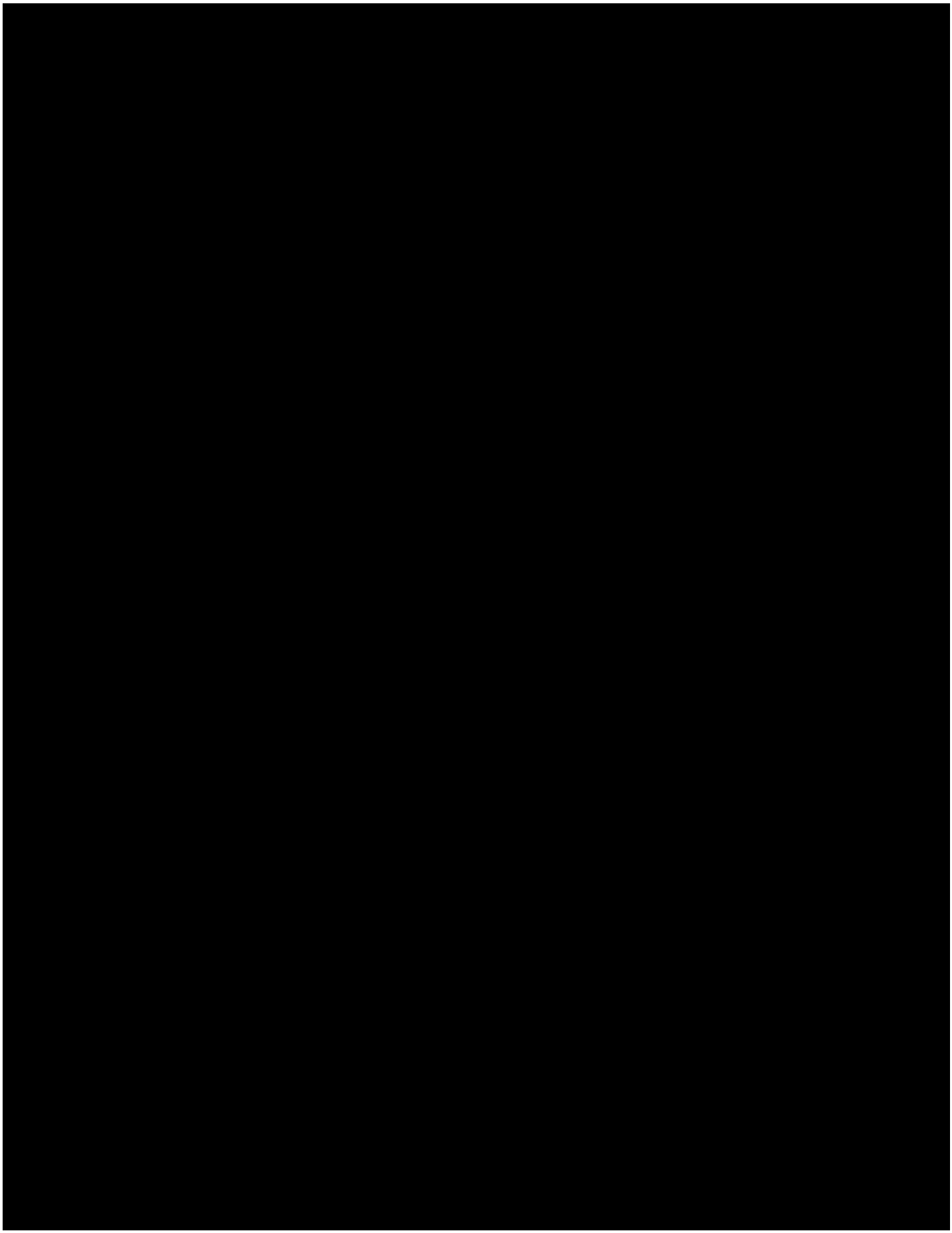

 WP/19/117

IMF Working Paper

Asia and Pacific Department

Transmission of Domestic and External Shocks through Input-Output Network: Evidence from Korean Industries[1]

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May 2019

Abstract

In the last two decades, manufacturing industries in Korea have become more concentrated, and interconnectedness across industries and to foreign countries has risen via vertical relationships and trade linkages. This paper investigates the transmission of economic shocks in such a highly concentrated and interconnected structure, focusing on the role of vertical and trade linkages and using the industry-level international input-output data. The results suggest that, first, the role of vertical and trade linkages in propagating growth shocks from both domestic sources and external sources is important. Second, the growth impact of a few key sources of economic shocks is relatively large. These findings highlight that economic shocks in a few key industries and/or major trading partners that are transmitted through vertical and trade linkages can lead to large swings in the overall economy. This paper contributes to the understanding of the potential interactions between the industrial structure and economic growth and stability.

JEL Classification Numbers: E32, F14, F44, F62, L14
Keywords: Transmission of Shocks, Vertical Linkage, Trade Linkage, Aggregate Fluctuations
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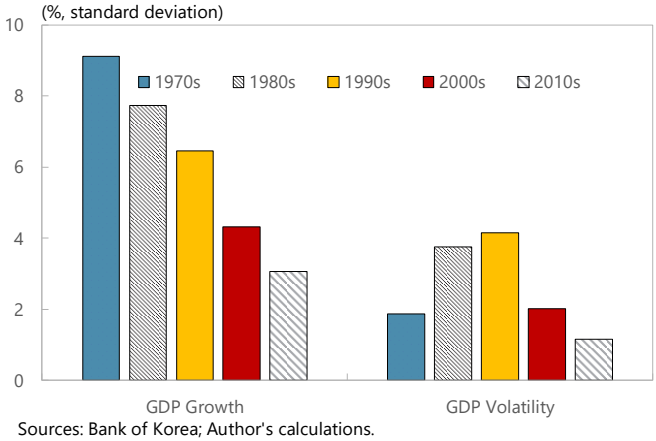
[1] The author is particularly grateful to Tarhan Feyzioglu and for his guidance and support. I would like to thank Yevgeniya Korniyenko, Brad McDonald and Johanna Schauer for helpful comments. All errors are the author's sole responsibility.

1. Introduction

After a remarkable growth spurt over several decades averaging above 6 percent, Korea's economic growth has been slowing significantly for the last two decades (Figure 1). The average growth rate declined to 4.3 percent in the 2000s and further to 2.8 percent in the 2010s. The volatility of growth has also declined since the 2000s, a trend that is commonly observed in advanced countries with economic development, such as during the "Great Moderation" of the 2000s in the U.S. (e.g., Blanchard and Simon 2001; Kim and Nelson 1999; Stock and Watson 2003). Although in the long run economic growth and stability can be determined by various structural factors, including population aging and development stages, the development path of Korea's industrial structure can also play an important role.

Figure 1. GDP Growth and Volatility



Sources: Bank of Korea; Author's calculations.
Notes: Volatility is measured as the standard deviation of annual GDP growth rate for each decade (e.g., 1970-79, 1980-89, ... , 2000-09, 2010-17).

In the last two decades, the Korean economy has experienced considerable structural changes in its industrial structure. The economy has become more concentrated in a few manufacturing industries, while its interconnectedness across industries has risen via vertical relationships. At the same time, the importance of international trade has increased with Korea's growing participation in global value chains (GVCs). The rise of economic concentration and interconnectedness could become sources of macroeconomic instability as macroeconomic fluctuations are primarily the results of many microeconomic shocks at the sectoral or firm level (e.g., Gabaix 2011; Carvalho and Gabaix 2013; Foerster et al. 2011) and the presence of concentrated sectoral hubs can lead to aggregate fluctuations (e.g., Acemoglu et al. 2012; Carvalho 2010).[2] Moreover, macroeconomic tail risks can be created from the propagation of microeconomic shocks through the input-output network (Acemoglu et al. 2017). In this respect, the recent decline in gross domestic product (GDP) volatility does not necessarily secure economic stability in the future.

This paper examines the role of vertical and trade linkages in the transmission of economic shocks using the industry-level international input-output data of the World Input-Output Database (WIOD, 2000–2014). The empirical model extends the model of Acemoglu et al.

[2] It should be noted that specialization may also generate higher productivity through economies of scale and selection, leading to the growth of productive firms/industries, which has arguably been at play in Korea over the last several decades.

(2016) to be more applicable to the Korean economy. The empirical analysis focuses on the role of vertical and trade linkages in propagating growth shocks from both domestic sources (domestic industry shocks) and external sources (external country shocks). Furthermore, the paper attempts to assess the size of the growth impact from the key sources of economic shocks in the Korean economy.

The main findings of the empirical analysis are as follows. First, domestic industry shocks have larger downstream effects (due to supplier shocks) than upstream effects (due to customer shocks). This finding implies that industries are more likely to be affected by the seller's growth shocks than by the buyer's growth shocks. Second, external country shocks are propagated to Korean industries mainly through their own (direct) export linkages to the country. That is, industries that are highly involved in exports transacted directly with foreign countries are significantly affected by the country's growth shocks. Third, the separate estimation for manufacturing industries demonstrates that the transmission of domestic industry shocks via both upstream and downstream linkages is significant, while the propagation of external country shocks via direct export linkages is also significant.

