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Working Papers in Trade and Development

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July 2008

Working Paper No. 2008/06

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The Impact of Production Fragmentation on Skill Upgrading: New Evidence from Japanese Manufacturing*

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Abstract:
This paper examines the hypothesis that industries engaged in international fragmentation of production experience greater skill upgrading using a panel dataset of Japanese manufacturing over the period 1980-2000. The novelty of the study comes from the use of a newly constructed index using trade data on parts and components to measure intra-industry variations in the degree of international vertical specialization (fragmentation intensity of trade). It also employs a methodology designed to embody peculiarities of Japan's fragmentation trade pattern. While the findings of existing studies are inconclusive, it is found that the expansion of fragmentation trade with developing East Asian countries has had a significant impact on the skills composition of Japanese manufacturing employment. At the same time, fragmentation trade with high income countries has had a skill downgrading effect.

Key Words: Production Fragmentation; Skill Upgrading; Japanese Manufacturing
JEL Classification: F14, F16, J31

Forthcoming in *Journal of the Japanese and International Economies*

* I am grateful to my supervisors Prema-chandra Athukorala and Martin Richardson for their guidance and useful comments. I wish to thank John Ries and two anonymous referees for detailed and very helpful comments for revising the paper. I would also like to thank Alberto Posso, Xin Liu, Ryo Ochiai, Russell Thomson, Jenny Corbett and the seminar participants at the Australian National University for discussion and useful comments. Institute of Economic Research at Hitotsubashi University provided a hospitable environment where part of this paper was written. I would especially like to thank Kyoji Fukao and Yumiko Moriyama for the arrangements and support for my visit.

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1. Introduction

International fragmentation of production - the cross-border splitting of the production process within vertically integrated manufacturing industries- generally involves the relocation of unskilled labour-intensive production segments to developing countries where labour costs are relatively low, while retaining the higher-end production activities that require high skills or sophisticated technologies in developed countries. This process of international specialisation implies two forms of structural adjustment in the manufacturing industry in developed countries. First, it changes the composition of manufactured trade by the increase of cross-border trade on parts and components ('fragmentation trade' for brevity). Second, it brings about compositional shifts in the skill composition of demand for labour. The latter is the focus of this paper. In particular, the rise of the intensity of production fragmentation has the effect of shifting labour demand away from less-skilled labour toward skilled labour *within* the manufacturing industry (or *within* the firm), since domestic production increasingly specialises in higher skilled and technology-intensive tasks. As a result, demand for skilled workers is pushed up, consequently raising the relative wage of skilled workers while suppressing demand and wages for unskilled workers.

Feenstra and Hanson (1996b, 1999, 2003) have demonstrated that the fragmentation-based trade contributed 15% to 24% of the total increase in the wage share of skilled workers in US manufacturing during the 1980s. Following these studies, similar analyses have been undertaken for a range of other developed countries: Strauss-Kahn (2004) for France, Hijzen et al., (2005) for the UK, Helg and Tajoli (2005) for Germany and Italy, Hsieh and Woo (2005) for Hong Kong, Egger and Egger (2003) for Austria, and Hansson (2000) for Sweden. Broadly speaking, the findings of these studies are consistent with the Feenstra-Hanson results for US manufacturing. However, the findings of the few available studies on Japanese manufacturing are inconclusive as to the skill upgrading effects of production fragmentation (Sakurai, 2000; Ito and Fukao, 2005; Sasaki and Sakura, 2005). This is rather surprising, given the active role played by

Japanese firms in global production sharing (Borrus, 1997; Ng and Yeats, 2001; Athukorala and Yamashita, 2006, 2008). The exploration in the present study is motivated by this inconclusiveness in the findings of existing studies on Japan. I argue that the failure to find a robust relationship between the increased fragmentation process and industry skill upgrading in Japanese manufacturing might be associated with methodological shortcomings.

The empirical analysis is based on a panel data set covering 52 Japanese manufacturing industries over the period 1980-2000. The major novelty is the use of a new measure of fragmentation intensity based on trade data on parts and components through regression analysis. Based on this new measure I find that the expansion of fragmentation trade with developing East Asian countries has had a significant impact on the skills composition of Japanese manufacturing employment. I also find that the impact of fragmentation trade on skill upgrading varies depending on the factor endowment characteristics of trading partners; trade with high income countries (OECD countries) has had a skill downgrading effect in contrast to the skill upgrading effect of trade with developing countries.[1]

The export intensity of fragmentation trade is also considered. While the existing studies only focus on the import side of production fragmentation, fragmentation trade is not confined to purchase of foreign intermediates inputs. Rather, it has mainly evolved due to the outward orientation of the fragmentation process by exporting parts and components manufactured in Japan to developing East Asian countries for the purpose of final assembly. Failure to capture the export orientation of production fragmentation might result in underestimating the actual impact of fragmentation on skill upgrading in Japan. More importantly, the existing studies might suffer from omitted variable bias by excluding the export-side of fragmentation trade.[2] Finally, the datasets compiled in this

[1] In the previous Japanese study, Sasaki and Sakura (2005) also considered distinguishing the sources of Japan's manufacturing imports, but only focused on total manufacturing imports from East Asian countries without making a distinction to components trade. As will be argued, the simple total import penetration ratio lacks precision on measuring the intensity of fragmentation trade. Strauss-Kahn (2004) also distinguishes imports of intermediate inputs between OECD and non-OECD countries in her study on French manufacturing.

[2] I would like to thank John Ries for pointing this out.

paper have a wider coverage in terms of the period and number of industries compared to previous studies. The updated time coverage is particularly important because fragmentation activities in Japanese manufacturing began to grow rapidly from the late 1980s.

The organization of this paper is as follows. The next section conceptually describes how accelerated growth of the fragmentation process has implications for skill upgrading of domestic manufacturing, followed by a survey of the relevant empirical studies. Section 3 discusses measurement issues central to the empirical analysis of a study. Section 4 describes the model specification, and the econometrics methodology, followed by the interpretation of the results. The final section concludes by summarising the key findings.

2. The Skill Upgrading Effect of Production Fragmentation

Fragmentation of production either takes the form of importing parts and components or exporting the domestically produced components for further processing and final assembly. The former case involves the lower-skill contents of the intermediate processing stage being performed in low-wage countries and then imported by a developed country for the further higher valued-added processing. In the latter case, the relatively high skills-intensive components are exported by a developed country for the purpose of further labour-intensive processing and final assembly in developing countries. In both cases an upgrading of the skills content of the remaining production process is implied, due to greater specialisation in the developed countries (called *the skill upgrading effects*). This is the key hypothesis to be examined in this paper.

While the labour market implication on the skill upgrading effect of production fragmentation is straightforward, the theory provides less clear-cut guidance to the impact of production fragmentation on different types of workers. Trade models in the spirit of Ricardo, Heckscher-Ohlin, and the specific-factor have been put forward to analyse the labour market consequences of production fragmentation (Feenstra and Hanson, 1996a; Arndt, 1997; Jones and Kiezkowski, 2001; Kohler, 2001; Grossman and Rossi-Hansberg, 2006). The key inferences derived from these models primarily depend on the model and the assumption chosen.[3]

Trends and Patterns of Skill Upgrading

The deteriorating position of unskilled workers is clearly one of the key policy concerns for developed countries in recent years (Katz and Revenga, 1989; Lawrence and Slaughter, 1993; Berman et al., 1994; Sachs and Sharzs, 1994; Krugman, 1995; Katz and Autor, 1999). A key aspect of this trend is summarized in Figure 1 (Figure 1a for Japanese manufacturing and Figure 1b for US manufacturing). These figures plot the wage of skilled workers (proxied by nonproduction workers) relative to unskilled workers (proxied by production workers), measured on the left axis and relative employment of skilled/unskilled workers on the right axis for the period of 1960-2004.

