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Abstract

This paper develops a simple accounting framework that measures the effect of resource misallocation on aggregate productivity. This framework is based on a multi-sector general equilibrium model with sector-specific frictions in the form of taxes on sectoral factor inputs. Our framework is flexible for the assumption on preferences or aggregate production functions. Moreover, this framework is consistent with that commonly used in productivity analysis. I apply this framework to measure the extent to which resource misallocation explains the difference in aggregate productivity across developed countries. I find that resource misallocation explains, on average, 17% of the difference in the measured aggregate productivity among developed countries. I also provide the methods to decompose the causes of the misallocation effect.

JEL Codes: E23, O11, O41, O47

Keywords: distortions; frictions; productivity; resource allocation

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1 Introduction

There are large disparities in incomes even across developed countries. Prescott (2002) reports that there is approximately a 30% to 40% difference in per capita income among highly developed countries. He argues that the most important factor in this disparity is the difference in the level of aggregate total factor productivity (TFP).[1] From this standpoint, many theoretical models have been proposed that try to explain the difference in aggregate TFP. Restuccia and Rogerson (2008) point out that many of these models can be characterized as following the theory of resource misallocation. This theory states that frictions due to various reasons prevent the efficient use of resources, resulting in a low aggregate TFP. Then, to what extent does resource misallocation actually affect aggregate TFP and explain the difference in aggregate TFP across countries?

To answer these problems, this paper proposes a simple accounting framework that measures the effect of resource misallocation on aggregate TFP from data. This framework is based on a multi-sector general equilibrium model with sector-specific frictions in the form of taxes on sectoral factor inputs (capital and labor). As in Chari, Kehoe and McGrattan (2002) and Restuccia and Rogerson (2008), the sector-specific frictions in the form of taxes for each firm or sector reflect the various kinds of frictions the firm or sector faces. As in Chari et al. (2002), I measure these sector-specific frictions using the model from data (which are measured from the difference in factor input returns between sectors) and assess the effect of these frictions on aggregate TFP. A characteristic of their tax (or wedge) approach is that this approach can deal with the various types of frictions that distort resource allocation all together.

Compared with the other papers (cited below) that measure the effect of resource misallocation on aggregate TFP, there are two distinct characteristics in this paper's framework. First, our framework is flexible for the assumption on preferences or aggregate production functions. In particular, when we measure the contribution of resource misallocation to the difference in measured aggregate TFP, we do not need to assume a specific form of preferences or aggregate production functions.[2] Second, this paper's framework is consistent with that commonly used in productivity analysis.

[1] Parente and Prescott (2000) argue that the most important factor in the income disparities between developed and developing countries is also the difference in aggregate TFP.

[2] When conducting a counterfactual exercise, our framework implicitly or explicitly needs assumptions on preferences or aggregate production functions to know how sectoral shares change.

I apply this framework to the sectoral data of countries that are included in the EU KLEMS database (Timmer, O'Mahony and van Ark, 2008).[3] I find that, on average, 17% of the difference in the measured aggregate TFP between the U.S. and other countries is due to sector-level resource misallocation. The correlation between aggregate TFP and the misallocation effect is high (0.55). The transport and financial sectors are the primary sources of capital misallocation, while the agricultural and financial sectors are primary sources of labor misallocation. I also find that the differences in sectoral shares between countries, which may be due to structural transformations, magnify the effect of sector-level resource misallocation on the difference in measured aggregate TFP.

Several papers measure resource misallocation from cross-sectional differences in factor input returns and calculate the resource misallocation effect on aggregate TFP using the general equilibrium framework. This paper fits into this literature. To the best of my knowledge, the earliest work in this field is de Melo (1977). A computable multi-sector general equilibrium model is applied to the Colombian economy by de Melo (1977) to calculate the effect of the removal of distortions on sector-level resource allocation. Recently, Restuccia, Yang and Zhu (2008) and Vollrath (2009) used a two-sector model to measure the magnitude of barriers to resource allocation between the agricultural and non-agricultural sectors. Using a standard model of monopolistic competition with heterogeneous firms and manufacturing plant-level data from China, India, and the U.S., Hsieh and Klenow (2007) estimated how resource misallocation affects aggregate TFP. As mentioned above, compared with these papers, our framework is flexible for the assumption on preferences or aggregate production functions.[4] Moreover, our framework is compatible with the framework commonly used in productivity analysis. Finally, using this paper's framework (to be precise, the framework of the previous version of this paper, Aoki, 2006), Miyagawa, Fukao, Hamagata and Takizawa (2008) used the Japanese Industrial Productivity (JIP) Database to measure the effect of sector-level resource misallocation on aggregate TFP.

Literature on productivity analysis has measured the effect of change in sectoral reallocation on aggregate TFP growth (see Syrquin, 1984, and Basu and Fernald, 2002, among others). I show that this paper's decomposition is a generalization of previous studies; while previous studies

[3]The countries are Australia, Austria, the Czech Republic, Denmark, Finland, Germany, Italy, Japan, Netherlands, Portugal, Sweden, the U.K., and the U.S.

[4]On the other hand, for example, Restuccia et al. (2008) assume the Stone-Geary utility function and Vollrath (2009) assumes a small open economy, which is equivalent to assuming that goods are a perfect substitute.

measured the effect of resource misallocation on the aggregate TFP growth rate over time, this paper's framework can also measure the effect on the level of aggregate TFP and on the difference in aggregate TFP across countries. This paper also provides the micro-foundations for the reallocation effect. Owing to this, the approach used herein can further decompose the causes of resource misallocation.

Several studies provide examples of resource misallocation. Caballero, Hoshi and Kashyap (2008) argue that during the Japanese stagnation of the 1990s, the forbearance lending of banks shifted resources from healthy firms to zombie firms and zombie-dominated sectors. Kiyotaki and Moore (1997) argue that the differences in the degree of borrowing constraint between firms can shift resources from high-productivity firms to low-productivity firms. Hayashi and Prescott (2008) argue that, for institutional reasons, there was a barrier to labor mobility between the agricultural and non-agricultural sectors in prewar Japan. In my model, frictions in the form of taxes capture the effect of these distortions on resource allocation.

The remainder of the paper is organized into four sections. Section 2 sets up and analyzes a static multi-sector general equilibrium model with frictions in the form of sector-specific taxes on factor inputs. Using the model, Section 3 develops methods to measure the effects of resource misallocation on aggregate TFP. Using the developed framework, Section 4 measures the effect of sector-level resource misallocation on aggregate TFP from data. Section 5 concludes.

2 The Model

In this section, I develop a multi-sector competitive equilibrium model with sector-specific frictions. In keeping with Chari et al. (2002), sector-specific frictions are modeled in the form of taxes on sectoral factor inputs, the firms are price-takers and pay linear taxes on capital and labor, and each firm's problem is static. I argue in Appendix A that several types of frictions in each sector are isomorphic to the taxes on the sector's factor inputs.[5]

[5]The term "isomorphic" implies having the same allocation.

2.1 I Industrial sectors

There are I industrial sectors in the economy. Firms in each sector produce goods (homogeneous within a sector but heterogeneous among sectors) by using two factor inputs: capital K and labor L (hereafter, J denotes the factor input in general). Firms are price-takers in both the goods and factor markets and pay linear taxes on capital and labor inputs, which vary by sectors. Thus, firms in sector i produce goods given the goods price of the sector p_i and capital and labor costs $(1 + \tau_{Ki})p_K$ and $(1 + \tau_{Li})p_L$, respectively, where τ_{Ki} and τ_{Li} are the capital and labor taxes of the sector, respectively, and p_K and p_L are the common factor prices of capital and labor across sectors, respectively. As each sector produces different goods, the goods price p_i can vary across sectors in equilibrium (even if there are no taxes). On the other hand, because capital and labor are homogeneous across sectors, if $\tau_{Ki} = 0$ and $\tau_{Li} = 0$, the factor costs incurred by firms equalize. As I assume a firm's production function to be constant-returns-to-scale (CRS), I will identify a sector using a firm below.

The firms possess the Cobb-Douglas production technology exhibiting CRS. Therefore, a firm i's production function can be written as follows:

$$V_i = F_i(K_i, L_i) \equiv A_i K_i^{\alpha_i} L_i^{1-\alpha_i}, \tag{1}$$

where V_i is the output, K_i is the capital input, L_i is the labor input, and A_i is the productivity of the firm. I assume that the capital intensity α_i can vary by sector.

In this setting, the firm's problem is written as

$$\max_{K_i, L_i} \; p_i F_i(K_i, L_i) - (1 + \tau_{Ki})p_K K_i - (1 + \tau_{Li})p_L L_i.$$

The first-order conditions (FOCs) are as follows:[6]

$$\begin{aligned} \frac{\alpha_i p_i V_i}{K_i} &= (1+\tau_{Ki})p_K, & (2)\\ \frac{(1-\alpha_i)p_i V_i}{L_i} &= (1+\tau_{Li})p_L. & (3) \end{aligned}$$

If a firm's profit is negative for any positive K_i and L_i, the firm chooses not to produce, and the above FOCs do not hold. Although hereafter, I assume that the above FOCs hold for all sectors, the results used in the later sections, i.e., (9)–(12), hold even when some sectors do not produce.

