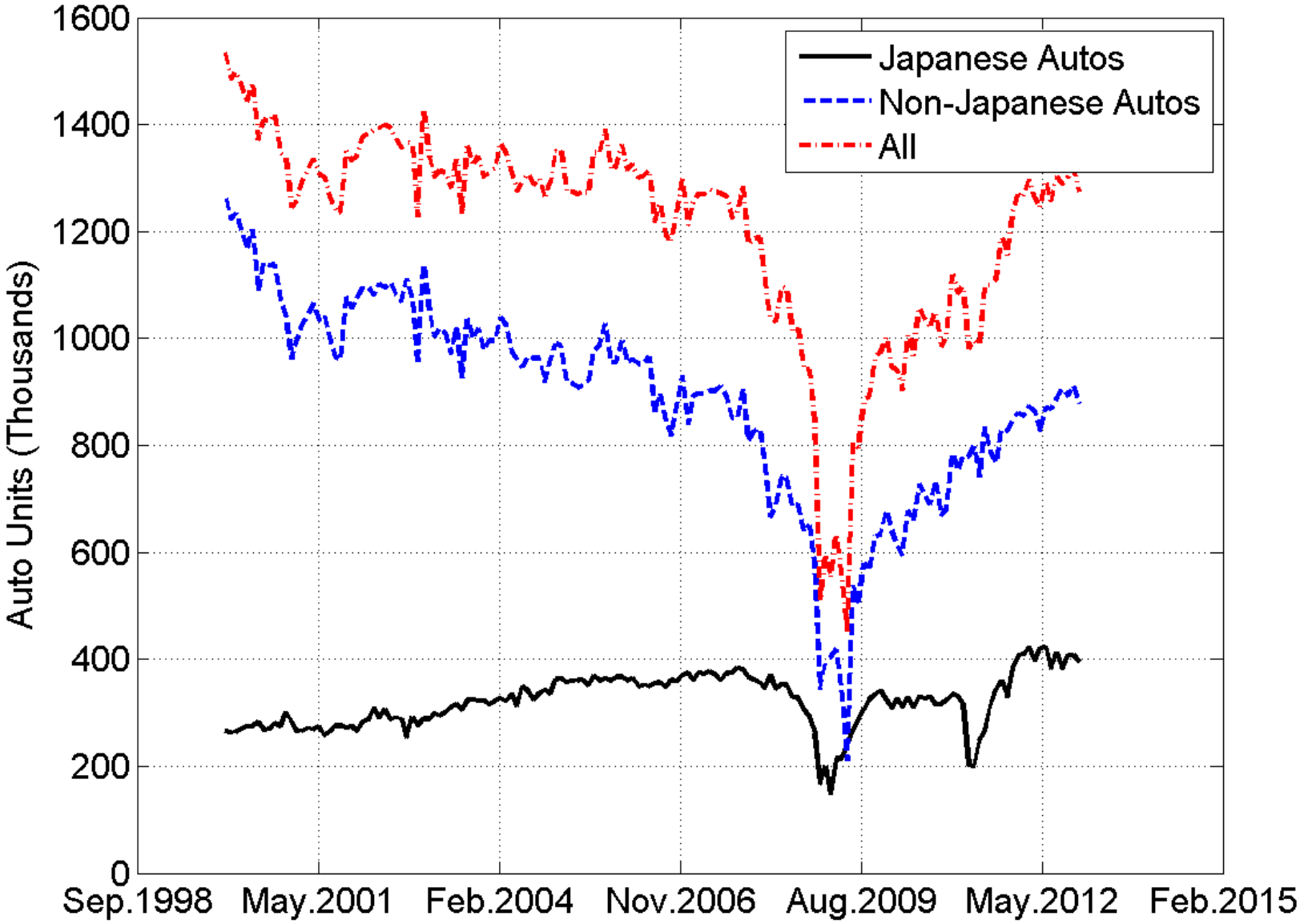
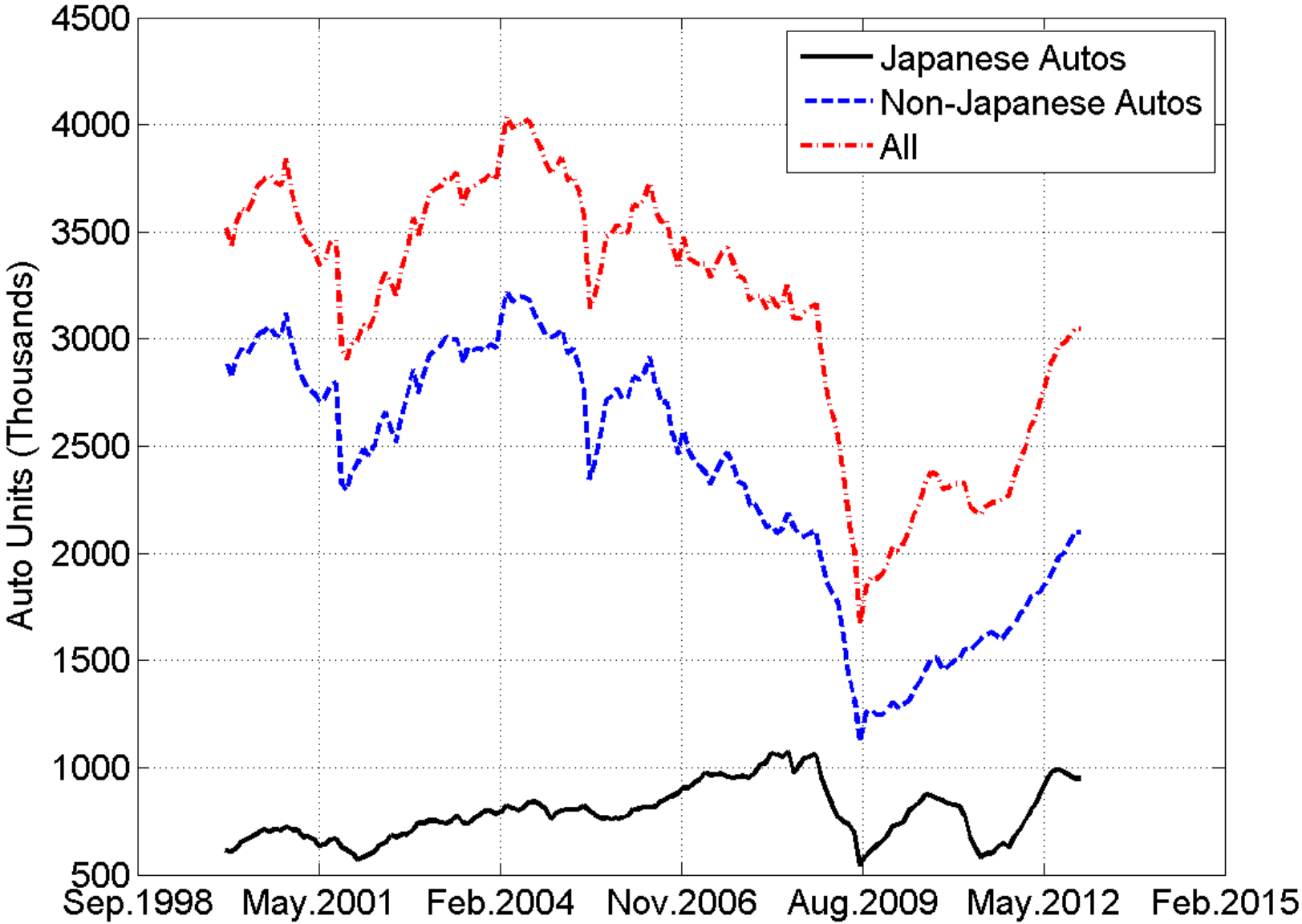