In addition, the average productivity growth impacts from domestic industry shocks and external country shocks are estimated to be relatively large. For domestic industry shocks, the growth shocks in chemicals are estimated to have the largest productivity impacts mainly due to the industry's high vertical linkages to other industries and high volatility, while the growth shocks in electronics and transportation are also expected to have substantial productivity impacts. For external country shocks, China's growth shocks would have the largest productivity impacts as the Korean economy is most highly linked to China via trade linkages, while the growth shocks in the U.S. and Japan would have smaller but substantial productivity impacts. Moreover, the overall productivity impacts of each one standard deviation of growth shocks for the top three manufacturing industries (i.e., electronics, transportation, and chemicals) and for the major three trading partners (i.e., China, the U.S., and Japan) are estimated to total 1.4 percentage points, on average, for the total industry and 3.2 percentage points for manufacturing. The estimates highlight that the economic shocks in key manufacturing industries and/or major trading partners can lead to large swings in the overall economy caused by the transmission of these shocks through vertical and trade linkages.

This paper is structured as follows. The next section reviews the related literature and discusses the main contributions of this paper. In Section 3, we present the overall industrial structure of the Korean economy and its changes over time, using the data derived at the sector level and industry level, while the developments of economic growth and volatility are also outlined. Section 4 explores the implications of structural changes in the industrial structure for economic growth and stability. We empirically examine the role of vertical and trade linkages, through which the economic shocks can be propagated, in determining the productivity growth of Korean industries. Section 5 concludes the paper and discusses the policy implications of the research.

2. Related Literature

This paper empirically contributes to the extensive literature on the propagation of economic shocks through production networks. In particular, this study closely relates to the literature on the industrial structure and its macroeconomic effects: i.e., (i) the propagation of microeconomic shocks to the economy through input-output network linkages; (ii) business cycle (BC)

comovement through trade linkages; and (iii) economic diversification (or specialization) and development.

First, the role of sectoral networks in the transmission of idiosyncratic shocks to aggregate fluctuations in output and aggregate volatility has gained increasing attention recently.[3] In the domestic context, a class of literature has studied how shocks to firms or sectors can spread to other firms or sectors through a network of input-output linkages, which leads to larger macroeconomic impacts (e.g., Acemoglu et al. 2012, 2016; Carvalho and Gabaix 2013; Foerster et al. 2011). In the external context, trade linkages can play a role in the transmission of external shocks across borders (e.g., Acemoglu et al. 2016).

This paper has the most in common with Acemoglu et al. (2016), which examined the propagation of supply and demand shocks to the US economy through sectoral interlinkages in the upstream and downstream markets. They found that the increased Chinese import penetration to the US economy had negative impacts on valued added and employment of the US industry and the impact was larger for industries with higher upstream exposure to Chinese imports. It is notable that unlike Acemoglu et al. (2016)—which considered both direct (first-order) and indirect (or higher-order) vertical linkages—this paper considers only direct upstream and downstream linkages across industries as in di Giovanni and Levchenko (2010) and di Giovanni et al. (2018). Although indirect network linkages can play a role in the transmission of economic shocks, this paper focuses on the transmission of shocks through direct vertical linkages, which are likely to comprise a dominant channel in most cases.

Second, this paper relates to the literature focusing on the effects of economic interlinkages on international BC comovement through trade and vertical linkages. Network interlinkages may cause the cross-border transmission of economic shocks, which in turn has led to international BC comovement. There has been an extensive body of literature studied international BC comovement since Frankel and Rose (1998)'s seminal paper uncovered a well-known empirical regularity: that is, countries that trade more with each other exhibit higher BC correlation. Shea (2002) documented that input-output linkages, not common shocks, played an important role in sectoral comovement in the U.S. More recently, the micro origins of international BC comovement have been studied using industry-level data (di Giovanni and Levchenko 2010) and firm-level data (di Giovanni et al. 2018). These researchers found clear evidence of a positive international trade-comovement relationship driven by the transmission of shocks at the industry level or firm level through trade and vertical linkages. Complementary to this paper, Lee (2019b) investigated the role of trade and vertical linkages in the Korean economy's BC comovement with its trading partners, using Korean industry-level data from the 2000s. The paper documented that export linkages play an important role in Korea's international BC comovement—which can be propagated domestically via vertical linkages—while the increase in trade with China contributed the most to the aggregate BC comovement.

Lastly, this paper is also linked to the study of economic diversification and its implications for economic growth and stability. Despite extensive empirical contributions on the linkages between economic diversification and growth, the empirical literature does not offer conclusive evidence on this relationship.[4] Many researchers have been interested in the causality from

[3] Early work in this literature includes that of Horvath (2000) and Shea (2002).

[4] See Cadot et al. (2013) and Mau (2016) for surveys of the empirical literature on export diversification and its linkages with economic growth.

economic development to domestic or export diversification, while similarly to our paper, others have focused on the causality from diversification to growth. The former identifies a hump- or *U*-shaped pattern of diversification and economic development—that is, production and export diversify at the earlier stage of development and then they begin to respecialize at a higher level of development (e.g., Imbs and Wacziarg 2003; Koren and Tenreyro 2007; Cadot et al. 2011).[5] The latter strand of literature explored the growth effects of diversification and mostly found that export diversification helped countries to hedge against the adverse terms of trade shocks by stabilizing export earnings and domestic outputs (e.g., Jansen, 2004; Cavallo et al., 2008). Korea's industrial structure appears to follow a *U*-shaped pattern, but empirical analyses on the relationship between Korea's industrial structure and growth or stability are limited.

This paper contributes to the understanding of the potential relationships between the industrial structure and economic growth and stability. The paper modifies the empirical model of Acemoglu et al. (2016) to explore the transmission of domestic and external shocks through vertical and trade linkages in Korea, which is highly dependent on international trade and highly interconnected in the upstream and downstream markets. The analysis using the Korean industry-level data is expected to shed light on the transmission mechanisms of domestic and external shocks to the Korean economy.

3. Data and Descriptive Statistics

3.1. Data

This section uses both sector-level and industry-level data from Korea's national accounts (1970–2017) and WIOD (2000–2014; 2016 release) to study the overall industrial structure of the Korean economy and its changes over time. The econometric analysis in Section 4 uses the industry-level data on input, output, value added, and international trade taken from the WIOD, which contains the World Input-Output Tables (WIOT) and the Socio-Economic Accounts (SEA) (see Table A.1 in the Appendix for data descriptions and sources). The WIOT is an extension of a national input-output table made by combining national supply and use tables and various trade databases. It covers 56 industries for each of the 43 countries over 15 years (2000–2014).[6] This paper focuses on the transmission of domestic and external shocks to the Korean economy through vertical and trade linkages: (i) idiosyncratic industry shocks (domestic); and (ii) foreign country shocks (external). For foreign country shocks, we focused on Korea's three largest trading partners, China, the U.S., and Japan. We combined or dropped some industries based on the availability of reliable data, which led to a total of 38 industries, including 14 manufacturing industries (see Table A.2 in the Appendix for the detailed industry classification used in this paper).[7]

[5] Cadot et al. (2011) documented that extensive margin drives this pattern, implying that countries expand products to their export basket during the early stages of economic development, while high-income countries remove goods for which they have lost the comparative advantage.

[6] For the construction method and source databases, see Timmer et al. (2016).

[7] It should be noted that several industries, for which data are available but the growth rates of industry value added are found to be identical, are combined. For these industries, it is suggested that originally, separate industry-level value-added data were unavailable, but extrapolation with a growth rate may have been used to produce separate data for value added levels.

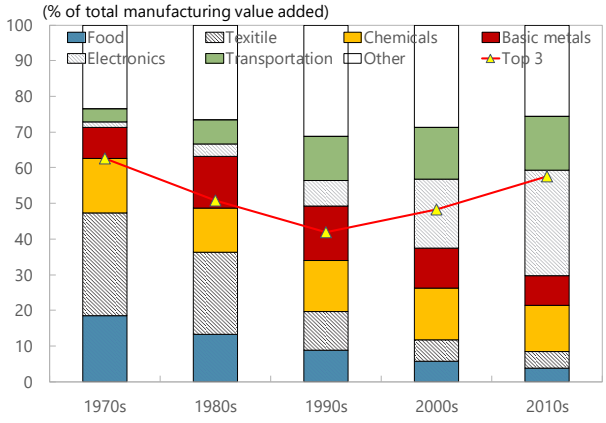
3.2. Industrial Structure: Concentration and Interconnectedness

We first reviewed the developments of industrial structure in Korea. The country is known as highly concentrated and interconnected compared to other advanced countries. The manufacturing and service sectors account for most of Korea's gross domestic product (GDP). Over the economic development, the share of manufacturing in GDP has risen to 31.6 percent, on average, in the 2010s from 12.7 percent in the 1970s. Meanwhile, the share of services in the GDP has remained stable at around 60 percent, while that of the other sectors (e.g., non-manufacturing and agriculture) has declined over time. As a result, the share of manufacturing and services has risen over the last several decades as the economy has developed, reaching over 90 percent of the GDP in 2017.