Figure 1 clearly shows relative employment has moved in favour of skilled workers in Japanese manufacturing. In particular, there has been a sharp rise in the relative employment of skilled workers since the early 1960s in Japanese manufacturing. On the other hand, the relative wages of skilled workers actually fell in the post-war industrialization period in the 1960s and early 1970s. This might be related to downward pressure on the relative wages of skilled workers due to a rapid increase in labour supply. However, since the mid-1970s, the relative wage of skilled workers in Japan has remained almost constant. Similarly, Katz and Revenga (1989) and Sakurai (2001) found an almost constant *relative* wage rate for skilled workers in Japan since the mid-1970s.[4] [5] This suggests that there has been increasing relative employment of skilled workers in

[3] Feenstra and Hanson (1996a) demonstrated that production fragmentation raises demand for skilled workers in both developed and developing countries (e.g., US and Mexico). On the other hand, Ardnt (1997) and Jones and Kierzkowski (2001) show less-skilled workers could get hurt or benefit from production fragmentation, depending on the complex interaction of factor endowment, factor intensity and the output pattern of a country in the canonical Heckscher-Ohlin model. Kohlar (2001) examines the impact on wages by allowing fragmentation in the specific-factor model. The latest theoretical treatment of fragmentation appears in Grossman and Rossi-Hansbarg (2006).

[4] While Sakurai (2001) makes a distinction between nonproduction and production workers, Katz and Revenga (1989) use education attainment data to measure the skill intensity of workers.

[5] Head and Ries (2002) observed a continuous increase in the share of skilled workers in total wage bills since the 1970s (See Figure 2 of Page 92 in their paper). This is consistent with the finding in this paper that the massive increase in relative employment of skilled workers contributes to the rising share in the total wages bill, despite the relatively stable wage rate. It was also observed that since 1970 there has been a declining share in the wage bill for production workers in Japanese manufacturing.

Japan since the mid-1970s, despite the lack of decrease in relative wages. This observed fact sits uncomfortably with the theory of supply and demand for labour. In theory, the uninterrupted massive increase of relative supply of skilled workers should have somehow lowered the relative wage for skilled workers. However, the strong rise of the relative demand for skilled workers might have worked against the relative supply effect, stopping the rise of the relative wage during this period. Sasaki and Sakura (2005) and Ahn et al. (2008) make a similar inference on this account. In contrast, US manufacturing experienced a massive increase in the relative wages of skilled workers from the mid-1980s to the early 2000s, with relatively little change in relative employment during the same period.[6]

In sum, both Japanese and US manufacturing have been experiencing skill upgrading in the past two decades or so. However, for Japan skill upgrading appeared in the form of an increase in the relative employment of skilled workers, and a relative wage increase favouring skilled workers in the case of US manufacturing.

<Figure 1 about here>

Evidence

There is an extensive empirical literature examining the skill upgrading effects of production fragmentation for developed countries. The findings of these studies are summarised in Table 1. Feenstra and Hanson (1996b, 1999) developed the seminar work. Their measurement of outsourcing intensity basically involves calculation of imported intermediate inputs from *the Annual Survey of Manufactures*, the US Bureau of the Census (see section 3 for more details on their measurement). The data set used in Feenstra and Hanson (1999) covers 447 manufacturing industries based on the US Standard Industrial Classification (SIC) over 1979-1990. In these regressions, the dependent variable is the change of nonproduction (skilled) workers' shares in total wage bills over the period. The estimation framework is based on a translog cost function, first employed in the literature by Berman et al. (1994). The results in Feenstra and Hanson

[6] Many studies have documented the modality of skill upgrading in the context of US manufacturing (Katz and Revenga, 1989; Lawrence and Slaughter, 1993; Berman et al., 1994; Sachs and Shatz, 1994; Katz and Autor, 1999).

(1996b, 1999) support the hypothesis that foreign outsourcing has had a positive impact on the nonproduction share of total wage bills, alongside technological change indicators. The Feenstra and Hanson (1996b, 1999) calculations suggest foreign outsourcing contributed 15% to 24% of the total change to the nonproduction wage shares associated with a shift in total demand for labour towards more skilled workers is US manufacturing over the period 1979-1990.

Following Feenstra and Hanson (1996b, 1999), a similar analysis has been undertaken for some other industrial countries. These include Anderton and Breton (1999) and Hijzen et al. (2005) for the UK; Strauss-Kahn (2004) for France; Hansson (2000) for Sweden, Helg and Tajoli (2005) for Germany and Italy and Hsieh and Woo (2005) for Hong Kong. Overall, the results suggest increased fragmentation of production has a sizable impact on shifting labour demand towards more-skilled workers, although the estimated magnitude of the impact varies across countries.

Sakurai (2000), Ito and Fukao (2005), and Sasaki and Sakura (2005) examined the skill upgrading effects of the fragmentation intensity in Japanese manufacturing using a similar methodology.[7] However, unlike other country studies, the studies on Japanese manufacturing have not been able to present clear-cut results. Sakurai (2000) used wage data for production and nonproduction workers for 39 manufacturing industries, compiled from *the Census of Manufacture*s, Japan Ministry of Economy, Trade and Industry (METI) over the period 1987-1990. He constructed measures of outsourcing intensity following Feenstra and Hanson (1996b) and tested for any statistical significance of change in nonproduction workers' share of total wage-bills in Japanese manufacturing. He found no statistical relationship between the intensity of imported intermediate inputs and skills upgrading. The relatively short time-period was considered to be the reason for this insignificant result.

Ito and Fukao (2005) extended the analysis to cover 35 manufacturing industries over a longer time period (1988-2000). Unlike Sakurai (2000), they examined the

[7] While not directly dealing with the issue of skill upgrading, Fukao et al. (2003) and Tomiura (2005) examined the pattern of foreign outsourcing for Japan.

employment effect of production fragmentation rather than wages due to the data constraint. In their various regression runs, the indices of intensity of production fragmentation based on the Input-Output (I-O) table exhibited the expected positive sign, indicating the skill upgrading effect, but they found no statistical significance.

Sasaki and Sakura (2005) examined the possible impact on industry skill upgrading, based on education attainment levels (higher or lower educated) for a panel of 14 Japanese manufacturing industries during the period 1988-2003. This study was motivated by a concern that the inconclusive evidence of the previous studies was due to the failure to allow for Japan's growing imports from countries in East Asia. They used the manufactured imports penetration ratio from East Asian countries as an indicator of the fragmentation intensity. They found increased imports penetration from developing East Asian countries contributed to around 10-13% increase in the highly educated workers' wage bill share across industries over the period 1988-2003. However, their analysis only focuses on the impact of increased manufacturing imports from East Asian countries. Additionally, their measure of fragmentation intensity is a crude proxy.

There are two main shortcomings in the existing Japanese studies. First, as will be elaborated below, the imported intermediate inputs from the I-O table as a proxy for the intensity of production fragmentation might not be appropriate in the context of Japan. Second, apart from Sasaki and Sakura (2005), the previous studies failed to take into account a geographic-specific effect of production fragmentation, an important aspect of fragmentation-based international specialisation which has so far been overlooked in the literature. The econometric analysis undertaken in Section 4 addresses these issues.

<Table 1 about here>

3. Measurement of Production Fragmentation

There is no unique way to measure the intensity of the fragmentation process in manufacturing. This section discusses the limitations of the widely-used measure of production fragmentation in the literature, before proposing a more appropriate measure.

The following formula is frequently employed to compute the degree of foreign outsourcing (Feenstra and Hanson, 1999);

$$(1) \quad \text{Imported intermediate inputs}_i = \underbrace{\sum_j [\text{inputs from industry } j \text{ to } i]}_{\text{Inter-industry intermediate inputs flows}} * \underbrace{[\frac{\text{imports}_j}{\text{domestic absorption}_j}]}_{\text{import penetration ratio}}$$

where subscript *i* is purchasing industry and *j* denotes supplying industry with intermediate inputs. The first term in Equation (1) comprises the total volume of intermediate inputs purchases of industry *i* from other manufacturing industries *j*. The first term is multiplied by the second, which comprises the import penetration of supplying industry *j*. Domestic absorption in the second term is defined as gross output, plus imports, and minus exports (outputs+imports-exports). 'Broad outsourcing' in the Feenstra and Hanson terminology is defined as the ratio of imported intermediate inputs to the total expenditure on intermediate inputs. On the other hand, *narrow outsourcing* is defined to only include intra-industry flows of imported intermediate inputs of industry *i* at the same two-digit industry classification.