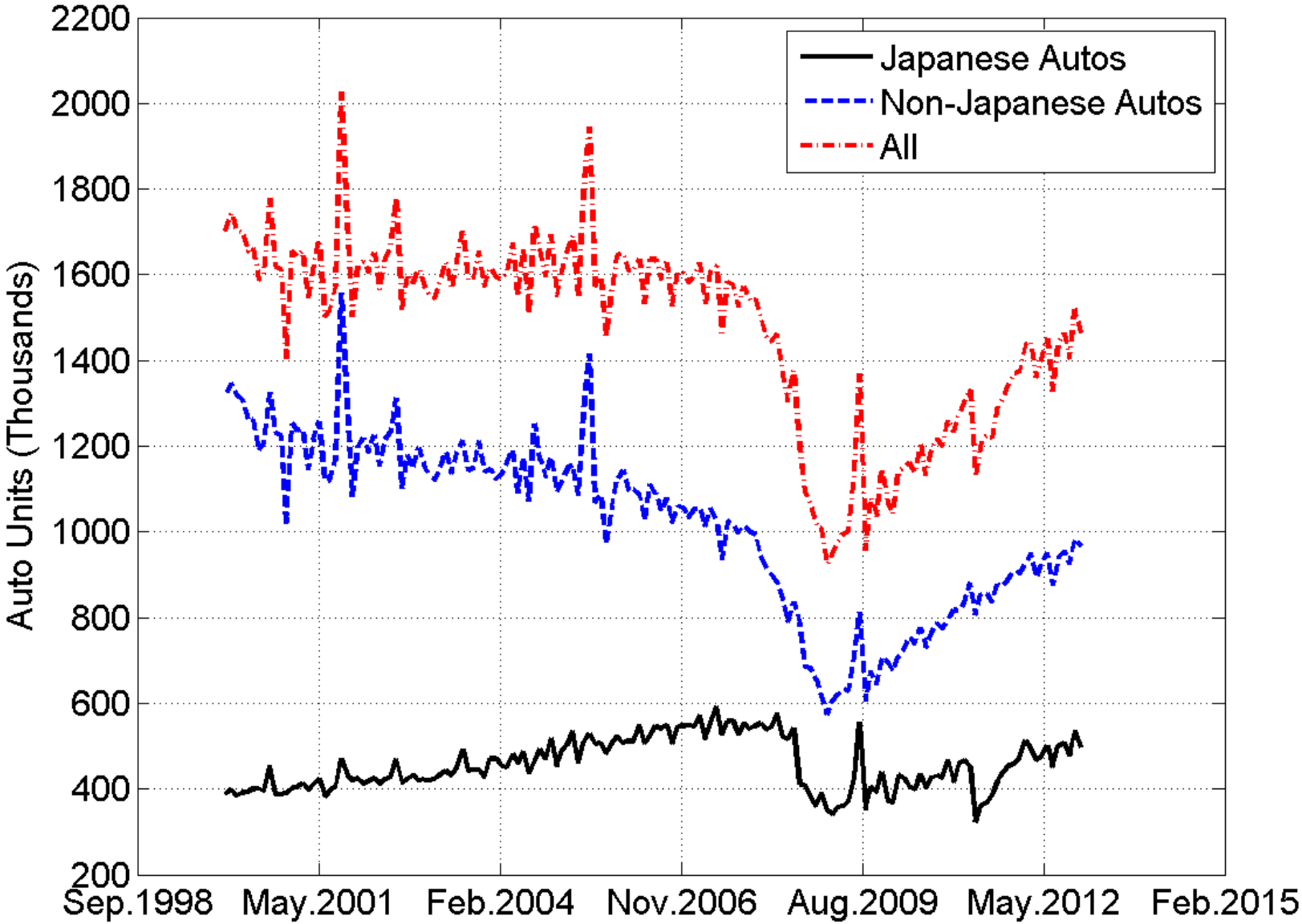
Production: North America



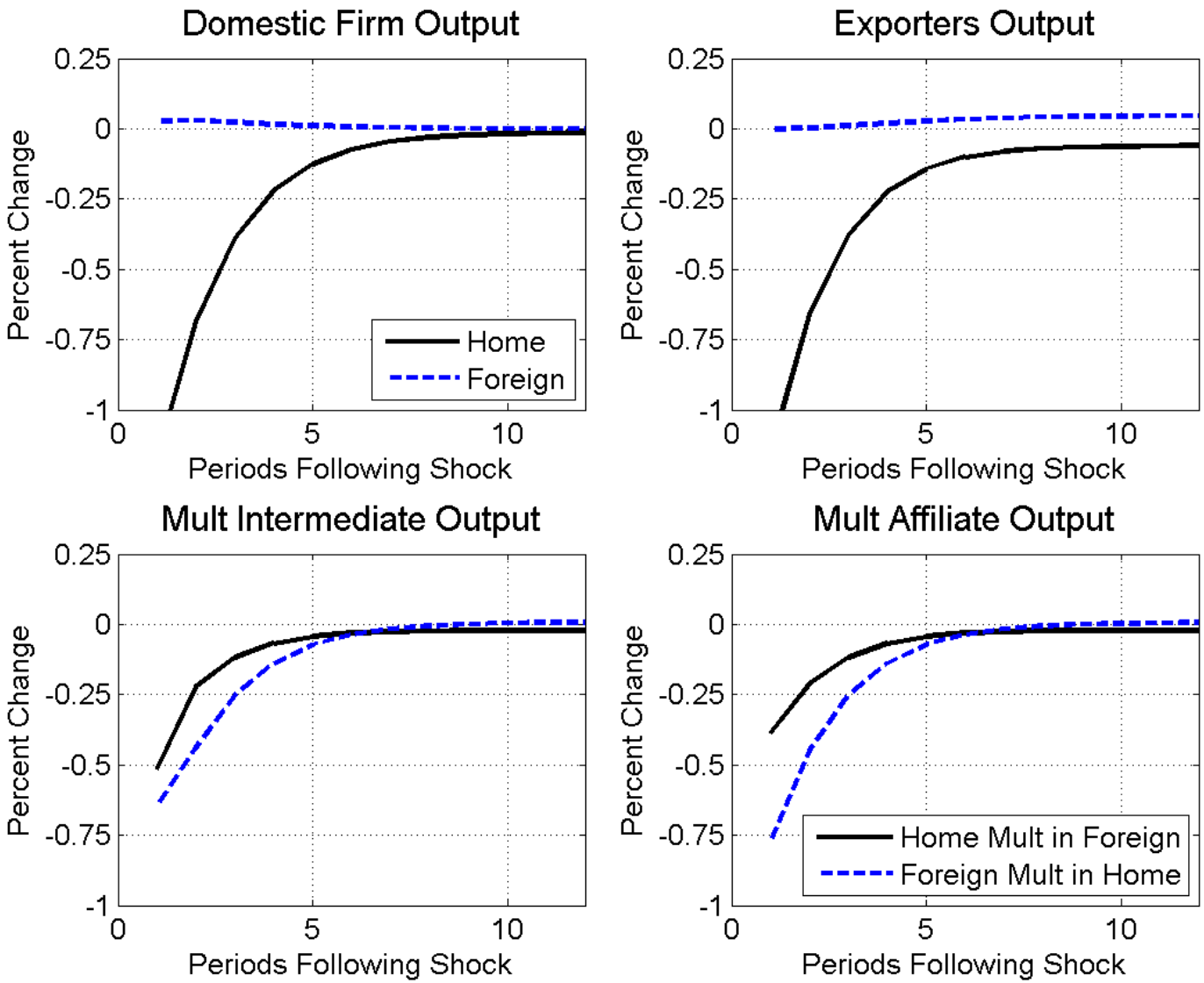