The manufacturing sector is highly concentrated in a few key industries, while services are not very concentrated. Figure 2 illustrates the trend of industrial share in manufacturing and services over several decades. Korea's industrial structure has followed a *U*-shaped relationship between economic development and diversification in manufacturing, but this relationship is not evident in services.[8] As the economy develops, the manufacturing sector first diversifies and starts to specialize (or concentrate) at relatively late stages of economic development. That is, the share of the largest three industries in manufacturing declined to 41.9 percent in the 1990s, but rose to 57.6 percent in the 2010s.[9] However, in services, the share of the top three industries has declined over the last several decades, reaching 39.5 percent in the 2010s.[10]

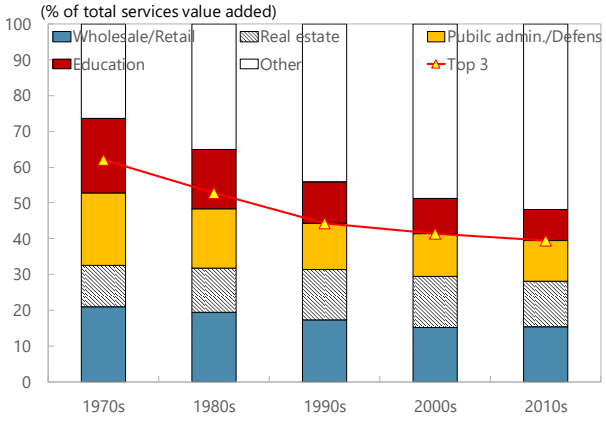
Figure 2. Industrial Share in Manufacturing and Services

<Manufacturing>



Sources: Bank of Korea; Author's calculations.

<Services>



Sources: Bank of Korea; Author's calculations.

The industry has been highly interconnected with other industries through input-output relationships. The overall domestic vertical linkages (the share of intermediate input in the total output) increased to 47.1 percent in 2009 from 44.3 percent in 2000, but remained stable afterwards. Figure 3 describes upstream and downstream linkages in manufacturing at the sector level and in some selected industries. Upstream (downstream) linkage is defined as the share of

[8] The hump- or *U*-shaped relationship of economic development and diversification (or specialization) is generally observed in many advanced economies (e.g., Imbs and Wacziarg 2003; Cadot et al. 2011).

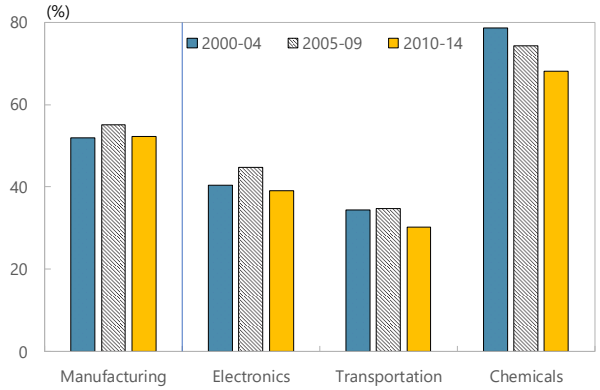
[9] Food, textiles, chemicals, and basic metals were the largest three manufacturing industries in the 1970s and 1980s, while electronics, transportation, and chemicals have been the main manufacturing industries since the 2000s.

[10] Wholesale and retail trade, real estate, and public administration and defense have been the largest three industries in services over the last several decades.

intermediate input supply (purchase) in sectoral or industrial gross output, which measures the intensity of connectedness to other industries as upstream sellers (downstream buyers).[11] The upstream and downstream terminology in network literature is somewhat ambiguous. Throughout the paper, we label upstream linkage as the connectedness to buyers of an industry that shocks to a buyer flow up the input-output network, while we label downstream linkages as the connectedness to sellers of an industry that shocks to a seller flow down the input-output network as in the literature (e.g., Acemoglu et al. 2016a; di Giovanni et al. 2018). At the sector level, upstream and downstream linkages in manufacturing increased until the global financial crisis (GFC) when they started to decline, while vertical linkages have remained stable in services. At the industry level, upstream and downstream linkages in the top three manufacturing industries since the 2000s (i.e., electronics, transportation, and chemicals) have declined slightly in the aftermath of the GFC.[12] Upstream linkages are highest in chemicals and almost twice higher than in electronics and transportation. On the other hand, downstream linkages show similar levels in all three industries at around 60 percent.

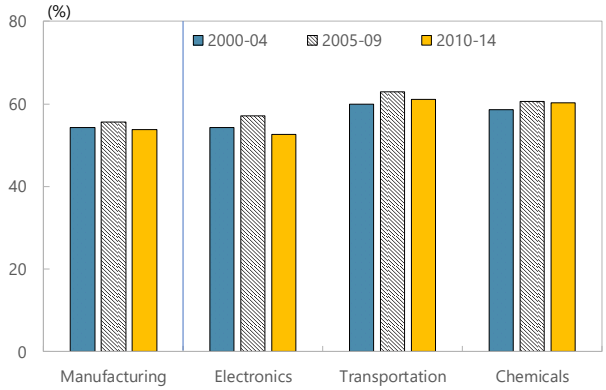
Figure 3. Vertical Linkages in Manufacturing Industries

<Upstream>



Sources: World Input-Output Database; Author's calculations.
Notes: Upstream linkage denotes the ratio of intermediate input supply to other industries in industrial gross output.

<Downstream>



Sources: World Input-Output Database; Author's calculations.
Notes: Downstream linkage denotes the ratio of intermediate input purchase from other industries in industrial gross output.

The Korean economy has become more interconnected to the global economy through trade relationships in the last two decades. Figure 4 shows export and import linkages in manufacturing at the sector level and in some selected industries. Export (import) linkage is measured as the share of gross export (imports) to (from) other countries in sectoral or industrial gross output.[13] Throughout the paper, we are looking at gross trade (exports and imports) unless otherwise indicated. The share of exports and imports in the total output has increased by about 5 percentage points each in the aftermath of the GFC. At the sector level, export and import linkages have been substantially higher in manufacturing than in other sectors, while we have also seen a sharp rise of export and import linkages in manufacturing since the 2000s. In services, however, export and import linkages have remained stable at around 5 percent and 3

[11] See Table A.1. in the Appendix for detailed data descriptions and sources.

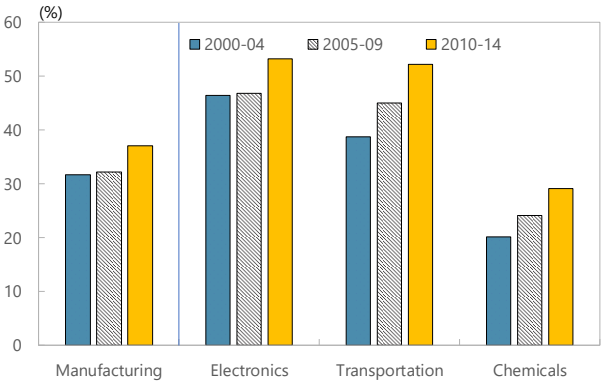
[12] The largest three industries are determined by the share of value added in 2014: (i) Electronics includes "Computer, electronic and optical products" and "Electrical equipment"; (ii) Chemicals includes "Chemical and chemical products" and "Basic pharmaceutical products and preparations"; and (iii) Transportation includes "Motor vehicles, trailers and semi-trailers" and "Other transport equipment" (see Table A.2 in the Appendix for a detailed list of industries).

[13] See Table A.1. in the Appendix for detailed data descriptions and sources.

percent, respectively. At the industry level, export and import linkages have risen in the major manufacturing industries in the aftermath of the GFC. Electronics and transportation show export linkages that are about two times higher than in chemicals, while import linkages are highest in electronics.

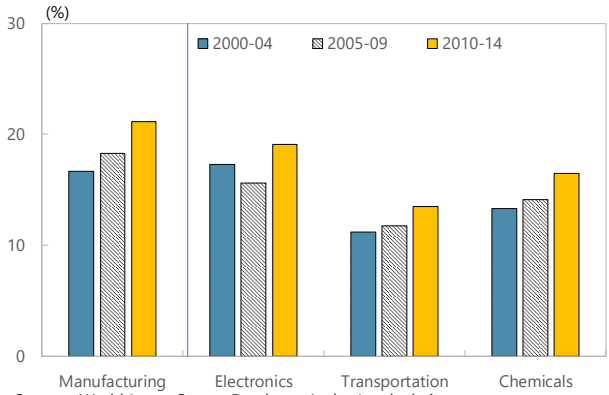
Figure 4. Trade Linkages in Manufacturing Industries

<Exports>



Sources: World Input-Output Database; Author's calculations.
Notes: Export linkage denotes the ratio of gross export to other countries in industrial gross output.