The purpose of the Feensrra-Hanson approach is to measure the overall degree of dependence on imported intermediate inputs, as an indication of the intensity of fragmentation trade for a given industry. Of these two measures, the broad outsourcing is often the second preference, because its definition is too broad. Narrow outsourcing measure is preferred because it only includes intra-industry purchase of intermediate inputs. The Feenstra-Hanson approach has been very popular ever since (Hansson, 2000; Strauss-Kahn, 2004; Ito and Fukao, 2005; Hijzen et al., 2005; Hsieh and Woo, 2005; Ekholm and Hakkala, 2006).

There are several reasons why these indicators do not appropriately capture the true dynamics of the fragmentation process in a meaningful way. First, the use of the total imports penetration ratio, the last term in Equation (1), limits the precision of measure of the imports dependency of the intermediate inputs. The ratio of imported intermediate inputs to the consumption of total intermediate inputs might be very different from the ratio of the imported final goods to the total final goods consumption (Strauss-Kahn, 2004).[8]

Second, the I-O table by construction does not permit separating imported intermediate inputs between ordinal intermediate inputs (raw materials), such as steel, metals, plastics, and chemical products and fragmentation-based intermediate inputs such as parts and components. This separation is important because the latter represents the rapidly growing production fragmentation, while the former is not a new type of trade flow (Yeats, 2001; Athukorala, 2005). This is particularly critical in the context of Japanese manufacturing given its high dependency on imported raw materials. While raw material imports are mainly driven by resource endowments, the newly arising parts and components trade is influenced by totally different factors. For example, the fragmentation intensity measure based on the I-O table assigns very high rankings to industries with high dependency on imported intermediate inputs such as processed marine products, lumber and wood products and pulps and papers (Ito and Fukao, 2005). However, these are not part of the rapidly growing production fragmentation process in Japanese manufacturing.

Third, by its very nature, the I-O table focuses only on the import side. However, the fragmentation process can also be important on the export side, when firms export domestically produced components to low-wage countries for further processing or assembling (Hijzen et al., 2005). In particular, Japanese and US multinational enterprises (MNEs) are heavily involved in this export orientation of the fragmentation process. More importantly, failing to capture both side of the fragmentation intensity might cause an omitted variable bias in the regression estimations.

Mindful of these limitations, this paper measures the intensity of fragmentation trade in a given industry, using detailed trade data in parts and components. (see the Appendix 1 for a description of the method of data compilation identifying trade in parts and components). The use of trade data on parts and component was pioneered by Yeats

[8] Hijzen et al. (2005) also identified this shortcoming, and computed the import penetration ratio of intermediate inputs directly from the import use matrix.

(2001), and then was subsequently extended by Athukorala (2005). The formulations are written as follows:

$$FRG^{import} = \frac{\text{Imports of Parts and Components}}{\text{Intermediate Inputs}}$$

(2)

$$FRG^{export} = \frac{\text{Exports of Parts and Components}}{\text{Gross Outputs}}$$

There are three added advantages of this approach compared to the conventional I-O table approach. First, it avoids mixing traditional intermediate inputs into the estimates by making a distinction between trade on parts and components and ordinary intermediate inputs. Second, trade data capture both export and import orientation of the fragmentation process. Third, controlling for the direction of trade in parts and components makes it possible to differentiate the possible heterogeneity effects of the fragmentation activity on skill upgrading. For example, the possible impact on skill upgrading might be different, depending on whether an increase in parts and components imports is from developing countries or developed countries due to the difference in skills content. Increased trade with developing countries is expected to have the *skill upgrading effects* in domestic manufacturing, whereas trade with developed countries is expected to have the *skill downgrading effects*.[9] This distinction is particularly crucial because recent years have witnessed a rapid increase in components imports from developing East Asian countries (especially in the Japanese electronics industry). This division of labour with East Asian countries through the fragmentation process might be expected to result in a significant impact on skill upgrading.

The main limitation of the trade data approach is the limited industry coverage, since a detailed separation of parts and components trade is only possible for machinery and transport equipment (Standard International Trade Classification, SITC, 7) and miscellaneous manufacturing (SITC 8) by the available trade commodity classification system. This automatically ignores the intensity of fragmentation trade in other industries. For instance, the textiles and garments and chemical industries have recently become

[9] Similarly, a seminal paper by Head and Ries (2002) demonstrates that the effects of offshore production by Japanese manufacturing MNEs on skill upgrading depend on the relative factor abundance of host countries. As predicted, the sign of the coefficient on the FDI variables confirms the skill upgrading effect in developing host countries, and the skill downgrading effect for developed host countries.

involved in the fragmentation process. However, a focus mainly on parts and components of machinery products is justified, because the available case study based literature confirms the bulk of production fragmentation is highly concentrated in the machinery industry (Brown and Linden, 2005).

4 Econometric Analysis

As documented in section 2, the existing empirical studies on Japan have found less clear cut evidence of the influence of the fragmentation intensity of trade on skill upgrading at the industry level. This section re-examines this hypothesis by conducting an econometric study of the panel data of 52 Japanese manufacturing industries over the period 1980-2000. The innovation of this analysis is the incorporation of a better measure of the fragmentation intensity of trade for a given industry, namely trade in parts and components. Following the standard approach in this literature (Berman et al. 1994; Feenstra and Hanson 1996b; 1999), the skill level of workers is measured by the standard occupational classification. Skill workers correspond to 'nonproduction' workers, consisting of technical workers (system engineers and computer programmers), managers, administrative, advertising and sales workers, whereas 'production workers' are a proxy for less-skilled workers with manual, assembling and operational jobs. The analysis is also conducted by narrowing the definition of skilled workers to engineers and technical occupations (denoted as *tech*).

The estimation is based on a reduced form of labour demand function widely used in this strand of literature (Berman et al., 1994; Feestra and Hanson, 1996b, 1999; Strauss-Kahn, 2004; Ito and Fukao, 2005). The baseline specification can be written as follows:

$$(3) \qquad \mathrm{Sh}_{z,t} = \phi_0 + \phi_1 \mathrm{Y}_{z,t} + \phi_2 \mathrm{K}_{z,t} + \phi_3 \mathrm{R\&D}_{z,t} + \phi_4 FRG^{\mathrm{m}}_{z,t} + \phi_5 FRG^{\mathrm{x}}_{z,t} + \alpha_Z + \gamma_t + \varepsilon_{z,t}$$

where subscripts z and t denote industry and time, respectively, and superscripts m and x represent imports and exports, respectively. The dependent variable (*Sh*) is the employment share of skilled workers as examined in Ito and Fukao (2005). As discussed in section 2, the employment indicator seems to be a more interesting variable of skill upgrading in the case of Japan.[10]

The most important explanatory variable is the measure of production fragmentation intensity (*FRG*) across industries. This is based on parts and components in trade data (See Equation 2 for the formulation). In general, positive signs are expected for *FRG*, since it is postulated that the fragmentation activity has the skills upgrading effects. An increasing component trade with developing East Asian countries is hypothesised to be positively related with change for employment of skilled workers (see Appendix Table 5 for the definitions of country groups). On the other hand, a skills downgrading effect with a negative sign is expected with higher intensity of the fragmentation activity with OECD countries.

Two potential candidates to represent the industry scale of production (*Y*) are value-added and gross output.[11] Value-added is used to represent the industry output measure, rather than gross output, because gross output might be too inclusive to serve as a clear indicator of industry output scale (Maskus, 1991).[12] The sign of this variable depends, *ceteris paribus*, on whether the expansion of the industry output scale would require more skilled workers. If the estimate coefficients are zero, the hypothesis that the underlying production function is homothetic cannot be rejected. Otherwise, it implies non-homothetic, suggesting the ratio of the optimal inputs demands depend on the level of outputs.

[10] An alternative measure is the share of skilled workers in the total wage bills of all workers. However, this cannot be computed for the time period covered in this paper because of the unavailability of wage data for nonproduction workers at the disaggregated industry level. Two data sources are generally available for compiling the wage bills of nonproduction/production workers at industry level of Japanese manufacturing, *the Census of Manufactures* (CM), Japan Ministry of Economy, Trade and Investment (METI), and *the Basic Survey on Wage Structure* (BSWS), the Ministry of Health, Labour, and Welfare. The CM includes cash earnings of production and nonproduction workers at the detailed 4-digit level of Japan Statistical Industry Classification (JSIC). However, since 1990 this information has become unavailable in the published data of the CM. The BSWS provides wage earnings data for nonproduction and production workers, but they are available only for the total manufacturing industry and 1985 onward.

