The Changing Structure of Global Value Chains and Technological Change: Evidence from the Firm-Level Patent Data

(Very preliminary. Please do not quote.)

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1. Introduction

Motivation

- ✓ Global Value Chains (GVCs)/Global Production Networks (GPNs) have been expanding and deepening in the last decades.
- ✓ The US, Germany, & Japan were the key hubs in GVCs in the 1990s ➔ Japan became "less central" in GVCs; Rising importance of China
- ✓ Changes in the position in GVCs may have some impacts on technological capabilities of the firms/industries/countries participating in GVCs. How?
- ✓ This paper examines how firms' technological changes (quality-adjusted patenting) are affected by the changes in relative position in the GVC network (centrality), using the patent statistics matched with the firm-level data.

Related literature & Hypothesis

- ✓ Knowledge diffusion through networks
  - ✓ Research collaboration (Belderbos et al., 2014; Briggs, 2015; Gonzalez-Brambia et al., 2013; Iino et al., 2020; Moaniba et al., 2019)
  - ✓ Peer effects in social networks (Calvó-Armengol 2009)
  - ✓ Spillovers through the GVC network (Criscuolo and Timmis 2018, Ito et al. 2023)
- ✓ Actors in a network are complementary each other and receive externalities from other actors both directly and ***indirectly*** (network externalities).
- ✓ Firms/industries closer to the key hubs in GVCs are likely to receive more knowledge from other actors in the network.
- ✓ More central country-industries in GVCs have access to a greater variety of foreign products and knowledge. → High-quality and/or diversified innovation output

2. Data

Data

- ✓ GVC network centrality: Katz-Bonacich-type Eigenvector Centrality calculated using the **OECD ICIO Tables** for each country-industry pair (Both direct & indirect links are taken into account)
- ✓ Innovation output & Technology portfolio: **PATSTAT** & Patent quality indicators for patents filed at the EPO/USPTO provided in the **OECD Patent Quality Database**
- ✓ Applicants' characteristics: Patent-firm matched data taken from the BvD's **Orbis Intellectual Property & Osiris Databases**

Centrality measures used in this study (country-industry-year level)

- ✓ **Out-degree centrality（Forward linkages), In-degree centrality（Backward linkages)**
- ✓ **Identify Core/Periphery country-industries in the GVC network**
- ✓ $c^{back}{}_i = \lambda \sum_j w_{ji} \cdot c_j^{back} + \eta$
- ✓ $c^{fwd}{}_i = \lambda \sum_j w_{ij} \cdot c_j^{fwd} + \eta$

$$c^{back} = \eta(I - \lambda W')^{-1}1$$

$$c^{fwd} = \eta(I - \lambda W)^{-1}1$$

Higher backward centrality
→ Key Customers in the GVC network

Higher forward centrality → Key Suppliers in the GVC network

→ Distinguish **Domestic** network part and **Foreign** network part by using the partitioned matrix

→ We focus on the centrality of **Foreign** segment of GVC

Measures for innovation output

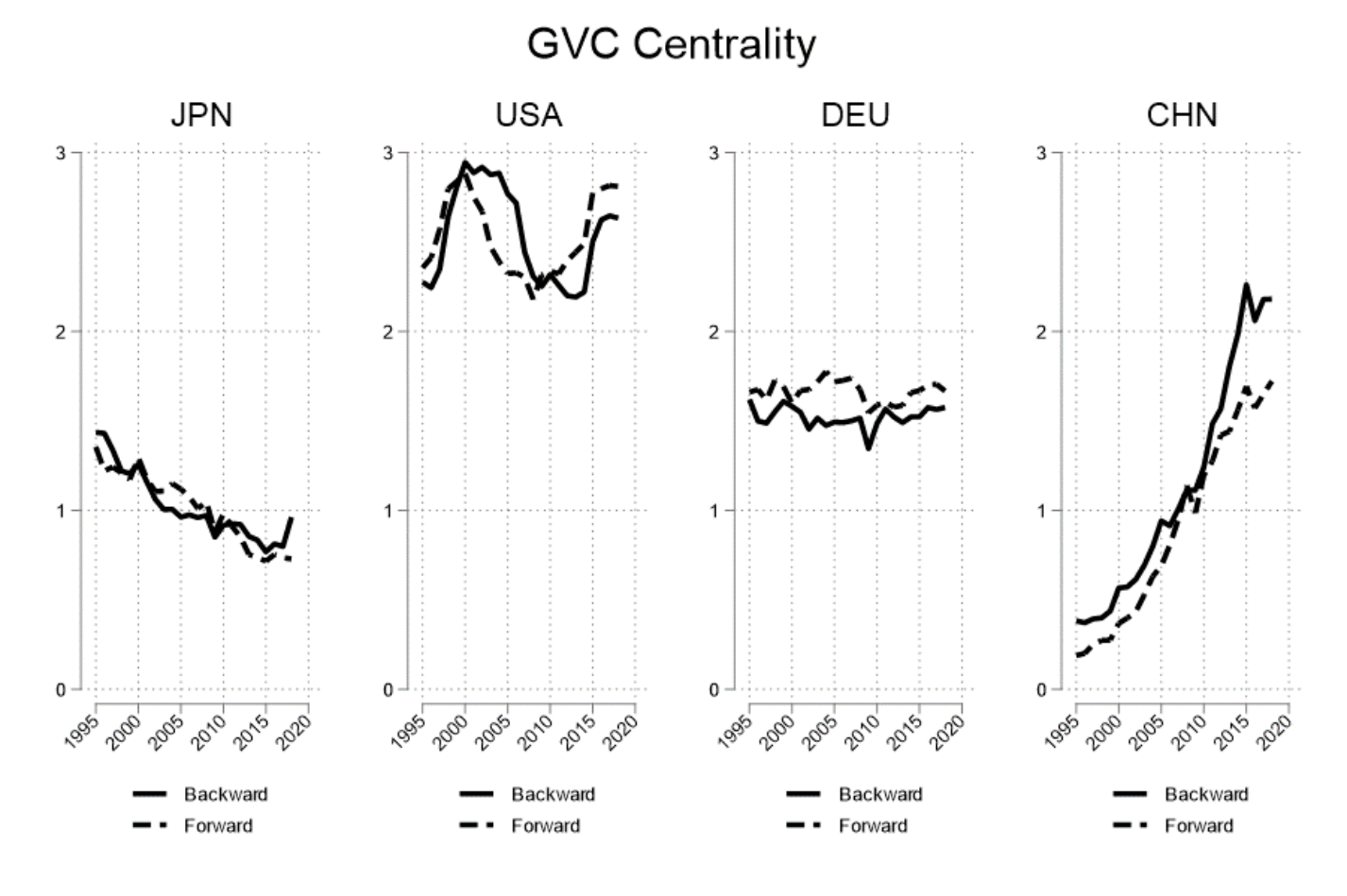
- ✓ Patent level: Patent quality indicators (OECD Patent Quality Indicators Database)
  - ✓ 14 indicators such as patent scope, **family size**, grant lag, backward and **forward citations**, **claims**, **generality**, originality, **composite quality index**, etc.
- ✓ Firm level: OECD Patent Database, PATSTAT, Orbis IP Database
  - ✓ Quality-adjusted number of patent applications (weighted by fwd citations)
  - ✓ Quality-adjusted number of patents granted (weighted by composite quality index)
  - ✓ Technological diversification (TD): entropy index (Chen et al., 2012; Kim et al., 2016)