<Imports>

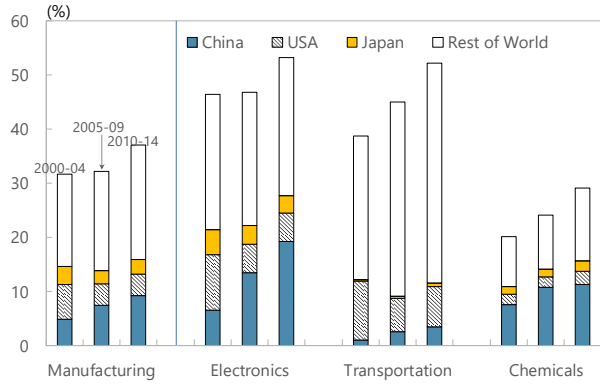


Sources: World Input-Output Database; Author's calculations.
Notes: Import linkage denotes the ratio of gross import from other countries in industrial gross output.

Looking at trade linkages by trading partners, export and import linkages to China rose drastically in major manufacturing industries throughout the 2000s. During the same period, trade linkages to the U.S. and Japan declined noticeably in the major manufacturing industries. In particular, electronics underwent the most drastic structural changes in trade linkages: that is, export and import linkages to China have risen significantly, while trade linkages to the U.S. have declined substantially over the last 15 years. This finding reflects the fact that the Korean economy has been exposed to the recent drastic changes in GVCs—the increasing presence of China in global trade.[14] It should also be noted that export and import exposures to the major three trading partners account for almost 50 percent of the total trade linkages in the major manufacturing industries, except for export linkages in the transportation industry.

Figure 5. Bilateral Trade Linkages in Manufacturing Industries

<Exports>



Sources: World Input-Output Database; Author's calculations.
Notes: Export linkage denotes the ratio of gross export to other countries in industrial gross output.

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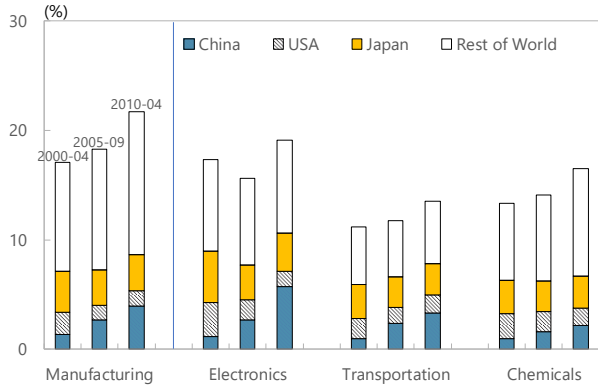


Sources: World Input-Output Database; Author's calculations.
Notes: Import linkage denotes the ratio of gross import from other countries in industrial gross output.

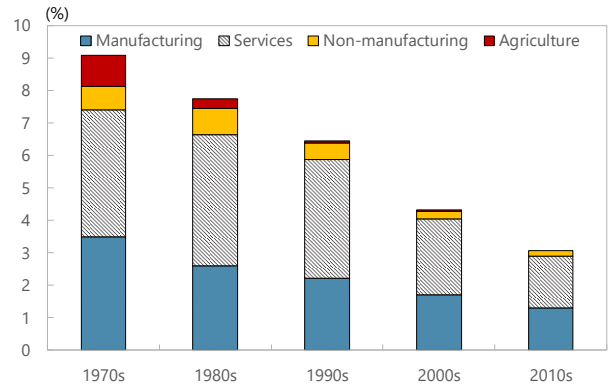
[14] The substantial increase in trade linkages to China in the 2000s may relate to the growing emergence of China's presence in the global economy, especially after China joined the World Trade Organization (WTO) in 2001.

3.3. Macroeconomic Development: Economic Growth and Volatility

This subsection overviews Korea's macroeconomic developments in terms of growth and volatility over the last several decades. The left panel of Figure 6 highlights the finding that manufacturing and services have been key contributors to economic growth. The contribution of manufacturing and services to GDP growth has been declining, while the contribution from these sectors still accounts for most GDP growth. It is also notable that the decline in the contribution to growth is observed across all industry sectors. Meanwhile, the right panel of Figure 6 illustrates that the volatility of value-added growth remained high until the 1990s in all industry sectors, while it declined afterwards. Although the high volatility of the 1990s partly reflects the large swings that occurred during the Asian Financial Crisis in the late 1990s, the standard deviation (volatility) of growth declined substantially through the 2000s, consistent with the overall GDP volatility illustrated in Figure 1. The level of volatility has been higher in manufacturing than in services and other sectors through the 2000s, which may partly relate to higher concentration and interconnectedness in manufacturing and its rise in the recent period.

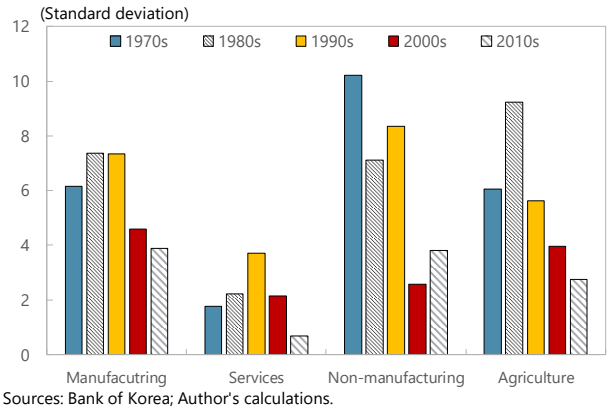
Figure 6. Sectoral GDP Growth and Volatility

<Growth>



Sources: Bank of Korea; Author's calculations.
Notes: Agriculture includes Agriculture, Forestry, and Fishing; Non-manufacturing includes Mining/Quarrying, Electricity/Gas, Water Supply, and Construction.

<Volatility>

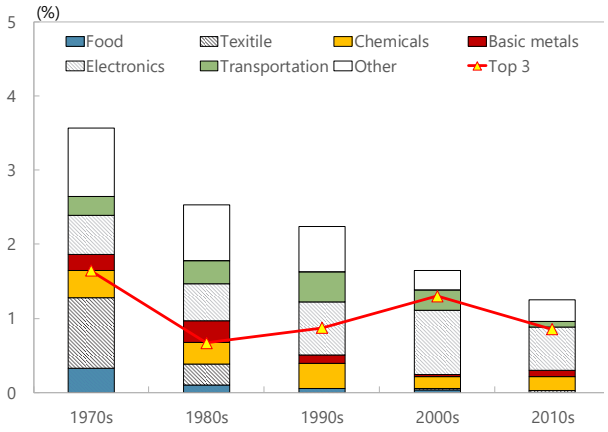


Sources: Bank of Korea; Author's calculations.
Notes: Agriculture includes Agriculture, Forestry, and Fishing; Non-manufacturing includes Mining/Quarrying, Electricity/Gas, Water Supply, and Construction.

The contribution to growth is highly concentrated in a few major manufacturing industries and the level of concentration has further risen over time. Figure 7 describes the industrial decomposition of growth separately for manufacturing and services. Electronics has contributed almost half of the manufacturing growth that has occurred since the 2000s. The growth contribution of the largest three industries in manufacturing was only 26.5 percent in the 1980s, but rose to almost 70 percent through the 2000s, which supports the existence of the *U*-shaped relationship of diversification and developments in terms of growth contribution. However, the service sector has been less concentrated in the growth contribution, while the share of the major three industries' contribution has remained at around 30 to 40 percent since the 1980s.

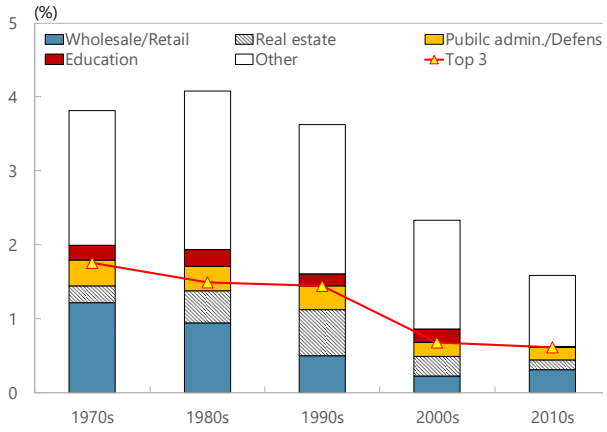
Figure 7. Industrial Decomposition of Growth in Manufacturing and Services

<Manufacturing>



Sources: Bank of Korea; Author's calculations.

<Services>

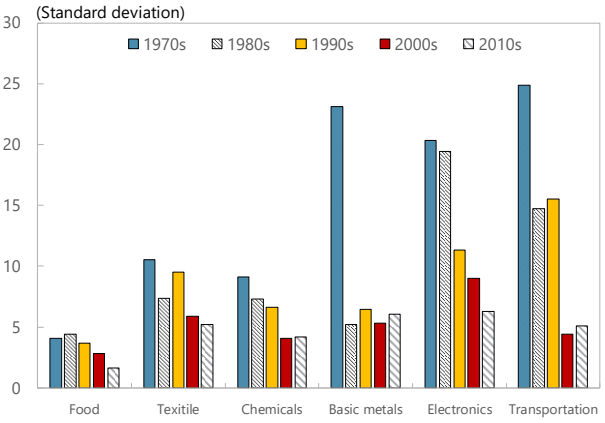


Sources: Bank of Korea; Author's calculations.