2.2 Aggregator function

I assume the CRS aggregator function:

$$V = V(V_1, \ldots, V_I). \tag{4}$$

I also assume that the following condition is satisfied:

$$\frac{\partial V}{\partial V_i} = p_i. \tag{5}$$

This condition is satisfied if V is an aggregate good and firms that produce V from V_i are competitive or if V is the household's utility and the household chooses V_i to maximize V. Under these conditions, the following equation holds[7]:

$$V = \sum_i p_i V_i. \tag{6}$$

[6] Note that from (1) and the FOCs, we also attain the following unit cost function:

$$p_i = \frac{1}{\alpha_i^{\alpha_i}(1-\alpha_i)^{1-\alpha_i}} \frac{\{(1+\tau_{Ki})p_K\}^{\alpha_i}\{(1+\tau_{Li})p_L\}^{1-\alpha_i}}{A_i}.$$

[7] I normalize the aggregate good price to unity.

2.3 Resource constraints

Finally, I assume that the aggregate capital and labor supply are exogenous. Thus, the following resource constraints apply:

$$\sum_i K_i = K, \tag{7}$$

$$\sum_i L_i = L, \tag{8}$$

where K and L are the aggregate capital and labor supply, respectively.

2.4 Equilibrium relations

A competitive equilibrium of this economy is defined in the following manner.

Definition. Given the productivities and taxes of I goods sectors $\{A_i, 1+\tau_{Ki}, 1+\tau_{Li}\}$, and the aggregate capital K and labor L, respectively, a *competitive equilibrium* is a set of the output, capital, labor, and prices of I goods sectors $\{V_i, K_i, L_i, p_i\}$, the aggregate value V, and the common factor prices p_K and p_L that satisfy the following conditions:

1. FOCs of firms in I goods sectors (2) and (3), where V_i is given by (1),
2. CRS assumption and marginal conditions (4) and (5),
3. resource constraints (7) and (8).

In what follows, I derive the expressions for K_i and L_i using the equilibrium conditions. Using (2) and (7), K_i can be rewritten as follows:

$$\begin{aligned} K_i &= \frac{\frac{(1+\tau_{Ki})p_K K_i}{(1+\tau_{Ki})p_K}}{\sum_j \frac{(1+\tau_{Kj})p_K K_j}{(1+\tau_{Kj})p_K}} K \\ &= \frac{p_i Y_i \alpha_i \frac{1}{(1+\tau_{Ki})p_K}}{\sum_j p_j Y_j \alpha_j \frac{1}{(1+\tau_{Kj})p_K}} K \\ &= \frac{\tilde{\sigma}_i \alpha_i \frac{1}{1+\tau_{Ki}}}{\sum_j \tilde{\sigma}_j \alpha_j \frac{1}{1+\tau_{Kj}}} K, \end{aligned}$$

where $\tilde{\sigma}_i$ is the sectoral share $p_i V_i / V$.[8] This equation is rearranged as follows:

$$K_i = \frac{\tilde{\sigma}_i \alpha_i}{\tilde{\alpha}} \tilde{\lambda}_{Ki} K, \tag{9}$$

where $\tilde{\alpha}$ is the weighted average of capital intensities $\sum_i \tilde{\sigma}_i \alpha_i$ and $\tilde{\lambda}_{Ki}$ is the term composed of frictions.[9] $\tilde{\lambda}_{Ki}$ is defined as

$$\tilde{\lambda}_{Ki} \equiv \frac{\lambda_{Ki}}{\sum_j \left(\frac{\tilde{\sigma}_j \alpha_j}{\tilde{\alpha}} \right) \lambda_{Kj}}, \text{ and } \lambda_{Ki} \equiv \frac{1}{1 + \tau_{Ki}}. \tag{10}$$

In the same way, we obtain the equilibrium allocation of L_i:

$$L_i = \frac{\tilde{\sigma}_i (1 - \alpha_i)}{1 - \tilde{\alpha}} \tilde{\lambda}_{L_i} L, \tag{11}$$

where

$$\tilde{\lambda}_{Li} \quad \equiv \quad \frac{\lambda_{Li}}{\sum_j \left(\frac{\tilde{\sigma}_j (1-\alpha_j)}{1-\tilde{\alpha}} \right) \lambda_{Lj}}, \text{ and } \lambda_{Li} \equiv \frac{1}{1 + \tau_{Li}}. \tag{12}$$

Equations (9)–(12) uncover several effects of taxes on the resource allocation of capital and labor. First, from (9) and (11), we find that taxes mainly affect the allocation of resources through $\tilde{\lambda}_{Ji}$, although taxes can also affect $\tilde{\sigma}_i$. Second, from (10) and (12), we find that $\tilde{\lambda}_{Ji}$ is the ratio of the reciprocal of sector i's return on the factor input and the mean of the reciprocals of the returns across sectors. Owing to this property, the absolute magnitude of taxes does not affect the resource allocation among sectors. For instance, if the tax on capital is identical across sectors, then $\tilde{\lambda}_{Ki}$ becomes unity, which is equal to the value when there were no frictions. On the other hand, the distribution of taxes across sectors affects resource allocation. For example, if λ_{Ki} is smaller than the weighted average of λ_{Kj} (i.e., sector i's capital is taxed more) and if $\tilde{\sigma}_i$ do not vary much, $\tilde{\lambda}_{Ki}$ becomes less than unity; in this case, the capital allocated to sector i is less than that allocated when there were no frictions.

In the empirical section, I do not measure frictions λ_{Ji} themselves, but measure $\tilde{\lambda}_{Ji}$, which

[8] I add a tilde (̃) to denote the variables that depend on the functional form of V.

[9] Hsieh and Klenow (2007) also derive a similar expression.

capture the distribution of these frictions. $\tilde{\lambda}_{Ji}$ are measured using the rewritten forms of equations (9) and (11):

$$\tilde{\lambda}_{Ki} = \left(\frac{\tilde{\sigma}_i \alpha_i}{\tilde{\alpha}}\right)^{-1} \frac{K_i}{K}, \text{ and } \tilde{\lambda}_{Li} = \left(\frac{\tilde{\sigma}_i (1-\alpha_i)}{1-\tilde{\alpha}}\right)^{-1} \frac{L_i}{L}. \tag{13}$$

3 Analyzing the Effects of Resource Misallocation on Aggregate TFP

In this section, in order to calculate the effects of resource misallocation on aggregate TFP, I decompose aggregate TFP into sectoral TFPs, sectoral shares, and resource misallocation by taking an approximation of aggregator function V. I provide an interpretation of the decomposition. This section also describes a method to identify which sector contributes to resource misallocation. Since the component of resource misallocation consists of a combination of sectoral frictions and sectoral shares, I also describe a method to identify the contribution of these factors.

3.1 Decomposition of aggregate TFP

In order to analyze the effect of resource misallocation on aggregate TFP, I compare the aggregator function at state S, V^S, with that at state T, V^T, and apply the mean value theorem (hereafter, the variables with the superscript S denote those at state S, such as V^S). State S, for example, corresponds to Japan, while state T corresponds to the U.S. I assume that the capital intensity of each sector α_i is the same across different states.

By applying the mean value theorem and using (5) and (6), we obtain

$$\begin{aligned}\ln\left(\frac{V^S}{V^T}\right) &= \sum_i \frac{\partial \ln V}{\partial \ln V_i} \ln\left(\frac{V_i^S}{V_i^T}\right) \\ &\simeq \sum_i \bar{\sigma}_i \ln\left(\frac{V_i^S}{V_i^T}\right),\end{aligned}$$

where $\bar{\sigma}_i \equiv (\tilde{\sigma}_i^S + \tilde{\sigma}_i^T)/2$.[10] The RHS is the Tornqvist index of the value added difference. By

[10] In order to derive the first equality, I define $\phi(x)$ as follows:

$$\phi(x) \equiv \ln V(\exp\{x \ln V_1^S + (1-x)\ln V_1^T\}, \ldots, \exp\{x \ln V_I^S + (1-x)\ln V_I^T\}),\ 0 \le x \le 1,$$

substituting (1), (9), and (11) into the above equation, we obtain the following decomposition:

$$
\begin{aligned}
\sum_i \bar{\sigma}_i \ln\left(\frac{V_i^S}{V_i^T}\right) &= \sum_i \bar{\sigma}_i \ln\left(\frac{A_i^S}{A_i^T}\right) \\
&+ \sum_i \bar{\sigma}_i \ln\left(\frac{\tilde{\sigma}_i^S}{\tilde{\sigma}_i^T} \Big/ \frac{(\tilde{\alpha}^S)^{\alpha_i}(1-\tilde{\alpha}^S)^{1-\alpha_i}}{(\tilde{\alpha}^T)^{\alpha_i}(1-\tilde{\alpha}^T)^{1-\alpha_i}}\right) \\
&+ \sum_i \bar{\sigma}_i \left\{\alpha_i \ln\left(\frac{\tilde{\lambda}_{Ki}^S}{\tilde{\lambda}_{Ki}^T}\right) + (1-\alpha_i)\ln\left(\frac{\tilde{\lambda}_{Li}^S}{\tilde{\lambda}_{Li}^T}\right)\right\} \\
&+ \bar{\alpha}\ln\left(\frac{K^S}{K^T}\right) + (1-\bar{\alpha})\ln\left(\frac{L^S}{L^T}\right), \qquad (14)
\end{aligned}
$$

where $\bar{\alpha} \equiv \sum_i \bar{\sigma}_i \alpha_i$.