$TD_{ft} = \sum_{k=1}^{N} PS_{fkt} ln\left(\frac{1}{PS_{fkt}}\right)$, where $PS_{fkt} = \frac{P_{fkt}}{P_{ft}}$ ← **Technology field is defined using the IPC class and IPC subclass.**

$TD_{ft} = \sum_{j=1}^{M} PS_{fjt} ln\left(\frac{1}{PS_{fjt}}\right) + \sum_{j=1}^{M} PS_{fjt}\left(\sum_{k \in j} PS_{fkt} ln\left(\frac{1}{PS_{fkt}}\right)\right)$ $= Unrelated\text{-}TD_{ft} + Related\text{-}TD_{ft}$

3. GVC Centrality and Patenting by Major Countries

Figure 1. GVC Centrality for Major Countries: 1995 to 2018



Higher backward centrality
→ Key Customer in the GVC network

Higher forward centrality
→ Key Supplier in the GVC network

Figure 1. GVC Centrality for Major Countries: 1995 to 2018

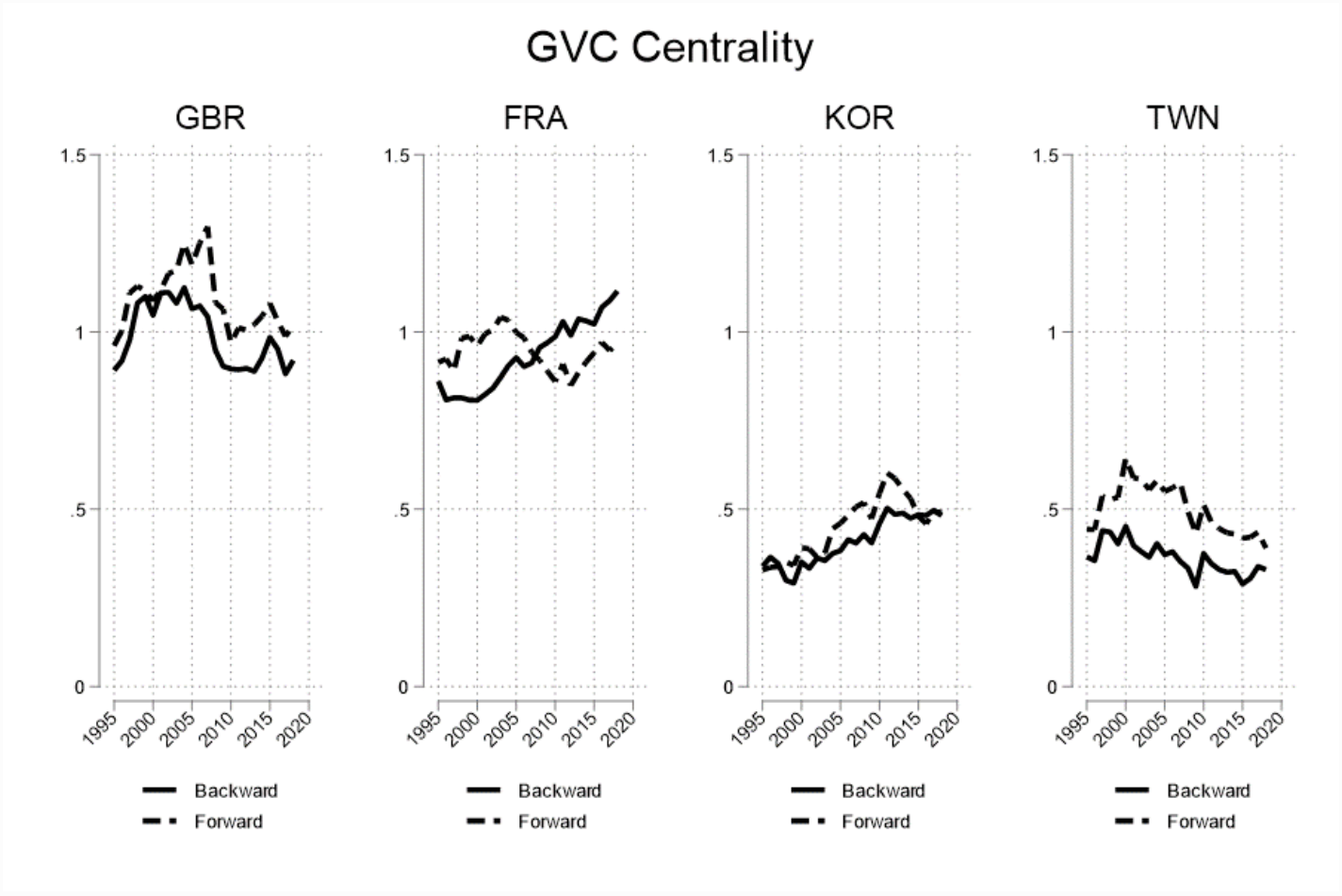
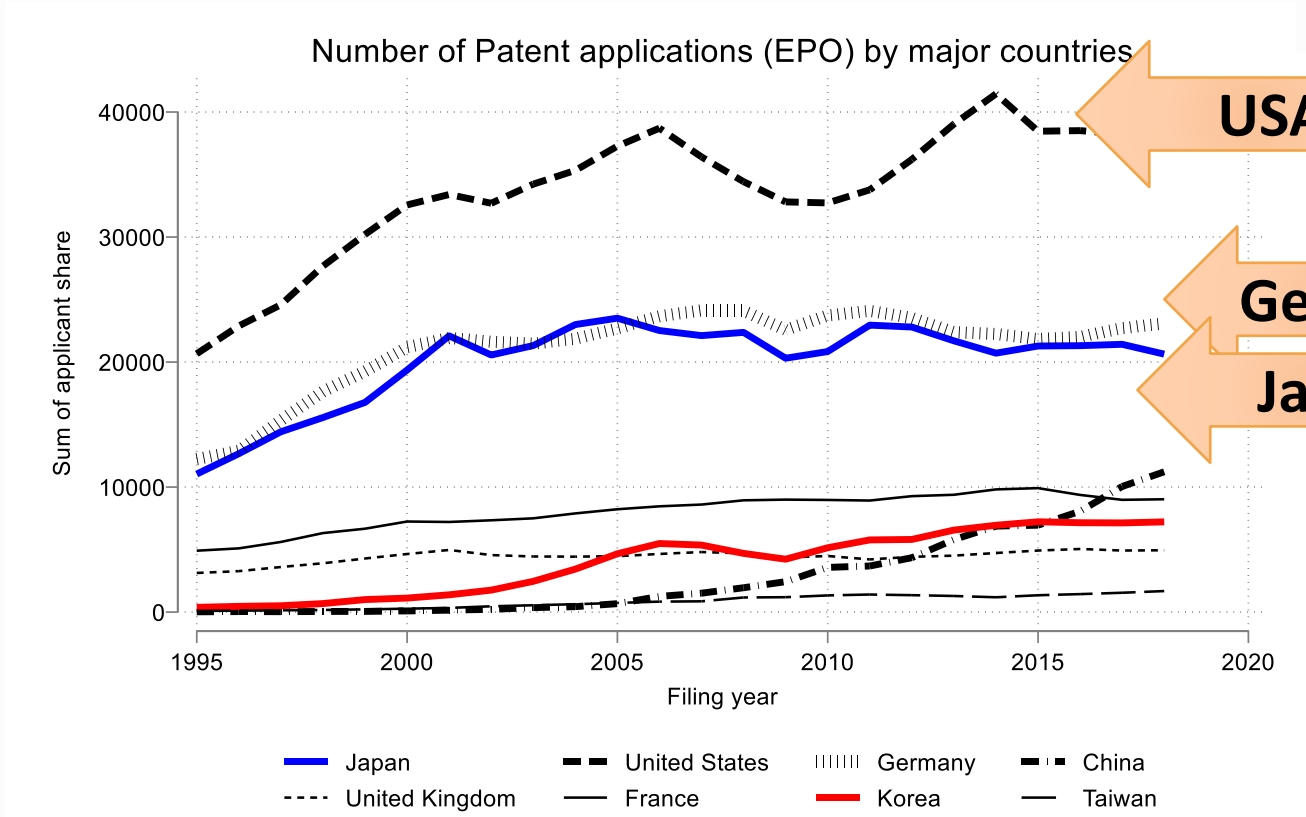


