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【日英共同研究による実証研究シリーズ】

外国人労働者の経済成長への影響：日本のケース

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【要旨】

本論文の目的は、外国人労働者が日本の経済成長に与える影響を分析することにある。このため、都道府県別のパネルデータを基にトランスログ生産関数を推計し、外国人労働者が県内総生産に及ぼす影響を、生産要素としての影響と、全要素生産性への影響に分けて求めた。この結果、外国人労働者、特に熟練外国人労働者が日本人労働者とは別個の生産要素として県内総生産に寄与しているとの結果を得た。しかし、同時に、外国人労働者だけでなく日本人労働者についても、県別労働者数の平均値においては県内総生産に対する弾力性がマイナスとなっていることも分かった。また、外国人労働者、特に非熟練外国人労働者が全要素生産性に及ぼす影響についても、それがマイナスであるとの結果を得た。こうした結果は、例えば Peri (2012) が米国について分析し、いずれにおいてもプラスの影響を検出したのとは大きく異なるものである。その理由としては、日本では企業間の労働移動が限定的であるなど、現在の雇用システムをはじめとする制度的な枠組みが影響している可能性がある。

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Impact of Foreign Workers on Economic Growth: The Case of Japan

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ABSTRACT

The aim of this paper is to analyse the impact of foreign workers on economic growth in Japan by estimating translog production functions on prefectural panel data. The estimation result shows that foreign workers, especially the skilled, can be identified as a distinctive factor of production for gross prefectural product (GPP). However, the result also finds that the elasticities of GPP with respect native workers as well as foreign workers are negative. In addition, the result indicates that foreign workers, especially the unskilled, have a negative impact on total factor productivity. These findings are in contrast with the findings of Peri (2012) which shows that foreign workers contribute to economic growth in the United States by their role as both factors of production and stimulants of productivity. The difference in the impact of foreign workers on economic growth may be explained by the inflexibility of the current institutional arrangement in Japan, especially that of the employment system.

Key Words: Immigration, Economic impact, Economic growth, Translog production function, Employment system
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1 Introduction

With the shortage of workers due to aging and shrinking of the population at the background, foreign workers have been increasing in Japan. According to the Ministry of Health, Labour and Welfare (MHLW), after a drop in 2012 in the aftermath of the Great East-Japan Earthquake, the number of foreign workers which was 682 thousand in October 2012 increased consistently until October 2019 when it reached 1,659 thousand, an annual average rate of increase of 13.5 percent during the period.

The COVID-19 pandemic reduced the number of foreign workers coming into Japan due to the strict border control: foreign workers only increased by 4.0 percent in October 2020 and by 0.2 percent in October 2021 compared to the same month previous year. There was a concern that COVID-19 may change the increasing trend of foreign workers and/or composition. However, the inflow of foreign workers gradually recovered, increasing by 5.5 percent in October 2022, and by 12.4 percent in October 2023. The number of foreign workers in October 2023 exceeded the pre-COVID-19 peak reached in October 2019 by 23.5 percent. The composition of foreign workers' home countries does not seem to have changed much as well. The top five home countries of the foreign workers are the same as before; Vietnam, China, the Philippines, Nepal, and Brazil. All in all, there does not seem to be a major change in the trend of foreign workers coming into Japan.

In light of the expectation that the aging and shrinking of the population will continue, at least for the next fifty years (National Institute of Population and Social Security Research 2023), the shortage of workers will make increase of foreign workers inevitable. The official population projection expects that the share of non-Japanese in total population will increase from 2.2 percent in 2020 to 10.8 percent in 2070. Consistent with the projection, the Government has introduced in April 2019 a new status of residence "Specified Skilled Workers" which makes it easier for less skilled workers to come into Japan. Also, the "Technical Intern Training Program" has been reviewed and a new "Skill Development Program" will be introduced (it should become effective within three years from 21st June 2024). The workers that have gone through this program should be equipped with skills that would be sufficient to be qualify as specified skill workers.[2]

The increase in foreign workers raises some concerns about the impact of foreign workers on the various aspects of the Japanese economy. On the one hand, a concern is their impact on wages and employment of native Japanese workers: Wouldn't they lower

[2] For a review of Japan's immigration policy, see, for example, OECD (2024).

the wages and reduce the employment of native Japanese workers? While there has been a rich stock of empirical analysis in the United States (U.S.), there has only been a limited number of empirical studies in Japan on the subject. An important contribution in this respect is Nakamura et al. (2009) which made use of the limited data available to analyse the impact of foreign works on various aspect of the economy, including the wages of the native workers.

On the other hand, another concern is their impact on economic growth: Will increase in foreign workers raise Japan's economic growth? While the expectation is that they will support Japan's economic growth that is subject to downward pressure coming from the aging and shrinking of the population, not much empirical analysis has been done in this area. The aim of this paper is to fill this gap by analysing the impact of the increase in foreign workers on Japan's economic growth by estimating translog production functions on prefectural panel data created specifically for this purpose.

The result of the estimation shows that foreign workers, especially the skilled, can be identified as a distinctive factor of production for gross prefectural product (GPP). However, the result also suggests that elasticities of GPP with regards native workers as well as foreign workers may be negative. In addition, the result indicates that foreign workers, especially the unskilled, have a negative impact on total factor productivity. These findings are in contrast with the findings of Peri (2012) which shows that foreign workers contribute to economic growth in the U.S. by their role as a factor of production and a stimulant of productivity. The difference in the impact of foreign workers on economic growth may be explained by the inflexibility of the institutional arrangement in Japan, especially that of the employment system.

The rest of the paper is organized as follows: Following this introduction, Section 2 will survey the literature on economic impact of foreign workers in the U.S. and Japan. Section 3 will introduce the methodology of the empirical analysis undertaken in this paper, and Section 4 will explain the data used in the analysis. The result of the analysis will be presented in Section 5, which will be followed by a discussion of the result in Section 6. The last Section provides some concluding remarks.

2 Literature on the economic impact of foreign workers

2.1 Studies in the United States[3]

[3] Literature in the U.S. is typically on "immigrants" that are usually defined as foreign-born population moving into the U.S. In contrast, literature in Japan is typically on "foreign workers" who are foreign national working in Japan. This paper follows the usage of the terminology in the two

2.1.1 *Impact of immigration on the labour market*

The analysis of the impact of immigration in the U.S. concentrated mainly on its impact on the labour market. According to economic textbooks, an increase in labour supply due to immigration in a competitive labour market will lower wage and reduce employment of the native workers. Whether this is true or not has been important for both economic and political reasons in the U.S. where large inflow of immigration has been taking place. Two streams of empirical studies have tried to answer this question.[4]

One stream on empirical studies uses data at city or regional levels. Grossman (1982) and Borjas (1987) used the data to estimate production functions to see the substitutability and complementarity between immigrants and natives. Rather than imposing a certain structure on the economy, Altonji and Card (1991), Card (20021), Ottaviano and Peri (2006) used the data to look into the correlation between the inflow of immigrants and wages of the natives ("spatial correlation"). Taking advantage of a sudden large increase in immigration (e.g., the Mariel Boatlift), Card (1990) used the occasion as a natural experiments and applied differences-in-difference methodology to see the impact of immigration on wages and employment in local labour markets. All in all, they tended to find that wages and employment of native workers were not significantly affected by increase in immigrants.