Lastly, Figure 8 represents the industry-level volatility in manufacturing and services. It highlights that at the industry level, electronics and transportation—the two largest share manufacturing industries through the 2000s—have been relatively volatile compared to other manufacturing and service industries. This implies that the potential factors of economic instability may still be embedded in the Korean economy, despite the recent decline in the overall growth volatility.

Figure 8. Industrial Volatility in Manufacturing and Services

<Manufacturing>



Sources: Bank of Korea; Author's calculations.

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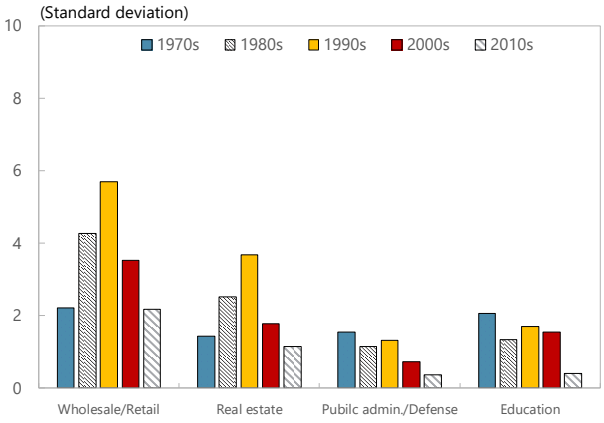


Sources: Bank of Korea; Author's calculations.

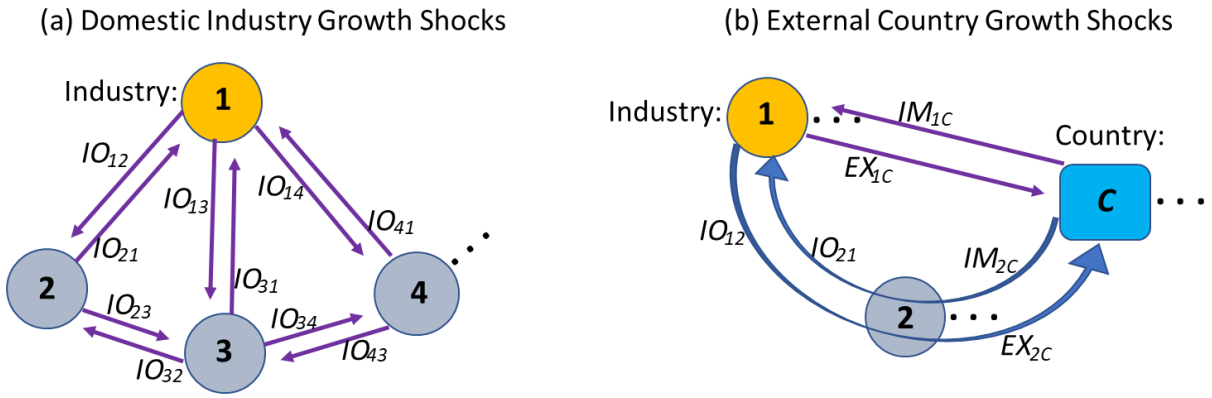
4. Transmission of Domestic and External Shocks

Korea's industrial structure is highly concentrated and interconnected to a few major industries that are relatively volatile and dominated by a few large firms.[15] It is also highly dependent on international trade. This implies that domestic or external shocks can be easily transmitted to the whole economy through vertical and trade linkages. Against this background, Section 4 empirically examines the role of trade and vertical linkages in the transmission of domestic and external shocks, and further attempts to estimate the size of potential growth impacts from the key sources of economic shocks in the Korean economy.

4.1. Empirical Specification

Economic shocks can be propagated to domestic industries via domestic upstream/downstream linkages to other industries or via export/import linkages to other countries. Input supply to other industries and input purchases (use) from other industries can act as a transmission channel of domestic shocks (Figure 9(a)). In addition, domestic industries can directly export/import products or services to/from foreign countries or they can be indirectly linked to foreign countries through upstream/downstream linkages to other industries that are involved in exports/imports with foreign countries (Figure 9(b)).[16] Direct and indirect trade linkages to foreign countries can play a role in the transmission of external shocks.

Figure 9. Transmission of Domestic and External Shocks



Here, IO_{ij} and IO_{ji} denote industry i's upstream and downstream linkages, while EX_{iC} and IM_{iC} stand for industry i's export and import linkages with country C (see Table A.1. in the Appendix for detailed data descriptions and sources).

[15] The industry concentration indices (top three firms' market share or Herfindahl-Hirschman index)—which were computed using the "Mining and Manufacturing Survey" by Korea Fair Trade Commission—for the top three industries (i.e., electronics, transportation, and chemicals) are also highly concentrated by the small number of firms.

[16] This paper considers only direct (first-order) trade and vertical linkages between Korea and other countries as well as between two industries, as in the existing literature (e.g., di Giovanni and Levchenko 2010; di Giovanni et al. 2018). For simplicity and empirical identification purposes, we assumed indirect (higher-order) effects are not likely to be large empirically, although Acemoglu et al. (2016) and other network literature introduced both direct and indirect trade and/or vertical linkages using a Leontief inverse matrix.

The role of vertical and trade linkages in the transmission of economic shocks can be empirically analyzed using the industry-level international input-output data of the WIOD (2000–2014). We first constructed the industry-specific domestic shocks illustrated graphically in Figure 9(a), which follow the terms in the context of the "network effect" adopted by Acemoglu et al. (2016) and di Giovanni et al. (2018):

$$UP_{it}^{DM} = \sum_j IO_{ijt} \times \Delta lnY_{jt} \quad (1)$$

$$DN_{it}^{DM} = \sum_j IO_{jit} \times \Delta lnY_{jt} \quad (2)$$

where *UP* and *DN* stand for the upstream and downstream effects; Y_{jt} denotes industry *j*'s real value added; and the superscript *DM* indicates domestic shocks, while the subscripts *i* and *j* denote industries and *t* denotes year, respectively. The upstream (downstream) effect is measured as the average industry-level growth shocks weighted by upstream (downstream) linkages to shock-originating industries. Similarly, the external country growth shocks illustrated in Figure 9(b) are defined as:

$$OWN_{it}^{EX} = \sum_C EX_{iCt} \times \Delta lnY_{Ct} \quad (3)$$

$$OWN_{it}^{IM} = \sum_C IM_{iCt} \times \Delta lnY_{Ct} \quad (4)$$

$$UP_{it}^{EX} = \sum_C \sum_j IO_{ijt} \times EX_{jCt} \times \Delta lnY_{Ct} \quad (5)$$

$$DN_{it}^{IM} = \sum_C \sum_j IO_{jit} \times IM_{iCt} \times \Delta lnY_{Ct} \quad (6)$$

where *OWN* stands for its own (or direct) effects; Y_{Ct} denotes country *C*'s real GDP; and EX_{iCt} and IM_{iCt} denote export and import linkages (see Table A.1. in the Appendix for detailed data descriptions and sources). The superscripts EX and IM denote exports and imports, while the subscript *C* denotes Korea's trading partners, such as China, the U.S., and Japan.

The empirical model extends the model of Acemoglu et al. (2016) to be more applicable to the Korean economy. Acemoglu et al. (2016) studied the impacts of four different industry-level demand and supply shocks—that is, China import penetration, federal spending, total factor productivity (TFP) growth, and foreign-patenting growth shocks—on U.S. industry growth. Our model focuses on the role of vertical and trade linkages in the transmission of economic shocks: (i) the role of domestic vertical linkages in the transmission of growth shocks from domestic sources (domestic industry shocks); and (ii) the role of direct and indirect trade linkages in the transmission of growth shocks from external sources (external country shocks). For external country shocks, our model considers the transmission of GDP growth shocks from Korea's three largest trading partners, China, the U.S., and Japan.

We examined the transmission of domestic and external shocks to the industry's labor productivity growth, which may have important implications for Korea's long-term economic growth. The estimating equations are constructed in three different specifications based on the types of economic shocks considered: (i) domestic industry shocks (Equation (7)); (ii) external country shocks (Equation (8)); and (iii) both domestic industry shocks and external country shocks (Equation (9)).

$$\Delta lnLP_{it} = \alpha_0 + \alpha_1 lnLP_{it-1} + \alpha_2 \Delta lnK_{it} + \beta_1 UP_{it}^{DM} + \beta_2 DN_{it}^{DM} + \mu_i + \delta_{st} + \varepsilon_{it} \quad (7)$$

$$\Delta lnLP_{it} = \alpha_0 + \alpha_1 lnLP_{it-1} + \alpha_2 \Delta lnK_{it} + \beta_1 OWN_{it}^{EX} + \beta_2 OWN_{it}^{IM} + \beta_3 UP_{it}^{EX} + \beta_4 DN_{it}^{IM} + \mu_i + \delta_{st} + \varepsilon_{it} \quad (8)$$

$$\Delta lnLP_{it} = \alpha_0 + \alpha_1\, lnLP_{it-1} + \alpha_2 \Delta lnK_{it} + \beta_1 UP_{it}^{DM} + \beta_2 DN_{it}^{DM} + \beta_3 OWN_{it}^{EX} + \beta_4 OWN_{it}^{IM} + \beta_5 UP_{it}^{EX} + \beta_6 DN_{it}^{IM} + \mu_i + \delta_{st} + \varepsilon_{it} \quad (9)$$

where LP_{it} and K_{it} denote industry i's labor productivity and capital intensity (capital/labor ratio); UP_{it}^{DM}, DN_{it}^{DM}, OWN_{it}^{EX}, OWN_{it}^{IM}, UP_{it}^{EX} and DN_{it}^{IM} are defined as Equations (1) to (6); μ_i, δ_{st} and ε_{it} denote industry fixed effects, sector-year fixed effects, and error terms, respectively.