[11] Berman et al. (1994) and Feenstra and Hanson (1999) both prefer the use of value-added, but in the empirical application, instead alternate with the value of industry shipment (ie, gross outputs) due to the absence of reliable price deflators.

[12] The estimation results are however less sensitive to the use of gross output.

The ratio of capital stock to value-added is used to measure capital intensity of production (denoted as *K*). The sign of this variable can be either positive or negative depending on whether skilled workers are complementary (the positive sign) or substitutes (the negative sign) to physical capital stock in the production process.

R&D intensity (denoted as *R&D*) is a ratio of the R&D expenditure to value-added. It is included in the model to capture any effect of skills-biased technological change introduced into working practices in association with change in production technologies, new capital investment, and the use of computers. The expected sign of the coefficient on this variable is positive. Alternatively, the stock of patents data can be used, but is not considered here due to data constraints.[13]

Finally, both the industry fixed effect (α) and time-specific effect (γ) are incorporated in order to guard against omitted variables for explaining the variation in the employment share of skilled workers in the respective dimensions: the former is needed to control for any unmeasurable (or unobserved) time-invariant heterogeneity, such as industry-specific persistent technological differences or difference in the average management quality. Time-specific effects are also introduced to control for a homogenous form of technological change across industries, but varying across time as well as capturing other macroeconomics shocks.

Data and Econometric Methodology

A regression analysis is performed using a panel dataset for 52 Japanese manufacturing industries at 5 year intervals over the period from 1980 to 2000 (namely, 1980, 1985, 1990, 1995, and 2000).[14]

The compilation of the index of fragmentation intensity of trade (*FRG*) involved the following steps. First, trade data on parts and components are compiled from the United Nations (UN) Comtrade database. They are based on 5-digit commodity level of machinery and transport equipment (SITC 7) and miscellaneous manufacturing (SITC 8)

[13] Feeestra and Hanson (1996b, 1999) employed more specific high-tech capital variables such as computer investment, whereas other studies have used employee computer usage.
[14] See the Appendix Table 4 for a list of 52 industries.

categories (see Appendix 1 for further details on the data compilation method). Second, the data on parts and components at the five-digit level are converted to the two-digit level industry classification of Japan Industrial Productivity (JIP 2006) using the concordance between SITC and JIP, as detailed in Appendix 1. This procedure mainly covers trade in parts and components in 20 manufacturing industries, tobacco (JIP 14), furniture (JIP 17), general machinery (JIP 42, 43 and 44), office machinery (JIP 45), electronic machinery (JIP 46 to 53), motor vehicles (JIP 54 and 55), precision machinery (JIP 57) and plastic products (JIP 58). Appendix Table 4 presents the computed fragmentation intensity of trade for those 20 manufacturing industries for the period of 1980-2000.

Due to the limited coverage of a list of parts and components in trade data, 'zeros' are assigned to other manufacturing industries which are not possible to compile trade data on components. The main regression analysis in Table 4 presents the results for using data for all 52 manufacturing industries. The regression analysis using the limited industry coverage (20 mainly machinery industries) is also performed to check the robustness of the findings in Appendix Table 3. The limited industry coverage does not seem to change the results significantly from using the full 52 manufacturing industries.

The other variables are sourced from the latest version of the Japan Industrial Productivity (JIP 2006) at the REITI (Research Institute of Economy, Trade and Industry).[15] The most desirable feature of this dataset is that it gives the employment proportion of nonproduction and production workers in each of 52 manufacturing industries. The original employment data across industries in JIP 2006 are based on the survey data of *the Population Census*, conducted by the Statistics Bureau, Japan Ministry of Public Management, Home Affairs, Posts and Telecommunications every 5 years.[16]

Gross output is measured as the sum of industry shipment, revenues from repairing and fixing services, and revenues from performing subcontracting works. Intermediate inputs are defined as the sum of raw materials, fuels, electricity, and

[15] See the Appendix 2 for further details on JIP 2006 database.
[16] See the RIETI website for the data compilation method: http://www.rieti.go.jp/jp/database/d04.html.

subcontracting expenditure. They are available in real terms in JIP 2006 database. Real value-added is defined as the difference between real gross output and real intermediate inputs. Capital stock refers to the nominal book value of tangible fixed assets including buildings, machinery tools, and transport equipments. Nominal R&D expenditures have been updated from the previous version of the JIP database (See Appendix 2 for more details).

For the estimation procedure, a fixed effect model is used in order to exploit the panel feature of the dataset.[17] There are three alternative estimation techniques available to purge the industry-specific effects; the time-demeaning (i.e., within-transformation), Least Square Dummy Variables (LSDV), and the first-difference estimator. The main inferences are based on the estimation result (Table 4) by the within-transformation method. While the first-differencing is frequently used in the literature (Berman et al., 1994; Feenstra and Hansen, 1996b, 1999; Ito and Fukao, 2005), it might not be suitable in the current context due to the nature of the dataset. When the number of time-periods exceeds two as in this dataset, two other estimators (within-transformation and LSDV) become more efficient under the assumption of no serial correlation in the error term (Wooldridge, 2000). Otherwise, the first-differencing method is preferred. However, the data are less likely to be prone to the problem of serial correlation for a panel of 5 year intervals of records. Moreover, the first-differencing data approach can exacerbate any potential problems arising from measurement errors in the data (Griliches and Hausman, 1986; Hijzen et al., 2005). While acknowledging this limitation, Appendix Table 2 presents the results based on the first-differencing for the purpose of comparison. The main results remain remarkably resilient.[18]

The choice of using the within-transformation or the LSDV is more subtle, since both estimators should give identical estimated coefficients and test-statistics under normal circumstances. The former is preferred, because the alternative method is not

[17] At the experimental stage, both fixed effect and random effect models were implemented, and the Hausman test was conducted to see which estimator is more appropriate. The test results were mixed, but the results based on fixed effect and random effect estimators were closely comparable. Therefore, the estimation results based on random effect are suppressed for brevity.
[18] Note that the statistical significance of the *R&D* variable in Appendix Table 2 was completely lost by the first-differencing method.

appropriate due to the problem of degree of freedom by the inclusion of the slope dummy for all 52 industries. Following standard practice, the model is then estimated by the weighted least squares (WLS) method, in which the weights are the manufacturing employment share. In this procedure, more 'weight' is placed on relatively large industries.

In order to demonstrate the superiority of the proposed measures of the intensity of fragmentation trade, Appendix Table 1 presents the results based on the alternative measure using the Feenstra-Hanson approach. As discussed in the previous section, the Feenstra-Hanson approach computes the dependency of the imported intermediate inputs across industries based on I-O table.[19]

Results

Summary statistics and the correlation matrix for the variables used in the estimation are presented in Tables 2 and 3 to facilitate interpretation of the key results. In order to guard against possible heteroscsdascity, White's robust standard errors clustered by industry have been used in calculating t-ratio. All variables, other than time-dummy variables, were used in natural logarithms, and hence the estimated coefficients can be interpreted as elasticises.

Alternative regression estimates with the employment share of nonproduction workers and the narrower definition of workers (*Tech*) as the dependent variable are reported in Table 4a and 4b respectively. There is no statistically significant evidence of skill upgrading effects of imports and exports intensity of fragmentation trade (Equation 1, Table 4). This finding is perhaps driven by the high correlation ratio between $FRG^{imports}$ and $FRG^{exports}$ (corr.=0.86 in Table 3). In order to investigate this possibility, regressions were estimated by including $FRG^{imports}$ and $FRG^{exports}$ separately in alternative specification. These alternative estimates are reported as Equations 2 and 3 in Table 4. The results are resilient to these alternative specifications.

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[19] I am grateful for Dr Keiko Ito for providing me the data of these outsourcing measures for JIP 2006 industries.