The other stream uses data at national level. Borjas et al. (1997), Borjas (2003), Ottaviano and Peri (2012) used the data to estimate elasticities of substitution among natives and immigrants with different skills. The results of their studies showed a wider variation than in the analysis using city and regional level data: some found larger negative impact of immigration on the natives, while others only a modest effect.

The reasons for the absence of negative impact of immigration seems to be twofold.

One is related to the substitutability of immigrant workers to native workers. If foreign workers are perfect substitute for native workers, the result should be as what textbooks tell us. However, Ottavio and Peri (2012) found that immigrant workers are not perfect substitutes for native workers but rather imperfect ones. As a result, native workers tended to experience a small increase in wages. Furthermore, Cortes (2008) found that those who were affected the most was the existing low-skilled immigrant workers rather than low-skilled natives. Peri and Sparber (2009) explained the difference in the impact of

countries.

[4] For a review of the literature, see Borjas (2003), Dustman, Schönberg, and Stuhler (2016), and Peri (2016). For review from the Japanese point of view, see Hagiwara and Nakajima (2014) and Kambayashi and Hashimoto (2017).

immigration on native and existing immigrant workers who are both low-skilled by the ability of native workers with low-skill to shift to jobs which require communication skills which low-skilled immigrant workers do not possess.

The other is related to the long-term demand-side response to supply-side changes brought about by immigration. Lewis (2011) found that the increased supply of immigrant workers encouraged employing those workers and discouraged investment in skill-biased technology. As a result, wages and employment would not be affected in the long-term.

2.2.2 Impact of immigration on economic growth

In contrast to the large literature on the impact of immigration on wages, employment, and other labour market attributes, there has been only a limited number of studies that tried to examined the impact of immigration on economic growth. The limited number of studies include Peri (2012) which analysed the impact of immigrants on economic growth using growth accounting framework.

More specifically, Peri (2012) assumed that a Cobb-Douglas production function represents the production taking place in the US states. By applying the production function to the U.S. gross state products, he first decomposed the growth rates of state output to growth of total employment and growth of output per worker, and the latter further into contribution made by four factors including, capital intensity, total factor productivity, average hours worked, and skill-intensity. He then examined the impact of immigration on the four factors by using instrumental variable method. He found that immigration had a strong positive impact on both total employment (implying that it does not crowd-out employment) and labour productivity. In turn, the latter was a result of positive impacts of immigration exceeding negative impacts coming from the promotion of more unskilled-intensive production techniques.

The positive impact of immigration on productivity could generally be claimed as being a result of enhanced diversity brought about by diversity (Lazear 1999; Ottaviano and Peri 2005). There are, however, more concrete channels through which positive impacts on productivity may appear (Peri 2024). First is the higher probability of skilled immigrants to engage in innovation (Hunt and Gauthier-Loiselle, 2010; Kerr and Lincoln, 2010). Second is the higher probability of graduates of U.S. colleges and universities with large share of international graduate students to innovate (Chellaraj et al. 2005). Third is increase in firm creation by immigrants who are more likely to be entrepreneurs than the natives (Azoulay et al., 2022). Fourth is the reallocation of native and immigrant workers across productive tasks, natives concentrating on manual-intensive tasks and unskilled natives specializing in communication-intensive production tasks (Peri and Sparber 2009).

The reason for immigration to have a negative impact on productivity comes from the tendency that increase in supply of unskilled immigrants promotes introduction of more unskilled-labour intensive production techniques (Lewis, 2011). It reduces productivity thorough lowering the skill intensity of the workers. However, as it was already mentioned, the negative impact was not large enough to offset the positive impact brought about by an increase in immigrants in the U.S.

2.2 Studies in Japan

2.2.1 Impact of immigration on the labour market

Compared to the studies in the U.S., studies in Japan have been limited. It was primarily because of the relatively small size of immigration coming into Japan due to the strict immigration control that was imposed after the Second World War. However, the bubble economy led to a growing demand for foreign workers by the business, while the accompanying appreciation of the yen increased the attractiveness of Japan as a migration destination. Following a period of increase in illegal foreign workers coming into Japan, immigration control was relaxed in 1990 to allow more skilled workers to come into Japan. As for the unskilled workers, they were, *de jure,* not allowed to come to Japan: however, the door was opened, *de facto*, for them to work in Japan. They came in as long-term residents, technical intern trainees, and students.

Against this backdrop, early studies regarding foreign workers in this period included Goto (1996) and Nakamura (1997) which constructed a macroeconomic model which was calibrated to data and run simulations to see the impact of increase in foreign workers. They found that the increase in foreign workers, especially when they are limited in size, would have a negative impact on the economy.

Empirical studies during this period consisted of Ohtake and Ohkusa (1993) and Mitani (1993). They made use of micro-data available to study the substitutability and complementarity of foreign and native workers. They found that foreign workers, who were mainly unskilled, substituted for unskilled native workers, female part-time workers in particular.

The accumulation of data following the increase in foreign workers since 1990s accommodated more comprehensive empirical analysis to take place.[5] For example, Nakamura et al. (2009) found that increase in foreign workers had a large and positive impact on the wages of unskilled native workers. It was partly due to the migration of

[5] For a review of availability of data on foreign workers, see Kambayashi and Hashimoto (2017).

native workers out from the region which saw an increase of foreign workers into other regions. However, the migration was not large enough to explain the positive impact of foreign workers to wages of unskilled native workers. Rather, the positive impact on wages seemed to have come from the firms' decision to invest in technology that is more unskilled labour-intensive so that it increased demand for unskilled native workers as well as unskilled foreign workers. Such a decision had also led to a rise in the survival rate of firms which had employed foreign workers. It meant that increase in the employment of foreign workers had delayed the decision of the firms to invest in more advanced technology.

Further advance in the empirical studies took place when the MHLW's Basic Survey of Wage Structure started to collect data for foreign workers separately from the natives in 2019. It has relaxed somewhat the data-constraint of the empirical studies. As they became available, studies such as Korekawa (2021), Hashimoto (2022), and Korekawa (2023) has been published. They found that there is a wage difference between the two but significant part of the difference can be explained by human capital, skill transferability, efficiency of the sorting process, and the mobility of the workers.

2.2.2 Impact of immigration on economic growth

Compared to the studies inspecting the impact of immigration on the labour market in Japan, empirical analysis of the impact of foreign works on economic growth has been almost absent.

An exception is Mizobata, Yamaguchi, and Watanabe (2019) which estimated the impact of immigration on labour productivity as well as on wages by making use of a panel data for prefectures in Japan. They regressed labour productivity of the manufacturing sector by the share of foreign workers in total employed and found a positive impact of foreign workers on productivity. The result is in line with the findings of the analysis made in the U.S. but the reason for the positive impact was not made clear. Whether their findings are robust to different approaches on different dataset awaits confirmation.

The aim of this paper is to fill the vacuum of empirical study on the impact of immigration on economic growth by estimating production functions on a prefectural pane dataset. It should enable us to analyse the role and the impact of foreign workers on aggregate value-added production by identifying the role of foreign workers as factors of production, and the impact of them on total factor productivity. The methodology will be explained in Section 3 and the dataset in Section 4.

3 Methodology

The methodology taken in this paper is inspired by Peri (2012) and takes a similar two step approach by first analysing the role of foreign workers as a factor of production, and then examining the role of foreign workers as a stimulant of total factor productivity (TFP).