4.2. Estimation Result

Table 1 reports the results of estimating Equations (7) to (9) separately for the total industry and the manufacturing industry. Specifications [1] to [3] correspond to Equations (7) to (9), which consider domestic industry shocks only, external country shocks only, and both domestic and external shocks, respectively. In addition to industry fixed effects, which are included in all specifications to consider industry-specific heterogeneity, the estimation for the total industry includes sector-year fixed effects to control for sector-specific macroeconomic shocks, while the estimation for manufacturing includes year fixed effects to account for global macroeconomic shocks. Other variables that are generally included in the labor productivity growth regression, such as lagged labor productivity and capital intensity growth, are included as explanatory variables to account for growth convergence and the role of capital accumulation in productivity growth.

The key findings from the estimation are summarized as follows. First, domestic industry shocks have larger downstream effects (due to supplier shocks) than upstream effects (due to customer shocks). That is, industries are more likely to be affected by the seller's growth shocks than by the buyer's growth shocks.[17] Second, external country shocks are propagated to Korean industries mainly through Korea's own (direct) export linkages. This finding implies that industries that are highly involved in exports transacted directly with foreign countries are significantly affected by the country's growth shocks.[18] It is also notable that the estimated sign and magnitude of coefficients are largely consistent across the specifications.

The separate estimation for manufacturing industries demonstrates that the transmission of domestic industry shocks via both upstream and downstream linkages is significant in specification [3], while the propagation of external country shocks via direct export linkages is also significant. In addition, the coefficients of direct export country shocks are estimated to be larger for manufacturing than for the total industry, while the sum of the upstream and downstream effects is also estimated to be larger for manufacturing. This result may be associated with higher vertical and trade linkages in manufacturing than in other industries. Other control variables have expected signs: that is, the coefficient of lagged labor productivity is negative and significant for most specifications and that of capital intensity is positive and significant in all specifications. This result supports the general findings in the previous literature that lower productivity industries have higher growth (convergence or catch-up) and industries with higher growth in capital intensity are growing faster.

[17] The result is consistent with Acemoglu et al. (2016)'s theoretical and empirical findings. Theory predicts that supply-side shocks propagate more strongly to downstream customers than to upstream suppliers because supply-side shocks affect the prices faced by customer industries, creating powerful downstream propagation.

[18] This result may relate to the important role of intermediate input export in productivity growth (e.g., Kasahara and Rodrigue 2008; Keller 2002; Lee 2019a).

Table 1. Transmission of Domestic and External Shocks: Baseline Result

Dependent variable: Labor productivity growth

	Total industry			Manufacturing		
	Domestic	External	Both	Domestic	External	Both
	[1]	[2]	[3]	[1]	[2]	[3]
Lagged log(labor productivity)	-4.717*	-6.523**	-5.997**	-2.062	-4.137*	-4.146
	(2.789)	(2.436)	(2.499)	(3.652)	(2.291)	(2.404)
Capital/labor growth	0.561***	0.567***	0.556***	0.669***	0.707***	0.659***
	(0.058)	(0.056)	(0.058)	(0.107)	(0.108)	(0.110)
Upstream domestic shock	0.082		0.100	0.767		1.031**
	(0.416)		(0.435)	(0.473)		(0.407)
Downstream domestic shock	1.619***		1.628***	0.795***		0.734**
	(0.354)		(0.363)	(0.231)		(0.251)
Own export shock		4.331	4.840*		4.490	5.843*
		(2.932)	(2.815)		(3.186)	(2.948)
Own import shock		-4.422	1.994		-0.354	12.60
		(17.14)	(15.64)		(21.03)	(19.56)
Upstream export shock		0.040	0.037		0.053	0.035
		(0.044)	(0.046)		(0.066)	(0.065)
Downstream import shock		0.502	0.267		0.284	-0.278
		(0.536)	(0.469)		(0.750)	(0.690)
Industry fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Sector-Year fixed effect	Yes	Yes	Yes	No	No	No
Year fixed effect	No	No	No	Yes	Yes	Yes
Observations	532	532	532	196	196	196
R^2 *-within*	0.688	0.664	0.694	0.714	0.693	0.728
Number of industries	38	38	38	14	14	14

Notes: 1) Constant is included in all specifications.
2) ***, **, * indicate levels of significance at 1%, 5%, 10%, respectively.

We now extend the above estimation to calculate estimates on the size of the expected growth impacts from domestic and external shocks. We here focus on only significant coefficients in specification [3], which corresponds to Equation (9)—considering both domestic industry shocks and external country shocks. Using the significant estimates of Equation (9), the average impact of shocks on industry productivity growth can be computed by:

$$\widehat{\Delta lnLP_{it}} = \widehat{\beta_1} UP_{it}^{DM} + \widehat{\beta_2} DN_{it}^{DM} + \widehat{\beta_3} OWN_{it}^{EX} \quad (10)$$

Equation (10) can be further expanded by substituting Equations (1) to (3) for each individual industry j and country C as:

$$\widehat{\Delta lnLP_{it}} = \widehat{\beta_1} IO_{ijt} \times \Delta lnY_{jt} + \widehat{\beta_2} IO_{jit} \times \Delta lnY_{jt} + \widehat{\beta_3} EX_{iCt} \times \Delta lnY_{Ct} \quad (11)$$

We can compute the average growth impacts of each individual shock from Equation (11) using the estimates of coefficients in specification [3] in Table 1 ($\widehat{\beta_1}$, $\widehat{\beta_2}$, $\widehat{\beta_3}$), and the data on upstream, downstream, and export linkages (IO_{ijt}, IO_{jit}, EX_{iCt}) for the given individual growth shocks (ΔlnY_{jt}, ΔlnY_{Ct}). The size of the shocks is assumed as one standard deviation of industry growth for the top three manufacturing industries (i.e., electronics, transportation, and chemicals) and that of country growth for the major three trading partners (i.e., China, the U.S., and Japan)

during the sample period of 2001−2014. For upstream, downstream, and export linkages, we used the industry average for the total industry or manufacturing.[19]

Table 2 presents the average productivity growth impacts from domestic industry shocks and external country shocks separately for the total industry and manufacturing, computed from the method explained above. Equation (11) implies that the size of growth impacts from individual shocks is decided by the size of the growth shocks (one standard deviation of shock variables) and upstream, downstream, and export linkages to shock-originating industries or countries. First, we found that the size of the growth shocks was larger for domestic industry shocks than for external country shocks, reflecting high volatility in industry-level growth. In addition, chemicals were the most volatile in value added growth among the three manufacturing industries that were considered as key domestic sources of idiosyncratic growth shocks.

Second, the average productivity impacts on the overall economy from domestic industry shocks and external country shocks are estimated to be relatively large. For domestic industry shocks, the growth shocks in chemicals (one standard deviation) were estimated to have the largest productivity impacts (0.52 percentage point) mainly due to the industry's high vertical linkages to other industries and high volatility, while the growth shocks in electronics and transportation were also expected to have substantial productivity impacts. For external country shocks, China's growth shocks would have the largest productivity impacts for the total industry (0.26 percentage point) as the Korean economy is most highly linked to China via trade linkages, while the growth shocks in the U.S. and Japan would have smaller but substantial productivity impacts.

Third, the average productivity impacts from domestic and external shocks on the manufacturing sector are expected to be two times larger than those on the total industry. This finding may be associated with the fact that manufacturing is highly interconnected with other industries via vertical linkages and with foreign countries via trade linkages. The relative size of the productivity impact is consistent with the results for the total industry.

The findings imply that high trade linkages to China and the U.S. may lead the Korean economy to be vulnerable to the unfavorable economic episodes in these countries. For instance, the growth shocks in China and the U.S. resulting from the recent trade tensions between the two countries are expected to have significant impacts on economic growth and stability in Korea through direct export linkages to these countries. Moreover, as Korea's key manufacturing industries, such as electronics, transportation, and chemicals, are highly trade-linked to China and the U.S., the adverse growth shocks in these industries from the trade tensions can be further transmitted to other industries through upstream and downstream linkages.

[19] Alternatively, we can compute the average growth impact by averaging the impacts on the individual industry's growth computed using each individual industry's vertical and trade linkages.

