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East Asian Production Networks Go Beyond the Gravity Prediction

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Abstract: *This paper provides empirical evidence that supports the continuing importance of machinery international production networks (IPNs) in East Asia. We first confirm their robustness and resilience, even during the coronavirus disease (COVID-19) pandemic, as well as the significance of East Asian countries as suppliers of machinery final products and parts and components for the world. Then, we demonstrate how deeply East Asian countries are committed to machinery IPNs by applying a gravity equation to pre-pandemic bilateral machinery trade and comparing actual values with fitted values of the estimated equation. The gravity estimation exercise indicates that machinery trade is basically regional – within Factory Asia, Factory America, and Factory Europe – but Factory Asia also has strong inter-regional linkages. It also verifies that the Association of Southeast Asian Nations (ASEAN) has played an important role in Factory Asia, going far beyond the gravity prediction, for the development of machinery IPNs.*

Keywords: international production networks, East Asia, gravity equation

JEL Code: F14, F23

1. Introduction

The coronavirus disease (COVID-19) turmoil is not yet over at the timing of writing. However, it has become obvious that global value chains (GVCs) – notably machinery international production networks (IPNs) in East Asia – have survived. East Asia, including Northeast and Southeast Asia, must reconfirm the role of IPNs to strengthen the region's international competitiveness and should maintain a favourable policy environment for IPNs.

East Asia has led the world in aggressively using the mechanics of IPNs (Ando and Kimura, 2005) or the second unbundling (Baldwin, 2016) through the task-by-task international division of labour. The machinery sectors consist of multi-layered production processes with different technologies and diversified materials, involving many players, domestically and internationally. Thus, the machinery sectors have become central players in IPNs and have developed long and sophisticated supply chains. Massive machinery IPNs have so far been formed only in three regions: East Asia, North America, and Europe. Factory Asia comprises countries at more widely different stages of development and extends tighter trade and investment links with other parts of world than Factory North America or Factory Europe. Since the mid-2000s, Factory Asia has established its dominance – especially in electric machinery – and has supplied a massive number of parts and components as well as final products to other regions (Ando and Kimura, 2013).

While pessimism over globalisation has grown in the world, particularly in developed countries, since the global financial crisis (GFC), East Asian IPNs have maintained their strong performance. After an incomplete recovery from the 'trade collapse' due to the GFC, there was a period of 'slow trade' during 2011–2016 in which the growth rate of world trade was lower than that of world gross domestic product (GDP). Even during this period, however, network trade in East Asia grew steadily (Obashi and Kimura, 2018). After Donald Trump became President of the United States (US) in 2017, the US–China confrontation and geopolitical

tensions weakened the confidence in the rules-based trading regime, and from the beginning of 2020, the whole world experienced the turmoil of the COVID-19 pandemic. The 16 May 2020 issue of *The Economist* was entitled 'Goodbye Globalisation', and substantial backward moves against GVCs were predicted. However, again, IPNs in East Asia showed their robust and resilient nature and even functioned as a built-in stabiliser for economies with deep wounds due to COVID-19 (Ando, Kimura, and Obashi, 2021; Ando and Hayakawa, 2021). Although inward-looking sentiments seem to be becoming stronger in other parts of the world, particularly in the European Union (EU), the momentum of globalisation is still alive in East Asia, and development strategies with widening and deepening IPNs continue to be relevant.

The essential elements of the success of East Asia in the formation of IPNs have been a long-lasting peace and a stable rules-based trading regime. The value of a free and predictable trading regime should not be underestimated. With the weakening role of the World Trade Organization (WTO) as a rule keeper, mega free trade agreements (FTAs) – including the Regional Comprehensive Economic Partnership (RCEP) agreement – must be used to reduce policy risks and defend the rules-based trading regime (Kimura, 2021). Trade in goods, particularly in IPN operations, is still crucial for East Asia.

In this paper, we attempt to convince researchers and policymakers of the continuing importance of machinery IPNs in East Asia. The next section presents the decline and recovery of machinery exports amid the COVID-19 pandemic in three regions – East Asia, North America, and Europe – to confirm the robustness and resilience of East Asian IPNs. The rest of the paper is devoted to the gravity equation exercise to show how deeply East Asian countries, particularly the Association of Southeast Asian Nations (ASEAN) Member States (AMS), are committed to machinery IPNs by comparing actual machinery trade with predicted machinery trade after controlling for country size and geography. The last section concludes the paper.

2. Robustness and Resilience of East Asian Machinery IPNs and COVID-19

One of the typical concerns about IPNs, due to their extensiveness, is that a shock could be propagated through the supply chains. Hayakawa and Mukunoki (2021), for instance, demonstrated a negative contagion during COVID-19 from countries supplying machinery parts and components to countries exporting final machinery products. On the other hand, as experienced in past shocks, we observe the robust and resilient nature of machinery IPNs, particularly those in East Asia even with COVID-19.[1]

Figure 1 shows the monthly machinery exports to the world in 2020 and 2021 until August (indexed as each month of 2019 = 1), with a distinction between machinery parts and components and machinery final products (Ando and Hayakawa, 2021).[2] Machinery sectors (Harmonized System (HS) 84-92) include general machinery, electric machinery, transport equipment, and precision machinery. As Figure 1 (a) clearly shows, worldwide machinery exports achieved a rapid V-shaped recovery in 2020, suggesting the resilient nature of machinery IPNs in general. One of the reasons is that the transactions of parts and components within machinery IPNs are unlikely to be disconnected because firms try to optimise their supply chains, considering both cost reduction and risk management, with substantial set-up costs for reliable links (Ando, Kimura, and Obashi, 2021).[3] In addition, the import origin diversity of inputs mitigated the harmful supply-side effects of COVID-19, particularly in February–March 2020,

[1] See Obashi (2010), Ando and Kimura (2012), and Okubo, Kimura, and Teshima (2014) for the robustness and resilience of machinery IPNs in East Asia during past crises such as the 1997 Asian financial crisis, the 2008–2009 GFC, and the 2011 Great East Japan Earthquake. Miroudot (2020) explained the terms 'robustness' (less likely to be interrupted) and 'resilience' (more likely to be resumed even if being interrupted).

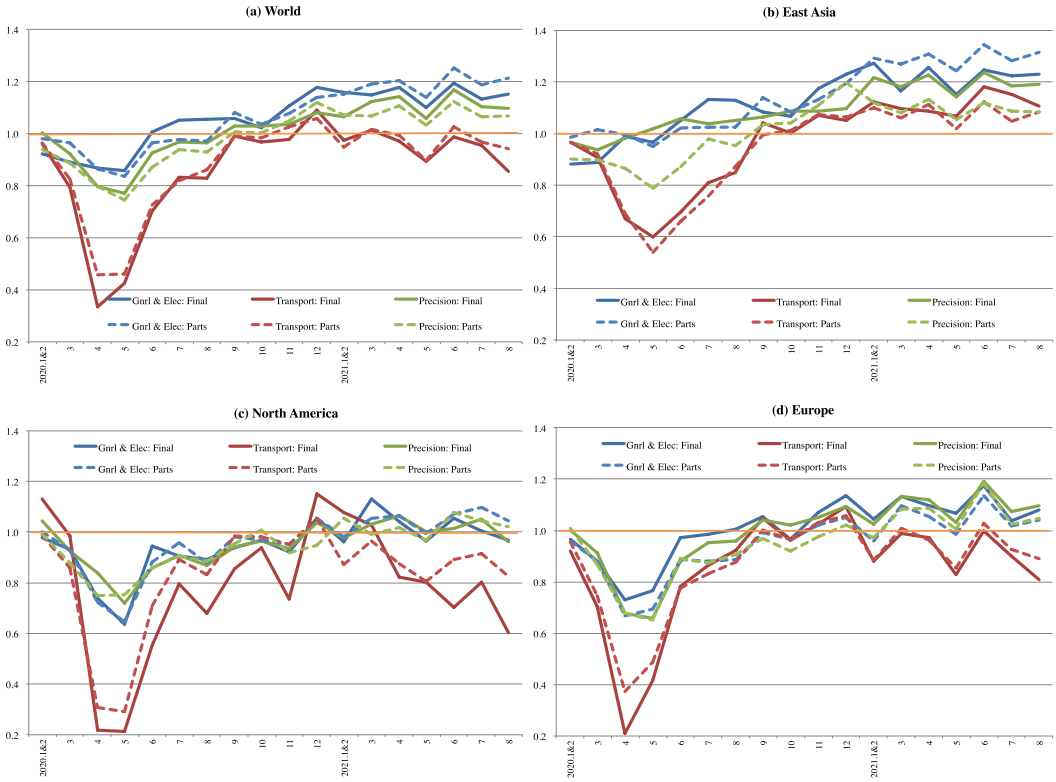
[2] See Kimura and Obashi (2010) for the definition of machinery parts and components for different versions of the Harmonized System (HS) classification. Machinery final products are regarded as machinery goods other than machinery parts and components.

[3] Their analysis of Japan's machinery trade decomposed the fall in trade into two intensive margins (quantity effect and price effect) and two extensive margins (entry effect and exit effect) and showed a small exit effect for parts and components.

as it allowed the flexible adjustment of transactions (Ando and Hayakawa, 2022). Moreover, an increased preference towards the use of e-commerce, reflecting the nature of COVID-19, partially mitigated the negative impacts on trade (Hayakawa, Mukunoki, and Urata, 2021). Furthermore, positive demand shocks due to COVID-19-specific demand for certain products related to teleworking, stay-at-home activities, and preventing infection partially offset negative supply and demand shocks (Ando, Kimura, and Obashi, 2021).