3.1 Step I: Estimating the role of foreign workers in production functions

While taking a similar two step approach, the methodology of this paper is different from that of Peri (2012). Instead of assuming, *a priori,* that the production function is of a Cobb-Douglas type, which assumes constant elasticity of substitution, we will estimate a Cobb-Douglas production function and a transcendental logarithmic (translog) production function, whose elasticity of substitution is more flexible, and will test which of the two has more explanatory power.

The estimated Cobb-Douglas and translog production functions are of the following type;

Eq.1 (Cobb-Douglas): $\ln Y = \alpha_0 + \sum_{i=1}^{n} \beta_i \ln X_i + \epsilon$, and

Eq.2 (Translog): $\ln Y = \alpha_0 + \sum_{i=1}^{n} \beta_i \ln X_i + \sum_{i=1}^{n} \sum_{j=1}^{n} \gamma_{ij} \ln X_i \ln X_j + \epsilon$.

where Y is gross prefectural products and X_i and X_j are one of the n factors of production.

As for the factors of production, five models with different combination of factors of production will be estimated (Table 1).

Model A consists of private capital stock (CAPP) and total number of workers (LAB). It represents the basic identification of factors of production.

Model B consists of private capital stock (CAPP), public capital stock (CAPG), and total number of workers (LAB). It adds public sector capital stock to Model A in response to the result of the analyses done in the 1990s identifying public-sector capital stock as an independent factor of production in Japan.[6]

Model C consists of private capital stock (CAPP), public capital stock (CAPG), number of skilled workers (LABS), and number of unskilled workers (LABX). It breaks down the total number of workers to those with tertiary education (which we will call "skilled workers"), and those without ("unskilled workers"). It tests the relevance of

[6] See, for example, Yoshino and Nakano (1996).

human capital as an independent factor of production.

Model D consists of private capital stock (CAPP), public capital stock (CAPG), number of native workers (LABN), and number of foreign workers (LABF). It distinguishes foreign workers from native workers. It allows us to test whether foreign workers can be identified as a separate factor of production from native workers.

Model E consists of private capital stock (CAPP), public capital stock (CAPG), number of native workers (LABN), number of foreign skilled workers (LABFS), and number of foreign unskilled workers (LABFX). It distinguishes foreign professional/specialist workers (which we will call "skilled foreign workers") from other foreign workers ("unskilled foreign workers"). It allows us to test whether foreign professional/specialist workers have different human capital.[7]

<Table 1>

The main interest is in Models D and E, which includes foreign workers as factors of production, but Models A, B, and C are also estimated to identify other factors of production and to check the consistency with the results of previous estimation of production functions.

3.2 Step II: estimating the impact of foreign workers on TFP

After estimating the production function with relevant factors of production, total factor productivity (TFP) will be extracted from the estimation results in the following way (Francis et al. 2020):

Eq.3: $$tfp_{it} = FE_i + FE_t + e_{it} ,$$

where tfp_{it} is total factor productivity (TFP) in prefecture i at time t, FE_i the fixed effect for prefecture i, FE_t the fixed effect for time t, and e_{it} the residual of the production function estimated in Step I.

TFP will be regressed against the shares of foreign workers, skilled foreign workers, and unskilled foreign workers in total number of workers to see whether foreign workers contribute to TFP. Considering the possibility of endogeneity between the dependent and explanatory variables, regression will be made by two-stage least squares (2SLS)

[7] It should be desirable to breakdown both native and foreign works by their educational attainment. However, data on educational attainment is not available for foreign workers.

estimation. With reference to the "shift-share" approach (Altonji and Card 1991), instrumental variables are created by expanding the prefectural employment pattern of foreign workers (total, skilled, and unskilled) at the base year (FY2010) by the annual rate of increase of foreign workers (total, skilled, and unskilled) in the following years.

4 Data

The analysis is made on a panel dataset created for each of the 47 prefectures for the period between FY2011 and FY2019.

The data on "gross prefectural product" (GPP) in constant prices are taken from the Prefectural Economic Accounts of the System of National Account (SNA) provided by the Economic Social Research Institute (ESRI) of the Cabinet Office. At the time of estimation, data for FY2011 to FY2020 was available on 2008 SNA basis with 2015 as the base year. FY2020 was removed from the estimation period in view of the extraordinary circumstance created by the COVID-19 pandemic.[8]

The data for "private capital stock" (CAPP) and "public capital stock" (CAPG) in real terms are taken from the database of the Prefectural Economic and Fiscal Model made available by the Bureau of Economic Assessment and Policy Analysis of the Cabinet Office. Since the total of public capital stock includes those which do not necessarily contribute to productive activity (such as city parks), only those which are considered to directly contribute to productive activity (i.e., industry-related public capital stock) has been selected and defined as public capital stock in the estimation: It includes public capital stock of roads; seaports; airports; agriculture, forestry, and fishery related facilities; and industrial water supply facilities. Since the data is for the end of fiscal year, a year's lag is taken when the private and public capital stock data are included in the production function.

The data for total number of "workers" (LAB) is taken from the SNA.[9] The data for total number of foreign workers (LABF) for each year is taken from the Employment Status of Foreign Nationals published by the Ministry of Health, Labour, and Welfare

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[8] FY2011 was also an extraordinary year when the Great East Japan Earthquake took place. To take that in to account, the impact of the Earthquake was controlled for the earthquake-affected prefectures (i.e., Iwate, Miyagi, and Fukushima) by taking dummies for those prefectures for the years FY2011, FY2012, and FY2013 in the estimation of production functions.

[9] Total number of the "employed" for each prefecture provided by the SNA is used because, while it includes self-employed as well as employees, it provided the number of workers who are working in the prefecture. To the contrary, the number of the "employees" for each prefecture in the SNA is recorded at their prefecture of residence, which is not appropriate from the point of view of the estimation of production functions.

(MHLW).[10] The difference between total employed persons and total foreign workers is denoted as “native workers” (LABN). The Employment Status of Foreign Nationals also provides data for the foreign workers who are working as “professionals/specialists”, who will be denoted as “skilled foreign workers” (LABFS) in this paper[11]. The difference between the total number of foreign workers and those who are professionals/specialists is non-professional/specialist foreign workers, who are denoted as “unskilled foreign workers” (LABFX). As for the number of employed persons who have tertiary education, who will be denoted as “skilled workers” (LABS), data is taken from the Basic Survey on Wage Structure published by MHLW.[12] The difference between the number of total employed persons and the number of workers with tertiary education is defined as non-tertiary education workers, denoted as “unskilled workers” (LABX).

The descriptive statistics of the variables used are shown in Table 2. Estimation in the following takes natural logarithms of the variables defined above. The logged variables are shown in lower cases.

<Table 2>

5 Estimation results

5.1 Step I Estimating the role of foreign workers in production function

5.1.1 Estimating Cobb-Douglas production function as pooled OLS models

Before starting to estimate translog production function, Cobb-Douglas-type production functions are first estimated. The Cobb-Douglas production function estimated for the five models by ordinary least squares (OLS) on pooled data yields a result shown in Table 3.

<Table 3>

Model A shows that the coefficients of private capital stock and number of workers

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[10] The data provided by the Employment Status of Foreign National is for October each year.