Figure 2. Number of Patent Applications at the EPO/USPTO for Major Countries



USA

Germany

Japan

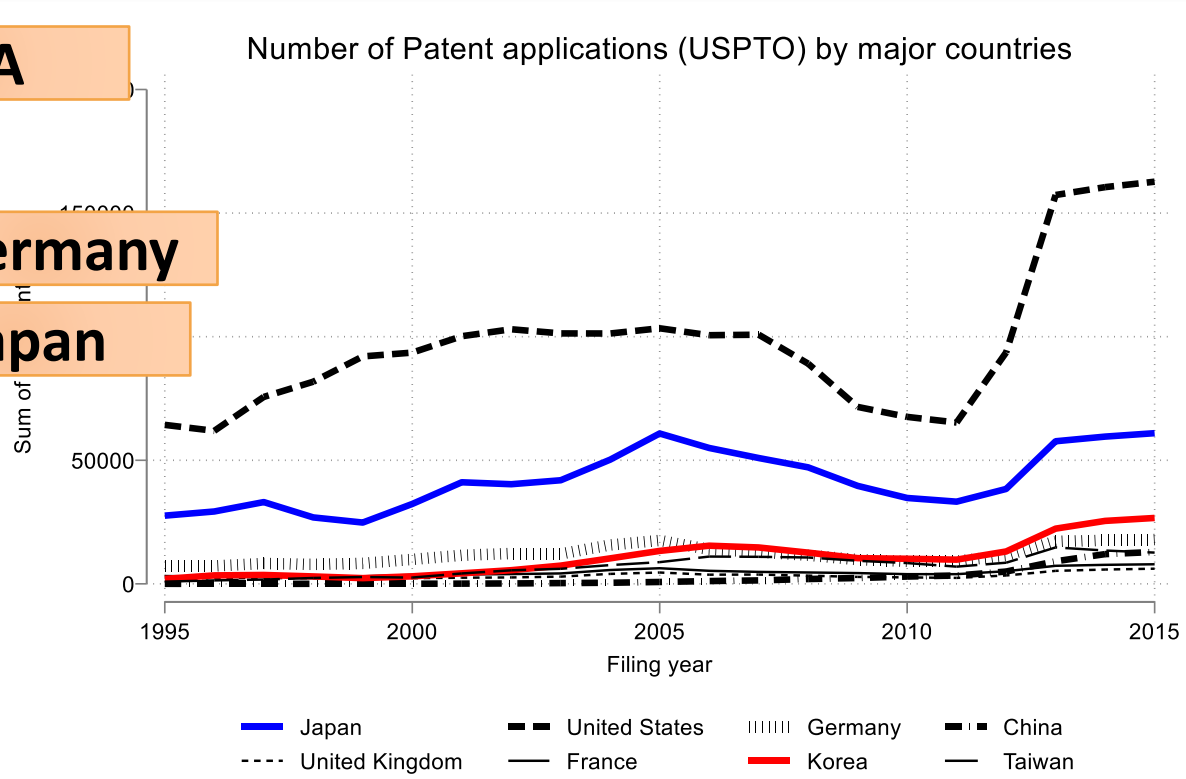
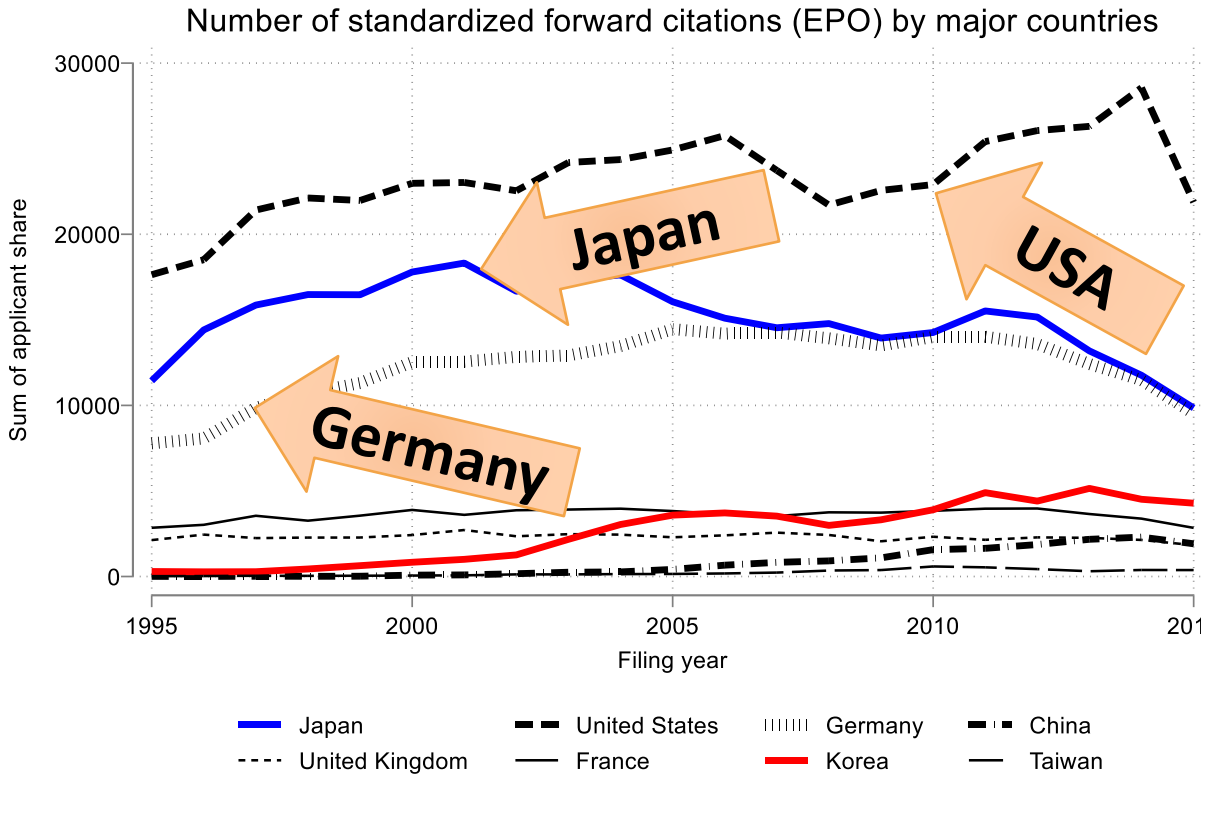


