Structural Propagation of Productivity Shocks: The Case of Korea

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Keywords: productivity, general equilibrium, structural propagation
JEL classification: C67, D57

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Structural Propagation of Productivity Shocks: The Case of Korea

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Abstract

We model the transition of technological structure that is associated with the changes in cost induced by the innovation that occurred, using a system of multi-sector, multi-factor production functions. Structural propagation is quantified by using a system of unit-cost functions compatible with multi-level CES, plain CES, Cobb–Douglas, and Leontief production functions whose parameters we estimate via two timely distant input–output accounts. The economy-wide welfare gain obtainable for an exogenously given innovation will hence be quantified via the technological structure after structural propagation. Welfare gain due to productivity doubling for the medical and health services (public) industry is studied as an example, using the 2000–2005 Korean linked input–output table as the source of data.

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1. Introduction

In this study, we present a methodology that fully accounts for the feedback effect from introducing new technologies into the system of economy-wide production. In so doing, we take the technological substitutions fully into account. While it is known that technology will not substitute under some standard conditions (hence, technological structure will maintain), as far as the change in the final demand is concerned,[1] this will not be the case when any new technology is actually introduced within an industry; technology can be substituted in accordance with the price changes in the factor inputs, which will be triggered by the introduction of a new technology or innovation in any other industry. As the disposition of potential (alternative) technologies is represented by the curvature (or the elasticity of substitution) of a production function, measurement of elasticities has been central to applied quantitative analyses based on general equilibrium frameworks.

Hence, in terms of purpose and motivation, this study is in the same vein of research as studies of computable general equilibrium (CGE) models. CGE modelers, however, frequently resort to selecting elasticities from the empirical literature on the basis of judgement and assumptions (Wing, 2009). Meanwhile, classic multi-sectoral analyses such as Kuroda et al. (1984) have used sector-wise translog production functions for multiple (KLEM) factor inputs, while Saito and Tokutsu (1989) used multi-level constant elasticity of substitution (CES) production functions, all based upon time-series data.[2] Even recently, production functions for KLEM factor inputs have been estimated by using time-series data (van der Werf, 2008; Okagawa and Ban, 2008; Koesler and Schymura, 2015).

In this study, we estimate the elasticity of substitution for multiple industrial sectors by relying more on cross-sectional data (specifically, linked input–output tables) than on time series. We explore two types of production function for multiple industrial sectors. The first is a multi-level, multi-factor CES whose elasticities (between one factor input and a composite of factor inputs) are measured in a stratified manner for all factor inputs for each sector. The stage elasticities are determined by using the price indices and coefficients of the linked input–output tables along with industry-wise productivity, which we estimate via Törnqvist aggregation. The second is a multi-

[1]This non-substitution theorem will hold under the conditions of constant returns to scale technology, one-to-one correspondences between commodity and industry, and when the number of primary inputs is one (Georgescu-Roegen, 1951).

[2]A two-factor CES function was first introduced by Arrow et al. (1961). It was later shown that the elasticities were still unique in the case of more than two factors (Uzawa, 1962; McFadden, 1963). A two-level CES production function was first introduced by Sato (1967).

factor (plain) CES whose elasticity of substitution is uniquely determined for each sector. Sector-wise elasticities of plain CES functions are estimated by regressing the log differences of the price ratios (which are obtainable by using price indices estimated from linked input–output tables) against the log differences of the cost shares (which are also obtainable from the coefficients of linked input–output tables). Moreover, sector-wise CES-compatible productivity gain can be estimated at the same time from the constant terms of the regression. The numbers of industries and intermediate inputs (excluding primary factors) are the same so that an equilibrium price can be obtained as the fixed point of a system of unit-cost functions that are dual to the production functions. The structural transition of the input–output structure can then be monitored as gradients for the unit-cost functions.

The remainder of this paper is organized as follows. In the next section, we measure the gain in sector-wise total factor productivity during 2000–2005, using linked input–output tables for Korea (BOK, 2015). In doing this, we aggregate labor and capital inputs so that there is a single primary input in addition to the intermediate inputs. In Section 2, we measure the parameters for the multi-factor (plain) CES, and the multi-level CES production functions via regression and solving simultaneous equations, respectively, based on the same database (linked input–output tables for Korea (BOK, 2015)). In Section 3, we formulate the structural propagation under the system of multi-sector, multi-factor production functions, and demonstrate structural propagations triggered by some exogenously given changes in productivity. Section 4 provides concluding remarks.