[11] “Professionals/specialists” are defined in the Employment Status of Foreign Nationals as workers who are working under the following status of residence: Professor, Art, Religion, Press, Highly Skilled Professional, Business Manager, Legal and Accounting Service, Medical Service, Researcher, Education, Technical/Humanities/International Business, Intra-Company Transferee, Nursing Care, Performance, Skills, and Specific Skills.

[12] Tertiary education is defined as education provided by technical colleges, junior colleges, universities, and graduate schools. Data was obtained from microdata provided by MHLW.

are both significant and positive and the sum of the two is close to one which is typically assumed to be the case for Cobb-Douglas production functions. The two coefficients are still significant even when we include public capital stock (Model B). However, public capital stock has a significant but a negative coefficient which is in contrast with the results of earlier studies in Japan which looked into the macroeconomic implications of public capital stocks. When the total number of workers is split into those of the skilled workers and the unskilled workers (Model C), both of them are found to be significant and positive. It confirms that human capital is recognized as a distinct factor of production in this Cobb-Douglas production function. On the other hands, coefficients for public capital stock remains to be negative but become insignificant in Model C.

In Model D, total number of workers is disaggregated into those of the native workers and the foreign workers. The result of the estimation shows that not only native workers but also foreign workers have significant and positive coefficients. Moreover, the coefficients imply that marginal product of foreign workers are higher than that of the native workers.[13] It suggests that foreign workers have human capital that is different from the native workers. The reason for this is revealed when foreign workers are further disaggregated into skilled foreign workers and unskilled foreign workers in Model E. In this Model, the coefficients of unskilled foreign workers become insignificant, but the coefficient for skilled foreign workers remains positive and significant. It suggests that skilled workers have a different human capital from native workers, with a high marginal product of labour.[14]

5.1.2 Estimating Cobb-Douglas production functions as fixed effects models on panel data

The above result seems to suggest that foreign workers, especially the skilled, contribute positively to production of gross prefectural product. However, F-test shows that null-hypothesis of pooled data OLS models is rejected against two-way fixed effects panel data models (Annex Table 1). The result of the estimation of Cobb-Douglas type production function estimated with two-way fixed effects (for years and prefectures) on panel data is shown in Table 4.

<Table 4>

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[13] It can be confirmed by comparing the value of their coefficients (foreign workers' is 8.3 percent of natives') taking into account the difference of the mean value of the two variables (foreign workers being 1.6 percent of native workers).

[14] Value of coefficient for foreign workers is 9.3 percent of that for natives while the difference of the mean value of foreign workers is only 0.3 percent of that of natives.

The result is, in many ways, similar to the one of OLS pooled data model. Coefficients for private capital stock are all significant and positive (Model A~E), coefficients for total workers (Model B), and its breakdown to skilled and unskilled workers are also significant and positive (Model C). However, the Models which includes foreign workers as factors of production shows some differences. On the one hand, coefficient for the unskilled foreign workers becomes less significant and becomes negative as well (Model E). Probably because of the latter, coefficient of foreign workers as a whole has become insignificant and negative (Model D). The positive contribution of foreign unskilled workers is no longer found in these Models. On the other hand, coefficient for skilled workers remains to have a significant and positive coefficient in Model E.

Cobb-Douglas-type is a popular kind of production function and is often employed as a base for theoretical and empirical analysis, including Peri (2012). However, as was mentioned earlier, the production function assumes a rather stringent condition to hold (elasticity of substitution to be unity), which should be tested empirically. In fact, the Wald test rejects Cobb-Douglas production function against translog production function when both are estimated as two-way fixed effects panel data model (Annex Table 2). Even though we are able to find a positive and significant impact of skilled foreign workers in GPP, we have to check whether it still holds when we estimate translog production functions.

5.1.3 Estimating Translog production functions as pooled OLS models

The result of the estimation of translog production function by OLS on pooled data is shown in Table 5. It shows that, in all of the models, private capital stock is no longer significant and, in some cases, becomes negative.[15] In comparison, total number of workers on its own in Model A and Model B has significant and positive coefficients. In Model C, both skilled and unskilled workers on their own have also significant and positive coefficients. When foreign workers are added as a factor of production in addition to native workers (Model D), coefficients for both workers have significant and positive signs. However, when foreign workers are split into skilled and unskilled foreign workers (Model E), it is the number of unskilled workers that has a significant and positive coefficient, while the number of skilled foreign workers is less significant and has a negative sign.

[15] The reason for the loss of significance of the coefficient for private capital stock is not pursued in this paper but it may come from the multicollinearity with other variables.

<Table 5>

In addition to what have been mentioned, it should be noted that, in Model E, there are number of squared and cross terms which have significant coefficients. In this regard, what is particularly important in relation to the impact of foreign workers is the difference in the substitutability and complementarity of the skilled and unskilled workers with private capital stock and native workers: skilled foreign workers are substitute for private capital stock (_capp*labfs<0_) but complements for native workers (_labn*labfs>0_) , whereas unskilled foreign workers are complement for private capital stock (_capp*labfx>0_) but substitute for native workers (_labn*labfx<0_).

5.1.4 Estimating Translog production function as fixed effects panel data models

In the case of translog production function as well, F-test rejects OLS pooled model against fixed effect panel data model (Annex Table 2). The result of the estimation of translog production function as a two-way fixed effects model on panel data is shown in Table 6.

<Table 6>

On the one hand, there are similarities with the result of the pooled OLS model we have just seen. Coefficients for native workers have significant and positive signs in Models A and B, and both of the coefficients for skilled and unskilled workers are significant and positive in Model C. On the other hands, there are differences when foreign workers are included in the fixed effect model. In the case of Model D, while native workers have a significant and positive coefficient, foreign workers no longer have such a coefficient. Furthermore, in Model E, in addition to native workers, it is now the skilled foreign workers that have a significant and positive coefficient whereas unskilled foreign workers have a less significant and negative coefficient. It is similar to the result obtained for the Cobb-Douglas production function as a fixed effects model.

As for the squared and cross terms, there are more of those that have significant coefficients in Model D and E. However, in the case of Model D, there is no squared or cross term that involve foreign workers that has a significant coefficient. In the case of Model E, skilled foreign workers have a weakly significant negative squared terms (coefficient for _labfs^2<0_, implying diminishing returns) while unskilled foreign workers have a weakly significant negative cross-terms with native workers (coefficient for _labn*labfx<0_, implying substitutability between the two factors of production). They may have important implications on the direction and the size of the impact on economic growth which could not be recognized in the Cobb-Douglas formulation of the production function. We will come back to this in the next Sections.

5.2 Step II: The role of foreign workers as stimulants of TFP

From Models A to E, total factor productivity (*tfp*) is derived by summing the residuals of the estimated models with fixed effects for time and prefecture (Equation 3). In Step II, total factor productivity obtained in this way is regressed by three explanatory variables; the ratios to logged total workers (lab) of logged foreign workers (*labfratio*), logged skilled foreign workers (*labfsratio*), and logged unskilled foreign workers (*labfxratio*). Share of the production by the manufacturing sector in gross prefectural products is also added to control for the influence of the difference in industrial composition of prefectures on total factor productivity.

Table 7 shows the results for each of the *tfp* derived from Model A to E. It shows that, in all Models, the coefficients for the ratio of logged foreign workers and the ratio of unskilled foreign workers are all significant and negative, while that of the share of skilled foreign workers is insignificant. It implies that total factor productivity decreases as foreign workers increase, and the reason for it basically is in the negative impact that unskilled foreign workers have on total factor productivity. On the other hand, skilled foreign workers have no significant impact on total factor productivity.