Figure 3. Number of Patent Applications Adjusted by the Forward Citations



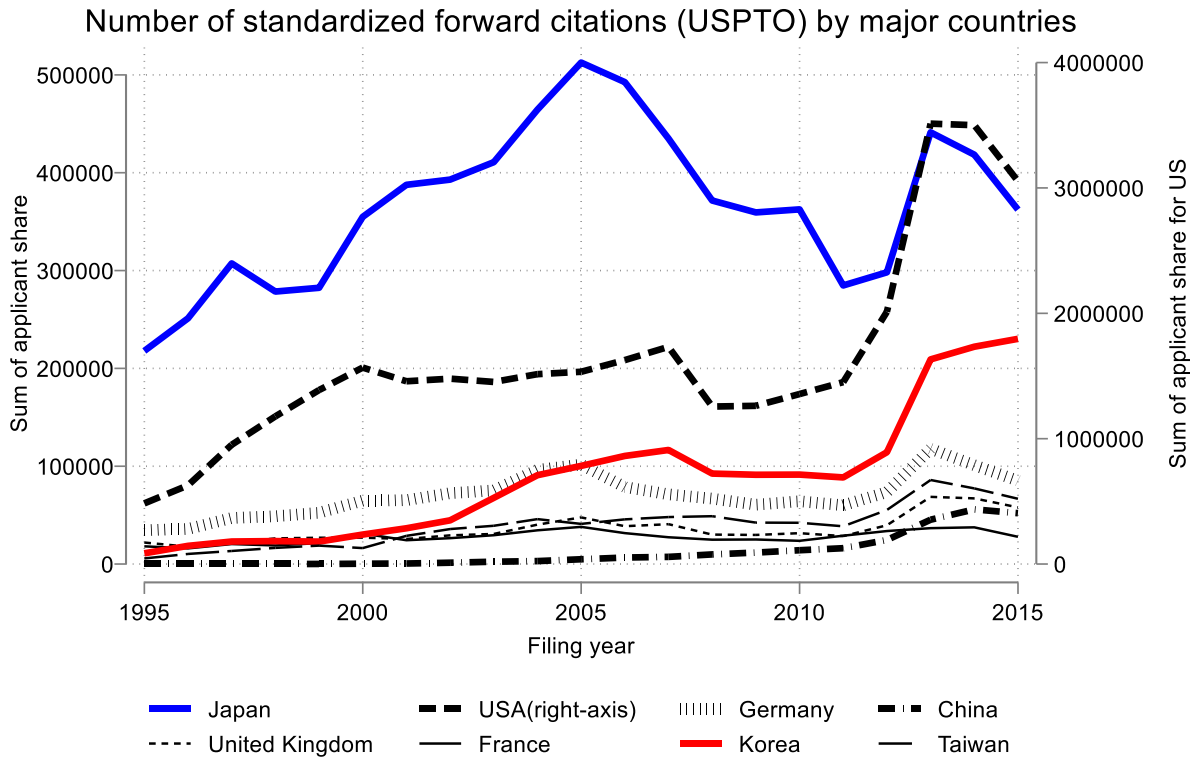
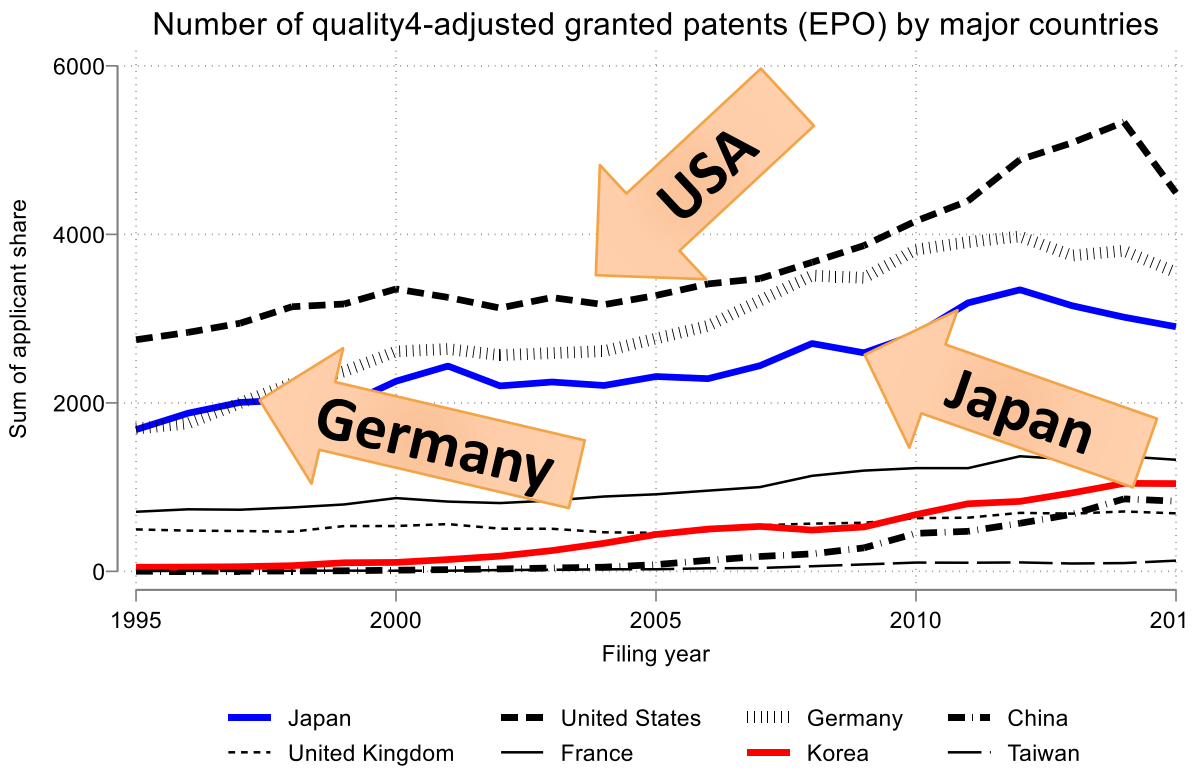