Figure 1: Comparison of Major Machinery International Production Networks Amid COVID-19: Machinery Exports to the World

(each month of 2019 = 1)



ASEAN = Association of Southeast Asian Nations, COVID-19 = coronavirus disease.
Notes: (a) World includes 40 exporting countries; (b) East Asia includes six ASEAN Member States, China, Hong Kong, Taiwan, the Republic of Korea, and Japan; (c) North America includes East Asia, the United States, Mexico, and Canada; and (d) Europe includes 14 European Union countries, the United Kingdom, and Switzerland. 'Gnrl & Elec', 'Transport', and 'Precision' refer to general and electric machinery, transport equipment, and precision machinery, respectively. 'Final' and 'Parts' indicate final products and parts and components, respectively.
Source: Ando and Hayakawa (2021).

Importantly, the negative impacts were much smaller for machinery IPNs in East Asia (Figure 1 (b)) than those in North America (Figure 1 (c)) and Europe (Figure 1 (d)). In addition, exports of general and electric machinery goods, as well as precision machinery final products, returned to their pre-pandemic levels in April 2020. Together with the activated e-commerce transactions, the positive demand shock products of these sectors contributed to such a rapid recovery by partially compensating for the effects of the negative supply and demand shocks.[4] East Asian countries are important suppliers of machinery final products as well as parts and components in the world; for instance, five (eight) out of the top 10 (20) export countries for general and electric machinery final products, six (10) for general and electric machinery parts and components, and six (10) for precision machinery parts and components are in East Asia in the pre-pandemic year (Table 1). This suggests how significant machinery sectors are for East Asian economies.

[4] Ando, Kimura, and Obashi (2021) presented examples of positive demand shock products that contribute significantly to trade increases (or partially mitigating trade decreases) in the case of Japan's machinery trade. Such products include laptop computers.

Table 1: Top 20 Export Countries and Their Shares in Global Machinery Exports, 2019

(%)

	Final products						Parts and components					
	Gnrl & Elec		Transport		Precision		Gnrl & Elec		Transport		Precision	
1	China	33.4	Germany	15.7	US	16.5	China	19.1	Germany	14.8	China	21.7
2	Germany	8.7	US	9.7	Germany	12.5	US	9.1	US	11.3	Japan	10.1
3	US	6.4	Japan	9.6	China	8.6	Germany	9.0	China	8.4	US	10.0
4	Mexico	4.5	Mexico	7.0	Switzerland	7.1	Rep. of Korea	6.7	Japan	7.5	Germany	8.8
5	Japan	3.8	France	6.3	Netherlands	6.9	Japan	6.3	Mexico	6.2	Rep. of Korea	7.5
6	Netherlands	3.2	Rep. of Korea	4.6	Japan	6.9	Taiwan	6.2	France	4.8	Taiwan	7.4
7	Viet Nam	3.2	China	4.5	Mexico	4.3	Singapore	3.6	UK	4.0	UK	3.3
8	Italy	3.1	Canada	4.2	Singapore	3.5	Malaysia	3.5	Rep. of Korea	3.8	France	2.4
9	Rep. of Korea	2.5	Spain	3.6	France	3.1	Mexico	3.0	Italy	3.7	Singapore	2.3
10	Taiwan	2.1	UK	3.6	UK	2.9	France	2.9	Czechia	3.2	Thailand	2.2
11	Thailand	2.0	Belgium	3.1	Ireland	2.8	Italy	2.7	Poland	3.2	Netherlands	2.1
12	Czech Rep.	2.0	Italy	2.4	Italy	2.2	UK	2.5	Canada	3.0	Malaysia	1.9
13	Malaysia	1.7	Netherlands	1.8	Belgium	2.0	Viet Nam	2.1	Spain	2.7	Mexico	1.8
14	UK	1.7	Czech Rep.	1.8	Rep. of Korea	2.0	Netherlands	2.0	Belgium	1.5	Italy	1.8
15	France	1.6	Slovakia	1.8	Malaysia	1.7	Philippines	1.5	Thailand	1.5	Switzerland	1.7
16	Poland	1.5	Turkey	1.7	Taiwan	1.1	Thailand	1.4	Hungary	1.5	Viet Nam	1.4
17	Singapore	1.3	Thailand	1.6	Canada	1.1	Czech Rep.	1.4	Sweden	1.4	Ireland	1.3
18	UAE	1.1	Poland	1.4	Israel	1.0	Poland	1.2	Romania	1.4	Canada	1.1
19	Sweden	1.1	Sweden	1.3	Austria	0.9	Canada	1.2	Taiwan	1.4	Hong Kong	1.0
20	Austria	1.1	India	1.2	Poland	0.9	Hong Kong	1.1	Netherlands	1.4	Philippines	0.7

UAE = United Arab Emirates, UK = United Kingdom, US = United States.
Note: East Asian countries, including Hong Kong and Taiwan, are highlighted.
Source: Authors' calculation.

In 2021, machinery IPNs faced new challenges, including a shortage of containers, a shortage of semiconductors, and the emergence of the delta variant of COVID-19. Although several countries experienced sporadic declines in specific sectors, East Asia has maintained its machinery exports beyond the pre-pandemic levels.[5]

On the other hand, the negative impacts were serious for machinery IPNs in North America and Europe, though they also showed a V-shaped recovery in 2020. In particular, their transport equipment exports had a more prolonged depression. In the case of North America, transport equipment exports experienced the greatest drop in April and May 2020, with a decline of 80% for final products and

[5] According to Ando and Hayakawa (2021), we observe, for instance, a drastic export decline of transport equipment final products in August and September 2021 in Japan, likely reflecting the shortage of semiconductors, a severe decrease in July in Indonesia due to a rapid expansion of the delta variant of COVID-19, and drastic declines in August and September in the transport equipment sectors of several AMS. On the other hand, China experienced an outstanding export increase in transport equipment final products from July to September, reflecting the expanding production of electric vehicles (EVs) in China by major EV manufactures such as Tesla and Volkswagen.

70% for parts and components. In addition, they began to decline again in 2021 after returning to pre-pandemic levels at the end of 2020. Similarly, in the case of Europe, transport equipment exports reached their lowest level in April 2020, with a decline of 80% for final products and 60% for parts and components. Although the export recovery by Europe since June 2020 was rapid for all machinery sectors, including the transport equipment sector, transport equipment exports returned to a declining trend in 2021 and fluctuated below pre-pandemic levels at least until August 2021.

To uncover the extent and depth of machinery IPNs in East Asia with the features mentioned above, we examine the pre-pandemic performance of machinery trade in the following sections.

3. Method and Data to Evaluate the Degree of Involvement in Machinery Trade

This section explains how to evaluate the extent and depth of machinery IPNs in East Asia and other regions. We employ the same methodology used in Ando, Yamanouchi, and Kimura (2021).[6] Specifically, we first estimate a traditional gravity equation for machinery trade (HS84-92). Then, we calculate the predicted values of bilateral machinery trade as fitted values to the estimated equation. The ratio of the actual trade value to the predicted value indicates the degree of actual trade from the perspective of the level predicted by the model, taking into account the economic size and the geographical conditions.

The gravity model is estimated in a conventional manner (Yotov et al., 2016). The estimating equation is as follows:

$$X_{ij} = \exp\left(\boldsymbol{x_i\beta_1} + \boldsymbol{x_j\beta_2} + \boldsymbol{d_{ij}\beta_3}\right) * u_{ij}.$$

[6] Their gap ratio is essentially the same concept as the export potential proposed by Mulabdic and Yasar (2021).

X_{ij} denotes the export value of machinery goods from country i to country j in 2019 (or 2010). $\boldsymbol{x_i}$ denotes a vector of explanatory variables specific to export country i. We include the log of GDP, log of population, WTO membership dummy, and log of remoteness index in the set of explanatory variables.[7] $\boldsymbol{x_j}$ denotes a vector of explanatory variables specific to import country j, and we use the same set of variables for importers as exporters. $\boldsymbol{d_{ij}}$ denotes a vector of bilateral variables of the country pair i and j, which includes bilateral distance, a contiguity dummy, a common language dummy, a common religion index, and a common coloniser dummy. u_{ij} is disturbance. Following Santos Silva and Tenreyro (2006), we estimate the above equation by Poisson pseudo maximum likelihood (PPML). We recognise that our estimating equation is in a naïve form (Head and Mayer, 2014), and the use of panel data and country-pair fixed effects is usually recommended. Nevertheless, we prefer using the conventional gravity model for estimation rather than using more sophisticated techniques because the purpose of our estimation is to evaluate how vigorous a country or a region trades machinery products given their economic size and geographical conditions.

In the second step, we calculate the predicted values, using estimated coefficients obtained in the first step as well as explanatory variables, to obtain the gap ratios between the actual and predicted values. The variation in unobservable bilateral factors is excluded from the predicted values. We can therefore interpret them as appropriate values for their economic size and geographical conditions. The predicted trade value for a region is calculated by totalling the predicted values of the countries in the region, as the actual trade value. Adding up the constraints of the PPML estimator ensures that the sum of the predicted values in the world must be equal to the world trade value.

The data for machinery trade were obtained from the BACI database of the Centre d'Etudes Prospectives et d'Informations Internationales (CEPII), which

[7] Head and Mayer (2014) criticised the remoteness index because it is not supported by theoretical background. We, however, use the index because our estimation is not based on a specific theory.

provides disaggregated data on bilateral trade flows for more than 5,000 products and 200 countries. The data for other variables used in the estimation of the gravity equation were obtained from the BACI database and the Gravity database of the CEPII, respectively.[8] Our sample comprises 176 countries and regions (see Table A1 in the Appendix).