<Table 7>

6 Discussion of the estimation results

As it was presented in the previous section, Cobb-Douglas and translog production functions have been estimated as a pooled OLS and fixed effects panel data models. Since translog production as fixed effect panel data models show a better performance than the other, the following discussion focuses on the result of the translog formulation.

6.1 Elasticity of GPP on number of workers

First, we focus on the Step I estimation result of Model E, which has the best explanatory power among the models and also allows us to consider the roles of skilled and unskilled foreign workers (Table 6).

The estimation result shows that skilled foreign workers on its own have a positive direct impact on gross prefectural products and unskilled foreign workers a negative impact. However, both of them have also indirect impact through squared and cross terms. Taking into account both direct and indirect impacts, elasticities of gross prefectural products with regards the number of skilled and unskilled foreign workers can be described as

Eq.4 (skilled workers): $\frac{\partial gpp}{\partial labfs} = 0.036^{***} - 0.018^{*} \times 2 \times labfs$

Eq.5 (unskilled workers): $\frac{\partial gpp}{\partial labfx} = -0.020^{*} - 0.087^{*} \times labn$

where * shows the significance levels (*p<0.1, ***p<0.05; ***p<0.01).

The problem emerges when the value of the marginal products is calculated. As it can be confirmed by replacing $labfs$ by its mean value (Table 1), not only the elasticity with regards the number of unskilled foreign workers is unambiguously negative (because two terms are both negative) but also the elasticity of skilled foreign workers will also be negative. It implies that, as we increase the number of foreign workers, skilled and unskilled, gross prefectural products fall. How should we understand these elasticities with negative values?

It may be an issue of which significance levels we choose. If we take only the coefficient that are significant by 5 percent significance levels, it will eliminate all of the negative terms in Eq. 4 and Eq. 5 and the elasticities of foreign skilled workers become positive and that for the unskilled zero. This is the same result we get from the estimation of Cobb-Douglas production functions.

However, this will not eliminate the similar problem that exists for native workers. The elasticity of gross prefectural products with regards the number of native workers can be shows as

Eq.6: $\frac{\partial gpp}{\partial labn} = 0.243^{***} - 0.391^{**} \times 2 \times labn + 0.554^{***} \times capp - 0.087^{*} \times labfx.$

In this case, even if we eliminate the last term by taking only the coefficients that are significant by 5 percent significance levels, the elasticity will still be negative for mean values of $labn$ and $capp$. There seems to be a more fundamental problem behind the negative elasticities.

One possibility is that it reflects the inefficient allocation of workers that is taking place in Japan. In Eq.6 (and in Eq.4 as well), the large negative value of the second term more than offsets the positive value of the first term. It suggests that workers are employed in excess of the optimal level in the economy as a whole so that employment is reaching a point where diminishing return reduces the value added that they produce.

If this is the reality, it may reflect the problem of the current institutional arrangement in Japan. In particular, the Japanese employment system, which is known for its lifetime employment arrangement, may be too inflexible for allowing firms to make adjustment of their workforce when they find employment exceeding the optimal level from the production point of view.[16]

In turn, this may be affecting the negative elasticity of foreign workers as well. The excess employment by the firms would mean that there is less need for foreign unskilled workers who are substitutes for native workers (recall that coefficient for $labn*labfx<0$). At the same time, excess employment of unskilled workers may lead to investment in unskilled labour-intensive technology which would lower the optimal level of skilled worker employment. This is an issue that comes up again in the next subsection.

It should be noted at this point that the issues that have been discussed above would not have been brough up if we had not estimated the translog production functions: Approximation by Cobb-Douglas production functions might have prevented us from realizing the existence of such an issue.

6.2 Foreign workers as stimulants of TFP

Next, we look into the result of Step II which found that foreign workers do not contribute to TFP, or even contribute negatively in the case of unskilled foreign workers. It is in stark contrast with the findings in the U.S., where immigrants were making positive contribution to innovation and other factors that contribute to TFP (Section 2).

As for the lack of positive contribution from foreign workers, unskilled in particular, to TFP, it may be a result of the smallness of the number of skilled foreign workers: skilled foreign workers are only 0.3 percent of total number of workers on average for the period. Even if they had positive impact on TFP, it could prove to be negligible for the economy as a whole.[17] While we cannot completely rule out such a possibility, we may need to look

[16] For the special features of the Japanese employment system compared to that of the U.S., see Kambayashi and Kato (2017).

[17] To check whether this kind of explanation holds, dummies for prefectures that have high density of foreign workers have been added to the TFP regressions shown in Table 7. However, their coefficients failed to be significant.

for other factors that explains the lack of positive contribution of foreign workers to TFP.

In the case of the U.S., a number of channels have been identified through which foreign workers make contribution to TFP (Section 2). They are (a) spurring innovation by increasing patents, (b) stimulating ideas of graduates by participating in education, (c) engaging in firm creation, and (d) encouraging reallocation of workers across production skills.

These channels may not be sufficiently established in Japan.

For example, the number of foreign scientist and engineers has increased in Japan. However, from their point of view, Japan has not been so attractive compared to the U.S. as their destination. Their Japanese employers, on their part, tended to see them only as a substitute of Japanese scientist and engineers when they are difficult to find (Murakami 2006). As a result, the Japanese firms have not been able to make full use of foreign talents' potential of infusing the workplace with new ideas and promoting innovation.

The number of foreign students entering Japan to attend universities and other educational institutions have also increased from 163,697 at May 2011 to 312,214 at May 2019, an increase by 90.7 percent. But the share of students who are attending Japanese language schools (included in the education institutions mentioned above) have increased from 15.7 percent to 26.8 percent, an increase by 227.1 percent during the period (JASSO 2024). It is therefore unclear whether the increase in students is able to inspire college or university students who would go on to engage in startup or to promote innovation.

Also, for foreigners to start a business in Japan, they need to obtain, in principle, a status of residence "Management and Administration". However, to obtain the status, the applicant needs to have more than 5 million yen as financial assets. Also, even after they obtained the status to engage in startups, they would have to complete the procedures for registering the business and others all in Japanese (or with Japanese translation). For this and other reasons, foreign residence who have the status of residence "Management and Administration" increased from 11,778 in end-2011 to 27,249 at end-2019, an increase by 131.4 percent, but remains to be limited: their share in total foreign residents is still only 0.9 percent at end-2019.

Partly reflecting these limitations, number of startups in Japan is still low (equivalent to 3.9 percent of total number of establishments in 2022; METI 2024) and the involvement of young generation (younger than 29 years old) in startups is limited (4.9 percent in 2019; JFC 2023).

Finally, the pressure to reallocate workers across production skills brough about by the increase in foreign workers may not lead to actual reallocation in Japan. That is because, for reallocation to be effective, there needs to be sufficient mobility of workers across firms. However, as it has already been mentioned in the last subsection, there is only a limited mobility of this kind in the current employment system in Japan, whose special features includes lifetime employment system. At best, reallocation takes place within firms but no so much between firms. Therefore, it is difficult to expect significant positive impact coming out from this aspect.