Figure 4. Number of Granted Patents Adjusted by the Four-Component Quality Index



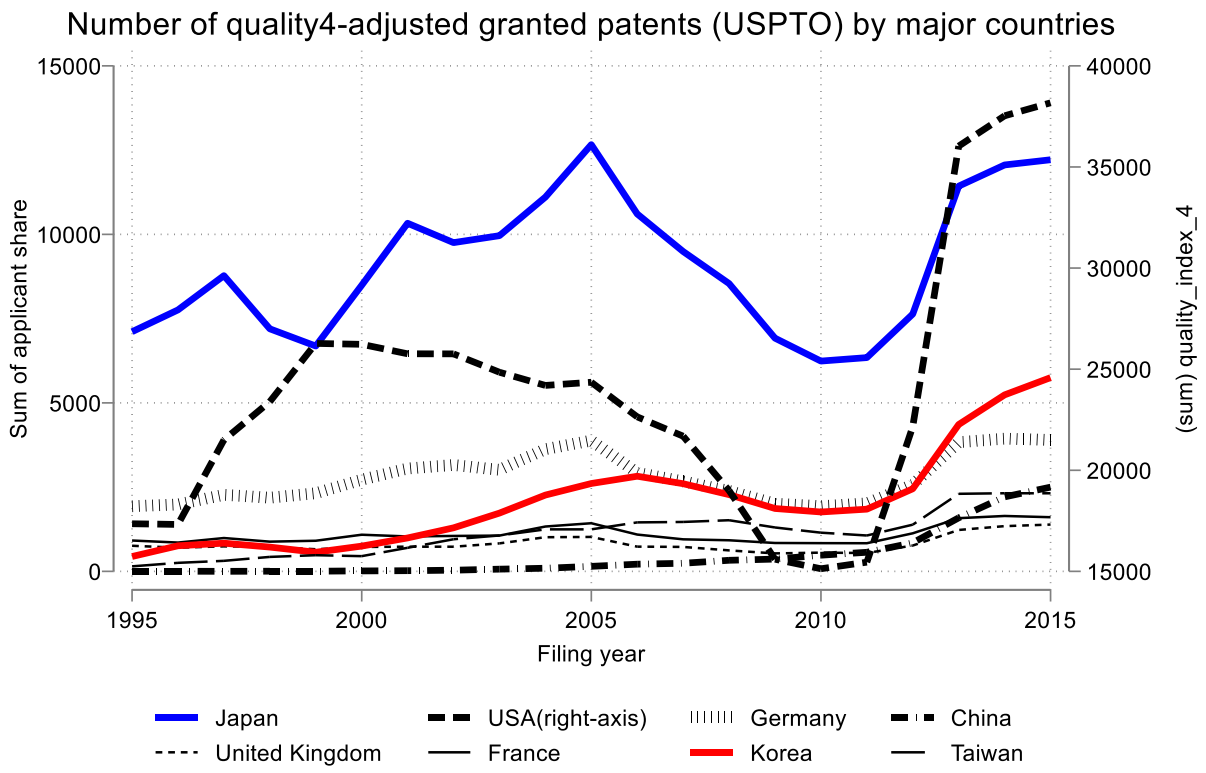
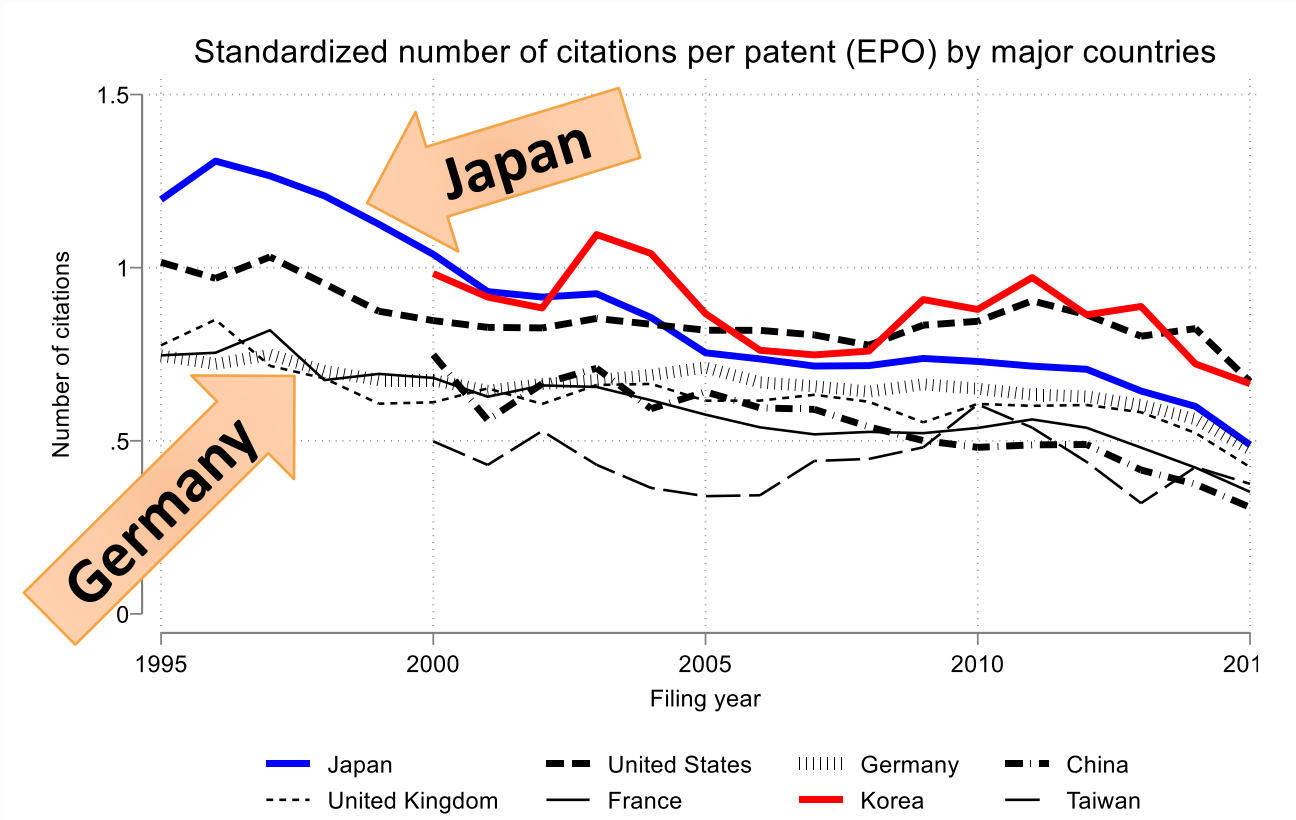