2. Production Functions

2.1. Productivity gain

We start with the production function of an industry (the index j is omitted):

$$y = zf\left(x_0, x_1, \ldots, x_n\right) = zf\left(\mathbf{x}\right). \tag{1}$$

Here, we denote the output of this production by y, and the ith input by x_i. The total factor productivity (TFP), which reflects the technology level of the industry, is denoted by z. The function $f(\mathbf{x})$ is assumed to be homogeneous of degree one with respect to the inputs (i.e., constant returns to scale are assumed). Taking the log and time derivatives, we have

$$\frac{\dot{y}}{y} = \frac{\dot{z}}{z} + \sum_{i=0}^{n} \left(\frac{\partial f\ (\mathbf{x})}{\partial x_i} \frac{x_i}{f\ (\mathbf{x})} \right) \frac{\dot{x}_i}{x_i} \tag{2}$$

The term in parentheses is the cost share. This will be true under the following monetary balance of constant returns to scale production:

$$py = pzf\ (\mathbf{x}) = \sum_{i=0}^{n} p_i x_i , \qquad pz \frac{\partial f\ (\mathbf{x})}{\partial x_i} = p_i$$

We may thus describe the cost share of input i, which we denote by α_i, as follows:

$$\frac{p_i x_i}{py} = \frac{\partial f\ (\mathbf{x})}{\partial x_i} \frac{x_i}{f\ (\mathbf{x})} = \alpha_i . \tag{3}$$

We integrate (2) over two periods $t = [0, 1]$ in order to obtain productivity growth $\int_0^1 \mathrm{d} \ln z = \Delta \ln z$ as

$$\int_0^1 \mathrm{d} \ln y = \int_0^1 \mathrm{d} \ln z + \sum_{i=0}^{n} \int_0^1 \alpha_i \mathrm{d} \ln x_i . \tag{4}$$

However, in regard to (2), the right-hand side involves integration by parts, that is, $\int_0^1 \alpha_i \mathrm{d} \ln x_i$. Assume that the trajectory scenarios for α_i and x_i follow

$$\alpha_i (t) = \left(a_i^1 - a_i^0\right) \tau(t) + a_i^0, \quad x_i (t) = x_i^0 \exp\left(\tau(t) \ln x_i^1 / x_i^0\right),$$

where $\tau(t)$ is a function of time satisfying $\tau(0) = 0$ and $\tau(1) = 1$, so that $x_i (0) = x_i^0$, $x_i (1) = x_i^1$, $\alpha_i (0) = a_i^0$, and $a_i (1) = \alpha_i^1$. Note that this will always be true for translog functions whose cost shares are linear with respect to the log of inputs. In this case, the integration reduces to

$$\int_0^1 \alpha_i \mathrm{d} \ln x_i = \frac{a_i^1 + a_i^0}{2} \Delta \ln x_i .$$

Thus, (4) is reduced as follows, obtaining productivity growth using Törnqvist aggregation (i.e., $\bar{a}_i = \left(a_i^1 + a_i^0\right)/2$):[3]

$$\Delta \ln z = \Delta \ln y - \sum_{i=0}^{n} \bar{a}_i \Delta \ln x_i .$$

The above formula can also be described by way of monetary output $Y = py$ and input $X_i = p_i x_i$, such that

$$\Delta \ln z = (\Delta \ln Y - \Delta \ln p) - \sum_{i=0}^{n} \bar{a}_i \left(\Delta \ln X_i - \Delta \ln p_i\right) . \tag{5}$$

The productivity gain observed between two periods $t = 0$ and $t = 1$ for an industrial sector j (i.e., $z_j^1/z_j^0 = \exp\left(\Delta \ln z_j\right)$) can then be calculated by way of input–output transactions X_{ij} and Y_j, cost share accounts a_{ij}, and deflators for all commodity prices $p_i^1/p_i^0 = \exp(\Delta \ln p_i)$, using (5). For subsequent study, we estimated total factor productivity gain for 350 industrial sectors from the Korean linked input–output tables (coefficients and transactions) and deflators for 2000–2005 (BOK, 2015). Note that we aggregated fixed capital with labor inputs for simplicity, so that there is only one primary factor ($i = 0$). Figure 1 illustrates the estimated values of productivity gain z_j^1/z_j^0 of sector j.