All in all, the arguments made so far provides the reason why positive impact of foreign workers, especially the skilled, on TFP has been absent in Japan. It should be able to explain the insignificance of the positive impact of skilled foreign workers we observed in Table 7. However, the reasons mentioned so far would not be able to explain the *negative* impact of foreign workers, especially of the unskilled, on TFP. There needs to be additional explanation as to why this is observed.

The reason for unskilled foreign workers to have a negative impact on TFP may come from the tendency that increase in supply of unskilled immigrants promotes introduction of more unskilled labour-intensive production techniques. It should lower the skill intensity of the workers and reduced productivity.

As mentioned in Section 2, this implication was suggested by Peri (2012), but he found that it was not large enough to offset the positive impact of increase in foreign workers in the case of U.S. This aspect was also found by Nakamura et al. (2009) through its analysis of the relationship between foreign workers and Japanese firms' investment behaviour and survival rates. It is natural to expect this to take place if we recall that the current employment system has to maintain employment of their employees including the unskilled. The firms endeavour to make the most of the unskilled workers by introducing unskilled-intensive technology.

This section discussed the results of the estimation presented in Section 5. Through the discussion, it was suggested that the lack of positive impact of foreign workers on economic growth in Japan has much to do with the institutional arrangement in Japan including, in particular, the current employment system. It should be important for Japan to be aware of this kind of a situation if it seeks to accept more foreign workers.

7 Concluding remarks

Japan is facing aging and shrinking of its population. The impact can be seen in various aspects of the society, but in terms of its impact on the economy, one of the most important concerns is downward pressure it would provide on the potential growth rate. While it is already low, further aging and shrinking of the population could reduce it to almost zero, or even to the negative territory. If the Japanese economy needs to grow, Japan needs to come up with measures to offset the negative impact of aging and shrinking of the population. One of the measures that could be taken in this respect is accepting more foreign workers. Japan has gradually increased the inflow of foreign workers since 1990 and it reached a record high in 2023, but it could be increased more by accepting more unskilled foreign workers as well as the skilled.

Increasing foreign workers raises a lot of controversies. Some of them are political or philosophical, but there are also economic issues to be discussed. In the case of economic issues, empirical analysis can contribute positively to the discussion. In the U.S., there has been a significant advance in understanding the economic impact of foreign workers on the labour market and the economy as a whole. It was made possible by data that has been accumulated in the course of large inflow of foreign workers over the years. In comparison, while Japan has seen an increase in foreign workers as mentioned above, it is still less than three percent of the total employed. As a result, there has not been sufficient data available, and empirical analyses of the impact of immigration has so far been limited.

This paper aimed to fill the gap by analysing the impact of foreign workers on gross prefectural products (GPP) by estimating translog production functions on a panel data of prefectural accounts. The results can be summarized as follows:

- Skilled foreign workers and unskilled foreign workers were both identified to be separate factors of production. However, the signs of their direct impact were opposite; the skilled had a positive sign while the unskilled had a negative one (which would be insignificant if a more stringent significance level is chosen).
- Elasticities of gross prefectural product with regards the number of skilled and unskilled foreign workers as well as that of native workers calculated on the basis of the production function estimated were all negative.
- Impact of foreign workers on TFP was negative for unskilled foreign workers, and positive but insignificant for the skilled.

The reason for the negative elasticities seems to have much to do with the firms' employment of workers in excess of the optimal level. It suggests that the inflexibility of the current Japanese employment system which prevents flexible adjustment of their workforce through mobility across firms.

The problem with the current economic system in Japan may also be at the background of the negative impact of unskilled foreign workers on TFP. It is because the current institutional arrangement with regards innovation, education, entrepreneurship, and mobility makes it difficult for the positive impact of foreign workers on TFP to show up as in the U.S, while they encourage the negative impact to emerge.

While the result of this analysis presented in this paper suggests that there is an important policy issues that need to be paid more attention to, it is also undeniable that the result of this paper has its limitations and is only a starting point. There is a number of areas that future research could pursue in order to overcome the limitations.

First, the database could be improved by including variable that takes into account the intensity by which the factors of production are used. For example, including working hours and capacity utilization rates of capital stocks could be considered.

Second, the estimation methodology could be improved by scrutinizing the reasons why the coefficients for private and public capita stocks lose significance as we depart from the simple Cobb-Douglas formulation of production function. The reasons for public capital stock to have negative coefficients (but insignificant in most of the case) could also be examined.

Third, the interpretation of the estimation result in relation to the Japanese employment system could be scrutinized by checking whether employment in excess of its optimal level can actually be detected by analysing firm-level data. Its implication on the employment of foreign workers needs to be clarified as well.

Fourth, the impact analysis of foreign workers on total factor productivity can be improved by inspecting in more detail the individual channels through which foreign workers can potentially have an impact (e.g., innovation, education, entrepreneurship, mobility, and investment).

To make progress in these areas, enlarging and improving collection of data on foreign workers by authorities is essential. It is hoped that further advance in this area, which is the infrastructure of economic analysis, will be made in the near future as well.

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Table 1: Estimated Models

		Model A	Model B	Model C	Model D	Model E
Dependent variable	gpp	○	○	○	○	○
	capp	○	○	○	○	○
	capg		○	○	○	○
	lab	○	○			
	labn				○	○
Explanatory variables	labx			○		
	labs			○		
	labf				○	
	labfx					○
	labfs					○

Note: Lower-case variables indicate they are natural logarithms of upper-case variables.

Table 2: Descriptive Statistics

	Mean	S.D.	Min.	Max.	Unit	Obs.
GPP	11,933,580	17,102,448	1,749,349	114,055,976	Thousand 2015 yen	423
CAPP	15,248,510	17,460,763	2,309,583	104,769,971	Thousand 2015 yen	423
CAPG	13,319,255	9,920,943	5,073,669	52,275,030	Thousand 2015 yen	423
LAB	1,384,373	1,632,395	293,173	10,416,378	Persons	423
LABX	640,347	500,052	171,857	2,807,398	Persons	423
LABS	744,026	1,178,469	108,812	8,083,079	Persons	423
LABN	1,362,474	1,589,414	290,052	9,931,033	Persons	423
LABF	21,899	49,174	1,124	485,345	Persons	423
LABFX	17,792	35,027	935	328,867	Persons	423
LABFS	4,108	14,860	131	156,478	Persons	423

Table 3: Estimated Results of Cobb-Douglas Production Function (Pooled OLS Model)

	Dependent Variable				
	gpp				
Explanatory Variables	Model A	Model B	Model C	Model D	Model E
Constant	0.078	1.054**	1.543***	1.235***	1.587***
	(0.241)	(0.425)	(0.320)	(0.356)	(0.354)
capp	0.376***	0.366***	0.374***	0.319***	0.345***
	(0.049)	(0.047)	(0.053)	(0.052)	(0.052)
capg		-0.119***	-0.058	-0.064	-0.057
		(0.044)	(0.041)	(0.042)	(0.040)
lab	0.704***	0.779***			
	(0.057)	(0.064)			
labx			0.234***		
			(0.081)		
labs			0.468***		
			(0.047)		
labn				0.720***	0.654***
				(0.061)	(0.061)
labf				0.060***	
				(0.016)	
labfx					0.016
					(0.022)
labfs					0.061**
					(0.024)
Observations	423	423	423	423	423
R2	0.992	0.993	0.993	0.994	0.994
Adjusted R2	0.992	0.993	0.993	0.994	0.994
F Statistic	10,218.030***	10,002.760***	8,790.468***	9,611.792***	9,008.213***

*p<0.1; **p<0.05; ***p<0.01

Notes:

1. Resut of estimation as pooled OLS models. Lower-case variables indicate they are natural logarithms of upper-case variables.
2. Heteroscedasticity-consistent standard errors are in parentheses.
3. Additonal variables not shown in the table are dummies for earthquake afected prefectures (Iwate, Miyagi and Fukushima) in 2011, 2012, and 2013.