4. Results

Table 2 shows the results of the gravity estimation in the first step.[9] The coefficients for GDP and WTO membership of both the origin and destination countries are positive and statistically significant. This suggests that countries with a larger economic size and WTO member countries tend to have larger machinery trade in terms of both origin and destination. The results are negative with statistical significance for the population of destination countries, distance, and common religion, while positive with statistical significance for remoteness of destination countries, contiguity, and common coloniser. This implies that countries with a smaller population and countries that are isolated from other countries are more likely to import machinery goods, and that countries without a common religion, countries within a shorter distance, countries sharing borders, and countries with common colonisers tend to have larger machinery trade. The coefficients for population and remoteness of origin countries and common language are insignificant. This indicates that the population size and the remoteness of origin countries, as well as whether countries have a common language, do not matter much for machinery trade.

[8] The BACI database was constructed by Gaulier and Zignago (2010). The Gravity database was constructed by Head, Mayer, and Ries (2010) and Head and Mayer (2014).
[9] The corresponding results for 2010 are presented in Table A2 in the Appendix.

Table 2: Results of Gravity Estimation, 2019

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ln(Origin GDP)	0.946***	0.928***	0.968***	0.892***	1.016***	0.819***	0.963***
	(0.0440)	(0.0402)	(0.0569)	(0.0499)	(0.0570)	(0.0575)	(0.0657)
ln(Destination GDP)	0.984***	1.054***	0.917***	0.965***	1.029***	0.967***	1.079***
	(0.0668)	(0.0783)	(0.0629)	(0.0692)	(0.103)	(0.0790)	(0.129)
ln(Origin population)	-0.00924	0.0566	-0.0775	0.0570	-0.100**	0.0782	-0.0706
	(0.0518)	(0.0495)	(0.0634)	(0.0626)	(0.0489)	(0.0717)	(0.0595)
ln(Destination population)	-0.264***	-0.337***	-0.194**	-0.261***	-0.300***	-0.289***	-0.304**
	(0.0710)	(0.0733)	(0.0790)	(0.0791)	(0.0934)	(0.0977)	(0.119)
Origin WTO membership	2.283***	2.029***	2.607***	2.707***	1.506***	3.122***	1.818***
	(0.438)	(0.464)	(0.416)	(0.444)	(0.457)	(0.414)	(0.599)
Destination WTO membership	0.426**	0.0765	0.896***	0.559***	0.0228	0.880***	-0.00242
	(0.172)	(0.192)	(0.164)	(0.191)	(0.223)	(0.265)	(0.237)
ln(Origin remoteness)	-0.0616	-0.256**	0.140	0.0765	-0.333**	0.367**	-0.245
	(0.128)	(0.128)	(0.149)	(0.144)	(0.169)	(0.184)	(0.207)
ln(Destination remoteness)	0.452***	0.357**	0.562***	0.524***	0.364**	0.625***	0.364*
	(0.143)	(0.139)	(0.169)	(0.164)	(0.163)	(0.188)	(0.193)
ln(Distance)	-0.688***	-0.550***	-0.841***	-0.758***	-0.588***	-0.877***	-0.660***
	(0.0569)	(0.0478)	(0.0755)	(0.0680)	(0.0603)	(0.0853)	(0.0712)
Contiguity dummy	0.698**	0.837***	0.564*	0.657**	0.934***	0.628	0.998***
	(0.293)	(0.297)	(0.330)	(0.315)	(0.346)	(0.404)	(0.382)
Common language dummy	-0.0339	-0.253	0.199	0.116	-0.472*	0.362	-0.636**
	(0.221)	(0.211)	(0.252)	(0.241)	(0.241)	(0.284)	(0.287)
Common coloniser dummy	0.595**	0.351*	0.690*	0.591*	0.336*	0.588	-0.537***
	(0.280)	(0.180)	(0.371)	(0.347)	(0.203)	(0.419)	(0.201)
Common religion index	-0.732***	-0.145	-1.525***	-1.407***	0.401**	-2.567***	0.542***
	(0.277)	(0.201)	(0.420)	(0.415)	(0.158)	(0.712)	(0.183)
Constant	6.489	0.0744	11.84***	9.420**	-0.131	16.27***	1.105
	(4.048)	(4.435)	(4.178)	(4.125)	(5.725)	(4.431)	(6.962)
Observations	30,450	30,450	30,450	30,450	30,450	30,450	30,450
R-squared	0.508	0.572	0.382	0.417	0.527	0.305	0.464
pseudo log-likelihood	-4262841	-2103155	-2573786	-3382415	-1335400	-2580101	-1187128
product	all	final	parts	section16	section17	hs85	hs87

GDP = gross domestic product, WTO = World Trade Organization.
Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.
Source: Authors' calculation.

Table 3 shows the actual and predicted values of machinery trade and their gap ratios for each country/region of the world for 2019, and Table 4 is the aggregated version to shed light on machinery IPNs in three regions. Similarly, Table 5 is the aggregated version showing (a) machinery final products and (b) machinery parts and components separately.[10] In these tables, East Asia comprises the ASEAN+3 countries (Factory Asia), while North America and Europe refer to Canada, Mexico, and the US (Factory America) and the 27 EU member countries and the United Kingdom (Factory Europe), respectively.

[10] The table for machinery final products and parts and components for 2019, which corresponds to Table 3, is available upon request.

Table 3: Actual and Predicted Machinery Trade, 2019

Exporter (row)/ Importer (column)	Value ($ million), %	China	Japan	Rep. of Korea	ASEAN	Australia and New Zealand	India	North America	Europe	Rest of the world	Total (World)
China	Actual (A)		75,889	58,515	161,657	7,708	37,831	296,546	249,381	476,571	**1,364,100**
	Predicted (B)		118,568	65,893	72,285	9,463	50,069	163,984	177,079	295,714	**953,054**
	(A)/(B) (%)		*64*	*89*	*224*	*81*	*76*	*181*	*141*	*161*	***143***
Japan	Actual (A)	81,031		20,245	59,962	2,582	5,817	126,272	64,669	110,199	**470,778**
	Predicted (B)	74,293		22,386	21,715	3,928	7,176	64,147	60,411	84,697	**338,752**
	(A)/(B) (%)	*109*		*90*	*276*	*66*	*81*	*197*	*107*	*130*	***139***
Rep. of Korea	Actual (A)	84,679	9,161		54,181	744	6,551	66,569	36,682	77,051	**335,618**
	Predicted (B)	45,860	24,865		8,639	1,307	2,996	21,772	22,348	35,613	**163,400**
	(A)/(B) (%)	*185*	*37*		*627*	*57*	*219*	*306*	*164*	*216*	***205***
ASEAN	Actual (A)	83,070	39,456	24,559	122,552	4,107	17,733	117,662	83,934	151,101	**644,176**
	Predicted (B)	39,799	18,528	6,644	45,225	2,846	8,388	34,797	38,940	65,409	**260,576**
	(A)/(B) (%)	*209*	*213*	*370*	*271*	*144*	*211*	*338*	*216*	*231*	***247***
Australia and New Zealand	Actual (A)	114	57	66	373	11	45	1,215	930	8,395	**11,206**
	Predicted (B)	2,694	1,766	531	1,521	300	540	7,916	5,269	13,322	**33,859**
	(A)/(B) (%)	*4*	*3*	*12*	*25*	*4*	*8*	*15*	*18*	*63*	***33***
India	Actual (A)	1,971	792	566	9,107	228		13,273	11,687	27,601	**65,224**
	Predicted (B)	56,238	12,864	4,836	18,953	2,042		32,905	45,745	87,819	**261,402**
	(A)/(B) (%)	*4*	*6*	*12*	*48*	*11*		*40*	*26*	*31*	***25***
North America	Actual (A)	63,106	28,621	23,338	43,379	5,678	9,328	617,230	161,678	177,220	**1,129,577**
	Predicted (B)	105,297	65,732	20,088	42,259	15,982	18,806	591,802	291,501	327,579	**1,479,047**
	(A)/(B) (%)	*60*	*44*	*116*	*103*	*36*	*50*	*104*	*55*	*54*	***76***
Europe	Actual (A)	144,804	37,144	30,659	64,599	8,846	24,562	286,773	1,517,637	428,107	**2,543,132**
	Predicted (B)	122,616	66,879	22,266	51,213	11,851	27,976	318,751	1,298,753	542,040	**2,462,344**
	(A)/(B) (%)	*118*	*56*	*138*	*126*	*75*	*88*	*90*	*117*	*79*	***103***
Rest of the world	Actual (A)	92,501	22,859	16,508	60,029	8,727	21,201	95,207	180,288	192,063	**689,382**
	Predicted (B)	137,665	59,758	23,082	55,204	17,478	38,627	227,839	380,672	360,433	**1,300,757**
	(A)/(B) (%)	*67*	*38*	*72*	*109*	*50*	*55*	*42*	*47*	*53*	***53***
Total (World)	**Actual (A)**	**551,277**	**213,978**	**174,456**	**575,838**	**38,631**	**123,069**	**1,620,747**	**2,306,885**	**1,648,311**	**7,253,193**
	Predicted (B)	**584,462**	**368,959**	**165,726**	**317,013**	**65,196**	**154,578**	**1,463,914**	**2,320,719**	**1,812,625**	**7,253,192**
	(A)/(B) (%)	***94***	***58***	***105***	***182***	***59***	***80***	***111***	***99***	***91***	***100***

Notes: 'Actual (A)' denotes the actual values of specific country/region pairs, 'Predicted (B)' denotes the corresponding predicted values, and '(A)/(B) (%)' denotes the ratio of actual to predicted values in percentage. North America refers to Canada, Mexico, and the United States; Europe refers to the 27 European Union member countries and the United Kingdom; and 'Rest of the world' refers to 128 countries and regions, including Hong Kong, Macao, and Taiwan. The predicted values for regions are calculated by totalling the member countries' predicted values.
Source: Authors' calculation.