2.2. Multi-level CES production function

The multi-level CES production function of $n + 1$ factors for an industrial sector (whose index j is omitted) is

$$\begin{aligned} y &= z\,\Xi_0 \\ \Xi_i &= \left(\delta_i^{\frac{1}{\sigma_i}} x_i^{\frac{\sigma_i - 1}{\sigma_i}} + (1-\delta_i)^{\frac{1}{\sigma_i}}\, \Xi_{i+1}^{\frac{\sigma_i - 1}{\sigma_i}}\right)^{\frac{\sigma_i}{\sigma_i - 1}}, \quad i = 0, 1, \cdots, n-1, \end{aligned} \tag{6}$$

where Ξ_{i+1} denotes the composite factor of the $i + 1$th and subsequent factors. The last composite factor must coincide with the last input factor, that is, $\Xi_n = x_n$. Also, we denote by δ_i the share parameter for the ith factor, and by σ_i the elasticity of substitution between the ith factor and the $i + 1$th composite factors.

[3] Star and Hall (1976) showed that Törnqvist aggregation is a robust approximation with respect to trajectory scenarios. Törnqvist aggregation gives the exact productivity index for translog functions (Diewert, 1976).

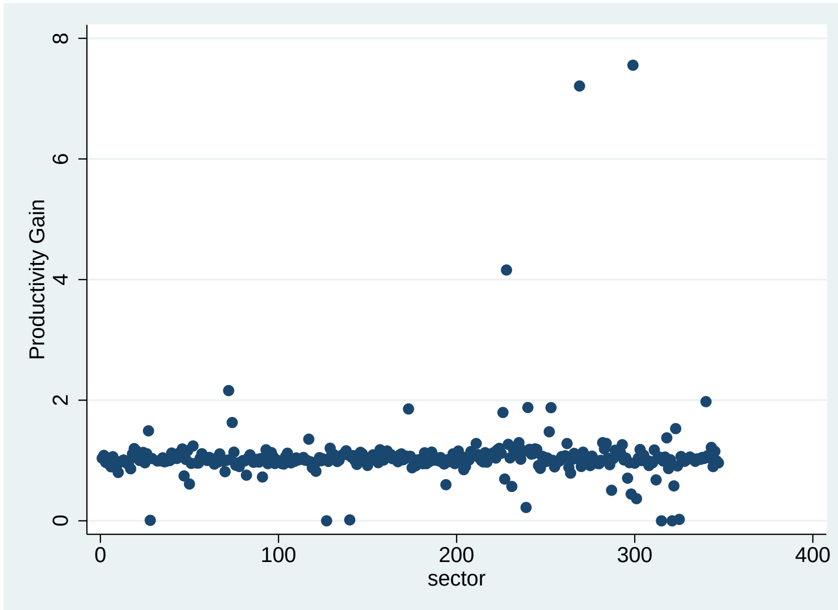

Figure 1: Estimates of TFP gain (z_j^1/z_j^0) for various industrial sectors, based on the 2000–2005 linked input–output tables of Korea (BOK, 2015). Notable sectors with large numbers are postal services (7.55), residential building construction (7.21), and household audio equipment (4.15).

The unit-cost function focusing on the baseline nest level $(i = 0)$ of (6) is

$$c = \frac{1}{z}\left(\delta_0 p_0^{1-\sigma_0} + (1-\delta_0)\,\Phi_1^{1-\sigma_0}\right)^{\frac{1}{1-\sigma_0}}, \tag{7}$$

where p_0 and Φ_1 denote prices for x_0 and Ξ_1, respectively.