Figure 5. Average Number of Forward Citations per Patent



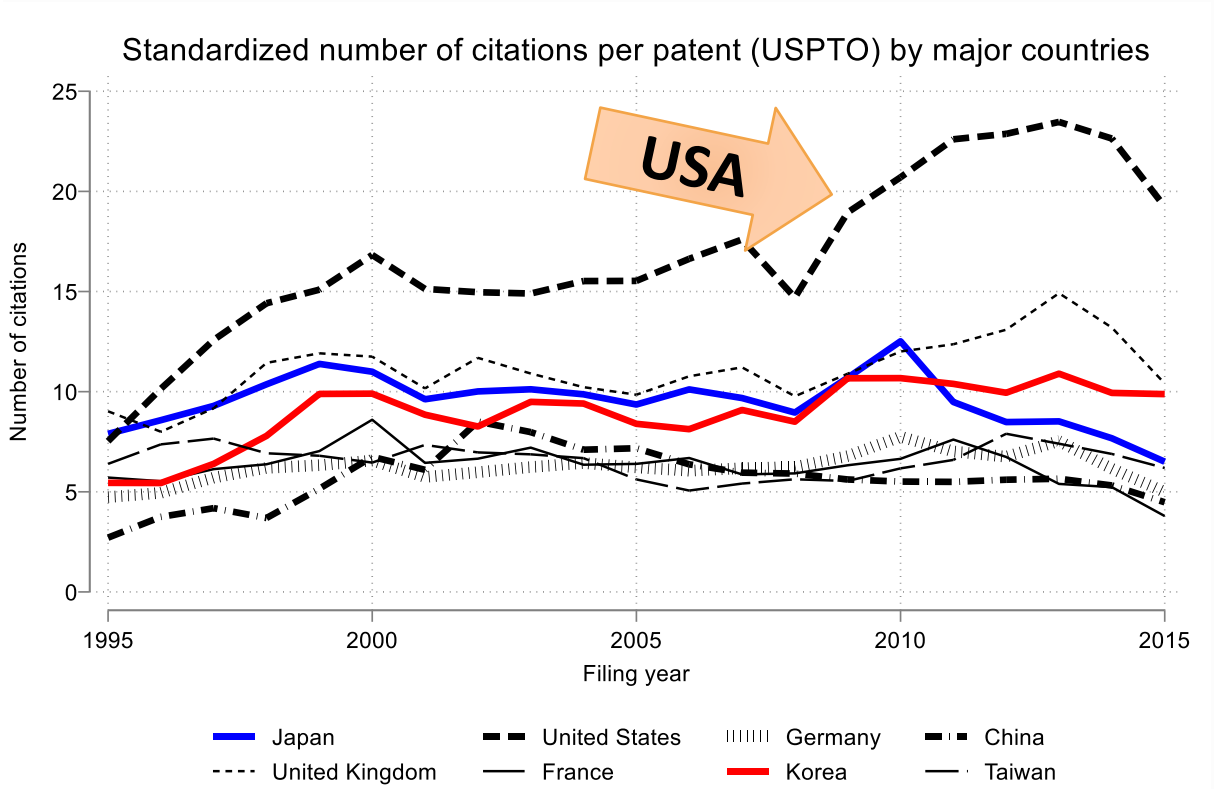
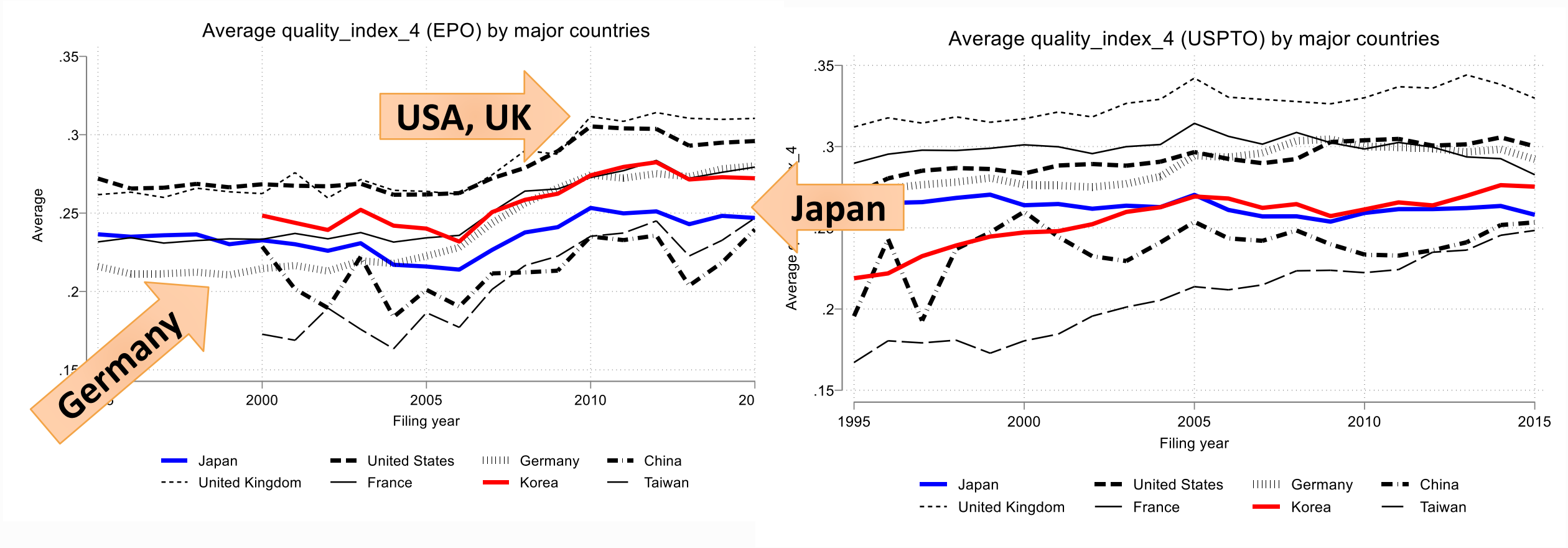


Figure 6. Average 4-Component Patent Quality Index



4. Empirical Analysis

Firms' innovation output and GVC Centrality (firm-level analysis)

<Baseline model: Patent-firm-matched data for 1995-2015>

$$Y_{fjct} = \beta_0 + \beta_1 CENT_{jct-1} + \eta_f + \tau_t + \varepsilon_{fjct}$$

- ✓ Dependent variables for firm *f* in industry *j* in country *c* in year *t* :
  - ✓ Quality-adjusted number of patent applications (weighted by forward citations)
  - ✓ Quality-adjusted number of patents granted (weighted by the 4-component quality index)
  - ✓ Average patent quality (fwd citation or quality index)
  - ✓ Technological diversification index
- ✓ Firm FE and year FE included.