The results reported in Equations 1 to 3, Table 4 are consistent with those based on Feenstra- Hanson measure of outsourcing intensity reported in Appendix Table 1. This comparison clearly demonstrates that the results in Table 4 are not dictated by the limited industry coverage of the intensity of fragmentation trade. More importantly, total component trade might be masking some heterogeneity skill upgrading effects of production fragmentation.

The baseline specification (Equation 1) in Table 4 is then re-estimated by disaggregating components trade into source and destination countries groups: developing East Asian countries and OECD countries (Equation 4, Table 4a).[20] The coefficient on components imports intensity of fragmentation trade from developing East Asian countries is now positive and statistically significant at the 1% level, suggesting significant skill upgrading effects on overall change in the employment share of nonproduction workers. In particular, it suggests on average a 1% increase of components imports ratios from developing East Asian countries would lead to about a 6% increase in skilled workers' employment share. This accounts for about a 12.3% of increase in the share of skilled workers during this period.[21] In other words, increasing components imports on parts and components with developing East Asian countries would involve a substantial increase in the employment share of skilled workers in Japanese manufacturing. Interestingly, the economic significance of this variable is similar to the impact of manufacturing import penetration from East Asian countries, computed in Sasaki and Sakura (2005) (see Table 1). In the narrow definition of skilled workers (Table 4b), the estimated coefficient of the same explanatory variables are larger, although the statistical significance of the variables have been reduced to some extent (Equation 4).

As expected, an increase in component imports intensity from OECD countries seems to have skill downgrading effects (Equation 4, Table 4a). This suggests increased components imports from OECD countries require more unskilled workers for further

[20] See Appendix Table 5 for the composition of countries in these groups.
[21] This is computed by multiplying the estimates coefficient by the weighted average of change in the import intensity of fragmentation, divided by the weighted average of change in the dependent variable.

processing. Quantitatively, the import intensity of fragmentation trade with OECD countries explains a marginal 1.02% *decline* in skilled workers' employment share. This is indeed consistent with the argument put forward that component imports from high-income countries, presumably highly capital and technology-intensive contents, might substitute for the domestic skilled worker.

Import and export intensity of fragmentation trade are used as separate explanatory variables in Equation 5 and 6 reported in Table 4. The results reinforce the inferences made in Equation 4 and even found stronger effects of exports side of fragmentation trade. A 1% increase of exports intensity of components to East Asian countries leads to a 2.7% increase of the employment share of skill upgrading (Equation 6). This is consistent with the well-known practice of Japanese companies in undertaking simple assembly activities in developing East Asia for exporting largely to third country markets, while retaining capital- and technology-intensive component production in Japan (Head and Ries 2002). On the other hand, the exports intensity of fragmentation trade with OECD countries has skill downgrading effects in Japanese manufacturing (Equation 6, Table 4). These findings corroborate the results of Head and Ries (2002) who found that the impacts of fragmentation trade on the skill structure of domestic manufacturing depend significantly on the country in which the production process is relocated.

All regressions in Table 4 show a negative industry output scale effect (*Y*) on the demand for skilled workers. The negative scale effect suggests Japanese manufacturing industries would require, *ceteris paribus*, less skilled workers as output expands. The estimated coefficient on capital-intensity (*K*) suggests capital utilisation has a positive relationship to skilled workers (i.e., the complementary relationship between skilled workers and capital investments), but is found to be statistically insignificant. In fact, capital-output ratio on average accounts for very little of the variation in the employment change of skilled workers. This finding is markedly different from the commonly found robust complementary relationship between capital utilization and skilled workers in US manufacturing (e.g., Berman et al., 1994). However, this is quite consistent with a previous study in Japanese manufacturing (e.g., Sakurai, 2000). The result for the R&D intensity variable suggests a positive and statistically significant effect on skill upgrading on average. This findings support the hypothesis that skills-biased technological change is strongly associated with the skill upgrading of Japanese manufacturing. It should be noted that the size of the estimated coefficient for the *R&D* variable is somewhat smaller than the *FRG* variable in most of the specifications in Table 4.

To sum up, the results indeed suggest a significant effect of increasing fragmentation trade on skill upgrading across industries in Japanese manufacturing over the period 1980-2000. In particular, the main skill upgrading effects come from the increased intensity of fragmentation trade with developing East Asian countries. On the other hand, the evidence points to skill downgrading effects from increasing components trade with OECD countries. These findings are in contrast to those of Sakurai (2000) and Ito and Fukao (2005) who failed to find any evidence that increasing practices of production fragmentation contribute to skill upgrading in Japanese manufacturing. They are consistent with Head and Ries (2002) on the impacts of Japanese MNEs activity on skill upgrading.

<Table 2 and 3 about here>

<Table 4 about here>

5 Conclusion

This paper examined the hypothesis that industries engaged in international fragmentation of production experience greater skill upgrading using a panel dataset of 52 Japanese manufacturing industries over the period 1980-2000. Previous studies have failed to find a significant effect of fragmentation trade intensity on skill upgrading for the Japanese industry-level data (Sakurai, 2000; Ito and Fukao, 2005). In particular, these studies have not been able to replicate the commonly found results for the US and other OECD countries (See Table 1). However, there are ample reasons to doubt their findings, since both skill upgrading and the fragmentation activity have been key features in Japanese manufacturing transformation over the last two decades.

The present paper improves upon the existing empirical framework by incorporating a better measure of the fragmentation trade intensity. It also explicitly allows for the possible differential impact of fragmentation trade intensity with developing East Asian countries and high income countries. It was found that increased fragmentation trade with developing East Asian countries significantly contributed to change in skilled worker employment in Japanese manufacturing over the period 1980-2000. At the same time, components trade with OECD countries had skills downgrading effects.

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Table 1 Survey of empirical studies on the skill upgrading effects of fragmentation trade

Study	Country	Data description	Indicator of fragmentation trade intensity	Main Results
Feenstra and Hanson (1996; 1999)	USA	1979-1990, 447 SIC manufacturing industry	Imported intermediate inputs from the Annual Survey of Manufactures	Fragmentation accounts for 15-24 % change for skilled workers wage share
Strauss-Kahn (2004)	France	1977-1993, 50 3-digit manufacturing industries (INSEE)	Imported intermediate input from the I-O Table	Fragmentation explains 11-15 % change in decline in the less-skilled workers' employment share for the period 1977-1985, and over 25 % the period 1985-1993.
Helg and Tajoli (2005)	Germany and Italy	20 mfg sector, 2-digit ISIC (Rev, 3)	OAP (Offshore Assembly Programme) data	Fragmentation increases relative employment of skilled workers in Italy, but not Germany
Hsieh and Woo (2005)	Hong Kong	1971-1996, 54 manufacturing industries	Imported intermediate input from China constructed from Industry Census	Outsourcing to China accounts for about 40 percent increase of the wage share of skilled workers.
Hijzen et al. (2005)	The UK	1982-1996, 50 manufacturing industries,	Imported intermediate input from I-O Table	Reduces the demand for less-skilled workers, but not for the semi-skilled and skilled workers
Anderton and Breton (1999)	The UK	1971-1986, 11 ISIC (textile and non-electrical machinery) industries	Import penetration ratio in manufacturing	Low wage imports accounts for 40% of decline in unskilled worker wage share and 33 % of decline in employment share in textiles
Skaksen and Søresen (2002)	Denmark	1981-1998, 50 manufacturing industries (ISIC Rev 3)	Imported intermediate inputs from I-O Table	Outsourcing measure decreases relative demand for unskilled workers and increases the relative demand for skilled workers. No impact of relative demand on the semi-skilled workers
Egger and Egger (2003)	Austria	1990-1998, 20 manufacturing industries (NACE 2-digit)	Imported intermediate input from I-O Table	Fragmentation accounts for 25 % increase in relative skilled employment ratio
Hansson (2000)	Sweden	1986-1995, 34 (19) manufacturing industries	Imported intermediate input I-O Table	Fragmentation accounts for 5.4 % change in relative demand for skilled workers
Sakurai (2000)	Japan	39 manufacturing industries, 1987-1990 (Census of Manufactures)	Imported intermediate input I-O Table	While the level of outsourcing measure accounts for around 45 % of change in the skilled workers wage share, there is no impact when it is measured in changes.
Ito and Fukao (2005)	Japan	35 manufacturing industries 1988-2000(2002) (JIP 2003 Database)	Imported intermediate input I-O Table	Positive association between outsourcing measure and change in the skilled workers' employment share, but not statistically significant
Sasaki and Sakura (2005)	Japan	14 manufacturing industries, 1988-2003 (mainly from Census of Manufactures, and Basic Structure of Wage)	Import penetration in manufacturing from East Asian countries	Import penetration from East Asian countries accounts for 10-13% of increase in the skilled workers' wage share