Table 2. Impact of Domestic and External Shocks on Productivity Growth

(%p)

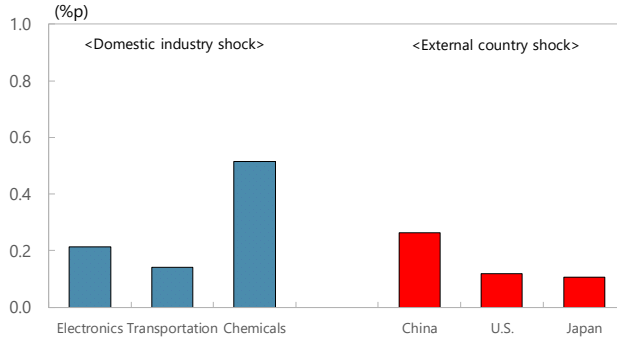
		Shock size (1SD)	Total industry			Manufacturing			
			Downtream linkage	Own export linkage	Average Impact	Upstream linkage	Downtream linkage	Own export linkage	Average Impact
Domestic industry shock	Electronics	5.39	0.02	-	0.21	8.91	3.59	-	0.62
	Transportation	5.71	0.02	-	0.14	7.74	2.40	-	0.54
	Chemicals	7.31	0.04	-	0.52	5.16	7.60	-	0.77
External country shock	China	1.92	-	0.03	0.26	-	-	6.29	0.70
	U.S.	1.65	-	0.01	0.12	-	-	3.03	0.29
	Japan	2.18	-	0.01	0.11	-	-	2.17	0.27

Notes: The average impact of one standard deviation increase in each industry's value added growth and each country's GDP growth is computed, using average upstream/downstream, export/import linkages for total industry and for manufacturing in 2014 and the significant coefficients of shock variables from specification [3] in Table 1. Standard deviation of these variables are calculuated for 2001-2014.

For expositional purposes, the estimated average impacts of each one standard deviation shock on productivity growth are also illustrated graphically in Figure 10. The overall productivity impacts of each shock—measured by the sum of the estimated impacts from individual shocks—can provide rough estimates on the total impacts of individual shocks when they occur simultaneously. The overall impacts of each one standard deviation of domestic and external shocks are estimated to be 1.4 percentage points on average for the total industry and 3.2 percentage points for manufacturing. The estimates highlight that the economic shocks in key manufacturing industries and/or in major trading partners can lead to large swings in the overall economy caused by the transmission of shocks through vertical and trade linkages.

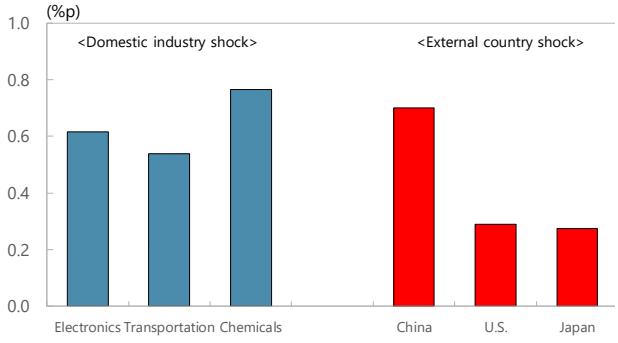
Figure 10. Impact of Domestic and External Shocks on Productivity Growth

<Total industry>



Source: Author's calculations.
Note: The bars denote the average impact on one standard deviation increase in each industry's value added growth and each country's GDP growth, computed using average upstream/downstream, export/import linkages for total industry in 2014 and the significant coefficients of shock variables from specification [3] for total industry in Table 1. Standard deviation of these variables are calculuated for 2001-2014.

<Manufacturing>



Source: Author's calculations.
Note: The bars denote the average impact on one standard deviation increase in each industry's value added growth and each country's GDP growth, computed using average upstream/downstream, export/import linkages for manufacturing in 2014 and the significant coefficients of shock variables from specification [3] for manufacturing in Table 1. Standard deviation of these variables are calculuated for 2001-2014.

4.3. Robustness

The baseline estimation (Table 1) can be extended to some alternative specifications as a robustness check. For example, we can examine if the significant role of downstream linkages and/or direct export linkages in the transmission of domestic and external shocks is found in the following specifications: (i) the transmission of shocks through the top five manufacturing industries (Table 3); (ii) the alternative external country shocks, considering the individual

country's growth shocks separately (Table 4); and (iii) the alternative export linkages, measured in intermediate input exports (Table 5).

Table 3 presents the estimation results for Equations (7) to (9) considering the transmission of domestic and external growth shocks only through the top five manufacturing industries. Robust to the baseline results in Table 1, the estimation results show that industry growth shocks are propagated to other Korean industries mainly through their downstream linkages to the five manufacturing industries. However, the propagation via direct export linkages is estimated to be insignificant, but the sign and magnitude are broadly consistent with the baseline results. The findings confirm that the French firm-level findings of di Giovanni et al. (2017) apply to the Korean economy at the industry level: that is, the small number of large industries exhibits higher trade and vertical linkages and significantly contributes to the transmission of domestic and external growth shocks.

Table 3. Transmission of Domestic and External Shocks: Top 5 Manufacturing Industries

Dependent variable: Labor productivity growth

	Total industry			Manufacturing		
	Domestic	External	Both	Domestic	External	Both
	[1]	[2]	[3]	[1]	[2]	[3]
Lagged log(labor productivity)	-5.021*	-6.456**	-6.159**	-1.415	-4.326*	-3.599
	(2.668)	(2.394)	(2.472)	(3.623)	(2.306)	(2.837)
Capital/labor growth	0.570***	0.568***	0.567***	0.704***	0.706***	0.698***
	(0.057)	(0.055)	(0.057)	(0.114)	(0.108)	(0.119)
Upstream domestic shock	-0.037		-0.021	-0.083		-0.061
	(0.588)		(0.604)	(0.761)		(0.817)
Downstream domestic shock	1.130***		1.067***	1.232***		1.177***
	(0.340)		(0.302)	(0.378)		(0.325)
Own export shock		4.020	4.160		4.336	4.429
		(2.943)	(2.818)		(3.074)	(2.692)
Own import shock		-5.961	-0.861		-4.209	1.529
		(16.34)	(16.46)		(19.00)	(20.63)
Upstream export shock		0.036	0.026		0.059	0.051
		(0.059)	(0.068)		(0.071)	(0.084)
Downstream import shock		0.620	0.418		0.487	0.229
		(0.509)	(0.480)		(0.657)	(0.678)
Industry fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Sector-Year fixed effect	Yes	Yes	Yes	No	No	No
Year fixed effect	No	No	No	Yes	Yes	Yes
Observations	532	532	532	196	196	196
R^2 *-within*	0.666	0.665	0.671	0.699	0.695	0.709
Number of industries	38	38	38	14	14	14

Notes: 1) Constant is included in all specifications.
2) ***, **, * indicate levels of significance at 1%, 5%, 10%, respectively.

Table 4 reports the estimation results for Equation (9)—the specification which considers both domestic industry shocks and external country shocks—using external shocks separately from China, the U.S., and Japan. That is, the estimation uses the external country growth shocks defined by Equations (3) to (6) for each country separately, instead of summing up the growth shocks from all three countries. The result highlights the important role of downstream linkages and direct export linkages in the transmission of domestic industry shocks and external growth

shocks from China and Japan, which is consistent with the baseline results provided in Table 1. However, for the U.S. growth shocks, domestic downstream effects are significant, while direct export effects are estimated to be negative but without significance for the total industry. In addition, for manufacturing industries, domestic upstream effects are also estimated to be significant for the U.S. and Japan, consistent with the baseline results shown in Table 1.

Table 4. Transmission of Domestic and External Shocks: Individual Countries

Dependent variable: Labor productivity growth

	Total industry			Manufacturing		
	China	U.S.	Japan	China	U.S.	Japan
Lagged log(labor productivity)	-6.644**	-4.538*	-4.497	-5.124	-2.056	-1.399
	(2.687)	(2.655)	(2.774)	(3.167)	(3.591)	(3.541)
Capital/labor growth	0.555***	0.575***	0.576***	0.655***	0.696***	0.682***
	(0.057)	(0.058)	(0.058)	(0.113)	(0.091)	(0.084)
Upstream domestic shock	0.055	0.175	0.418	0.843	0.865*	0.964**
	(0.401)	(0.407)	(0.348)	(0.480)	(0.442)	(0.383)
Downstream domestic shock	1.698***	1.642***	1.449***	0.852***	0.817***	0.702*
	(0.350)	(0.339)	(0.322)	(0.269)	(0.240)	(0.362)
Own export shock	7.072***	-8.470	49.09**	7.290***	-2.423	57.33*
	(2.233)	(5.426)	(21.37)	(2.069)	(7.138)	(27.23)
Own import shock	-11.24	23.75	42.64	-0.692	131.9	58.17
	(17.63)	(66.81)	(36.21)	(17.06)	(96.91)	(42.48)
Upstream export shock	0.088	-0.509**	-0.849***	0.032	-0.464	-1.461**
	(0.064)	(0.213)	(0.226)	(0.050)	(0.367)	(0.646)
Downstream import shock	0.700	-3.929	-1.070	0.264	-7.653**	-1.067
	(0.503)	(2.471)	(1.245)	(0.559)	(3.419)	(1.753)
Industry fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Sector-Year fixed effect	Yes	Yes	Yes	No	No	No
Year fixed effect	No	No	No	Yes	Yes	Yes
Observations	532	532	532	196	196	196
R^2 *-within*	0.698	0.699	0.704	0.728	0.741	0.742
Number of industries	38	38	38	14	14	14

Notes: 1) Constant is included in all specifications.
2) ***, **, * indicate levels of significance at 1%, 5%, 10%, respectively.