Table 4: Actual and Predicted Machinery Trade for Three Major Regions, 2019

Exporter (row)/ **Importer** (column)	**Value ($ million), %**	**East Asia**	**North America**	**Europe**	**Rest of the world**	**Total (World)**
East Asia	Actual (A)	874,958	607,050	434,667	897,997	**2,814,672**
	Predicted (B)	564,700	284,701	298,778	567,605	**1,715,783**
	(A)/(B) (%)	*155*	*213*	*145*	*158*	***164***
North America	Actual (A)	158,443	617,230	161,678	192,226	**1,129,577**
	Predicted (B)	233,376	591,802	291,501	362,368	**1,479,047**
	(A)/(B) (%)	*68*	*104*	*55*	*53*	***76***
Europe	Actual (A)	277,206	286,773	1,517,637	461,516	**2,543,132**
	Predicted (B)	262,974	318,751	1,298,753	581,866	**2,462,344**
	(A)/(B) (%)	*105*	*90*	*117*	*79*	***103***
Rest of the world	Actual (A)	204,942	109,694	192,904	258,272	**765,812**
	Predicted (B)	375,111	268,660	431,686	520,561	**1,596,019**
	(A)/(B) (%)	*55*	*41*	*45*	*50*	***48***
Total (World)	**Actual (A)**	**1,515,549**	**1,620,747**	**2,306,885**	**1,810,011**	**7,253,193**
	Predicted (B)	**1,436,160**	**1,463,914**	**2,320,719**	**2,032,400**	**7,253,193**
	(A)/(B) (%)	***106***	***111***	***99***	***89***	***100***

Notes: 'Actual (A)' denotes the actual values of specific country/region pairs, 'Predicted (B)' denotes the corresponding predicted values, and '(A)/(B) (%)' denotes the ratio of actual to predicted values in percentage. East Asia refers to the Association of Southeast Asian Nations (ASEAN) Plus Three countries; North America refers to Canada, Mexico, and the United States; Europe refers to the 27 European Union member countries and the United Kingdom; and 'Rest of the world' refers to 128 countries and regions in Table 3 plus Australia, New Zealand, and India.
Source: Authors' calculation.

Table 5: Actual and Predicted Machinery Final and Parts Trade for Three Major Regions, 2019

(a) Machinery final products

Exporter (row)/ **Importer** (column)	**Value ($ million), %**	**East Asia**	**North America**	**Europe**	**Rest of the world**	**Total (World)**
East Asia	Actual (A)	324,138	366,838	264,327	452,041	**1,407,343**
	Predicted (B)	246,955	170,022	185,804	295,464	**898,245**
	(A)/(B) (%)	*131*	*216*	*142*	*153*	***157***
North America	Actual (A)	80,302	346,496	98,509	115,329	**640,636**
	Predicted (B)	120,477	283,655	179,980	186,445	**770,557**
	(A)/(B) (%)	*67*	*122*	*55*	*62*	***83***
Europe	Actual (A)	153,114	161,200	874,782	274,152	**1,463,248**
	Predicted (B)	147,028	203,399	740,159	317,146	**1,407,733**
	(A)/(B) (%)	*104*	*79*	*118*	*86*	***104***
Rest of the world	Actual (A)	55,586	57,537	109,080	147,342	**369,545**
	Predicted (B)	182,034	144,614	232,524	245,066	**804,238**
	(A)/(B) (%)	*31*	*40*	*47*	*60*	***46***
Total (World)	**Actual (A)**	**613,140**	**932,070**	**1,346,699**	**988,863**	**3,880,772**
	Predicted (B)	**696,494**	**801,690**	**1,338,468**	**1,044,121**	**3,880,772**
	(A)/(B) (%)	***88***	***116***	***101***	***95***	***100***

(b) Machinery parts and components

Exporter (row)/ **Importer** (column)	**Value ($ million), %**	**East Asia**	**North America**	**Europe**	**Rest of the world**	**Total (World)**
East Asia	Actual (A)	550,821	240,212	170,340	445,956	**1,407,328**
	Predicted (B)	325,939	116,372	116,424	273,188	**831,922**
	(A)/(B) (%)	*169*	*206*	*146*	*163*	***169***
North America	Actual (A)	78,141	270,734	63,169	76,897	**488,941**
	Predicted (B)	110,466	303,043	112,290	173,316	**699,115**
	(A)/(B) (%)	*71*	*89*	*56*	*44*	***70***
Europe	Actual (A)	124,092	125,573	642,854	187,364	**1,079,884**
	Predicted (B)	114,790	118,886	556,542	264,690	**1,054,908**
	(A)/(B) (%)	*108*	*106*	*116*	*71*	***102***
Rest of the world	Actual (A)	149,355	52,158	83,824	110,930	**396,267**
	Predicted (B)	194,268	120,963	196,716	274,527	**786,475**
	(A)/(B) (%)	*77*	*43*	*43*	*40*	***50***
Total (World)	**Actual (A)**	**902,409**	**688,677**	**960,186**	**821,147**	**3,372,420**
	Predicted (B)	**745,462**	**659,264**	**981,973**	**985,721**	**3,372,420**
	(A)/(B) (%)	***121***	***104***	***98***	***83***	***100***

Notes: 'Actual (A)' denotes the actual values of specific country/region pairs, 'Predicted (B)' denotes the corresponding predicted values, and '(A)/(B) (%)' denotes the ratio of actual to predicted values in percentage. East Asia refers to Association of Southeast Asian Nations (ASEAN) Plus Three countries; North America refers to Canada, Mexico, and the United States; Europe refers to the 27 European Union member countries and the United Kingdom; and 'Rest of the world' refers to 128 countries and regions in Table 3 plus Australia, New Zealand, and India.
Source: Authors' calculation.

Our results provide several interesting insights. First, machinery trade is basically regional within Factory Asia, Factory America, and Factory Europe, but inter-regional linkages are also strong for Factory Asia. The second unbundling or trade in machinery parts and components is actively conducted within a region because such transactions require the procurement at appropriate timing, subtle coordination amongst production blocks, low services link costs, tight information and information and communication technology (ICT) connectivity, reliable logistics connectivity, and so on. In that sense, it is natural to have active trade within a region. The intra-regional gap ratios over 100% for each region confirm active machinery trade within a region for Factory Asia, Factory America, and Factory Europe: 155% (131% for machinery final products only) for East Asia, 104% (122%) for North America, and 117% (118%) for Europe.

On the other hand, inter-regional linkages are also substantial for East Asia. Exports by East Asia reveal that not only the intra-regional gap ratio (155%) but

also the inter-regional gap ratios (213% for North America and 145% for Europe) are high. This indicates that Factory Asia has strong linkages with Factory America and Factory Europe as a supplier. Moreover, the corresponding ratios are high for both machinery final products and machinery parts and components: 216% and 206% in the case of exports from East Asia to North America and 142% and 146% in the case of exports to Europe, respectively.[11] Furthermore, the inter-regional gap ratios are even higher than the intra-regional ratios of East Asia for both final products and parts and components in the case of exports from East Asia to North America and for final products in the case of exports to Europe. These results suggest that Factory Asia has played an important role not only as a supplier of intermediate goods but also as a supplier of final products in these two regions. In other words, Factory Asia is open to the world.

In contrast, the inter-regional gap ratios for exports by North America and Europe are lower than the aforementioned ratios for exports by East Asia: much less than 100% for North America and more or less 100% for Europe. In addition, the intra-regional gap ratios are likely to rise in North America and Europe: the ratios increased from 87% in 2010 to 104% in 2019 (from 104% to 122% for final products and from 73% to 89% for parts and components) for North America, and from 112% to 117% (from 112% to 118% for final products and from 112% to 116% for parts and components) for Europe (Tables 3 and 4 for 2019 and Table A3 in the Appendix for 2010). Such a tendency implies stronger regionalisation and possibly regional reshoring for Factory America and Factory Europe.

Second, ASEAN has been playing an important role in Factory Asia. Table 3 confirms ASEAN's tight connectivity not only amongst AMS but also with other East Asian countries in terms of both exports and imports. Specifically, intra-ASEAN trade and ASEAN trade with China, Japan, and the Republic of Korea (henceforth, Korea) are more than twice the predicted values for both

[11] These ratios were already high in 2010. The table corresponding to Table 4 for 2010 is available upon request.

exports and imports. This suggests that ASEAN participates in machinery IPNs in East Asia much more actively than the predicted levels explained by the model, considering its economic size and distance, and plays a central role in machinery IPNs in East Asia. Moreover, exports from ASEAN to North America and Europe are also more than twice their predicted values, with gap ratios of 338% and 216%, respectively. This indicates that ASEAN contributes to the active inter-regional linkages with these two regions.

On the other hand, as for trade amongst China, Japan, and Korea, these countries are not connected each other as closely as we expected, after controlling for country size and geographical distance: China's exports to Japan and Korea (64% and 89%), Japan's to Korea (90%), and Korea's to Japan (37%) are lower than predicted. Moreover, the rest of the countries within the ASEAN+6 – Australia, New Zealand, and India – are not active in machinery trade. Their connection with ASEAN in terms of exports is much weaker than that in terms of imports and is even below the predicted levels (25% and 48%, respectively).[12] Their connection with China, Japan, and Korea is also low, with much lower actual values than predicted for all cases of exports and imports except the case of India's imports from Korea (219%), and the corresponding gap ratios for exports are even lower: less than 10% for their exports to China and Japan and 12% for those to Korea.