Table 2 Statistical Summary of the Key Variables

	Minimum	Maximum	Mean	Std. Deviation	Coefficient of Variation
Sh	-0.674	-0.190	-0.156	0.098	0.628
Y	0.276	5.871	1.928	1.004	0.521
K	0.009	0.311	0.117	0.061	0.521
R&D	0.000	0.061	0.008	0.009	1.125
$FRG^{imports}$	0.000	0.024	0.001	0.003	3.182
$FRG^{exports}$	0.000	0.059	0.002	0.006	3.224

Table 3 Correlation Matrix of the Key Variables

	Sh	*Y*	*K*	*R&D*	$FRG^{imports}$	$FRG^{exports}$
Sh	1.00					
Y	-0.92	1.00				
K	-0.71	0.76	1.00			
R&D	-0.05	0.19	0.24	1.00		
$FRG^{imports}$	-0.04	0.11	0.20	0.28	1.00	
$FRG^{exports}$	-0.04	0.10	0.19	0.27	0.86	1.00

Variable Definitions:
Sh: Nonproduction (skilled) workers employment share,
Y: Real value added,
K: Ratio of capital stock to value added,
R&D: Ratio of R&D expenditure to value-added,
$FRG^{imports}$: Ratio of parts and components imports to total intermediate inputs,
$FRG^{exports}$: Ratio of parts and components exports to gross output.

Notes: All variables are weighted by the industry employment share of total manufacturing and are converted into the natural logarithms. Variables for *R&D,* $FRG^{imports}$ and $FRG^{exports}$ are converted into logarithmic form by log(1+*x*) where *x* is the variable.

Table 4
Evidences of skill upgrading effects in Japanese manufacturing, 1980-2000, weighted fixed-effect (within-transformation) estimates

(a) – Dependent variable (*Sh*) = the employment share of nonproduction workers

	(1)	(2)	(3)	(4)	(5)	(6)
Y	-0.10	-0.10	-0.10	-0.11	-0.11	-0.10
	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***
K	0.02	0.02	0.03	0.04	0.04	0.03
	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)
R&D	1.36	1.42	1.38	1.38	1.36	1.40
	(0.29)***	(0.30)***	(0.29)***	(0.27)***	(0.27)***	(0.29)***
$FRG^{imports}$	1.13	0.01				
	(1.03)	(0.78)				
$FRG^{exports}$	-0.79		-0.36			
	(0.44)*		(0.36)			
$FRG^{imports}$ *East Asia*				5.71	6.69	
				(2.00)***	(1.14)***	
$FRG^{imports}$ *OECD*				-2.85	-2.45	
				(1.28)**	(0.91)***	
$FRG^{exports}$ *East Asia*				1.50		2.73
				(0.96)		(0.69)***
$FRG^{exports}$ *OECD*				-0.39		-1.87
				(0.81)		(0.46)***
Constant	0.01	0.02	0.02	0.02	0.02	0.02
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Observations	260	260	260	260	260	260
Adjusted R-squared	0.73	0.73	0.73	0.75	0.75	0.74

Notes:
All variable are in natural logarithms. Time-dummy variables are included for all estimations, but the results are suppressed here. Weighted least-square (WLS), weights equal to the industries' employment share in total manufacturing. Standard errors based on White's heteroscadasticity correction are given in brackets, with statistical significance (two-tailed test) denoted as: *** 1per cent, ** 5 per cent, and * 10 per cent. East Asian countries and OECD countries are defined in Appendix Table 5.

Variable Definitions:
Sh: Nonproduction (skilled) workers employment share,
Y: Real value added,
K: Ratio of capital stock to value added,
R&D: Ratio of R&D expenditure to value-added,
$FRG^{imports}$: Ratio of parts and components imports to total intermediate inputs,
$FRG^{exports}$: Ratio of parts and components exports to gross output.

Table 4 (continued)
(b) – Dependent variable = the employment share of technical workers

	(1)	(2)	(3)	(4)	(5)	(6)
Y	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25
	(0.04)***	(0.04)***	(0.03)***	(0.04)***	(0.04)***	(0.03)***
K	0.13	0.14	0.14	0.17	0.16	0.14
	(0.25)	(0.26)	(0.25)	(0.26)	(0.26)	(0.26)
R&D	2.90	3.01	2.92	2.94	2.89	2.96
	(1.05)***	(1.06)***	(1.05)***	(1.05)***	(1.03)***	(1.06)***
$FRG^{imports}$	0.99	-0.83				
	(2.23)	(2.04)				
$FRG^{exports}$	-1.28		-0.91			
	(0.94)		(0.95)			
$FRG^{imports}$ *East Asia*				10.87	10.27	
				(4.93)**	(4.17)**	
$FRG^{imports}$ *OECD*				-6.53	-4.88	
				(3.55)*	(2.94)	
$FRG^{exports}$*East Asia*				0.66		2.29
				(1.63)		(1.94)
$FRG^{exports}$*OECD*				0.82		-2.20
				(1.10)		(1.51)
Constant	-0.05	-0.05	-0.05	-0.04	-0.05	-0.05
	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)
Observations	260	260	260	260	260	260
Adjusted R-squared	0.67	0.67	0.67	0.67	0.67	0.67

Notes:
All variable are in natural logarithms. Time-dummy variables are included for all estimations, but the results are suppressed here. Weighted least-square (WLS), weights equal to the industries' employment share in total manufacturing. Standard errors based on White's heteroscadasticity correction are given in brackets, with statistical significance (two-tailed test) denoted as: *** 1per cent, ** 5 per cent, and * 10 per cent. East Asian countries and OECD countries are defined in Appendix Table 5.

Appendix

A1 Trade Data

This paper takes a systematic approach in identifying parts and components in trade data as detailed below. First, it refers to the classification system of the United Nations, Broad Economic Category (BEC) and selects the relevant parts and components items. The BEC classification system is originally constructed in order to categorize SITC-based trade statistics by approximate class of goods in the Social National Accounts framework (See the further details on development of the BEC system and the industry classification at http://unstats.un.org/unsd/cr/family2.asp?Cl=10>. Among seven major categories, industrial supplies (BEC 2), capital goods (BEC 4), and transport equipment category (BEC 5) include a sub-category for 'parts and accessories'. However, not all items classified as parts and accessories of BEC 2, 4, and 5 correspond to parts and components in a strict sense. Therefore, only the items under the BEC sub-category that also correspond to Standard International Trade Classification, SITC 7 (machinery and transport equipment) and SITC8 (miscellaneous manufacturing) are identified as parts and components in this paper. Limiting to SITC 7 and 8 prevents the inclusions of some components which are traded as 'products in their own right' under specific trade names (e.g., Michelin tyres). The final list prepared though this procedure contains a total of 264 items at the 5-digit level of SITC.[22]

The compiled trade data in this procedure are then mapped two-digit level of industry classification of JIP 2006. However, there are no formal concordance tables developed between JIP 2006 industry classification and SITC system, only the *reference* table between the standard trade commodity and JIP industry classification.[23] This table is used to map SITC to JIP 2006 industries.

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[22] All the commodity classification systems used are stored in the UN Statistical Division: Classification Registry Website: <http://unstats.un.org/unsd/cr/registry/regdnld.asp?Lg=1>

[23] <http://www.esri.go.jp/en/archive/bun/abstract/bun170index-e.html>

A2 Japan Industrial Productivity 2006 Database (JIP 2006)

The JIP 2006 database is the outcome of a research collaboration between the Research Institute of Economy, Trade and Industry (RIETI) as a part of its research project 'Study on Industry-Level and Firm-Level Productivity in Japan' and Institute of Economic Research, Hitotsubashi University as a part of '21st-Century COE Program, Research Unit for Statistical Analysis in the Social Sciences (Hi-Stat) project'. The JIP 2006 can be accessed at http://www.rieti.go.jp/en/database/d05.html. The original version of the JIP Database (JIP 2003) was compiled by the Economic and Social Research Institute (ESRI), Cabinet Office, Government of Japan as part of its research project on "Japan's Potential Growth" and the Hi-Stat project of Hitotsubashi university. A brief description of the variables used in the regression analysis is given below.