By applying Shephard's Lemma to (7), the cost share of the 0th input a_0 is derived as

$$a_0 = \frac{\partial c}{\partial p_0}\frac{p_0}{c} = \delta_0\,(zc/p_0)^{\sigma_0-1} = \delta_0\,(\Phi_0/p_0)^{\sigma_0-1}, \tag{8}$$

where we used $\Phi_0 \equiv zc$, or the baseline unit cost.[4] Suppose cost shares (a_i), relative prices (p_i), and the relative productivity (z) for two periods are available via a linked input–output table for all sectors. By taking the log of (8) at two periods (where time periods $(t = 0, 1)$ are indexed via superscripts with parenthesis) while assuming the

[4]We call Φ_0 the baseline unit cost because it reflects the unit cost without productivity gain.

parameters are stable between the two periods, we have

$$\begin{aligned}\ln a_0^{(0)} &= \ln \delta_0 + (\sigma_0 - 1) \ln \Phi_0^{(0)} / p_0^{(0)} \\ \ln a_0^{(1)} &= \ln \delta_0 + (\sigma_0 - 1) \ln \Phi_0^{(1)} / p_0^{(1)}.\end{aligned}$$

By subtracting and reorganizing terms we obtain

$$\sigma_0 = \frac{\Delta \ln a_0 / p_0 + \Delta \ln \Phi_0}{\Delta \ln \Phi_0 / p_0} = \frac{\ln a_0^{(1)} - \ln a_0^{(0)}}{\ln \Phi_0^{(1)} / p_0^{(1)} - \ln \Phi_0^{(0)} / p_0^{(0)}} + 1 \tag{9}$$

$$\delta_0 = a_0 p_0^{\sigma_0 - 1} \Phi_0^{1-\sigma_0} = a_0^{(0)} \left(\Phi_0^{(0)} / p_0^{(0)} \right)^{1-\sigma_0} = a_0^{(1)} \left(\Phi_0^{(1)} / p_0^{(1)} \right)^{1-\sigma_0}. \tag{10}$$

We thus see that the 0th level parameters are derivable by values available from a linked input–output table. Further, by substituting the parameters (9) and (10) into (7) we obtain

$$\Phi_1 = \left(\frac{\Phi_0^{1-\sigma_0} - \delta_0 p_0^{1-\sigma_0}}{1 - \delta_0} \right)^{\frac{1}{1-\sigma_0}}.$$

Next, consider the unit-cost function of the 1st level composite:

$$\Phi_1 = \left(\delta_1 p_1^{1-\sigma_1} + (1 - \delta_1) \Phi_2^{1-\sigma_1} \right)^{\frac{1}{1-\sigma_1}}. \tag{11}$$

From (7) and (11), we have

$$\frac{\partial c}{\partial \Phi_1} = (1 - \delta_0) c^{\sigma_0} z^{\sigma - 1} \Phi_1^{-\sigma_0}, \qquad \frac{\partial \Phi_1}{\partial p_1} = \delta_1 \Phi_1^{\sigma_1} p_1^{-\sigma_1}, \tag{12}$$

so by (12) the cost share for the 1st (nesting-level) input factor becomes

$$a_1 = \frac{\partial c}{\partial p_1} \frac{p_1}{c} = \frac{\partial c}{\partial \Phi_1} \frac{\partial \Phi_1}{\partial p_1} \frac{p_1}{c} = \delta_1 (1 - \delta_0) \Phi_0^{\sigma_0 - 1} \Phi_1^{\sigma_1 - \sigma_0} p_1^{1-\sigma_1}. \tag{13}$$

Here again by taking the log and subtracting the two observations on (13), we obtain the parameters

$$\sigma_1 = \frac{\Delta \ln a_1 / p_1 + \Delta \ln \Phi_0^{1-\sigma_0} + \Delta \ln \Phi_1^{\sigma_0}}{\Delta \ln \Phi_1 / p_1} \tag{14}$$

$$\delta_1 = \frac{a_1 p_1^{\sigma_1 - 1} \Phi_0^{1-\sigma_0} \Phi_1^{\sigma_0 - \sigma_1}}{1 - \delta_0}. \tag{15}$$

We may then substitute (14) and (15) into (11) to obtain Φ_2 as

$$\Phi_2 = \left(\frac{\Phi_1^{1-\sigma_1} - \delta_1 p_1^{1-\sigma_1}}{1-\delta_1} \right)^{\frac{1}{1-\sigma_1}}.$$