Third, with a focus on individual AMS except Brunei Darussalam, some countries are global players while others are regional players. The original AMS other than Brunei and Indonesia – Malaysia, the Philippines, Singapore, and Thailand – as well as Viet Nam have larger intra-ASEAN trade than the predicted values by almost twice or even more than twice for both exports and imports (Table 6).[13] In addition, these five countries are tightly connected with diversified

[12] Their connection with ASEAN in terms of imports became stronger in the 2010s – from 88% to 144% for Australia and New Zealand and from 132% to 211% for India – but is still lower than the case of ASEAN's exports to the world (247%) in 2019. See Table A3 in the Appendix for the table corresponding to Table 3 for 2010.

[13] All cases of their trade in terms of both exports and imports, except imports by Malaysia from

AMS, as suggested by the large gap ratios for their exports to individual AMS.[14] Moreover, gap ratios for their exports to China, Japan, and Korea and those for their exports to the world are high – around 200% or much larger than 200%, which indicates that exports by these AMS to the world as well as their exports to China, Japan, and Korea are larger than the predicted values by almost twice or much more than twice. These findings suggest that the aforementioned five AMS – Malaysia, the Philippines, Singapore, Thailand, Viet Nam – have been global suppliers of machinery goods.

other AMS with a gap ratio of slightly less than 200%, show that the corresponding ratios are much larger than 200%.

[14] For instance, Singapore has large exports to most other AMS. Thailand specialises in the automobile sector; exports in this industry account for $9 billion out of machinery exports of $24 billion. The Philippines has a particularly close relationship with Singapore amongst the AMS.

Table 6: Actual and Predicted Machinery Trade for Individual ASEAN Member States, 2019

Exporter (row)/ **Importer** (column)	**Value ($ million), %**	**Singapore**	**Brunei**	**Malaysia**	**Thailand**	**Indonesia**	**Philippines**	**Viet Nam**	**Lao PDR**	**Cambodia**	**Myanmar**	**ASEAN**	**China, Japan, and Rep. of Korea**	**Total (World)**
Singapore	Actual (A)		393	13,234	3,955	5,543	4,543	3,470	30	338	815	32,321	34,364	**156,011**
	Predicted (B)		128	5,444	678	1,469	274	210	34	59	150	8,446	6,468	**34,514**
	(A)/(B) (%)		*309*	*243*	*583*	*377*	*1,657*	*1,653*	*88*	*572*	*543*	*383*	*531*	***452***
Brunei	Actual (A)	90		55	4	2	0	4	0	0	0	155	42	**250**
	Predicted (B)	74		70	25	38	19	10	1	2	6	245	327	**1,416**
	(A)/(B) (%)	*122*		*79*	*15*	*5*	*1*	*38*	*2*	*0*	*0*	*63*	*13*	***18***
Malaysia	Actual (A)	19,879	110		6,593	1,785	1,609	2,958	8	97	86	33,125	27,355	**147,174**
	Predicted (B)	8,476	188		1,486	2,124	269	214	36	62	161	13,015	6,308	**38,377**
	(A)/(B) (%)	*235*	*59*		*444*	*84*	*598*	*1,384*	*22*	*156*	*54*	*255*	*434*	***383***
Thailand	Actual (A)	3,786	49	4,377		3,574	3,860	4,798	915	1,581	827	23,768	22,145	**113,417**
	Predicted (B)	1,310	82	1,844		1,114	435	513	231	283	538	6,348	11,006	**44,997**
	(A)/(B) (%)	*289*	*59*	*237*		*321*	*888*	*935*	*397*	*559*	*154*	*374*	*201*	***252***
Indonesia	Actual (A)	3,471	40	1,210	2,311		3,226	1,851	21	91	147	12,367	4,551	**30,530**
	Predicted (B)	3,323	150	3,087	1,305		691	455	71	109	171	9,361	16,248	**70,177**
	(A)/(B) (%)	*104*	*26*	*39*	*177*		*467*	*407*	*30*	*83*	*86*	*132*	*28*	***44***
Philippines	Actual (A)	5,852	2	1,497	2,189	473		1,061	0	10	6	11,090	17,663	**62,111**
	Predicted (B)	608	74	383	499	678		239	32	44	65	2,623	9,235	**27,307**
	(A)/(B) (%)	*962*	*3*	*391*	*438*	*70*		*445*	*0*	*23*	*9*	*423*	*191*	***227***
Viet Nam	Actual (A)	1,718	20	1,493	2,535	1,122	1,073		105	295	244	8,606	40,332	**131,657**
	Predicted (B)	492	40	322	623	472	252		225	162	85	2,674	11,129	**28,431**
	(A)/(B) (%)	*349*	*51*	*464*	*407*	*238*	*425*		*47*	*182*	*286*	*322*	*362*	***463***
Lao PDR	Actual (A)	6	0	8	397	4	0	27		1	0	444	82	**770**
	Predicted (B)	45	3	30	159	42	19	127		17	19	462	814	**2,460**
	(A)/(B) (%)	*13*	*0*	*28*	*250*	*9*	*0*	*21*		*8*	*1*	*96*	*10*	***31***
Cambodia	Actual (A)	8	0	16	202	1	62	47	1		2	341	346	**1,403**
	Predicted (B)	91	6	62	225	74	30	107	19		10	624	658	**2,906**
	(A)/(B) (%)	*9*	*0*	*27*	*90*	*2*	*206*	*44*	*7*		*18*	*55*	*53*	***48***
Myanmar	Actual (A)	133	0	13	113	6	11	60	0	0		336	205	**852**
	Predicted (B)	304	19	209	564	153	60	74	30	13		1,426	2,777	**9,993**
	(A)/(B) (%)	*44*	*0*	*6*	*20*	*4*	*19*	*81*	*0*	*1*		*24*	*7*	***9***
ASEAN	Actual (A)	34,944	614	21,904	18,299	12,510	14,385	14,276	1,082	2,412	2,126	122,552	147,085	**644,176**
	Predicted (B)	14,723	690	11,451	5,563	6,163	2,050	1,948	679	752	1,205	45,225	64,971	**260,576**
	(A)/(B) (%)	*237*	*89*	*191*	*329*	*203*	*702*	*733*	*159*	*321*	*177*	*271*	*226*	***247***
China, Japan, and Rep. of Korea	Actual (A)	49,071	427	34,230	41,200	31,174	25,148	86,404	995	2,485	4,664	275,800	329,520	**2,170,496**
	Predicted (B)	18,495	1,609	11,602	16,517	20,509	11,853	14,692	1,893	1,236	4,234	102,639	351,865	**1,455,207**
	(A)/(B) (%)	*265*	*27*	*295*	*249*	*152*	*212*	*588*	*53*	*201*	*110*	*269*	*94*	***149***
Total (World)	**Actual (A)**	**154,458**	**1,729**	**86,621**	**81,632**	**58,174**	**57,501**	**119,042**	**2,257**	**6,313**	**8,112**	**575,838**	**939,711**	**7,253,192**
	Predicted (B)	**72,025**	**5,168**	**47,512**	**50,633**	**65,241**	**27,378**	**28,933**	**4,342**	**4,069**	**11,713**	**317,013**	**1,119,147**	**7,253,192**
	(A)/(B) (%)	***214***	***33***	***182***	***161***	***89***	***210***	***411***	***52***	***155***	***69***	***182***	***84***	***100***

ASEAN = Association of Southeast Asian Nations.
Notes: 'Actual (A)' denotes the actual values of specific country/region pairs, 'Predicted (B)' denotes the corresponding predicted values, and '(A)/(B) (%)' denotes the ratio of actual to predicted values in percentage. The predicted values for regions are calculated by totalling the member countries' predicted values.
Source: Authors' calculation.

In contrast, Indonesia, the Lao People's Democratic Republic (Lao PDR), Cambodia, and Myanmar seem to be regional players. In the case of Indonesia, its exports to the Philippines and Viet Nam are much higher than the predicted values, and those to ASEAN slightly increased from 120% to 132% in the 2010s, but its gap ratio is still substantially lower than the ratios of other AMS that are mentioned above as global players.[15] As for the Lao PDR, Cambodia, and Myanmar, their exports to AMS are still less than the predicted values in 2019, though the export values expanded in the 2010s. Since Cambodia and Myanmar significantly increased the corresponding ratios for imports, these countries have just started to be involved in IPNs in East Asia. The Lao PDR has strong connections with only Thailand; its export value to Thailand is 2.5 times higher than predicted. Besides, exports from these four countries to China, Japan, and Korea, as well as those to the world, are much less than the predicted levels. This implies that four countries contribute to Factory Asia as regional players.

Fourth, the extent and depth of machinery IPNs in East Asia developed further in the 2010s. We observe a drastic change for some countries, particularly Viet Nam. As mentioned above, Viet Nam became one of the global players by the end of the 2010s. However, at the beginning of the 2010s, its exports to the world (and those to China, Japan, and Korea) were less than the predicted level as the gap ratio of 95% (87%) suggests. Indeed, Viet Nam significantly expanded trade with ASEAN in the 2010s; the gap ratios increased from 144% in 2010 to 322% in 2019 for exports and from 392% to 732% for imports. This indicates how rapidly Viet Nam became involved in IPNs in the 2010s and transformed into one of the core players. In addition, Viet Nam substantially expanded exports to the world, including China, Japan, and Korea, producing gap ratios of 463% for the world (362% for China, Japan, and Korea).