I define the aggregate TFP of state S relative to state T and refer to it as ATFP as follows:

$$
\text{ATFP} \equiv \sum_i \bar{\sigma}_i \ln\left(\frac{V_i^S}{V_i^T}\right) - \bar{\alpha}\ln\left(\frac{K^S}{K^T}\right) - (1-\bar{\alpha})\ln\left(\frac{L^S}{L^T}\right). \qquad (15)
$$

This is the standard definition of aggregate TFP.[11] By rewriting (14) using the definition of aggregate TFP, I obtain

$$
\begin{aligned}
\text{ATFP} = &\sum_i \bar{\sigma}_i \ln\left(\frac{A_i^S}{A_i^T}\right) + \sum_i \bar{\sigma}_i \ln\left(\frac{\tilde{\sigma}_i^S}{\tilde{\sigma}_i^T} \Big/ \frac{(\tilde{\alpha}^S)^{\alpha_i}(1-\tilde{\alpha}^S)^{1-\alpha_i}}{(\tilde{\alpha}^T)^{\alpha_i}(1-\tilde{\alpha}^T)^{1-\alpha_i}}\right) \\
&+ \sum_i \bar{\sigma}_i \left\{\alpha_i \ln\left(\frac{\tilde{\lambda}_{Ki}^S}{\tilde{\lambda}_{Ki}^T}\right) + (1-\alpha_i)\ln\left(\frac{\tilde{\lambda}_{Li}^S}{\tilde{\lambda}_{Li}^T}\right)\right\}. \qquad (16)
\end{aligned}
$$

I refer to the first term of the RHS in (16) as the sectoral TFP term (STFP). STFP is the weighted average of sectoral TFPs and is the same as the Domar (1961) weighted aggregate TFP. I refer to the second term as the sectoral share term (SS); this term mainly consists of sectoral shares. Theoretically, when the differences in $\tilde{\sigma}_i$ between states S and T are small, SS is approximately zero (for the proof, see Appendix B). In addition, as reported in Section 4, SS is small in our data. I refer to the third term in (16) as the allocational efficiency term (AE), which represents resource misallocation because it consists of $\tilde{\lambda}_i$ that, as can be seen from (9) and (11), distort resource

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and apply the mean value theorem in the following manner:

$$
\phi(1) - \phi(0) = \phi'(\theta)(1-0),
$$

where $0 \leq \theta \leq 1$.

[11]See Christensen, Jorgenson and Lau (1973) and Caves, Christensen and Diewert (1982).

allocation. When the friction level is identical across the sectors for each state (i.e., $\lambda_i^S = \lambda_j^S$ and $\lambda_i^T = \lambda_j^T$), AE $= 0$.

3.2 Interpretation of the decomposition

The decomposition in (16) can be used to calculate the *measured* difference in aggregate TFP between the two actual states due to the differences in sectoral TFPs measured by STFP and due to the difference in the distribution of sectoral frictions measured by AE. When used in this manner, this paper's decomposition can be considered as an extension of that by Syrquin (1984) and Basu and Fernald (2002): we can show that when S and T correspond to periods t and $t-1$, respectively, AE is equal to their reallocation term.[12] Compared with theirs, our framework enables further decompositions of AE in several different ways. For example, AE in (16) can be decomposed into a state S frictions component that consists of $\tilde{\lambda}_{Ki}^S$ and $\tilde{\lambda}_{Li}^S$ and a state T frictions component that consists of $\tilde{\lambda}_{Ki}^T$ and $\tilde{\lambda}_{Li}^T$. In a later section, I explain how to decompose AE into sectoral contributions.

The decomposition in (16) can also be used to measure how aggregate TFP *would* change when frictions *counterfactually* disappear under certain conditions. Applying the framework of this paper, Miyagawa et al. (2008) calculate this effect under the following conditions: state S corresponds to an actual state, state T corresponds to a no-frictions state (i.e., $\tilde{\lambda}_{Ji}^T = 1$), and sectoral TFPs and sectoral shares of state T are the same as those of state S.

We can also reinterpret the measured AE or SS + AE between two actual states from this viewpoint: the negative of the AE (or SS + AE) between the two actual states measures how the difference in aggregate TFP between the two states would change when frictions counterfactually disappear in both cases. This is under the condition that the differences in sectoral shares $\tilde{\sigma}_i$ between states S and T are due to factors other than the differences in sectoral frictions between the states (or due to the differences in sectoral frictions).

To show this, first, let us consider the case where the differences in sectoral shares $\tilde{\sigma}_i$ between states S and T are due to factors other than the differences in sectoral frictions λ_i between the states. In this case, when frictions disappear for both states, AE becomes zero while STFP and SS remain unchanged because sectoral frictions do not affect $\tilde{\sigma}_i$ (and sectoral TFPs). Then, ATFP

[12] Note that since the differences in $\tilde{\sigma}_i$ between t and $t-1$ are small, SS is approximately zero (see Appendix B).

without friction is equal to STFP + SS, while ATFP with frictions is equal to STFP + SS + AE. The misallocation effect is equal to the difference between these two ATFPs, i.e., −AE.

Next, let us consider another case in which the differences in sectoral shares $\tilde{\sigma}_i$ between states S and T are due to the differences in sectoral frictions λ_i between the states. In this case, when the frictions at state S change to those at state T, $\tilde{\sigma}_i$, $\tilde{\alpha}$, and $\tilde{\lambda}_i$ are the same for states. Then, the change in aggregate TFP by the change in frictions is equal to $-(\mathrm{SS}+\mathrm{AE})$. It is also equal to the change in aggregate TFP when the frictions in both cases are eliminated.

Since, as noted above, SS is small in our data, I will henceforth focus on AE.

3.3 Contribution of each sector to AE

An advantage of our framework is that it can identify which sector's frictions cause the difference in aggregate TFP. This section provides the method.[13] In order to identify the contribution of the frictions of a particular sector (referred to as sector i), I calculate a fictitious AE under the following assumptions (while I drop out superscripts S and T for convenience, note that these assumptions are applied to both states). For both states, I fix the factor inputs of sector i to the actual observed values and *efficiently* reallocate the *remaining* factor inputs across the remaining sectors of the economy. Then, the only source of distortion would be in sector i. For simplicity, I also assume that sectoral shares $\tilde{\sigma}_i$ are fixed. I refer to the AE calculated under this assumption as AE_i.

AE_i is measured as follows (here, I decompose AE_i into capital and labor components). First, under the above assumption, from (9) and (11), sector i's $\tilde{\lambda}_{Ji}$ is the same as the actual $\tilde{\lambda}_{Ji}$. Second, under the above assumption, since factor prices are the same across the remaining sectors, $\tilde{\lambda}_{Jm} = \tilde{\lambda}_{Jn} = \tilde{\lambda}_{J-i}$ for the remaining sectors (m and n are the sectors other than sector i, and are summarized by $-i$). By rearranging

$$K_{-i} \equiv K - K_i = \sum_{m \neq i} K_m = \sum_{m \neq i} \frac{\tilde{\sigma}_m \alpha_m}{\tilde{\alpha}} \tilde{\lambda}_{K-i} K \tag{17}$$

[13] In (16), I do not simply decompose AE into sectoral components. The reason for this is as follows. From (9) and (11), we find that the (absolute) distance of $\tilde{\lambda}_{Ji}$ from unity represents the magnitude of distortion. However, a simple decomposition of AE in (16) by sectors does not capture this characteristic. Suppose that $\tilde{\lambda}^S_{Ki} > \tilde{\lambda}^T_{Ki} = 1$. Then, although the state S's allocation of capital in sector i is distorted while state T's is not, a simple sectoral decomposition of capital AE, $\bar{\sigma}_i \alpha_i \ln(\tilde{\lambda}^S_{Ki}/\tilde{\lambda}^T_{Ki})$, becomes positive (this implies that the sector's friction has a positive effect on ATFP; this is a contradiction).