Further, let us decompose the 2nd composite price into the 2nd factor input and the remaining (3rd) composite as

$$\Phi_2 = \left(\delta_2 p_2^{1-\sigma_2} + (1-\delta_2)\, \Phi_3^{1-\sigma_2} \right)^{\frac{1}{1-\sigma_2}}. \tag{16}$$

From (11) and (16), we have

$$\frac{\partial \Phi_1}{\partial \Phi_2} = (1-\delta_1)\Phi_1^{\sigma_1}\Phi_2^{-\sigma_1}, \qquad \frac{\partial \Phi_2}{\partial p_2} = \delta_2 \Phi_2^{\sigma_2} p_2^{-\sigma_2}, \tag{17}$$

so by (12) and (17) the cost share for the 2nd (nesting-level) input factor becomes

$$\begin{aligned} a_2 &= \frac{\partial c}{\partial p_2}\frac{p_2}{c} = \frac{\partial c}{\partial \Phi_1}\frac{\partial \Phi_1}{\partial \Phi_2}\frac{\partial \Phi_2}{\partial p_2}\frac{p_2}{c} \\ &= \delta_2\,(1-\delta_1)\,(1-\delta_0)\,\Phi_0^{\sigma_0-1}\Phi_1^{\sigma_1-\sigma_0}\Phi_2^{\sigma_2-\sigma_1}\,p_2^{1-\sigma_2}. \end{aligned} \tag{18}$$

By taking the log and subtracting the two observations on (18), we obtain the parameters

$$\sigma_2 = \frac{\Delta \ln a_2/p_2 + \Delta \ln \Phi_0^{1-\sigma_0} + \Delta \ln \Phi_1^{\sigma_0-\sigma_1} + \Delta \ln \Phi_2^{\sigma_1}}{\Delta \ln \Phi_2/p_2} \tag{19}$$

$$\delta_2 = \frac{a_2 p_2^{\sigma_2-1}\Phi_0^{1-\sigma_0}\Phi_1^{\sigma_0-\sigma_1}\Phi_2^{\sigma_1-\sigma_2}}{(1-\delta_0)(1-\delta_1)}. \tag{20}$$

We may then substitute (19) and (20) into (16) to obtain Φ_3:

$$\Phi_3 = \left(\frac{\Phi_2^{1-\sigma_2} - \delta_2 p_2^{1-\sigma_2}}{1-\delta_2} \right)^{\frac{1}{1-\sigma_2}}.$$

We can execute this procedure for $i = 1, \cdots, n$ until it reaches the last input factor.

The generic formula for obtaining parameters is

$$\sigma_i = \frac{\Delta \ln a_i / p_i + \Delta \ln \Phi_0^{1-\sigma_0} + \sum_{k=1}^{i-1} \Delta \ln \Phi_k^{\sigma_{k-1}-\sigma_k} + \Delta \ln \Phi_i^{\sigma_{i-1}}}{\Delta \ln \Phi_i / p_i} \tag{21}$$

$$\delta_i = \frac{a_i p_i^{\sigma_i - 1} \Phi_0^{1-\sigma_0} \prod_{k=1}^{i} \Phi_k^{\sigma_{k-1}-\sigma_k}}{\prod_{k=1}^{i} (1 - \delta_{k-1})}, \tag{22}$$

where the initial parameter values are given by (9) and (10). Furthermore, the generic composite price is

$$\Phi_i = \left(\frac{\Phi_{i-1}^{1-\sigma_{i-1}} - \delta_{i-1} p_{i-1}^{1-\sigma_{i-1}}}{1 - \delta_{i-1}} \right)^{\frac{1}{1-\sigma_{i-1}}}. \tag{23}$$

Note that the initial value is given as $\Phi_0 = zc$, while the last composite price is that of the nth input factor, so that $\Phi_n = p_n$.