[15] See Table A4 in the Appendix for the table corresponding to Table 6 for 2010.

In addition to Viet Nam, some low-income countries – particularly Cambodia – substantially changed the international division of labour in the 2010s. In 2010, the Lao PDR and Cambodia had machinery exports mostly to Thailand alone, while Myanmar had almost no machinery exports. However, the destinations of exports from Cambodia and Myanmar were diversified amongst AMS (such as Thailand, the Philippines, and Viet Nam) and other East Asian countries by the end of the 2010s, though their actual exports were still lower than predicted. In addition, their gap ratios for imports from ASEAN and other East Asian countries significantly increased to reach 321% and 201% for Cambodia and 177% and 110% for Myanmar, respectively. Thus, these two countries have just started to be involved in IPNs in East Asia, but Cambodia achieved a particularly outstanding change in terms of participating in Factory Asia. The drastic change in Viet Nam and these countries confirms the further development in the extent and depth of machinery IPNs in East Asia in the 2010s.

Fifth, inter-regional linkages in addition to intra-regional linkages for East Asia are more strongly observed for general and electric machinery exports. Table 7 shows the results of (a) general and electric machinery trade and (b) transport equipment trade for three major regions.[16] In the case of East Asia, inter-regional linkages with North America and Europe are stronger for general and electric machinery exports (particularly electric machinery exports only) than for the whole machinery exports; gap ratios are 231% (252%) for North America and 166% (184%) for Europe for general and electric machinery exports (electric machinery exports only), which are larger than those for the whole machinery sector, 213% and 145%. In addition, exports to these two regions from East Asia are above the predicted levels even in the transport equipment sector, with gap ratios of 196% and 100%, respectively – particularly automobile exports, with

[16] See Table A5 in the Appendix for the results for (a) electric machinery trade and (b) automobile trade.

ratios of 226% and 113% – although inter-regional linkages are not as strong as in the general and electric machinery sector.

Table 7: Actual and Predicted Machinery Trade for Two Sectors, 2019

(a) HS84–HS85: General and electric machinery sector

Exporter (row)/ **Importer** (column)	**Value ($ million), %**	**East Asia**	**North America**	**Europe**	**Rest of the world**	**Total (World)**
East Asia	Actual (A)	704,143	449,603	336,265	691,745	**2,181,757**
	Predicted (B)	438,661	194,263	202,735	430,208	**1,265,867**
	(A)/(B) (%)	*161*	*231*	*166*	*161*	***172***
North America	Actual (A)	85,729	322,198	77,617	106,603	**592,147**
	Predicted (B)	150,854	376,919	165,018	236,790	**929,580**
	(A)/(B) (%)	*57*	*85*	*47*	*45*	***64***
Europe	Actual (A)	146,020	150,032	819,874	266,816	**1,382,742**
	Predicted (B)	149,580	161,754	699,557	340,819	**1,351,709**
	(A)/(B) (%)	*98*	*93*	*117*	*78*	***102***
Rest of the world	Actual (A)	161,938	69,982	105,830	160,627	**498,376**
	Predicted (B)	271,010	179,988	282,827	374,039	**1,107,865**
	(A)/(B) (%)	*60*	*39*	*37*	*43*	***45***
Total (World)	**Actual (A)**	**1,097,830**	**991,815**	**1,339,585**	**1,225,791**	**4,655,022**
	Predicted (B)	**1,010,105**	**912,924**	**1,350,136**	**1,381,856**	**4,655,022**
	(A)/(B) (%)	***109***	***109***	***99***	***89***	***100***

(b) HS86–HS89: Transport equipment sector

Exporter (row)/ **Importer** (column)	**Value ($ million), %**	**East Asia**	**North America**	**Europe**	**Rest of the world**	**Total (World)**
East Asia	Actual (A)	89,317	117,731	64,754	151,783	**423,584**
	Predicted (B)	98,164	60,174	64,961	107,708	**331,007**
	(A)/(B) (%)	*91*	*196*	*100*	*141*	***128***
North America	Actual (A)	36,105	256,728	49,475	58,556	**400,864**
	Predicted (B)	50,814	149,338	82,941	81,556	**364,649**
	(A)/(B) (%)	*71*	*172*	*60*	*72*	***110***
Europe	Actual (A)	92,225	95,532	581,635	142,085	**911,477**
	Predicted (B)	75,265	113,988	487,171	175,884	**852,308**
	(A)/(B) (%)	*123*	*84*	*119*	*81*	***107***
Rest of the world	Actual (A)	14,277	20,939	61,603	74,648	**171,468**
	Predicted (B)	75,637	61,216	109,404	113,171	**359,429**
	(A)/(B) (%)	*19*	*34*	*56*	*66*	***48***
Total (World)	**Actual (A)**	**231,924**	**490,930**	**757,467**	**427,072**	**1,907,393**
	Predicted (B)	**299,880**	**384,717**	**744,477**	**478,319**	**1,907,393**
	(A)/(B) (%)	*77*	***128***	***102***	***89***	***100***

Notes: 'Actual (A)' denotes the actual values of specific country/region pairs, 'Predicted (B)' denotes the corresponding predicted values, and '(A)/(B) (%)' denotes the ratio of actual to predicted values in percentage. East Asia refers to the Association of Southeast Asian Nations (ASEAN) Plus Three countries; North America refers to Canada, Mexico, and the United States; Europe refers to the 27 European Union member countries and the United Kingdom; and 'Rest of the world' refers to 128 countries and regions in Table 3 plus Australia, New Zealand, and India.
Source: Authors' calculation.

In the case of North America, intra-regional linkages are much stronger in the transport equipment sector, with weak connectivity with other regions; the intra-regional gap ratio is 172% in this sector (185% in the automobiles sector only), which is much higher than 104% for the whole machinery sector, while the inter-regional gap ratios with East Asia and Europe are only around 60%–70%. As for Europe, regardless of whether the targeted sectors are broader (Table 7) or specific (Table A5), its exports to East Asia exceed the predicted values in the transport equipment sector (and in the automobile sector only), but do not do so in the general and electric machinery sector (and in the electric machinery sector only).

5. Conclusion

In this paper, we have provided empirical evidence that supports the continuing importance of machinery IPNs in East Asia. We first confirmed their robustness and resilience – even with COVID-19 – particularly for those in East Asia, as well as the significance of East Asian countries as suppliers of machinery final products and parts and components in the world. Worldwide machinery exports achieved a rapid V-shaped recovery in 2020, and the negative impacts on exports were much smaller for East Asia than for North America and Europe. Together with the activated e-commerce transactions, the positive demand shock contributed to such a rapid recovery in East Asia by partially compensating for the effects of the negative supply and demand shocks. Then, we applied a gravity equation to pre-pandemic bilateral machinery trade and compared actual values with fitted values of the estimated equation to show how deeply East Asian countries are committed to machinery IPNs. The gravity estimation exercise demonstrated that machinery trade is basically regional within Factory Asia, Factory America, and Factory Europe, but Factory Asia also has strong inter-regional linkages, contributing as suppliers of machinery parts and components as well as machinery final products to Factory America and Factory

Europe. It also demonstrated that ASEAN has played an important role in Factory Asia, going far beyond the gravity prediction. Furthermore, it showed that the extent and depth of machinery IPNs in East Asia developed further in the 2010s and that East Asia's inter-regional linkages – in addition to intra-regional linkages – are particularly strong in the general and electric machinery sector.

A series of empirical findings indicate ASEAN's strong commitment to machinery IPNs. ASEAN emphasises ASEAN centrality, which is firmly supported by its economic structure. The RCEP, based on the ASEAN initiative, could be used effectively to reduce policy risks throughout East Asia and to maintain the healthy rules-based trading regime. While the decoupling pressure caused by the US–China confrontation and geopolitical tensions may intensify, middle powers wedged between the two superpowers are trying to maintain close economic relationships with both. In practice, the US has a truly deep economic relationship with China, so the decoupling is likely to be limited in scope. What private companies are afraid of is the unlimited application of trade controls and the shrinkage of economic dynamism due to the expanded concept of national security and sensitive technologies. Therefore, it is necessary to keep the coverage governed by the rules-based trading regime as broad as possible.

Digitalised services trade based on the third unbundling by Baldwin (2016) or the person-to-person international division of labour may become a major international division of labour in the coming few decades. Trade in goods, however, is still dominant at this moment. It is important to evaluate properly the value of the importance of IPNs covering East Asia and to make an effort to maintain the economic dynamism.