Table 4: Estimated Results of Cobb-Douglas Production Function (Fixed Effects Panel Data Model)

	Dependent variable:				
	gpp				
Explanatory variables	Model A	Model B	Models C	Model D	Model E
capp	0.218**	0.258**	0.261**	0.250**	0.234**
	(0.090)	(0.102)	(0.102)	-0.103	-0.099
capg		-0.184	-0.204	-0.185	-0.172
		(0.180)	(0.183)	(0.179)	(0.176)
lab	0.203***	0.220**			
	(0.076)	(0.086)			
labx			0.138**		
			(0.055)		
labs			0.115**		
			(0.047)		
labn				0.278***	0.247***
				(0.106)	(0.096)
labf				-0.02	
				(0.015)	
labfx					-0.027*
					(0.014)
labfs					0.029**
					(0.014)
Observations	423	423	423	423	423
R2	0.223	0.24	0.241	0.245	0.267
Adjusted R2	0.097	0.114	0.113	0.118	0.141
F Statistic	20.822*** (df = 5; 363)	19.066*** (df = 6; 362)	16.396*** (df = 7; 361)	16.763*** (df = 7; 361)	16.382*** (df = 8; 360)

*p<0.1; **p<0.05; ***p<0.01

Notes:

1. Resut of estimation as two-way fixed effects model on panel data. Lower-case variables indicate they are natural logarithms of upper-case variables.

2. Heteroscedasticity-consistent standard errors are in parentheses.

3. Additonal variables not shown in the table are dummies for earthquake afected prefectures (Iwate, Miyagi and Fukushima) in 2011, 2012, and 2013.

Table 5: Estimated Results of Translog Production Function (Pooled OLS Model)

Explanatory variables	lngpp Model A	Model B	Model C
Constant	0.602	13.976	2.231
	(4.842)	(11.978)	(13.363)
capp	0.037	-0.655	-0.167
	(0.593)	(1.193)	(1.393)
capg		-1.005	0.164
		(1.117)	(1.223)
lab	1.087***	1.078***	
	(0.021)	(0.020)	
labx			0.364***
			(0.069)
labs			0.672***
			(0.055)
capp^2	-0.054	0.138	0.241
	(0.290)	(0.328)	(0.271)
capg^2		-0.027	0.049
		(0.120)	(0.124)
lab^2	-0.071	-0.094	
	(0.410)	(0.361)	
labx^2			-0.049
			(0.319)
labs^2			-0.154
			(0.130)

Explanatory variables	lngpp Model A	Model B	Model C
capp*capg		-0.137	-0.312*
		(0.217)	(0.182)
capp*lab	0.122	-0.124	
	(0.697)	(0.672)	
capg*lab		0.297	
		(0.268)	
capp*labx	v		-0.248
			(0.4)
capp*labs			0.043
			(0.297)
capg*labx			0.188
			(0.261)
capg*labs			0.075
			(0.134)
labx*labs			0.168
			(0.304)
Observations	423	423	423
R2	0.984	0.985	0.987
Adjusted R2	0.983	0.984	0.987
F Statistic	3,131.613*** (df = 8;	2,215.843*** (df = 12;	823.762*** (df = 17; 405)

p<0.1; **p<0.05; ***p<0.01

Notes:

1. Resut of estimation as pooled OLS models. Lower-case variables indicate they are natural logarithms of upper-case variables.
2. Heteroscedasticity-consistent standard errors are in parentheses.
3. Additonal variables not shown in the table are dummies for earthquake affected prefectures (Iwate, Miyagi and Fukushima) in 2011, 2012, and 2013.

Explanatory variables	Model D	Model E	Explanatory variables	Model D	Model E
	Dependent variable: gpp			Dependent variable: gpp	
Constant	5.075 (7.884)	-10.143 (6.909)	capp*capg	-0.134 (0.233)	-0.197 (0.187)
capp	-0.045 (0.910)	-0.281 (0.628)	capp*labn	-0.008 (0.478)	1.270*** (0.398)
capg	-0.351 (0.903)	1.811* (0.956)	capp*labf	0.105 (0.074)	
labn	0.927*** (0.026)	0.908*** (0.037)	capp*labfx		0.562*** (0.122)
labf	0.118*** (0.015)		capp*labfs		-0.566*** (0.126)
labfx		0.107*** (0.021)	capg*labn	0.016 (0.275)	0.031 (0.242)
labfs		0.034 (0.033)	capg*labf	0.021 (0.043)	
capp^2	0.037 (0.289)	-0.472** (0.236)	labn*labf	-0.141 (0.095)	
capg^2	0.069 (0.100)	0.019 (0.083)	capg*labfx		-0.017 (0.087)
labn^2	0.043 (0.230)	-0.696*** (0.181)	capg*labfs		0.08 (0.072)
labf^2	-0.004 (0.015)		labn*labfx		-0.640*** (0.145)
labfx^2		0.02 (0.043)	labn*labfs		0.568*** (0.154)
labfs^2		0.028 (0.046)	labfx*labfs		-0.042 (0.090)
			Observations	423	423
			R2	0.99	0.993
			Adjusted R2	0.99	0.992
			F Statistic	2,419.567*** (df = 17; 405)	2,372.207*** (df = 23; 399)

*p<0.1; **p<0.05; ***p<0.01

Notes:

1. Resut of estimation as pooled OLS models. Lower-case variables indicate they are natural logarithms of upper-case variables.

2. Heteroscedasticity-consistent standard errors are in parentheses.

3. Additonal variables not shown in the table are dummies for earthquake affected prefectures (Iwate, Miyagi and Fukushima) in 2011, 2012, and 2013.

Table 6: Estimated Results of Translog Production Function (Fixed Effects Panel Data Model)

Explanatory variables	Model A	Model B	Model C
	Dependent variable: lngpp		
capp	-2.321	0.237	0.463
	(1.542)	(2.247)	(2.206)
capg		-3.476	-4.86
		(4.734)	(4.460)
lab	0.229***	0.232***	
	(0.074)	(0.084)	
labx			0.145***
			(0.043)
labs			0.123***
			(0.041)
capp^2	-0.002	-0.076	-0.232
	(0.119)	(0.173)	(0.161)
capg^2		0.286	0.299
		(0.206)	(0.200)
lab^2	-0.113	-0.333*	
	(0.154)	(0.185)	
labx^2			-0.101
			(0.099)
labs^2			-0.170***
			(0.049)
capp*capg		-0.343	-0.169
		(0.239)	(0.247)
capp*lab	0.17	0.548	
	(0.262)	(0.348)	
capg*lab		-0.001	
		(0.199)	
capp*labx			0.288*
			(0.171)
capp*labs			0.455***
			(0.161)
capg*labx			-0.042
			(0.112)
capg*labs			-0.101
			(0.100)
labx*labs			-0.115
			(0.09)
Observations	423	423	423
R2	0.274	0.306	0.321
Adjusted R2	0.149	0.178	0.184
F Statistic	16.986*** (df = 8; 360)	13.092*** (df = 12; 356)	9.767*** (df = 17; 351)

*p<0.1; **p<0.05; ***p<0.01

Notes:
1. Resut of estimation as two-way fixed effects model on panel data. Lower-case variables indicate they are natural logarithms of upper-case variables.
2. Heteroscedasticity-consistent standard errors are in parentheses.
3. Additonal variables not shown in the table are dummies for earthquake affected prefectures (Iwate, Miyagi and Fukushima) in 2011, 2012, and 2013.