(note that K, K_i, and consequently K_{-i} are the same as the actual ones while $K_m (m \neq i)$ is not), we obtain

$$\tilde{\lambda}_{K-i} = \left(\frac{\tilde{\sigma}_{-i} \alpha_{-i}}{\tilde{\alpha}} \right)^{-1} \frac{K_{-i}}{K}, \tag{18}$$

where $\tilde{\sigma}_{-i} \equiv 1 - \tilde{\sigma}_i$ and $\alpha_{-i} \equiv \sum_{m \neq i} (\tilde{\sigma}_m / (1 - \tilde{\sigma}_i)) \alpha_m$ (i.e., α_{-i} is a weighted average of a_m $(m \neq i)$). Then, the capital component of AE_i, denoted by capital AE_i, is calculated as follows:

$$\text{capital AE}_i = \bar{\sigma}_i \alpha_i \ln \left(\frac{\tilde{\lambda}^S_{Ki}}{\tilde{\lambda}^T_{Ki}} \right) + \bar{\sigma}_{-i} \bar{\alpha}_{-i} \ln \left(\frac{\tilde{\lambda}^S_{K-i}}{\tilde{\lambda}^T_{K-i}} \right), \tag{19}$$

where $\bar{\sigma}_{-i} \equiv 1 - \bar{\sigma}_i$ and $\bar{\alpha}_{-i} \equiv \sum_{m \neq i} (\bar{\sigma}_m / (1 - \bar{\sigma}_i)) \alpha_m$ (i.e., $\bar{\alpha}_{-i}$ is a weighted average of a_m $(m \neq i)$). In the same manner, labor AE_i is calculated by

$$\text{labor AE}_i = \bar{\sigma}_i (1 - \alpha_i) \ln \left(\frac{\tilde{\lambda}^S_{Li}}{\tilde{\lambda}^T_{Li}} \right) + \bar{\sigma}_{-i} (1 - \bar{\alpha}_{-i}) \ln \left(\frac{\tilde{\lambda}^S_{L-i}}{\tilde{\lambda}^T_{L-i}} \right), \tag{20}$$

where $\tilde{\lambda}_{L-i}$ is measured by

$$\tilde{\lambda}_{L-i} = \left(\frac{\tilde{\sigma}_{-i} (1 - \alpha_{-i})}{1 - \tilde{\alpha}} \right)^{-1} \frac{L_{-i}}{L}, \tag{21}$$

where $L_{-i} \equiv L - L_i$.

As is obvious from (19) and (20), AE_i is equal to AE when there are only two sectors: sectors i and $-i$. In Appendix C, I show that the sum of AE_i calculated above is approximately equal to the actual AE.[14]

3.4 Contribution of sectoral frictions and sectoral shares to AE

AE depends on not only the differences in sectoral frictions λ_{Ji} across states but also those in sectoral shares $\tilde{\sigma}_i$, because $\tilde{\lambda}_{Ji}$ depends on both factors. This section illustrates why the distinction between the two factors is important and provides a method for identifying the effect due to each factor.

To understand the importance of the differences in $\tilde{\sigma}_i$ across states for AE, suppose a two-

[14] They are also close in our data.

sector model (an agricultural sector A and a non-agricultural sector N). Additionally, I assume that $\alpha_i = 0$ for these sectors. Further, suppose that the λ_{Li} are the same for states S and T but $\tilde{\sigma}_i$ are not. Then, AE is calculated as

$$\begin{aligned}\text{AE} &= \bar{\sigma}_A \ln\left(\frac{\tilde{\lambda}^S_{LA}}{\tilde{\lambda}^T_{LA}}\right) + \bar{\sigma}_N \ln\left(\frac{\tilde{\lambda}^S_{LN}}{\tilde{\lambda}^T_{LN}}\right) \\ &= \ln\left(\tilde{\sigma}^T_A \lambda_{LA} + \tilde{\sigma}^T_N \lambda_{LN}\right) - \ln\left(\tilde{\sigma}^S_A \lambda_{LA} + \tilde{\sigma}^S_N \lambda_{LN}\right).\end{aligned}$$

Now further assume that $\tilde{\sigma}^S_A > \tilde{\sigma}^T_A$ and $\lambda_{LA} > \lambda_{LN}$. The former assumption is reasonable when T is a more mature economy than S. The latter is also reasonable because, in data, λ_{LA} is higher than the average of all sectors.[15] AE then becomes negative, irrespective of the same λ_{Li}. In this case, the differences in $\tilde{\sigma}_i$ generate the effect of sector-level resource misallocation on aggregate TFP.

In order to identify how much is due to sectoral shares, I calculate a counterfactual AE using $\tilde{\lambda}_{Ji}(\{\tilde{\sigma}^S_j, \lambda^T_{Jj}\})$ instead of $\tilde{\lambda}^S_{Ji}$, where $\tilde{\lambda}_{Ji}(\{\tilde{\sigma}^S_j, \lambda^T_{Jj}\})$ is calculated from the sectoral shares of state S $\tilde{\sigma}^S_j$ and the sectoral frictions of state T λ^T_{Jj} as follows ($\bar{\sigma}_i$ and the state T remain unchanged):

$$\tilde{\lambda}_{Ki}(\{\tilde{\sigma}^S_j, \lambda^T_{Kj}\}) \equiv \frac{\lambda^T_{Ki}}{\sum_j \left(\frac{\tilde{\sigma}^S_j \alpha_j}{\tilde{\alpha}^S}\right) \lambda^T_{Kj}}, \quad \tilde{\lambda}_{Li}(\{\tilde{\sigma}^S_j, \lambda^T_{Lj}\}) \equiv \frac{\lambda^T_{Li}}{\sum_j \left(\frac{\tilde{\sigma}^S_j (1-\alpha_j)}{1-\tilde{\alpha}^S}\right) \lambda^T_{Lj}}.$$

I refer to the AE calculated using these frictions as the counterfactual AE. If the magnitude of AE is large owing to the differences in $\tilde{\sigma}_i$ across countries, the counterfactual AE will be close to the AE calculated using $\tilde{\lambda}^S_{Ji}$. If the results are due to the differences in $\tilde{\lambda}_{Ji}$ across countries, the counterfactual AE will be small in magnitude.

In the empirical section, $\tilde{\lambda}_{Ki}(\{\tilde{\sigma}^S_j, \lambda^T_{Kj}\})$ is measured from

$$\tilde{\lambda}_{Ki}(\{\tilde{\sigma}^S_j, \lambda^T_{Kj}\}) = \frac{\tilde{\lambda}^T_{Ki}}{\sum_j \left(\frac{\tilde{\sigma}^S_j \alpha_j}{\tilde{\alpha}^S}\right) \tilde{\lambda}^T_{Kj}}, \tag{22}$$

because the denominator of the $\tilde{\lambda}^T_{Kj}$ (i.e., $\sum_m (\tilde{\sigma}^T_m \alpha_m / \tilde{\alpha}^T) \lambda^T_{Km}$) is canceled out and λ^T_{Kj} appear on the RHS of the numerator and denominator of (22). In the same way, $\tilde{\lambda}_{Li}(\{\tilde{\sigma}^S_j, \lambda^T_{Lj}\})$ is measured

[15] We can confirm this in Figure 2.

from

$$\tilde{\lambda}_{Li}(\{\tilde{\sigma}_j^S, \lambda_{Lj}^T\}) = \frac{\tilde{\lambda}_{Li}^T}{\sum_j \left(\frac{\tilde{\sigma}_j^S(1-\alpha_j)}{1-\tilde{\alpha}^S}\right) \tilde{\lambda}_{Lj}^T}. \tag{23}$$

4 Empirical Results

In this section, using the framework developed in the previous sections and the sectoral data of countries that are included in the EU KLEMS database, I calculate the contribution of sector-level resource misallocation to cross-country differences in aggregate TFP. After measuring the distribution of sector-level frictions from the data, I calculate sectoral share (SS), allocational efficiency (AE), and aggregate TFP (ATFP) between the U.S. and other countries (in the model, state T corresponds to the U.S. and state S, to other countries). I also identify the sector that causes the resource misallocation and whether or not misallocation is due to the differences in sectoral shares across countries. Since I impose an assumption that α_i is the same across countries, I also check its robustness.

4.1 Measurement procedure

We can measure AE by measuring $\tilde{\lambda}_{Ji}$, $\tilde{\lambda}_{J-i}$, $\tilde{\lambda}_{Ji}(\{\tilde{\sigma}_j^S, \lambda_{Jj}^T\})$, α_i, and $\tilde{\sigma}_i$.

$\tilde{\lambda}_{Ji}$ can be measured from (13) because K_i, K, L_i, and L are available from the data, and $\tilde{\sigma}_i$ and α_i can be measured as discussed below. Measuring $\tilde{\lambda}_{Ji}$ in this way would capture several kinds of distortions that affect cross-sectional, sector-level resource allocation such as those in Appendix A. In the same manner, $\tilde{\lambda}_{J-i}$ and $\tilde{\lambda}_{Ji}(\{\tilde{\sigma}_j^S, \lambda_{Jj}^T\})$ are measured from (18), (21), (22), and (23).