Value added is derived from gross output (100 millions in Japanese yen) and intermediate inputs use (100 millions in Japanese Yen). Gross output is measured as the sum of industry shipment, revenue from repairing and fixing services, and revenue from performing subcontracting work. Intermediate inputs are defined as the sum of raw materials, fuel, electricity, and subcontracting expenditure. The notable feature of the JIP database is that a price index of intermediate input use is constructed, making it possible to convert the nominal values into the real series. Therefore, real value added is approximated for a given industry by subtracting real intermediate input from real gross output.

Capital stock (100 millions in Japanese yen) refers to the nominal book value of tangible fixed assets including buildings, machinery, tools, and transport equipment. Nominal R&D expenditures (100 millions of Japanese yen) are not available in JIP2006, but are available in JIP2003. R&D expenditure is reported in the industry classification of JIP2003 and this series updated to JIP 2006. A close inspection of the concordance table between JIP2003 and JIP2006 industry classification reveals that some JIP2003 industry is further disaggregated and others are aggregated in JIP2006. In the case of the disaggregation of industry from JIP2003, it is assumed that R&D expenditure does not vary across the corresponding JIP2006 industries. On the other hand, in the case of aggregation, the average value of R&D expenditure in JIP2003 is used for the corresponding JIP2006 industry. Data on the employment share of nonproduction and production workers in JIP2006 are originally from *the Population Census of Japan,* published by the Statistics Bureau, Japan Ministry of Internal Affairs and Communication. This is conducted every five years, covering detailed occupational categories (3 digit, close to 300 different occupations) and industries. Nonproduction workers are defined as those with the occupation of professional and technical, managers and administrators, clerical and secretarial, sales, and services. Production workers are plant and machine operators and also engage in craft and related occupations.

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Table A1

Evidences of Skill Upgrading Effects in Japanese Manufacturing, 1980-2000: Regression with the Feenstra and Hanson (1996b; 1999) measure of outsourcing

	Dependent variable=the employment share of skilled workers			
	(1)	(2)	(3)	(4)
	Skill=nonprod.	Skill=tech	Skill=nonprod.	Skill=tech.
	Within-transformation estimator		First-difference estimator	
Y	-0.11	-0.26	-0.10	-0.26
	(0.01)***	(0.04)***	(0.01)***	(0.03)***
K	0.03	0.11	-0.00	-0.10
	(0.10)	(0.29)	(0.04)	(0.15)
R&D	1.32	2.53	0.21	0.46
	(0.41)***	(1.17)**	(0.19)	(0.51)
Outsourcing (narrow)	0.40	5.08	0.31	0.51
	(2.64)	(7.71)	(1.35)	(4.19)
Outsourcing (difference)	1.51	4.13	1.01	2.97
	(1.01)	(4.09)	(0.53)*	(2.35)
Constant	0.02	-0.05	-0.00	0.01
	(0.02)	(0.08)	(0.00)	(0.00)*
Observations	260	260	208	208
Adjusted R-squared	0.74	0.68	0.67	0.68

Notes:
All variable are in natural logarithms. The within transformation estimator is implemented for Reg 1 and 2. The first-difference estimator is used for Reg 3 and 4. For Reg 1 and 3, the dependent variable is the share of nonproduction workers, while the employment share for Reg 2 and 4 is only confined to profession and technical workers (denoted as *tech*). Time-dummy variables are included for all estimations, but the results are suppressed here. Weighted least-square (WLS), weights equal to the industries' employment share in total manufacturing. Standard errors based on White's heteroscadasticity correction are given in brackets, with statistical significance (two-tailed test) denoted as: *** 1per cent, ** 5 per cent, and * 10 per cent. East Asian countries and OECD countries are defined in Appendix Table 5.

Variable Definitions:
Y: Real value added,
K: Ratio of capital stock to value added,
R&D: Ratio of R&D expenditure to value-added,
Outsourcing (narrow): Ratio of narrow outsourcing measure to the total intermediate inputs,
Outsourcing (difference): Difference between broad and narrow outsourcing

Table A2

Evidences of skill upgrading effects in Japanese manufacturing, 1980-2000, weighted first-difference estimates

(a) – Dependent variable = the employment share of nonproduction workers

	(1)	(2)	(3)	(4)	(5)	(6)
Y	-0.09	-0.09	-0.09	-0.10	-0.09	-0.09
	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***
K	0.01	0.00	0.01	0.02	0.03	0.01
	(0.04)	(0.04)	(0.04)	(0.05)	(0.05)	(0.04)
R&D	0.19	0.20	0.19	0.24	0.23	0.21
	(0.17)	(0.17)	(0.17)	(0.17)	(0.17)	(0.17)
$FRG^{imports}$	0.47	-0.30				
	(1.15)	(0.45)				
$FRG^{exports}$	-0.40		-0.26			
	(0.51)		(0.24)			
$FRG^{imports}$ *East Asia*				4.30	4.81	
				(2.08)**	(1.44)***	
$FRG^{imports}$ *OECD*				-2.15	-2.11	
				(1.55)	(0.67)***	
$FRG^{exports}$ *East Asia*				0.66		0.96
				(1.00)		(0.92)
$FRG^{exports}$ *OECD*				-0.32		-0.90
				(1.02)		(0.75)
Constant	0.00	0.00	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Observations	208	208	208	208	208	208
Adjusted R-squared	0.66	0.66	0.66	0.67	0.67	0.67

Notes:

All variable are in natural logarithms. Time-dummy variables are included for all estimations, but the results are suppressed here. Weighted least-square (WLS), weights equal to the industries' employment share in total manufacturing. Standard errors based on White's heteroscadasticity correction are given in brackets, with statistical significance (two-tailed test) denoted as: *** 1per cent, ** 5 per cent, and * 10 per cent. East Asian countries and OECD countries are defined in Appendix Table 5.

Table A2 (continued)

(b) – Dependent variable = the employment share of technical workers

	(1)	(2)	(3)	(4)	(5)	(6)
Y	-0.26	-0.26	-0.26	-0.27	-0.26	-0.26
	(0.03)***	(0.03)***	(0.03)***	(0.03)***	(0.03)***	(0.03)***
K	-0.11	-0.11	-0.10	-0.08	-0.06	-0.10
	(0.16)	(0.16)	(0.16)	(0.17)	(0.17)	(0.16)
R&D	0.32	0.33	0.34	0.44	0.40	0.35
	(0.42)	(0.42)	(0.43)	(0.42)	(0.42)	(0.44)
$FRG^{imports}$	-2.04	-1.87				
	(1.97)	(1.25)				
$FRG^{exports}$	0.07		-0.54			
	(0.72)		(0.45)			
$FRG^{import\ s}$ *East Asia*				11.85	9.81	
				(4.39)***	(3.67)***	
$FRG^{imports}$ *OECD*				-9.26	-6.01	
				(3.07)***	(2.18)***	
$FRG^{exports}$ *East Asia*				-0.68		-1.30
				(2.24)		(1.63)
$FRG^{exports}$ *OECD*				2.14		0.20
				(1.40)		(1.21)
Constant	0.01	0.01	0.01	0.01	0.01	0.01
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Observations	208	208	208	208	208	208
Adjusted R-squared	0.66	0.66	0.66	0.66	0.66	0.66

Notes:

All variable are in natural logarithms. Time-dummy variables are included for all estimations, but the results are suppressed here. Weighted least-square (WLS), weights equal to the industries' employment share in total manufacturing. Standard errors based on White's heteroscadasticity correction are given in brackets, with statistical significance (two-tailed test) denoted as: *** 1per cent, ** 5 per cent, and * 10 per cent. East Asian countries and OECD countries are defined in Appendix Table 5.