Explanatory variables	Dependent variable: gpp Model D	Model E
capp	2.09	1.011
	(2.097)	(1.872)
capg	-3.16	-1.388
	(3.466)	(3.346)
labn	0.246**	0.243***
	(0.098)	(0.080)
labf	-0.011	
	(0.012)	
labfx		-0.020*
		(0.012)
labfs		0.036***
		(0.013)
capp^2	-0.340**	-0.19
	(0.165)	(0.127)
capg^2	0.153	0.084
	(0.196)	(0.175)
labn^2	-0.557***	-0.391**
	(0.160)	(0.176)
labf^2	0.009	
	(0.01)	
labfx^2		0.006
		(0.013)
labfs^2		-0.018*
		(0.011)
capp*capg	-0.192	-0.181
	(0.217)	(0.196)
capp*labn	0.840***	0.554**
	(0.263)	(0.240)
capp*labf	0.029	
	(0.025)	
capp*labfx		0.056
		(0.04)
capp*labfs		-0.033
		(0.045)
capg*labn	0.113	0.124
	(0.220)	(0.183)
capg*labf	-0.007	
	(0.020)	
labn*labf	-0.04	
	(0.034)	
capg*labfx		0.002
		(0.032)
capg*labfs		-0.009
		(0.031)
labn*labfx		-0.087*
		(0.046)
labn*labfs		0.053
		(0.052)
labfx*labfs		0.021
		(0.022)
Observations	423	423
R2	0.378	0.426
Adjusted R2	0.252	0.298
F Statistic	12.556*** (df = 17; 351)	11.139*** (df = 23; 345)

*p<0.1; **p<0.05; ***p<0.01

Notes:
1. Resut of estimation as two-way fixed effects model on panel data. Lower-case variables indicate they are natural logarithms of upper-case variables.
2. Heteroscedasticity-consistent standard errors are in parentheses.
3. Additonal variables not shown in the table are dummies for earthquake afected prefectures (Iwate, Miyagi and Fukushima) in 2011, 2012, and 2013.

Table 7: Estimated Results of Contribution of Foreign Workers on TFP

	Dependent variable		
	TFP (Model A)		
Explanatory variables	Model X	Model Y	Model Z
manushare	-0.086	-0.015	-0.088
	(0.059)	(0.049)	(0.060)
labfratio	-3.258***		
	(1.154)		
labfsratio		6.031	
		(7.170)	
labfxratio			-3.012***
			(1.036)
Observations	423	423	423
R2	0.0002	0.00004	0.0004
Adjusted R2	-0.153	-0.153	-0.153
F Statistic	6.915**	1.145	6.567**

Note: *p<0.1; **p<0.05; ***p<0.01

(Note) Estimation is made using instrumental variables (see text for details).

Explanatory variables	Dependent variable: TFP (Model B)		
	Model X	Model Y	Model Z
manushare	-0.089	-0.02	-0.09
	(0.058)	(0.054)	(0.058)
labfratio	-3.190***		
	(1.194)		
labfsratio		6.59	
		(7.567)	
labfxratio			-2.941***
			(1.075)
Observations	423	423	423
R2	0.0001	0.0001	0.0002
Adjusted R2	-0.153	-0.153	-0.153
F Statistic	6.084**	1.211	5.755*
Note:	*p<0.1; **p<0.05; ***p<0.01		

(Note) Estimation is made using instrumental variables (see text for details).

	Dependent variable		
	TFP (Model C)		
Explanatory variables	Model X	Model Y	Model Z
manushare	-0.084	-0.018	-0.086
	(0.056)	(0.050)	(0.056)
labfratio	-3.075***		
	(1.129)		
labfsratio		6.027	
		(7.056)	
labfxratio			-2.835***
			(1.015)
Observations	423	423	423
R2	0.0001	0.0002	0.0002
Adjusted R2	-0.153	-0.153	-0.153
F Statistic	6.224**	1.149	5.888*
Note:	*p<0.1; **p<0.05; ***p<0.01		

(Note) Estimation is made using instrumental variables (see text for details).

	Dependent variable		
	TFP (Model D)		
Explanatory variables	Model X	Model Y	Model Z
manushare	-0.084	-0.018	-0.086
	(0.06)	(0.05)	(0.06)
labfratio	-3.075***		
	(1.129)		
labfsratio		6.027	
		(7.056)	
labfxratio			-2.835***
			(1.015)
Observations	423	423	423
R2	0.0001	0.0002	0.0002
Adjusted R2	-0.153	-0.153	-0.153
F Statistic	6.224**	1.149	5.888*

Note: *p<0.1; **p<0.05; ***p<0.01

(Note) Estimation is made using instrumental variables (see text for details).

Explanatory variables	Dependent variable TFP (Model E) Model X	Model Y	Model Z
manushare	-0.083	-0.018	-0.085
	(0.055)	(0.049)	(0.056)
labfratio	-3.039***		
	(1.084)		
labfsratio		6.065	
		(7.122)	
labfxratio			-2.807***
			(0.972)
Observations	423	423	423
R2	0.00004	0.0002	0.0001
Adjusted R2	-0.153	-0.153	-0.153
F Statistic	6.700**	1.229	6.356**

Note: *p<0.1; **p<0.05; ***p<0.01

(Note) Estimation is made using instrumental variables (see text for details).

<Appendix>

Appendix Table 1: F-Test of Two-Way Fixed Effects Model against Pooled OLS Model (Cobb-Douglas Production Function)

	Cobb-Douglas Production Function				
	Two-Way Fixed Effects on Panel Data				
Null	Model A	Model B	Model C	Model D	Model E
OLS on Pooled Data	F=129.41 (df=54,363)	F=111.35 (df=54,363)	F=108.05 (df=54,361)	F=98.874 (df=54,361)	F=94.304 (df=54,360)

Appendix Table 2: Wald-Test of Translog formulation against Cobb-Douglas formulation of Production Function (Two-Way Fixed Effects Panel Data Model)

	Translog Production Function				
	Two-Way Fixed Effects on Panel Data				
Null	Model A	Model B	Model C	Model D	Model E
Cobb-Douglas Two-Way Fixed Effects on Panel Data	χ^2=40.167 (df=3)	χ^2=52.591 (df=6)	χ^2=59.831 (df=10)	χ^2=92.423 (df=10)	χ^2=106.84 (df=15)

Appendix Table 3: F-Test of Two-Way Fixed Effects Model against Pooled OLS Model (Translog Production Function)

	Translog Production Function				
	Two-Way Fixed Effects on Panel Data				
Null	Model A	Model B	Model C	Model D	Model E
OLS on Pooled Data	283.53 (df=54,360)	F=273.89 (df=54,356)	F=233.5 (df=54,351)	F=191.61 (df=54,351)	F=150.73 (df=54,345)