For the reasons explained below, I use α_i measured from the U.S. data, under the assumption that the biases on measured α_i are small in the U.S. and that the α_i of a given sector is the same across developed countries. For the robustness check, in Section 4.6, I also measure AE where α_i is measured from each country's data.

The reason I do not use α_i in each country is because the measured α_i can be biased if there are market imperfections. Since the taxes in our model do not correspond to those in the tax data, we cannot measure an unbiased α_i by simply using FOCs in (2) and (3). Thus, we have to deal with the same difficulties in measuring capital intensity, as discussed in previous studies. First, it is known that if there are imperfections in the goods market, α_i measured from revenue share can have biases (for details, see Basu and Fernald, 2002). On the other hand, if there are imperfections in the factor markets, the α_i measured from the factor input costs can have biases (for details, see Appendix A.4).

The $\tilde{\sigma}_i$ can be measured from the sectoral nominal shares, which is consistent with the model's assumption.

4.2 Data

I mainly use the annual sectoral data of the EU KLEMS database (Timmer et al., 2008), except for the data on purchasing power parity (PPP) rate for value added which are taken from the Groningen Growth and Development Centre (GGDC) Productivity Level database (Inklaar and Timmer, 2008, hereafter the GGDC database), and that on PPP rate for capital which are taken from OECD (2002).[16] The countries studied are Australia, Austria, the Czech Republic, Denmark, Finland, Germany, Italy, Japan, Netherlands, Portugal, Sweden, the U.K., and the U.S. for 1985, 1995, and 2005.[17] The sectors considered in this study include (1) "Agriculture, Hunting, Forestry and Fishing" (hereafter, the agricultural sector), (2) "Mining and Quarrying" (the mining sector), (3) "Total Manufacturing" (the manufacturing sector), (4) "Electricity, Gas and Water Supply" (the electricity sector), (5) "Construction" (the construction sector), (6) "Wholesale and Retail Trade" (the wholesale sector), (7) "Hotels and Restaurants" (the hospitality sector), (8) "Transport and Storage and Communication" (the transport sector), and (9) "Financial Intermediation" (the financial sector).[18]

We need data on sectoral capital inputs K_i, sectoral labor inputs L_i, sectoral capital intensities α_i, and sectoral shares $\tilde{\sigma}_i$, in order to measure SS and AE. For K_i, I use "real fixed capital stock, 1995 prices" of "all assets" in the EU KLEMS database. For L_i, I use "total hours worked by persons engaged." The α_i are measured as the "capital compensation"/("capital compensation" +

[16] Although the GGDC database also provides capital and labor data for cross-country comparisons, I do not use these data. This is because the capital and labor data in the database are constructed assuming that the rate of return on an input—which, roughly speaking, corresponds to $(1 + \tau_{Ji})p_J$ in our model, is the same across sectors.

[17] They are the countries whose output, capital, and labor data are available in the EU KLEMS database. For the Czech Republic, Germany, Portugal, and Sweden, I use the data for 1995 and 2005 due to data availability. For the U.S., I use "United States-NAICS based" data. Moreover, for the measurement of α_i, I use the U.S. data from 1977 to 2005.

[18] I choose these sectors on the basis of the major division of the Statistical Classification of Economic Activities in the European Community (NACE).

"labor compensation") for the U.S. (average figures for the years 1977 to 2005). The $\tilde{\sigma}_i$ are measured from the share of nominal value added ("gross value added at current basic prices") of each country during each period.

In order to measure ATFP, we need the PPP-adjusted sectoral output V_i^{PPP} and the sectoral capital K_i^{PPP}.[19] The PPP-adjusted output of sector i at year t, V_{it}^{PPP}, is obtained as the nominal value added $\times$ price-adjustment rate, where the price-adjustment rate is calculated as the inflation rate divided by the PPP rate, $(P^c_{\text{VA},i,1997}/P^c_{\text{VA},i,t})/\text{PPP}^c_{\text{VA},i,1997}$ ($P^c_{\text{VA},i,t}$ is the "gross value added, price indices" for sector i in country c at year t, and $\text{PPP}^c_{\text{VA},i,1997}$ is the PPP rate for value added for sector i in the country c's currency per U.S. dollar in 1997).[20] The PPP-adjusted sectoral capital K_i^{PPP} is calculated in a similar manner, except that we use the same price-adjustment rate across the sectors to be consistent with the model (in the model, capital is homogeneous). More precisely, the price-adjustment rate for capital is calculated as $(P^c_{K,\text{TOT},1999}/P^c_{K,\text{TOT},1995})/\text{PPP}^c_{K,1999}$ ($P^c_{K,\text{TOT},t}$ is the "gross fixed factor formation price index" of "all assets" for "Total Industries" in country c in year t, and $\text{PPP}^c_{K,1999}$ is the PPP rate for "capital goods" in country c's currency per U.S. dollar in 1999).[21]

For reference, I report the measured $\tilde{\lambda}_{Ki}$ and $\tilde{\lambda}_L$ in Figures 1 and 2 (the values are the averages of the years for each country and each sector). The higher the sectoral return on capital or labor as compared with the other sectors of the same country, the lower the measured $\tilde{\lambda}_{Ki}$ or $\tilde{\lambda}_{Li}$.

[Figure 1]

[Figure 2]

4.3 SS, AE, and the contribution to ATFP

Using (15) and (16), I calculate the sectoral share (SS), allocational efficiency (AE), and aggregate TFP (ATFP) between the U.S. and other countries. Note that in the equations, state T corresponds to the U.S. while state S corresponds to other countries. Table 1 reports the averages of these

[19] Note that the choice of the PPP rates only affects ATFP and not SS or AE.

[20] In the GGDC database, the PPP rates for value added in the manufacturing and transport sectors are not available, while those for their subsectors are available. I obtain the PPP rates in the manufacturing and transport sectors by taking the geometric average of the subsectors' PPP rates, where the weights are the averages of the nominal value added shares in the two countries.

[21] The PPP rate is taken from Table 2 in OECD (2002).

I do not use the PPP rate for capital in the GGDC database because it is the PPP rate for the cost of capital. Moreover, there are problems, as noted in footnote 16.

results over the years. For reference, in Table 2, I also report the decomposition of AE into two components—the U.S. and other countries as discussed in Section 3.2.[22] Further, AE is decomposed into a capital frictions component that consists of $\tilde{\lambda}^S_{Ki}$ and $\tilde{\lambda}^T_{Ki}$ and a labor frictions component that consists of $\tilde{\lambda}^S_{Li}$ and $\tilde{\lambda}^T_{Li}$. To see how AE and ATFP change over the years, Figure 3 plots the scatter graph of AE and ATFP.

[Table 1]

[Table 2]

[Figure 3]

The first column in Table 1 reports the sectoral shares (SS). We find that SS is small and approaches zero. The second column reports the allocational efficiency (AE). For example, the result on AE for Japan implies that the aggregate TFP of Japan as compared with that of the U.S. is 8.6% lower because of sector-level resource misallocation. The third column calculates the differences in aggregate TFP (ATFP) between the U.S. and other countries.

The importance of resource misallocation for the difference in aggregate TFP can be measured by dividing AE by ATFP. The results are shown in the fourth column in Table 1. The results range from less than 0% for Germany to more than 100% for the Netherlands. The average figure across countries, when we exclude Germany and the Netherlands, is 17%.[23] This implies that, on average, 17% of the differences in aggregate TFP between the U.S. and other countries are explained by resource misallocation. In addition, the correlation between AE and ATFP in the table is 0.55 (see also the scatter graph in Figure 3). These results suggest that the sector-level resource misallocation is an important factor of cross-country differences in aggregate TFP between these developed countries.

4.4 Contribution of each sector to AE

Using the result in Section 3.3, this section analyzes which sector contributes to AE. Figures 4 and 5 report the capital and labor AE_i calculated using equations (18)–(21).

[22] Although we might expect the value of the U.S. component to be stable across countries, unfortunately, it is not so.

[23] The average of AE/ATFP, when we set the scale as 0% for Germany and 100% for the Netherlands, is 23%.

[Figure 4]

[Figure 5]

Figure 4 reports that for these countries, the magnitude of capital AE_i is large for the transport and financial sectors; this implies that these sectors are the causes of resource misallocation of capital. This is because the return on capital is low (i.e., $\tilde{\lambda}_{Ki}$ is high) in the transport sector, while the return on capital is high (i.e., $\tilde{\lambda}_{Ki}$ is low) in the financial sector (see Figure 1).[24] On the other hand, Figure 5 suggests that the agricultural and financial sectors are the causes of labor misallocation. As in capital AE_i, this is because the return on labor is low (i.e., $\tilde{\lambda}_{Li}$ is high) in the agricultural sector, while the return on labor is high (i.e., $\tilde{\lambda}_{Li}$ is low) in the financial sector (see Figure 2).