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Appendix

Table A1: Country List

Afghanistan	Cambodia	Gambia	Latvia	Pakistan	Suriname
Albania	Cameroon	Georgia	Lebanon	Panama	Swaziland
Algeria	Canada	Germany	Lesotho	Papua New Guinea	Sweden
Andorra	Central African Rep.	Ghana	Liberia	Paraguay	Switzerland
Angola	Chad	Greece	Libya	Peru	Taiwan
Antigua and Barbuda	Chile	Grenada	Luxembourg	Philippines	Tajikistan
Argentina	China	Guatemala	Macao	Poland	Thailand
Armenia	Colombia	Guinea	Macedonia	Portugal	Togo
Australia	Comoros	Guinea-Bissau	Madagascar	Qatar	Tonga
Austria	Congo	Guyana	Malawi	Rep. of Korea	Trinidad and Tobago
Azerbaijan	Costa Rica	Haiti	Malaysia	Rep. of Moldova	Tunisia
Bahamas	Côte d'Ivoire	Honduras	Maldives	Romania	Turkey
Bahrain	Croatia	Hong Kong	Mali	Russian Federation	Uganda
Bangladesh	Cyprus	Hungary	Malta	Rwanda	Ukraine
Barbados	Czech Republic	Iceland	Mauritania	Saint Kitts and Nevis	United Arab Emirates
Belarus	Dem. Rep. of the Congo	India	Mauritius	Saint Lucia	United Kingdom
Belgium	Denmark	Indonesia	Mexico	St. Vincent&Grenadines	United States
Belize	Djibouti	Iraq	Mongolia	Samoa	United Rep. of Tanzania
Benin	Dominica	Ireland	Morocco	Sao Tome and Principe	Uruguay
Bermuda	Dominican Rep.	Israel	Mozambique	Saudi Arabia	Uzbekistan
Bhutan	Ecuador	Italy	Myanmar	Senegal	Vanuatu
Bolivia	Egypt	Jamaica	Namibia	Seychelles	Viet Nam
Bosnia Herzegovina	El Salvador	Japan	Nepal	Sierra Leone	Yemen
Botswana	Equatorial Guinea	Jordan	Netherlands	Singapore	Zambia
Brazil	Estonia	Kazakhstan	New Zealand	Slovakia	Zimbabwe
Brunei Darussalam	Ethiopia	Kenya	Nicaragua	Slovenia	
Bulgaria	Fiji	Kiribati	Niger	Solomon Islands	
Burkina Faso	Finland	Kuwait	Nigeria	South Africa	
Burundi	France	Kyrgyzstan	Norway	Spain	
Cabo Verde	Gabon	Lao PDR	Oman	Sri Lanka	

Table A2: Results of Gravity Estimation, 2010

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ln(Origin GDP)	0.897***	0.862***	0.936***	0.833***	1.054***	0.762***	1.063***
	(0.0461)	(0.0434)	(0.0544)	(0.0497)	(0.0539)	(0.0550)	(0.0694)
ln(Destination GDP)	0.870***	0.915***	0.828***	0.876***	0.860***	0.906***	0.923***
	(0.0518)	(0.0600)	(0.0495)	(0.0604)	(0.0624)	(0.0657)	(0.0828)
ln(Origin population)	0.0567	0.146**	-0.0354	0.113	-0.0799	0.117	-0.0963
	(0.0637)	(0.0664)	(0.0678)	(0.0742)	(0.0530)	(0.0785)	(0.0661)
ln(Destination population)	-0.147**	-0.211***	-0.0859	-0.155**	-0.168***	-0.219***	-0.136*
	(0.0594)	(0.0541)	(0.0724)	(0.0690)	(0.0556)	(0.0834)	(0.0739)
Origin WTO membership	2.413***	2.218***	2.681***	2.696***	1.738***	3.171***	2.103***
	(0.208)	(0.219)	(0.221)	(0.233)	(0.225)	(0.232)	(0.351)
Destination WTO membership	0.452***	0.156	0.890***	0.640***	-0.0279	0.965***	0.0483
	(0.120)	(0.125)	(0.135)	(0.133)	(0.155)	(0.147)	(0.178)
ln(Origin remoteness)	0.0683	-0.166	0.309**	0.175	-0.166	0.445***	-0.0272
	(0.107)	(0.101)	(0.126)	(0.128)	(0.109)	(0.161)	(0.140)
ln(Destination remoteness)	0.495***	0.419***	0.575***	0.524***	0.456***	0.628***	0.514***
	(0.121)	(0.110)	(0.149)	(0.147)	(0.105)	(0.164)	(0.129)
ln(Distance)	-0.735***	-0.579***	-0.902***	-0.780***	-0.623***	-0.882***	-0.762***
	(0.0681)	(0.0541)	(0.0876)	(0.0744)	(0.0626)	(0.0882)	(0.0742)
Contiguity dummy	0.661**	0.872***	0.435	0.633*	0.946***	0.656	0.839***
	(0.265)	(0.248)	(0.323)	(0.327)	(0.210)	(0.439)	(0.261)
Common language dummy	0.0691	-0.109	0.265	0.177	-0.323**	0.308	-0.401**
	(0.190)	(0.173)	(0.222)	(0.225)	(0.135)	(0.275)	(0.180)
Common coloniser dummy	0.506	0.206	0.644*	0.553	0.0715	0.563	-0.323
	(0.309)	(0.210)	(0.381)	(0.364)	(0.188)	(0.423)	(0.250)
Common religion index	-1.181***	-0.746***	-1.730***	-1.730***	-0.181	-2.391***	0.0962
	(0.276)	(0.217)	(0.383)	(0.400)	(0.188)	(0.600)	(0.226)
Constant	8.953***	1.968	14.60***	10.62***	3.780	17.16***	6.718
	(3.224)	(3.274)	(3.491)	(3.652)	(3.605)	(3.800)	(4.484)
Observations	30,450	30,450	30,450	30,450	30,450	30,450	30,450
R-squared	0.513	0.556	0.414	0.379	0.665	0.268	0.601
pseudo log-likelihood	-3256365	-1696389	-1849790	-2540376	-1046850	-1723387	-770034
product	all	final	parts	section16	section17	hs85	hs87

GDP = gross domestic product, WTO = World Trade Organization.
Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.
Source: Authors' calculation.

Table A3: Actual and Predicted Machinery Trade, 2010

Exporter (row)/ Importer (column)	Value ($ million, %)	China	Japan	Rep. of Korea	ASEAN	Australia and New Zealand	India	North America	Europe	Rest of the world	Total (World)
China	Actual (A)		61,357	34,720	70,256	5,837	20,252	200,895	194,895	306,947	**895,159**
	Predicted (B)		98,784	37,037	40,885	5,782	31,181	75,556	99,167	165,836	**554,227**
	(A)/(B) (%)		*62*	*94*	*172*	*101*	*65*	*266*	*197*	*185*	***162***
Japan	Actual (A)	92,461		26,971	67,993	2,240	5,390	110,241	71,787	140,295	**517,380**
	Predicted (B)	58,756		26,427	25,539	5,063	9,641	62,682	70,938	102,445	**361,491**
	(A)/(B) (%)	*157*		*102*	*266*	*44*	*56*	*176*	*101*	*137*	***143***
Rep. of Korea	Actual (A)	73,765	11,191		24,744	1,036	5,943	47,576	47,382	86,787	**298,426**
	Predicted (B)	22,400	26,872		6,059	984	2,419	12,332	15,417	25,156	**111,639**
	(A)/(B) (%)	*329*	*42*		*408*	*105*	*246*	*386*	*307*	*345*	***267***
ASEAN	Actual (A)	52,845	30,760	13,488	98,785	2,076	9,417	56,587	57,379	103,551	**424,888**
	Predicted (B)	18,892	19,854	4,628	33,993	2,353	7,120	21,307	28,649	48,436	**185,232**
	(A)/(B) (%)	*280*	*155*	*291*	*291*	*88*	*132*	*266*	*200*	*214*	***229***
Australia and New Zealand	Actual (A)	90	89	41	297	9	141	1,567	1,025	10,702	**13,963**
	Predicted (B)	1,758	2,562	492	1,530	315	663	6,664	5,019	15,302	**34,305**
	(A)/(B) (%)	*5*	*3*	*8*	*19*	*3*	*21*	*24*	*20*	*70*	***41***
India	Actual (A)	663	275	209	5,158	148		4,598	9,095	15,137	**35,283**
	Predicted (B)	29,153	15,155	3,740	15,346	1,986		24,514	38,921	73,305	**202,119**
	(A)/(B) (%)	*2*	*2*	*6*	*34*	*7*		*19*	*23*	*21*	***17***
North America	Actual (A)	41,334	25,933	18,227	43,134	6,376	7,657	420,690	123,460	152,993	**839,805**
	Predicted (B)	53,670	74,778	14,469	33,137	14,400	18,667	481,303	220,498	272,978	**1,183,900**
	(A)/(B) (%)	*77*	*35*	*126*	*130*	*44*	*41*	*87*	*56*	*56*	***71***
Europe	Actual (A)	100,279	24,625	22,255	49,995	7,803	21,766	175,399	1,208,933	421,630	**2,032,685**
	Predicted (B)	67,414	81,259	17,356	42,513	10,556	28,100	213,355	1,079,059	479,288	**2,018,900**
	(A)/(B) (%)	*149*	*30*	*128*	*118*	*74*	*77*	*82*	*112*	*88*	***101***
Rest of the world	Actual (A)	63,689	17,388	15,818	41,579	13,771	8,047	63,739	139,780	149,428	**513,239**
	Predicted (B)	59,068	64,072	15,734	39,597	17,673	31,578	144,050	278,169	269,074	**919,016**
	(A)/(B) (%)	*108*	*27*	*101*	*105*	*78*	*25*	*44*	*50*	*56*	***56***
Total (World)	**Actual (A)**	**425,128**	**171,618**	**131,730**	**401,941**	**39,297**	**78,614**	**1,081,293**	**1,853,736**	**1,387,471**	**5,570,828**
	Predicted (B)	**311,111**	**383,335**	**119,882**	**238,599**	**59,113**	**129,370**	**1,041,763**	**1,835,836**	**1,451,819**	**5,570,828**
	(A)/(B) (%)	***137***	***45***	***110***	***168***	***66***	***61***	***104***	***101***	***96***	***100***

ASEAN = Association of Southeast Asian Nations.
Notes: 'Actual (A)' denotes the actual values of specific country/region pairs, 'Predicted (B)' denotes the corresponding predicted values, and '(A)/(B) (%)' denotes the ratio of actual to predicted values in percentage. North America refers to Canada, Mexico, and the United States; Europe refers to the 27 European Union member countries and the United Kingdom; and 'Rest of the world' refers to 128 countries and regions, including Hong Kong, Macao, and Taiwan. The predicted values for regions are calculated by totalling the member countries' predicted values.
Source: Authors' calculation.