Table A3
Evidences of skill upgrading effects in 20 Japanese manufacturing industries, 1980-2000

	(1)	(2)	(3)	(4)	(5)	(6)
Y	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08
	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***
K	-0.04	-0.05	-0.04	-0.02	-0.03	-0.03
	(0.04)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
R&D	0.59	0.60	0.58	0.70	0.68	0.67
	(0.22)**	(0.23)**	(0.23)**	(0.21)***	(0.22)***	(0.22)***
$FRG^{imports}$	1.36	0.23				
	(0.78)*	(0.54)				
$FRG^{exports}$	-0.75		-0.22			
	(0.39)*		(0.31)			
$FRG^{imports}$ *East Asia*				2.58	4.23	
				(2.44)	(1.64)**	
$FRG^{imports}$ *OECD*				-0.53	-1.16	
				(1.32)	(0.77)	
$FRG^{exports}$ *East Asia*				1.43		2.36
				(0.93)		(0.68)***
$FRG^{exports}$ *OECD*				-1.05		-1.53
				(0.79)		(0.42)***
Constant	-0.02	-0.02	-0.01	-0.02	-0.02	-0.02
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Observations	100	100	100	100	100	100
Adjusted R-squared	0.79	0.77	0.77	0.80	0.79	0.79

(a) Dependent variable= the employment share of nonproduction workers

Notes:
The number of manufacturing industries is restricted to 20 industries (mainly machinery sector) which are possible to compute the intensity of fragmentation trade. See Appendix Table 4 for those industries. All variable are in natural logarithms. Time-dummy variables are included for all estimations, but the results are suppressed here. Weighted least-square (WLS), weights equal to the industries' employment share in total manufacturing. Standard errors based on White's heteroscadasticity correction are given in brackets, with statistical significance (two-tailed test) denoted as: *** 1per cent, ** 5 per cent, and * 10 per cent. East Asian countries and OECD countries are defined in Appendix Table 5.

Table A3 (continued)

(b) – Dependent variable = the employment share of technical workers

	(1)	(2)	(3)	(4)	(5)	(6)
Y	-0.20	-0.20	-0.20	-0.20	-0.20	-0.20
	(0.03)***	(0.03)***	(0.03)***	(0.031)***	(0.030)***	(0.026)***
K	0.04	0.03	0.04	0.05	0.04	0.04
	(0.19)	(0.20)	(0.20)	-0.21	-0.21	-0.20
R&D	1.11	1.12	1.11	1.19	1.18	1.16
	(0.567)*	(0.566)*	(0.568)*	(0.541)**	(0.544)**	(0.573)*
$FRG^{imports}$	0.81	-0.42				
	(2.04)	(1.57)				
$FRG^{exports}$	-0.82		-0.50			
	(0.98)		-0.80			
$FRG^{imports}$ *East Asia*				1.13	2.29	
				(6.05)	-4.64	
$FRG^{imports}$ *OECD*				-0.90	-1.33	
				(2.81)	-2.43	
$FRG^{exports}$ *East Asia*				1.03		1.02
				(2.29)		(1.94)
$FRG^{exports}$ *OECD*				-0.74		-1.07
				(1.73)		(1.42)
Constant	-0.08	-0.07	-0.07	-0.07	-0.07	-0.07
	(0.07)	(0.07)	(0.06)	(0.07)	(0.07)	(0.06)
Observations	100	100	100	100	100	100
Adjusted R-squared	0.78	0.78	0.78	0.77	0.78	0.78

Notes:
The number of manufacturing industries is restricted to 20 industries (mainly machinery sector) which are possible to compute the intensity of fragmentation trade. See Appendix Table 4 for those industries. All variable are in natural logarithms. Time-dummy variables are included for all estimations, but the results are suppressed here. Weighted least-square (WLS), weights equal to the industries' employment share in total manufacturing. Standard errors based on White's heteroscadasticity correction are given in brackets, with statistical significance (two-tailed test) denoted as: *** 1per cent, ** 5 per cent, and * 10 per cent. East Asian countries and OECD countries are defined in Appendix Table 5.

Table A4: A list of 52 manufacturing industries in JIP 2006 and indexes of fragmentation trade (%), 1980-2000

		1980		2000		Annual average growth	
JIP2006	Industry descriptions	$FRG^{imports}$	$FRG^{exports}$	$FRG^{imports}$	$FRG^{exports}$	$FRG^{imports}$	$FRG^{exports}$
8	Livestock products	-	-	-	-	-	-
9	Processed marine products	-	-	-	-	-	-
10	Rice polishing, flour milling	-	-	-	-	-	-
11	Other foods	-	-	-	-	-	-
12	Fertilizers	-	-	-	-	-	-
13	Beverages	-	-	-	-	-	-
14	Tobacco	0.0	0.0	0.1	0.0	7.4	-10.6
15	textiles	-	-	-	-	-	-
16	Lumber and wood products	-	-	-	-	-	-
17	Furniture	1.2	0.7	2.2	1.2	3.1	2.9
18	Pulp, paper,	-	-	-	-	-	-
19	paper products	-	-	-	-	-	-
20	Publishing and printing	-	-	-	-	-	-
21	Leather and leather products	-	-	-	-	-	-
22	Rubber products	-	-	-	-	-	-
23	Chemical fertilizers	-	-	-	-	-	-
24	Organic chemical basic products	-	-	-	-	-	-
25	Non-organic chemical basic products	-	-	-	-	-	-
26	Organic chemical products	-	-	-	-	-	-
27	Chemical fibres	-	-	-	-	-	-
28	Chemical Final products	-	-	-	-	-	-
29	Other chemicals	-	-	-	-	-	-
30	Petroleum products	-	-	-	-	-	-
31	Coal products	-	-	-	-	-	-
32	Glass products	-	-	-	-	-	-
33	Clay products	-	-	-	-	-	-
34	Stone products	-	-	-	-	-	-
35	Other stone, clay & glass products	-	-	-	-	-	-
36	Steel manufacturing	-	-	-	-	-	-
37	Other steel	-	-	-	-	-	-
38	Non-ferrous metals	-	-	-	-	-	-
39	Non-ferrous metals processed products	-	-	-	-	-	-
40	Metal products	-	-	-	-	-	-
41	Other metal products	-	-	-	-	-	-
42	General machinery equipment	4.0	6.3	7.5	13.0	3.2	3.7
43	Special machinery equipment	3.7	7.9	5.9	12.8	2.3	2.5
44	Other general machinery products	0.2	0.3	0.4	0.3	3.9	0.4
45	Office and services	0.4	6.8	1.8	11.1	7.4	2.5
46	Electrical machinery	1.8	0.4	7.1	2.1	7.1	8.1
47	Equipment and supplies for household	2.3	7.0	11.5	15.4	8.4	4.0
48	Electric computing equipment	5.7	13.0	17.0	16.8	5.6	1.3
49	Wired communication equipment	0.6	0.5	2.6	0.4	7.9	-1.7
50	Electric measuring instruments	3.2	2.7	5.1	7.1	2.4	5.0
51	Semiconductor devices	3.0	1.4	4.0	2.2	1.5	2.5
52	Electron parts	1.4	6.5	2.7	7.7	3.5	0.9
53	Other electrical machinery	5.5	0.6	10.8	4.6	3.4	10.3
54	Motor vehicles	0.8	9.1	1.9	12.5	4.4	1.6
55	Motor vehicles, components	0.1	0.9	0.2	0.8	4.0	-0.6
56	Other transportation equipment	2.8	9.1	4.6	12.0	2.6	1.4
57	Precision machinery & equipment	1.5	5.5	3.5	9.5	4.5	2.7
58	Plastic products	0.2	0.4	0.2	0.3	-0.1	-1.1
59	Other manufacturing	0.0	0.1	0.0	0.0	-0.6	-1.3

Notes: Based on the formula presented in equation (2) in the main text.

Table A5
Definition of country groups

Developing East Asian Countries (10 countries)	OECD Countries (21 countries)
Hong Kong	Austria
Korea, Republic of	Belgium
Singapore	Denmark
Taiwan	Finland
China	France
Indonesia	Germany
Malaysia	Greece
Philippines	Ireland
Thailand	Italy
Vietnam	Netherlands
	Norway
	Portugal
	Spain
	Sweden
	Switzerland
	United Kingdom
	United States
	Mexico
	Canada
	Australia
	New Zealand

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