4.5 Contribution of sectoral frictions and sectoral shares to AE

As argued in Section 3.4, the AE results depend on the differences in sectoral frictions and the differences in sectoral shares across countries. The interpretation of the results in the previous sections differs depending on the actual cause of the AE. If the former is the cause, the differences in sectoral frictions between countries are a cause of the differences in aggregate TFP between countries. On the other hand, if the latter is the cause, other mechanisms that affect sectoral shares generate the effect of sector-level resource misallocation on the differences in aggregate TFP. Here, in order to identify this problem, I calculate the counterfactual AE discussed in Section 3.4.

The first column in Table 3 reports the counterfactual AE for each country. The magnitude of the counterfactual AE is not small. In order to ascertain the magnitude, I calculate the ratio of the counterfactual AE and the original AE in the second column of Table 3. The ratio varies from less than 0% for Japan to more than 100% for Australia, the Czech Republic, Germany, and the U.K. This result implies that all of the measured misallocation for Japan is due to the differences in sectoral frictions between Japan and the U.S. On the other hand, most of the misallocation effect for Australia is due to the differences in sectoral shares between Australia and the U.S.

[Table 3]

[24] A more explicit reason is that in addition to the fact that the return on capital is low (high), the capital friction of the sector λ_{Ki} is lower (higher) or the sectoral share is higher (lower) in other countries (see Section 3.4).

4.6 Capital intensity α_i

I measure α_i from the U.S. data, under the assumption that the α_i are the same across developed countries. For the robustness check, I also calculate the cross-country AE for the case where the α_i are measured for each country for each year.[25] I report the results in the third column of Table 3. We can confirm that the results are similar to the AE in Table 1.

5 Concluding Remarks

In this paper, I proposed a simple multi-sector accounting framework to measure the effect of resource misallocation on aggregate productivity. The characteristics of this framework are that it is micro-founded, flexible for the assumption on preferences or aggregate production functions, and consistent with the framework commonly used in productivity analysis. Using this framework, I measured the extent to which resource misallocation explains the difference in aggregate TFP across developed countries. I found that sector-level resource misallocation accounted for, on average, 17% of the differences in aggregate TFP among developed countries. I also provided methods to identify the causes of the resource misallocation.

There are some limitations in this paper's analysis. The first involves the interpretation of cross-sectional differences in returns on factor inputs. In this paper, cross-sectional differences in returns are interpreted as distortions. However, other interpretations such as the differences in efficiency wage and the quality of factor inputs (e.g., differences in educational attainment) across sectors, and the existence of investment adjustment costs are also possible. For the former two instances, some of these effects might cancel each other out in a cross-country analysis if the degree of these effects is similar across countries. The effect in the last case might be inferred from the change in the effect of measured frictions over a period of time. However, further improvements are needed to solve these problems. Second, this paper does not take into account material inputs. If frictions on the allocation of materials exist, there can be effects on aggregate productivity.

[25] AE expressed in (16) is modified as follows:

$$\mathrm{AE} = \sum_i \bar{\sigma}_i \left\{ \alpha_i^S \ln \tilde{\lambda}_{Ki}^S - \alpha_i^T \ln \tilde{\lambda}_{Ki}^T \right\} + \sum_i \bar{\sigma}_i \left\{ (1-\alpha_i^S) \ln \tilde{\lambda}_{Li}^S - (1-\alpha_i^T) \ln \tilde{\lambda}_{Li}^T \right\}.$$

The years when $\alpha_i \notin [0,1]$ is measured are eliminated from the calculation (this is the reason why the result for Germany is not available).

Exploration of this issue is also left for future research.

Appendix

A Examples of Sector-level or Firm-level Frictions

In the model in Section 2, the frictions that firms face appear as taxes imposed on their factor inputs, firms are price-takers, and a firm's problem is static. In the following examples, following Chari et al. (2002), I argue that the effect of several types of frictions in each sector is isomorphic to the taxes on this sector's factor inputs—the allocation is the same. In particular, in the last example, the effect of frictions in a *dynamic* model is isomorphic to taxes in the static model in Section 2 in terms of the current period allocation.

As mentioned in Section 4.1, Appendix A.4 explains that α_i measured from factor input cost can have biases for the following models.

A.1 Barrier to labor mobility

Hayashi and Prescott (2008) argue that a barrier to labor mobility from the agricultural sector to the non-agricultural sector was one of the causes of stagnation in prewar Japan. I demonstrate that the allocation of this model can be achieved in the model in Section 2.

First, let us consider a labor immobility model. Suppose that there are two sectors (the agricultural sector A and the non-agricultural sector N). The firms in each sector are competitive. However, there is a constraint on labor mobility between the sectors: labor input in sector A, L_A, has to be at least $\bar{L}_A$ (i.e., $L_A \geq \bar{L}_A$). Notations of the model are basically the same as in Section 2. Then, the typical firm's problem is

$$\max_{K_i, L_i} \; p_i F_i(K_i, L_i) - p_K K_i - p_{Li} L_i, \; i \in \{A \text{ or } N\}. \tag{24}$$

The factor price on labor, p_{Li}, can be different between the sectors, because of the constraint on labor mobility:

$$p_{LA} \neq p_{LN}. \tag{25}$$

Therefore, the allocation may differ from that in the no-friction case.

Suppose that other settings are the same as in Section 2. Then, if I set $(1 + \tau_{LA})p_L = p_{LA}$, $(1 + \tau_{LN})p_L = p_{LN}$, and $(1 + \tau_{Ki}) = 1$ in the Section 2 model, the effect of the barrier to labor mobility is isomorphic to the taxes in the Section 2 model. For the proof, check that equilibrium conditions for these two models are identical.

A.2 Imperfect competition

I demonstrate that frictions caused by imperfect competition such as monopoly, oligopoly, or monopolistic competition can also be expressed as taxes on factor inputs.

Let us consider the following firm's problem: the firm is a price-taker in the factor market but a price-setter in the output market. Notations of the model are basically the same as in Section 2. Accordingly, the firm's cost minimization problem is

$$\min_{K_i, L_i} \; p_K K_i + p_L L_i, \tag{26}$$

$$\text{s.t. } V_i = F_i(K_i, L_i). \tag{27}$$

The FOCs of the problem are

$$p_i \frac{\partial F_i(K_i, L_i)}{\partial K_i} = \frac{p_i}{\gamma_i} p_K, \tag{28}$$

$$p_i \frac{\partial F_i(K_i, L_i)}{\partial L_i} = \frac{p_i}{\gamma_i} p_L, \tag{29}$$

where γ_i is the Lagrange multiplier and p_i is the price of the good that the firm produces. Since γ_i is equal to the marginal cost, p_i/γ_i is the markup and is equal to unity when the firm is a price-taker in the output market.

Suppose that the other settings are the same as in Section 2. Then, if I set $(1 + \tau_{Ki}) = (1 + \tau_{Li}) = p_i/\gamma_i$ in the Section 2 model, the effect of imperfection is isomorphic to the taxes in the Section 2 model. The proof is the same as that in Section A.1.

A.3 Borrowing constraint

Kiyotaki and Moore (1997) show that the differences in the degree of borrowing constraint between firms can affect resource allocation and aggregate productivity. I demonstrate that the allocation of this model at a certain period can be achieved in the model in Section 2.

First, let us consider a recursive borrowing constraint model under no uncertainty. Suppose a typical firm i. The state of the firm is as follows: $K_{i,-1}$ is the capital input and $B_{i,-1}$ is the borrowing. The firm chooses labor input, L_i, new capital, K_i, and new borrowing B_i. For simplicity, the prices are constant. Then, the firm's problem is written as follows:

$$
\begin{aligned}
J_i(K_{i,-1}, B_{i,-1}) = \max_{K_i, L_i, B_i} \quad & \pi_i + mJ_i(K_i, B_i), \\
\text{s.t.} \quad & \pi_i = p_i F_i(K_i, L_i) - p_L L_i - q_K(K_i - (1-\delta)K_{i,-1}) \\
& \qquad + \frac{B_i}{R} - B_{i,-1}, \\
& B_i \leq \theta_i q_K (1-\delta) K_i, \qquad (30)
\end{aligned}
$$

where m is the discount factor, R is the gross interest rate, q_K is the price of capital (not the rental price but the asset price), δ is the depreciation rate, (30) is the firm's borrowing constraint in the next period, and θ_i is the firm's collateral constraint parameter. The other notations are the same as in Section 2. This firm's problem is similar to that of Jermann and Quadrini (2006) except for the timing of the investment and the formulation of the borrowing constraint. Then, the FOCs are rearranged as follows:

$$
\begin{aligned}
p_i \frac{\partial F_i(K_i, L_i)}{\partial K_i} &= q_K - mq_K(1-\delta) - \eta_i \theta_i q_K (1-\delta), \qquad (31) \\
p_i \frac{\partial F_i(K_i, L_i)}{\partial L_i} &= p_L,
\end{aligned}
$$

where η_i is the Lagrange multiplier of the firm's borrowing constraint and is zero when the constraint is not bound.