Table A4: Actual and Predicted Machinery Trade for ASEAN Member States, 2010

Exporter (row)/ Importer (column)	Value ($ million), %	Singapore	Brunei	Malaysia	Thailand	Indonesia	Philippines	Viet Nam	Lao PDR	Cambodia	Myanmar	ASEAN	China, Japan, and Rep. of Korea	Total (World)
Singapore	Actual (A)		244	12,853	4,627	7,841	3,251	1,551	11	137	301	30,816	30,067	**136,061**
	Predicted (B)		98	4,238	477	1,186	208	130	12	38	127	6,514	4,266	**23,950**
	(A)/(B) (%)		*248*	*303*	*969*	*661*	*1,565*	*1,193*	*92*	*366*	*237*	*473*	*705*	***568***
Brunei	Actual (A)	101		37	16	2	1	0	0	0	0	158	1	**200**
	Predicted (B)	53		63	24	38	19	8	1	2	6	215	291	**1,239**
	(A)/(B) (%)	*191*		*59*	*68*	*6*	*4*	*4*	*0*	*11*	*0*	*74*	*0*	***16***
Malaysia	Actual (A)	15,495	79		5,487	1,610	1,182	1,040	8	31	50	24,981	24,727	**108,725**
	Predicted (B)	6,021	167		1,203	1,824	218	158	15	47	162	9,815	4,933	**29,125**
	(A)/(B) (%)	*257*	*47*		*456*	*88*	*541*	*659*	*51*	*65*	*31*	*255*	*501*	***373***
Thailand	Actual (A)	4,917	66	5,124		3,886	2,302	1,720	609	621	497	19,744	20,297	**93,810**
	Predicted (B)	830	76	1,472		949	326	355	92	193	546	4,838	7,373	**31,920**
	(A)/(B) (%)	*593*	*87*	*348*		*410*	*705*	*485*	*664*	*321*	*91*	*408*	*275*	***294***
Indonesia	Actual (A)	4,870	28	1,129	1,603		945	364	1	5	24	8,968	4,015	**24,441**
	Predicted (B)	2,440	146	2,642	1,123		590	349	32	85	194	7,599	12,867	**56,494**
	(A)/(B) (%)	*200*	*19*	*43*	*143*		*160*	*104*	*3*	*5*	*12*	*118*	*31*	***43***
Philippines	Actual (A)	7,463	1	2,052	1,546	383		164	0	3	1	11,614	13,473	**47,019**
	Predicted (B)	388	65	287	351	536		150	12	28	60	1,876	6,125	**17,823**
	(A)/(B) (%)	*1,924*	*2*	*715*	*441*	*72*		*109*	*0*	*12*	*2*	*619*	*220*	***264***
Viet Nam	Actual (A)	544	1	218	590	306	389		38	102	9	2,197	4,483	**14,124**
	Predicted (B)	246	29	210	386	321	152		66	79	70	1,560	5,246	**15,145**
	(A)/(B) (%)	*221*	*3*	*104*	*153*	*96*	*256*		*57*	*128*	*13*	*141*	*85*	***93***
Lao PDR	Actual (A)	0	0	0	51	0	0	4		1	0	57	1	**61**
	Predicted (B)	2	0	2	8	2	1	5		1	1	21	30	**104**
	(A)/(B) (%)	*11*	*0*	*2*	*672*	*1*	*1*	*83*		*107*	*26*	*267*	*2*	***59***
Cambodia	Actual (A)	11	0	2	210	1	0	13	0		0	239	13	**394**
	Predicted (B)	44	4	39	132	49	18	49	5		8	349	339	**1,571**
	(A)/(B) (%)	*24*	*0*	*5*	*160*	*3*	*2*	*27*	*9*		*1*	*68*	*4*	***25***
Myanmar	Actual (A)	2	0	4	2	0	1	2	0	0		11	17	**53**
	Predicted (B)	205	19	184	507	152	52	60	14	11		1,204	1,903	**7,862**
	(A)/(B) (%)	*1*	*0*	*2*	*0*	*0*	*2*	*3*	*0*	*0*		*1*	*1*	***1***
ASEAN	Actual (A)	33,403	418	21,418	14,133	14,032	8,072	4,859	668	899	882	98,785	97,093	**424,888**
	Predicted (B)	10,229	605	9,137	4,210	5,056	1,584	1,264	249	483	1,174	33,993	43,373	**185,232**
	(A)/(B) (%)	*327*	*69*	*234*	*336*	*278*	*510*	*384*	*269*	*186*	*75*	*291*	*224*	***229***
China, Japan, and Rep. of Korea	Actual (A)	44,606	273	28,215	34,171	22,134	15,033	15,418	390	548	2,206	162,993	300,466	**1,710,965**
	Predicted (B)	11,550	1,432	9,413	11,544	16,671	8,719	8,264	614	777	3,500	72,483	270,276	**1,027,356**
	(A)/(B) (%)	*386*	*19*	*300*	*296*	*133*	*172*	*187*	*63*	*70*	*63*	*225*	*111*	***167***
Total (World)	**Actual (A)**	**133,761**	**1,036**	**80,507**	**66,142**	**49,779**	**36,022**	**28,329**	**1,191**	**1,796**	**3,378**	**401,941**	**728,476**	**5,570,828**
	Predicted (B)	**47,608**	**4,702**	**38,589**	**38,135**	**56,030**	**20,257**	**18,100**	**1,582**	**2,717**	**10,879**	**238,599**	**814,329**	**5,570,828**
	(A)/(B) (%)	***281***	***22***	***209***	***173***	***89***	***178***	***157***	*75*	***66***	***31***	***168***	***89***	***100***

ASEAN = Association of Southeast Asian Nations.
Notes: 'Actual (A)' denotes the actual values of specific country/region pairs, 'Predicted (B)' denotes the corresponding predicted values, and '(A)/(B) (%)' denotes the ratio of actual to predicted values in percentage. The predicted values for regions are calculated by totalling the member countries' predicted values.
Source: Authors' calculation.

Table A5: Actual and Predicted Machinery Trade for Two Specific Sectors, 2019

(a) HS85: Electric machinery sector

Exporter (row)/ **Importer** (column)	**Value ($ million), %**	**East Asia**	**North America**	**Europe**	**Rest of the world**	**Total (World)**
East Asia	Actual (A)	467,905	259,219	189,474	475,992	**1,392,591**
	Predicted (B)	289,610	102,073	106,126	263,841	**761,650**
	(A)/(B) (%)	*162*	*254*	*179*	*180*	***183***
North America	Actual (A)	48,734	146,983	31,532	47,806	**275,055**
	Predicted (B)	75,362	203,557	70,325	120,507	**469,751**
	(A)/(B) (%)	*65*	*72*	*45*	*40*	***59***
Europe	Actual (A)	58,423	41,341	355,685	88,093	**543,542**
	Predicted (B)	64,989	61,444	304,926	160,454	**591,813**
	(A)/(B) (%)	*90*	*67*	*117*	*55*	***92***
Rest of the world	Actual (A)	119,684	32,466	53,883	97,848	**303,880**
	Predicted (B)	171,361	108,028	166,786	245,679	**691,854**
	(A)/(B) (%)	*70*	*30*	*32*	*40*	***44***
Total (World)	**Actual (A)**	**694,745**	**480,009**	**630,574**	**709,739**	**2,515,068**
	Predicted (B)	**601,321**	**475,102**	**648,163**	**790,481**	**2,515,068**
	(A)/(B) (%)	***116***	***101***	***97***	***90***	***100***

(b) HS87: Automobile sector

Exporter (row)/ **Importer** (column)	**Value ($ million), %**	**East Asia**	**North America**	**Europe**	**Rest of the world**	**Total (World)**
East Asia	Actual (A)	68,415	107,985	52,865	107,691	**336,956**
	Predicted (B)	81,712	47,785	46,777	75,421	**251,694**
	(A)/(B) (%)	*84*	*226*	*113*	*143*	***134***
North America	Actual (A)	19,111	235,407	28,070	35,263	**317,851**
	Predicted (B)	36,205	127,447	59,145	52,614	**275,411**
	(A)/(B) (%)	*53*	*185*	*47*	*67*	***115***
Europe	Actual (A)	63,057	68,683	501,071	96,470	**729,281**
	Predicted (B)	53,627	90,056	421,602	123,007	**688,293**
	(A)/(B) (%)	*118*	*76*	*119*	*78*	***106***
Rest of the world	Actual (A)	7,782	13,142	45,322	50,509	**116,755**
	Predicted (B)	62,572	52,598	88,849	81,425	**285,445**
	(A)/(B) (%)	*12*	*25*	*51*	*62*	***41***
Total (World)	**Actual (A)**	**158,366**	**425,217**	**627,328**	**289,933**	**1,500,843**
	Predicted (B)	**234,116**	**317,887**	**616,373**	**332,468**	**1,500,843**
	(A)/(B) (%)	***68***	***134***	***102***	***87***	***100***

Notes: 'Actual (A)' denotes the actual values of specific country/region pairs, 'Predicted (B)' denotes the corresponding predicted values, and '(A)/(B) (%)' denotes the ratio of actual to predicted values in percentage. East Asia refers to the Association of Southeast Asian Nations (ASEAN) Plus Three countries; North America refers to Canada, Mexico, and the United States; Europe refers to the 27 European Union member countries and the United Kingdom; and 'Rest of the world' refers to 128 countries and regions in Table 3 plus Australia, New Zealand, and India.
Source: Authors' calculation.

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