Inventories: North America



Sales: North America



Impulse Response: Neg. TFP Shock in Home



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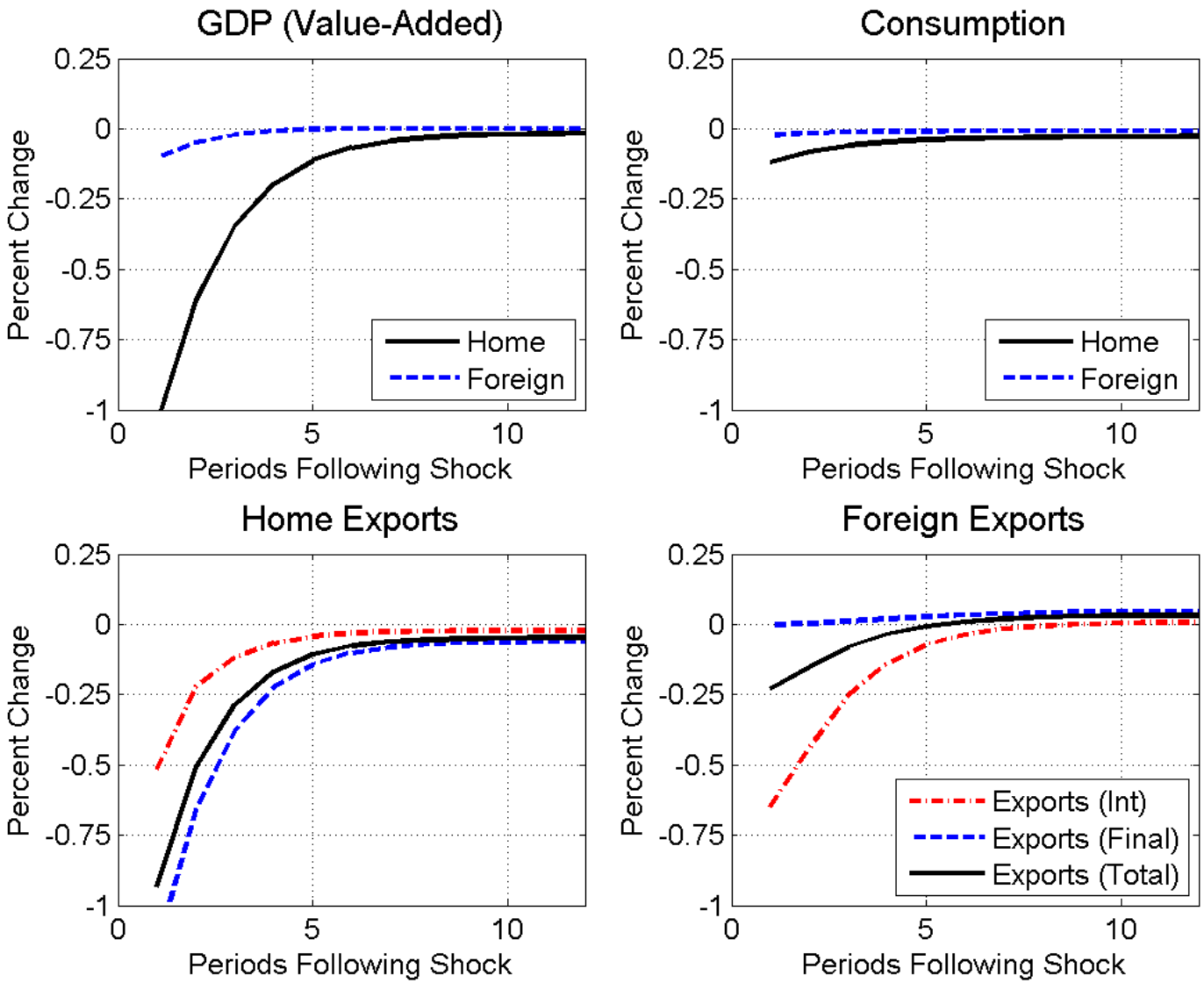
Impulse Response: Neg. TFP Shock in Home



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