Suppose that, in the above model, other settings, aggregate capital, and labor of the current period are the same as in the model in Section 2. Then, if I set $(1 + \tau_{Ki})p_K$ to be equal to the RHS of (31) and $(1 + \tau_{Li}) = 1$ in the model in Section 2, the effect of the borrowing constraint is isomorphic to the taxes in the model in Section 2. For the proof, check that (intratemporal) equilibrium conditions for these two models are identical.

A.4 Biases arising in the measurement of α_i

Here, I argue that if there are imperfections in the factor market as in Appendices A.1 and A.3, α_i measured from factor input cost can have biases.

To examine this, take the labor immobility model in Section A.1 as an example. In this model, because of the barrier to labor mobility, the labor input cost is different across sectors, although the quality of labor input is homogeneous in the model. However, the labor input cost is usually measured under the assumption that the cost of labor input with the same quality level is the same between sectors. Thus, measured $1-\alpha_i$ can have biases, if the labor input cost measured in this way is used.[26] A similar problem arises on the capital side in the case of the borrowing constraint model in Section A.3.

B Value of SS when the Differences in $\tilde{\sigma}_i$ are Small

Here, I show that SS defined in Section 3.1 is approximately zero when the differences in $\tilde{\sigma}_i$ between the states S and T are small. When $\sum_i \gamma_i = 1$, the following relationship holds:

$$\begin{aligned}\sum_i \gamma_i \Delta \ln \gamma_i &\simeq \sum_i \gamma_i \frac{\Delta \gamma_i}{\gamma_i}\\ &= 1-1\\ &= 0.\end{aligned}$$

By setting $\gamma_i \equiv \tilde{\sigma}_i \alpha_i / \tilde{\alpha}$ or $\gamma_i \equiv \tilde{\sigma}_i(1-\alpha_i)/(1-\tilde{\alpha})$, we find that

$$\bar{\alpha} \sum_i \frac{\bar{\sigma}_i \alpha_i}{\bar{\alpha}} \Delta \ln \left(\frac{\tilde{\sigma}_i \alpha_i}{\tilde{\alpha}} \right) \text{ and } (1-\bar{\alpha}) \sum_i \frac{\bar{\sigma}_i (1-\alpha_i)}{1-\bar{\alpha}} \Delta \ln \left(\frac{\tilde{\sigma}_i (1-\alpha_i)}{1-\tilde{\alpha}} \right)$$

are approximately zero (Δ denotes the difference between states S and T). Finally, SS is the sum of these terms.

[26] In this case, $1-\alpha_i$ measured from the revenue share does not have biases.

C Relation between AE_i and AE

This appendix shows that if $\tilde{\sigma}_i^S$ and $\tilde{\sigma}_i^T$ are small for each sector, the sum of AE_i is approximately equal to AE. The sum of the capital AE_i, AE_{Ki}, in (19) can be written as follows:

$$\sum_i \mathrm{AE}_{Ki} = \mathrm{AE}_K + \sum_i (\bar{\alpha} - \bar{\sigma}_i \alpha_i) \ln \left(\frac{\tilde{\lambda}^S_{K-i}}{\tilde{\lambda}^T_{K-i}} \right),$$

where AE_K is the capital component of AE ($\mathrm{AE}_K \equiv \sum_i \bar{\sigma}_i \alpha_i \ln \left(\tilde{\lambda}^S_{Ki} / \tilde{\lambda}^T_{Ki} \right)$). We show that the second term of the RHS of the above equation approximately becomes zero. Then, the sum of AE_{Ki} is approximately equal to AE_K. In the same manner, we can show that the sum of AE_{Li} is also approximately equal to AE_{Li}. Thus, we can show the statement of the appendix.

To demonstrate that the second term of the RHS of the above equation approximately becomes zero, I further focus on the state S component (the same result applies to the state T component). Thus, I show

$$\sum_i (\bar{\alpha} - \bar{\sigma}_i \alpha_i) \ln \tilde{\lambda}^S_{K-i} \simeq 0, \tag{32}$$

when $\tilde{\sigma}_i^S$ and $\tilde{\sigma}_i^T$ are small (note that $\bar{\sigma}_i$ depends on $\tilde{\sigma}_i^T$). From (18), we obtain the following relationship:

$$\tilde{\lambda}^S_{K-i} = 1 + \frac{1 - \tilde{\lambda}^S_{Ki}}{\frac{\tilde{\alpha}^S}{\tilde{\sigma}_i^S \alpha_i} - 1}$$

By substituting the above in the LHS of (32) and rearranging, we obtain

$$\begin{aligned}
(32) &= \sum_i \left(\frac{\bar{\alpha} - \bar{\sigma}_i \alpha_i}{\tilde{\alpha}^S - \tilde{\sigma}_i^S \alpha_i} \right) \left(\frac{\tilde{\alpha}^S}{\tilde{\sigma}_i^S \alpha_i} - 1 \right) \tilde{\sigma}_i^S \alpha_i \ln \left(1 + \frac{1 - \tilde{\lambda}^S_{Ki}}{\frac{\tilde{\alpha}^S}{\tilde{\sigma}_i^S \alpha_i} - 1} \right) \\
&= \sum_i \left(\frac{\bar{\alpha} - \bar{\sigma}_i \alpha_i}{\tilde{\alpha}^S - \tilde{\sigma}_i^S \alpha_i} \right) \tilde{\sigma}_i^S \alpha_i \ln \left(1 + \frac{1 - \tilde{\lambda}^S_{Ki}}{\frac{\tilde{\alpha}^S}{\tilde{\sigma}_i^S \alpha_i} - 1} \right)^{\frac{\tilde{\alpha}^S}{\tilde{\sigma}_i^S \alpha_i} - 1}.
\end{aligned}$$

For sufficiently small $\tilde{\sigma}_i^S$ and $\tilde{\sigma}_i^T$,

$$\left(\frac{\bar{\alpha} - \bar{\sigma}_i \alpha_i}{\tilde{\alpha}^S - \tilde{\sigma}_i^S \alpha_i}\right) \simeq \frac{\bar{\alpha}}{\tilde{\alpha}^S}, \text{ and } \left(1 + \frac{1 - \tilde{\lambda}_{Ki}^S}{\frac{\tilde{\alpha}^S}{\tilde{\sigma}_i^S \alpha_i} - 1}\right)^{\frac{\tilde{\alpha}^S}{\tilde{\sigma}_i^S \alpha_i} - 1} \simeq \exp\left(1 - \tilde{\lambda}_{Ki}^S\right).$$

Thus, if $\tilde{\sigma}_i^S$ and $\tilde{\sigma}_i^T$ are small in all the sectors,

$$\begin{aligned}(32) &\simeq \frac{\bar{\alpha}}{\tilde{\alpha}^S} \sum_i \tilde{\sigma}_i^S \alpha_i \left(1 - \tilde{\lambda}_{Ki}^S\right) \\ &= 0.\end{aligned}$$

The last equation becomes zero, because from definition $\sum_i \tilde{\sigma}_i^S \alpha_i = \tilde{\alpha}^S$ and $\sum_i \tilde{\sigma}_i^S \alpha_i \tilde{\lambda}_{Ki}^S = \tilde{\alpha}^S$.

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	SS	AE	ATFP	AE/ATFP
Australia	0.9%	−5.0%	−28.5%	17%
Austria	−0.3%	−8.2%	−46.0%	18%
Czech Republic	−0.8%	−4.8%	−82.5%	6%
Denmark	0.2%	−5.9%	−16.5%	36%
Finland	−1.0%	−9.3%	−29.2%	32%
Germany	−0.7%	1.8%	−15.1%	−12%
Italy	−0.4%	−4.9%	−42.2%	12%
Japan	−1.6%	−8.6%	−71.9%	12%
Netherlands	0.5%	−5.8%	−0.2%	2584%
Portugal	0.0%	−16.0%	−78.1%	20%
Sweden	−0.5%	−4.6%	−25.1%	18%
U.K.	0.3%	−0.7%	−24.2%	3%
Average				17%
Correlation				0.55

Table 1: Sectoral share (SS), allocational efficiency (AE), aggregate TFP (ATFP), and AE divided by ATFP (AE/ATFP) of the countries compared with the U.S. Notes: AE (or SS + AE) measures the effect of resource misallocation on the difference in aggregate TFP (ATFP) between other countries and the U.S. Moreover, AE/ATFP measures the extent to which the differences in aggregate TFP between the countries are explained by resource misallocation. "Average" is the average of AE/ATFP across the countries when we exclude Germany and the Netherlands. "Correlation" is the correlation between AE and ATFP. These values are the averages over the years.