Firms' innovation output and GVC Centrality (firm-level analysis)

<Extended model: Firm-patent-matched data for 1995-2015>

$$Y_{fjct} = \beta_0 + \beta_1 CENT_{jct-1} + \beta_2 Initial\_Tech_f * CENT_{jct-1} + \eta_f + \tau_t + \varepsilon_{ifjct}$$

- ✓ Initial_tech: Firms' initial-year technological capabilities
- ✓ **CORETEC** (firm-specific core-technology competence) index in initial year
- ✓ $CORETEC_{ft} = ln\left[max\left\{RTA_{fjt} \cdot P_{fjt}\right\}\right]$
- ✓ RTA_{fjt}: Revealed comparative advantage for firm *f* within technological class *j* in year *t* ←degree of specialization into technological field *j* (firm *f*'s relative strength in field *j*)
- ✓ P_{fjt}: Number of patent applications by firm *f* for technological field *j* (firm *f*'s absolute strength in field *j*)
- ✓ **Maximum quality of patents** filed by firm *f* in initial year

Endogeneity: Instrument for GVC centrality

$$Y_{fjct} = \beta_0 + \beta_1 CENT_{jct-1} + \eta_f + \tau_t + \varepsilon_{fjct}$$

- ✓OLS using the 1-year lagged or 3-year lagged explanatory variables
- ✓IV estimation: Simple average of the GVC centrality for industry *j* in year *t* for all other countries in the same income-class with country *c*. The income class as of 1995 is used.

- ✓Firms included in the Osiris database: Listed or large firms in the world
- ✓Restrict the sample to the Osiris firms with at least one patent filing at EPO/USPTO during 1995-2015 → approx. 4000-7000 firms per year (Jpn+USA >40%)

Table 1a. IV Estimation Results: GVC centrality and quality-adjusted patenting (fwd citation)

(a) Dependent variable: ln(1+Number of patent applications); Quality-adjusted using the forward citation index

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	EPO						USPTO					
Centrality measure	Backward	Forward	Backward	Forward	Backward	Forward	Backward	Forward	Backward	Forward	Backward	Forward
Technology measure	n.a.	n.a.	CORETEC	CORETEC	Max QI4	Max QI4	n.a.	n.a.	CORETEC	CORETEC	Max QI4	Max QI4
L1.GVC_centrality	0.0385	0.0296	-0.724***	-0.609***	-0.548***	-0.477***	-0.111	-0.0265	-0.577**	-0.492***	-0.414***	-0.349***
	(0.041)	(0.026)	(0.172)	(0.110)	(0.124)	(0.076)	(0.077)	(0.050)	(0.228)	(0.154)	(0.160)	(0.110)
L1.Initial_technology*GVC_ centrality			0.163***	0.136***	2.373***	2.020***			0.118**	0.118***	1.318***	1.339***
			(0.038)	(0.024)	(0.498)	(0.312)			(0.053)	(0.035)	(0.452)	(0.328)
N	103645	103645	103645	103645	69481	69481	132660	132660	132660	132660	113455	113455
Kleibergen-Paap rk LM	547	765	470	619	331	490	668	881	629	794	502	617
Kleibergen-Paap Wald rk F	486	613	216	252	151	183	626	793	296	364	247	278

Positive impact on patenting for firms with higher initial technological capabilities

Table 1b. IV Estimation Results: GVC centrality and quality-adjusted patenting (quality index)

(b) Dependent variable: ln(1+Number of granted patents); Quality-adjusted using the 4-component quality index

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	EPO						USPTO					
Centrality measure	Backward	Forward	Backward	Forward	Backward	Forward	Backward	Forward	Backward	Forward	Backward	Forward
Technology measure	n.a.	n.a.	CORETEC	CORETEC	Max QI4	Max QI4	n.a.	n.a.	CORETEC	CORETEC	Max QI4	Max QI4
L1.GVC_centrality	-0.00560	-0.0201	-0.263**	-0.217***	-0.184**	-0.154***	-0.125***	-0.0781***	-0.322***	-0.257***	-0.181***	-0.157***
	(0.025)	(0.016)	(0.113)	(0.073)	(0.074)	(0.046)	(0.032)	(0.021)	(0.118)	(0.080)	(0.063)	(0.045)
L1.Initial_technology*GVC_ centrality			0.0550**	0.0420***	0.693**	0.496**			0.0501*	0.0451**	0.264	0.326**
			(0.026)	(0.016)	(0.318)	(0.201)			(0.030)	(0.020)	(0.206)	(0.151)
N	103645	103645	103645	103645	69481	69481	132660	132660	132660	132660	113455	113455
Kleibergen-Paap rk LM	547	765	470	619	331	490	668	881	629	794	502	617
Kleibergen-Paap Wald rk F	486	613	216	252	151	183	626	793	296	364	247	278

Positive impact on patenting for firms with higher initial technological capabilities

Table 2a. IV Estimation Results: GVC centrality and average patent quality (fwd citation)

(a) Dependent variable: ln(mean forward citations)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	EPO						USPTO					
Centrality measure	Backward	Forward	Backward	Forward	Backward	Forward	Backward	Forward	Backward	Forward	Backward	Forward
Technology measure	n.a.	n.a.	CORETEC	CORETEC	Max QI4	Max QI4	n.a.	n.a.	CORETEC	CORETEC	Max QI4	Max QI4
L1.GVC_centrality	0.132*	0.0497	0.126	0.0211	-0.286*	-0.226**	0.190***	0.148***	0.497***	0.327***	0.330**	0.189*
	(0.069)	(0.045)	(0.206)	(0.135)	(0.172)	(0.095)	(0.064)	(0.046)	(0.127)	(0.093)	(0.147)	(0.100)
L1.Initial_technology*GVC_ centrality			0.00108	0.00513	1.257***	0.842***			-0.0733***	-0.0420***	-0.402	-0.099
			(0.034)	(0.022)	(0.456)	(0.251)			(0.022)	(0.015)	(0.303)	(0.206)
N	21629	21629	21629	21629	18929	18929	44556	44556	44556	44556	42720	42720
Kleibergen-Paap rk LM	180	188	164	182	160	180	353	372	364	390	368	367
Kleibergen-Paap Wald rk F	165	236	75.8	104	77.7	113	307	388	159	193	173	187

Positive impact but different results for EPO and USPTO

Table 2b. IV Estimation Results: GVC centrality and average patent quality (quality index)