Lastly, Table 5 presents the results of estimating Equations (8) and (9) using export linkages computed as the share of intermediate input exports to gross output, instead of the share of gross exports to gross output. Export linkages measured in gross exports can be exposed to double-counting issues, which can be mitigated in intermediate input exports.[20] The results are broadly in line with the baseline estimation results provided in Table 1: that is, (i) domestic industry shocks have larger downstream effects than upstream effects on the total industry, while both upstream and downstream linkages play a significant role for manufacturing; and (ii) external country shocks are propagated to Korean industries mainly through direct export linkages.

[20] There is some possibility that direct and indirect export linkages are not fully mutually exclusive, which in turn may lead to double-counting issues from using gross exports instead of value-added exports (see Foster-McGregor and Stehrer (2013), Johnson (2014) and Koopman et al. (2014) for more details). However, the double-counting issue would be less critical for export linkages measured in intermediate inputs because intermediate inputs purchased from other industries are less likely to be used for the production of intermediate input exports to other countries, while they are more likely to be used for the production of final export goods.

Table 5. Transmission of Domestic and External Shocks: Intermediate Input Exports

Dependent variable: Labor productivity growth

	Total industry		Manufacturing	
	External	Both	External	Both
Lagged log(labor productivity)	-6.156**	-5.757**	-3.708	-3.802
	(2.459)	(2.579)	(2.511)	(2.693)
Capital/labor growth	0.572***	0.561***	0.714***	0.665***
	(0.056)	(0.058)	(0.107)	(0.107)
Upstream domestic shock		0.116		0.954**
		(0.429)		(0.398)
Downstream domestic shock		1.672***		0.832**
		(0.366)		(0.281)
Own export shock	5.246	7.755*	4.916	7.723
	(4.376)	(3.923)	(5.218)	(4.529)
Own import shock	-1.026	4.349	2.581	15.16
	(16.39)	(16.09)	(20.07)	(19.38)
Upstream export shock	-0.021	-0.020	-0.008	-0.046
	(0.046)	(0.052)	(0.079)	(0.062)
Downstream import shock	0.470	0.225	0.296	-0.254
	(0.519)	(0.447)	(0.728)	(0.675)
Industry fixed effect	Yes	Yes	Yes	Yes
Sector-Year fixed effect	Yes	Yes	No	No
Year fixed effect	No	No	Yes	Yes
Observations	532	532	196	196
R^2 *-within*	0.663	0.694	0.690	0.726
Number of industries	38	38	14	14

Notes: 1) Constant is included in all specifications.
2) ***, **, * indicate levels of significance at 1%, 5%, 10%, respectively.

5. Concluding Remarks

Throughout the 2000s, the Korean economy has become more concentrated in a few manufacturing industries, while its interconnectedness across industries and to foreign countries has risen via vertical relationships and trade linkages. The dominant industries are highly interconnected with other domestic industries via upstream/downstream linkages and with foreign markets via export/import linkages. Moreover, these industries are dominated by a few large firms. The rise of economic concentration and interconnectedness could become sources of macroeconomic instability.

This paper investigated the role of vertical and trade linkages in the transmission of economic shocks using the industry-level international input-output data. Using the extended model of Acemoglu et al. (2016), which is more applicable to the Korean economy, the empirical analysis identified the important role of vertical and trade linkages in propagating growth shocks from both domestic sources and external sources. This paper contributes to the understanding of potential interactions between the industrial structure and economic growth and stability.

The key findings of this paper are that: (i) domestic industry shocks have larger downstream effects than upstream effects, implying industries are more likely to be affected by the seller's growth shocks than by the buyer's growth shocks; and (ii) external country shocks are propagated to Korean industries mainly through direct export linkages, implying industries that

are highly involved in exports made directly to foreign countries are significantly affected by the country's growth shocks.

Furthermore, the growth impacts from the key sources of economic shocks in the Korean economy are estimated to be relatively large. For domestic industry shocks, the growth shocks in chemicals are estimated to have the largest productivity impacts mainly due to the industry's high vertical linkages to other industries and high volatility. For external country shocks, China's growth shocks would have the largest productivity impacts as the Korean economy is most highly linked to China via trade linkages. Moreover, the overall productivity impacts of each one standard deviation of growth shocks for the top three manufacturing industries (i.e., electronics, transportation, and chemicals) and for the major three trading partners (i.e., China, the U.S., and Japan) are estimated to be 1.4 percentage points, on average, for the total industry and 3.2 percentage points for manufacturing. The estimates highlight that the economic shocks in key manufacturing industries and/or in major trading partners can lead to large swings in the overall economy caused by the transmission of shocks through vertical and trade linkages.

The analysis can be extended to an alternative measure of trade linkages using value-added exports, which is expected to be more relevant in assessing the transmission of external country growth shocks through trade linkages. Trade linkages between the gross exports used in this paper and the value-added exports documented in the recent literature may have different features across countries and industries (e.g., Foster-McGregor and Stehrer 2013; Johnson 2014; Koopman et al. 2014). Furthermore, the analysis can be extended to consider higher-order interconnectedness across industries to capture the possibility of "cascade effects" whereby growth shocks to a sector propagate not only to its immediate downstream customers, but also to the rest of the economy (e.g., Acemoglu et al. 2012, 2016).

Appendix

Table A.1. Data Description and Source

Variable	Description	Source
GDP (Y_C)	Real gross domestic product of country C	IMF World Economic Outlook
Real value added (Y_i)	Industry i's gross value added /i's price level in gross value added	World Input-Output Database (2016)
Labor productivity (LP_i)	Industry i's real value added /i's total hours worked by employee	World Input-Output Database (2016)
Capital-labor ratio (K_i)	Industry i's nominal capital stock/ (i's price level in gross value added×total hours worked by employee)	World Input-Output Database (2016)
Upstream linkage (IO_{ij})	Industry i's input supply to industry j /i's gross output	World Input-Output Database (2016)
Downstream linkage (IO_{ji})	Industry i's input purchase from industry j /i's gross output	World Input-Output Database (2016)
Export linkage (EX_{iC})	Industry i's gross export to country C /i's gross output	World Input-Output Database (2016)
Import linkage (IM_{iC})	Industry i's gross import from country C /i's gross output	World Input-Output Database (2016)

Table A.2. List of Industries

Industry Sector	ISIC Rev.4	Description
Agriculture (3)	A01	Crop and animal production, hunting and related service activities
	A02	Forestry and logging
	A03	Fishing and aquaculture
Manufacturing (14)	C10-C12	Food products, beverages and tobacco products
	C13-C15	Textiles, wearing apparel and leather products
	C16	Wood and of products of wood and cork, except furniture; etc.
	C17-C18	Paper and paper products; printing and reproduction of recorded media
	C19	Coke and refined petroleum products
	C20-C21	Chemicals and chemical products; basic pharmaceutical products and preparations
	C22	Rubber and plastic products
	C23	Other non-metallic mineral products
	C24	Basic metals
	C25	Fabricated metal products, except machinery and equipment
	C26-C27	Computer, electronic and optical products; Electrical equipment
	C28	Machinery and equipment n.e.c.
	C29-C30	Motor vehicles, trailers and semi-trailers; other transport equipment
	C31-C32	Furniture; other manufacturing
Non-manufacturing industry (4)	B	Mining and quarrying
	D	Electricity, gas, steam and air conditioning supply
	E36-E39	Water collection, treatment and supply; sewerage; waste collection, treatment and disposal activities; materials recovery; etc.
	F	Construction
Services (17)	G45	Wholesale and retail trade and repair of motor vehicles and motorcycles
	G46	Wholesale trade, except of motor vehicles and motorcycles
	G47	Retail trade, except of motor vehicles and motorcycles
	H49-H52	Land and via pipelines, water, air transport; warehousing and support activities
	H53	Postal and courier activities
	I	Accommodation and food service activities
	J58-J60	Publishing activities; motion picture, video and television programme production, sound recording and music publishing activities; etc.
	J61	Telecommunications
	J62-J63	Computer programming, consultancy and related activities; information service activities
	K64-K66	Financial service activities; insurance, reinsurance and pension funding; activities auxiliary to financial services and insurance activities
	L	Real estate activities
	M69-M75	Legal and accounting activities; activities of head offices; management consultancy activities; architectural and engineering activities, technical testing and analysis; scientific research and development; advertising and market research; other professional, scientific and technical activities; veterinary activities
	N	Administrative and support service activities
	O84	Public administration and defence; compulsory social security
	P85	Education
	Q	Human health and social work activities
	R-S	Other service activities

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