	Each country	U.S.	Capital	Labor
Australia	−7.8%	2.8%	−4.4%	−0.6%
Austria	−12.1%	4.0%	−3.1%	−5.1%
Czech Republic	−7.8%	3.0%	−3.6%	−1.2%
Denmark	−10.2%	4.3%	−3.8%	−2.1%
Finland	−12.9%	3.5%	−5.3%	−4.1%
Germany	−4.5%	6.2%	0.1%	1.6%
Italy	−8.8%	3.9%	0.1%	−5.1%
Japan	−13.9%	5.3%	−4.0%	−4.6%
Netherlands	−9.9%	4.0%	−1.2%	−4.6%
Portugal	−19.0%	3.1%	−2.7%	−13.3%
Sweden	−9.8%	5.2%	−4.3%	−0.3%
U.K.	−5.3%	4.6%	−0.5%	−0.2%

Table 2: Two decompositions of AE. Notes: In the first two columns, the AE in Table 1 is decomposed into two components: each country and the U.S.; in the last two columns, the AE is decomposed into capital and labor components. (In both cases, the sum of the components is equal to the AE in Table 1.) These values are the averages over the years.

	CFAE	CFAE/AE	AE with diff α_i
Australia	−7.1%	142%	−5.8%
Austria	−3.1%	38%	−9.6%
Czech Republic	−6.1%	126%	−3.9%
Denmark	−2.7%	45%	−5.9%
Finland	−3.6%	39%	−5.6%
Germany	1.8%	100%	n.a.
Italy	−3.2%	65%	−5.9%
Japan	0.3%	−4%	−9.7%
Netherlands	−4.2%	73%	−4.4%
Portugal	−6.4%	40%	−13.5%
Sweden	−0.6%	14%	−4.3%
U.K.	−2.6%	381%	−3.2%

Table 3: Counterfactual AE_i (CFAE in the table), the ratio of CFAE and AE (CFAE/AE), and AE with country-specific α_i (AE with diff α_i). Notes: Counterfactual AE measures the effect of resource misallocation on aggregate TFP when the frictions of each country are the same as those of the U.S., but the sectoral shares are not. AE with country-specific α_i is calculated using α_i measured for each country for each year. These values are the averages over the years.

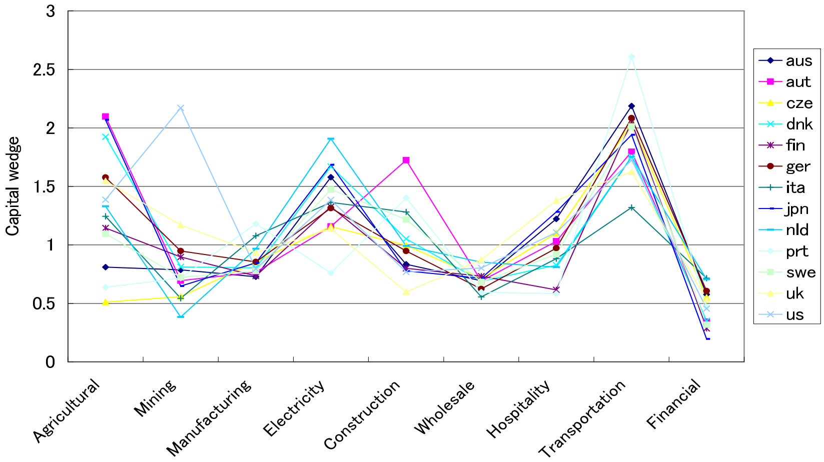

Figure 1: Measured capital wedge $\tilde{\lambda}_{Ki}$ for each country. Note: These values are the averages over the years.

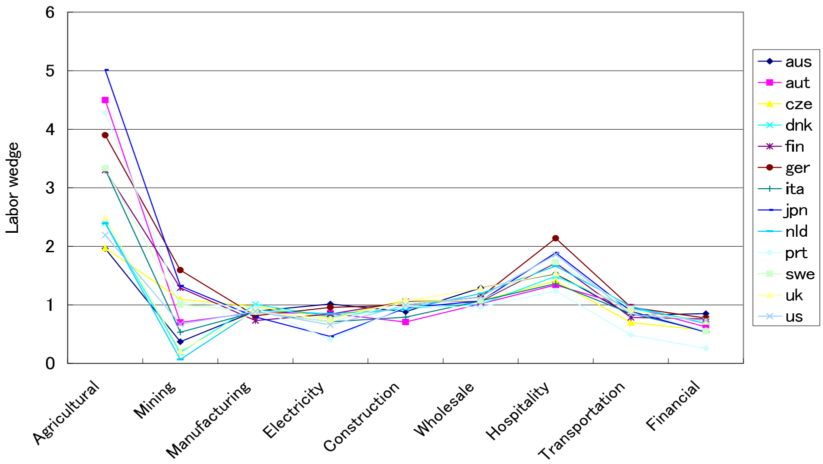

Figure 2: Measured labor wedge $\tilde{\lambda}_{Li}$ for each country. Note: These values are the averages over the years.

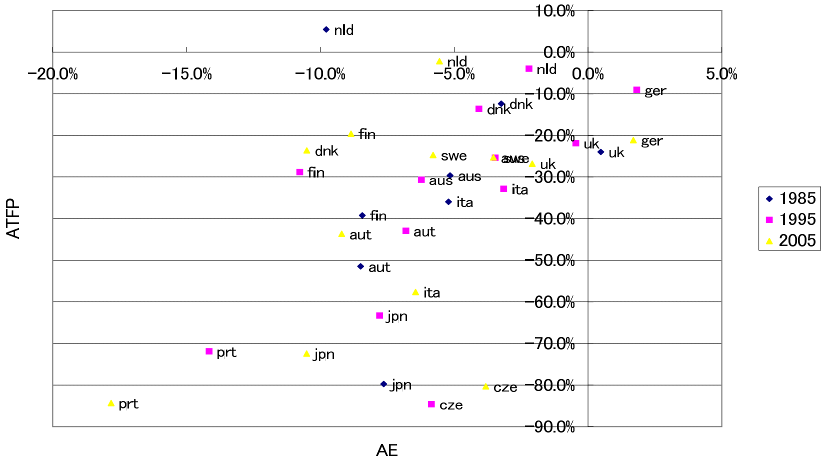

Figure 3: Scatter graph of allocational efficiency (AE) and aggregate TFP (ATFP) of the countries compared with the U.S. for 1985, 1995, and 2005. Note: AE measures the effect of resource misallocation on the difference in aggregate TFP (ATFP) between other countries and the U.S.

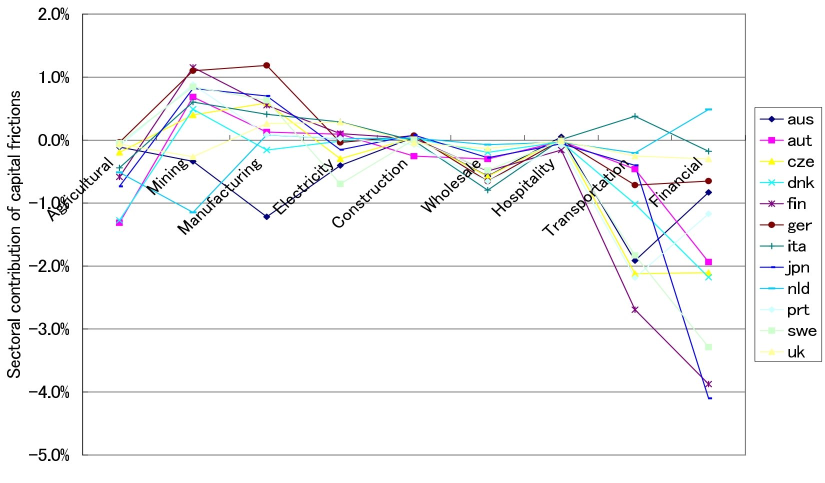

Figure 4: Sectoral contribution of capital frictions, capital AE_i. Notes: Capital AE_i measures the effect of sector i's capital frictions on aggregate TFP. These values are the averages over the years.

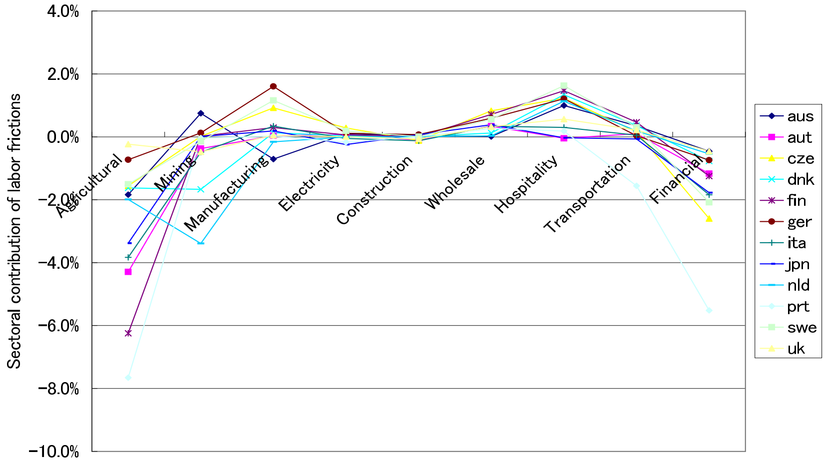

Figure 5: Sectoral contribution of labor frictions, labor AE_i. Notes: Labor AE_i measures the effect of sector i's labor frictions on aggregate TFP. These values are the averages over the years.