(b) Dependent variable: ln(mean of 4-component quality index)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	EPO						USPTO					
Centrality measure	Backward	Forward	Backward	Forward	Backward	Forward	Backward	Forward	Backward	Forward	Backward	Forward
Technology measure	n.a.	n.a.	CORETEC	CORETEC	Max QI4	Max QI4	n.a.	n.a.	CORETEC	CORETEC	Max QI4	Max QI4
L1.GVC_centrality	-0.00725	-0.0402**	-0.0112	-0.128**	-0.230***	-0.282***	-0.0931***	-0.0679***	-0.186***	-0.138***	-0.474***	-0.391***
	(0.027)	(0.017)	(0.084)	(0.053)	(0.073)	(0.044)	(0.025)	(0.018)	(0.051)	(0.038)	(0.072)	(0.052)
L1.Initial_technology*GVC_ centrality			0.000720	0.0160*	0.705***	0.800***			0.0220***	0.0164***	1.168***	0.985***
			(0.013)	(0.008)	(0.191)	(0.115)			(0.008)	(0.006)	(0.162)	(0.116)
N	26263	26263	26263	26263	23423	23423	43067	43067	43067	43067	41990	41990
Kleibergen-Paap rk LM	212	231	198	227	194	227	354	367	366	383	363	355
Kleibergen-Paap Wald rk F	193	263	90.4	117	93.6	125	310	380	161	189	175	181

Positive impact on patent quality for firms with higher initial technological capabilities

Table 3. IV Estimation Results: GVC centrality and technological diversification

(a) Dependent variable: Technological diversification (TD)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	EPO						USPTO					
Centrality measure	Backward	Forward	Backward	Forward	Backward	Forward	Backward	Forward	Backward	Forward	Backward	Forward
Technology measure	n.a.	n.a.	CORETEC	CORETEC	Max QI4	Max QI4	n.a.	n.a.	CORETEC	CORETEC	Max QI4	Max QI4
L1.GVC_centrality	0.0196	-0.0296	-0.354*	-0.488***	-0.321**	-0.463***	-0.137**	-0.109***	-0.597***	-0.462***	-0.516***	-0.478***
	(0.056)	(0.037)	(0.181)	(0.117)	(0.142)	(0.087)	(0.054)	(0.037)	(0.116)	(0.083)	(0.130)	(0.091)
L1.Initial_technology*GVC_centrality			0.0708**	0.0864***	1.086***	1.354***			0.111***	0.0836***	1.193***	1.147***
			(0.031)	(0.019)	(0.389)	(0.240)			(0.022)	(0.015)	(0.274)	(0.194)
N	33507	33507	33507	33507	27563	27563	48907	48907	48907	48907	46378	46378
Kleibergen-Paap rk LM	260	295	243	289	206	256	382	409	390	425	393	399
Kleibergen-Paap Wald rk F	233	318	109	145	98.4	139	335	421	173	209	187	201

Positive impact on diversification for firms with higher initial technological capabilities

Table 4a. IV Estimation Results: Heterogeneous impacts (Quality-adjusted number of patent applications)

(a) Dependent variable: ln(1+Number of patent applications); Quality-adjusted using the forward citation index

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	EPO				USPTO			
ıtrality measure	Backward	Backward	Forward	Forward	Backward	Backward	Forward	Forward
nology measure	CORETEC	Max QI4	CORETEC	Max QI4	CORETEC	Max QI4	CORETEC	Max QI4
L1.GVC_centrality	-0.147**	-0.227**	-0.0922*	-0.216***	-0.252**	-0.286**	-0.186**	-0.217**
	(0.074)	(0.108)	(0.051)	(0.059)	(0.128)	(0.143)	(0.092)	(0.102)
L1.Initial_tech_Q2	0.171*	0.189	0.0770	0.165**	0.223	0.179	0.184	0.222*
*GVC_centrality	(0.095)	(0.126)	(0.065)	(0.074)	(0.165)	(0.187)	(0.118)	(0.130)
L1.Initial_tech_Q3	0.0857	0.265**	0.0216	0.234***	-0.113	0.19	-0.00633	0.138
*GVC_centrality	(0.090)	(0.127)	(0.064)	(0.075)	(0.178)	(0.190)	(0.125)	(0.135)
L1.Initial_tech_Q4	0.427***	0.585***	0.330***	0.531***	0.364**	0.487***	0.389***	0.493***
*GVC_centrality	(0.104)	(0.148)	(0.068)	(0.091)	(0.159)	(0.161)	(0.115)	(0.118)
N	103645	69481	103645	69481	132660	113455	132660	113455
Kleibergen-Paap rk	410	210	524	438	600	496	777	535
Kleibergen-Paap W	91.4	50.6	107	83.2	141	120	178	121

GVC centrality affects positively only for firms with the Top25% initial technological capabilities.

Table 4b. IV Estimation Results: Heterogeneous impacts (Quality-adjusted number of patents granted)

(b) Dependent variable: ln(1+Number of granted patents); Quality-adjusted using the 4-component quality index

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	EPO				USPTO			
ıtrality measure	Backward	Backward	Forward	Forward	Backward	Backward	Forward	Forward
nology measure	CORETEC	Max QI4	CORETEC	Max QI4	CORETEC	Max QI4	CORETEC	Max QI4
L1.GVC_centrality	-0.0638	-0.101	-0.0462	-0.109***	-0.171***	-0.148***	-0.124***	-0.117***
	(0.046)	(0.063)	(0.032)	(0.034)	(0.049)	(0.054)	(0.036)	(0.039)
L1.Initial_tech_Q2	0.0607	0.0956	0.0146	0.0825**	0.0568	0.0368	0.0447	0.0559
*GVC_centrality	(0.058)	(0.068)	(0.040)	(0.040)	(0.065)	(0.071)	(0.046)	(0.050)
L1.Initial_tech_Q3	0.0381	0.0802	-0.0103	0.0873*	-0.0165	0.024	-0.00859	0.0145
*GVC_centrality	(0.055)	(0.076)	(0.040)	(0.045)	(0.071)	(0.073)	(0.050)	(0.052)
L1.Initial_tech_Q4	0.118*	0.169*	0.0854**	0.131**	0.123*	0.0828	0.124**	0.106**
*GVC_centrality	(0.065)	(0.093)	(0.043)	(0.058)	(0.070)	(0.067)	(0.050)	(0.050)
N	103645	69481	103645	69481	132660	113455	132660	113455
Kleibergen-Paap rk	410	210	524	438	600	496	777	535
Kleibergen-Paap W	91.4	50.6	107	83.2	141	120	178	121

GVC centrality affects positively only for firms with the Top25% initial technological capabilities.

Robustness checks

- ✓ OLS: 1-year lagged or 3-year lagged explanatory variables
- ✓ Excluding Japanese firms from the sample (Japan's GVC centrality conspicuously declined).
- ✓Include firm-level productivity variable (revenue per employee) --- consistent results, but the sample size is reduced by 40%.

Summary

- ✓ GVC centrality tends to have a positive impact on firms' innovation output and technological diversification for firms with initially higher technological capabilities.
- ✓ Firms closer to the central hubs in GVCs are more likely to have access to a greater breadth of knowledge, with greater potential for knowledge spillovers.
- ✓ However, only firms with sufficient absorptive capacity (top25%) realize higher quality innovation and technological diversification by utilizing knowledge spilled over through the GVC network.

Caveats of this study

- ✓Parent-subsidiary relationships
- ✓Multinational operation
- ✓Firm-level and/or country-level heterogeneity
- ✓Sample selection
- ✓Non-linear estimations such as PPML

Thank you for your attention!
I welcome any questions and comments.