2.3. Plain CES production function

A plain CES production function of an industrial sector (the index j is omitted) is of the form

$$y = zf(\mathbf{x}) = z \left(\delta_0^{\frac{1}{\sigma}} x_0^{\frac{\sigma-1}{\sigma}} + \delta_1^{\frac{1}{\sigma}} x_1^{\frac{\sigma-1}{\sigma}} + \cdots + \delta_n^{\frac{1}{\sigma}} x_n^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}, \tag{24}$$

where the share parameters ($\delta_i > 0, \sum_i \delta_i = 1$) and the elasticity of substitution $\sigma \geq 0$ are subject to estimation. Because we assume that the productivity gain is available, we set the benchmark ($t = 0$) absolute productivity $z^0 = 1$ and the ex-post ($t = 1$) absolute productivity $z^1 = \exp(\Delta \ln z)$ in regard to (5).

The CES unit-cost function compatible with the production function (24) is

$$h(p_0, \mathbf{p}; z) = \frac{1}{z} \left(\delta_0 p_0^{1-\sigma} + \delta_1 p_1^{1-\sigma} + \cdots + \delta_n p_n^{1-\sigma} \right)^{1/(1-\sigma)}. \tag{25}$$

The cost share of the ith input α_i can be found, in regard to Shephard's Lemma, by differentiating this unit-cost function. That is,

$$\alpha_i = \frac{\partial h(p_0, \mathbf{p}; z)}{\partial p_i} \frac{p_i}{p} = \delta_i (zp/p_i)^{\sigma-1}. \tag{26}$$

We suppose that the cost shares can be monitored for two periods $t = 0, 1$. That is,

$$\alpha_i^0 = \delta_i \left(z^0 p^0 / p_i^0 \right)^{\sigma-1}, \quad \alpha_i^1 = \delta_i \left(z^1 p^1 / p_i^1 \right)^{\sigma-1}. \tag{27}$$

Naturally, the parameters δ_i and σ are assumed to be constant over time, but there is only a small chance that these identities are simultaneously true. We therefore find the parameters that best fit the two observations. We first rewrite (27) to describe the share parameter δ_i as a function of σ that is consistent with observations for the two periods. That is,

$$\delta_i(\sigma; t = 0) \equiv \alpha_i^0 \left(z^0 p^0 / p_i^0\right)^{1-\sigma}, \quad \delta_i(\sigma; t = 1) \equiv \alpha_i^1 \left(z^1 p^1 / p_i^1\right)^{1-\sigma}.$$

These parameters are constant, so we search for the value of σ for which these two parameters are as close as possible. In other words, we set

$$\sigma = \arg\max_{\sigma \geq 0} D\left(\boldsymbol{\delta}(\sigma; t = 0), \boldsymbol{\delta}(\sigma; t = 1)\right), \tag{28}$$

where $D(\mathbf{r}, \mathbf{s})$ is some distance function between vectors $\mathbf{r}$ and $\mathbf{s}$. In this study, we employ the following squared sum of log-deviations:

$$D(\mathbf{r}, \mathbf{s}) = \textstyle\sum_i (\ln r_i - \ln s_i)^2 .$$

The rationale for using this distance metric is as follows. By taking the log of the cost shares equality (26), we have

$$\ln \alpha_i = \ln \delta_i + (\sigma - 1) \ln (zp/p_i) .$$

Hence, we may consider estimating $(\sigma - 1)$ via regression through the origin, using two time-distant observations of the variables as

$$\Delta \ln \alpha_i = (\sigma - 1) \Delta \ln (zp/p_i) + \Delta \ln \delta_i, \tag{29}$$

assuming that $\Delta \ln \delta_i$ (which is supposed to be null for every i) is normally distributed with mean zero. That is, the solution for (28) is essentially the same as the estimate via regression through the origin (29).[5]

Figure 2 shows the estimated elasticities with corresponding P-values for 350 industrial sectors, using the Korean linked input–output tables for 2000 and 2005 (BOK, 2015). Of the 350 sectors, 168 had P-values over 10%, for which we accepted the null hypothesis (so we set $\sigma - 1 = 0$). As a result, no sector was estimated to be Leontief ($\sigma = 0$), while one sector (regenerated fiber yarn) was estimated to be sub-Cobb–

[5] The only difference is that all negative estimates for σ via (29) are zeroed in the case of (28).

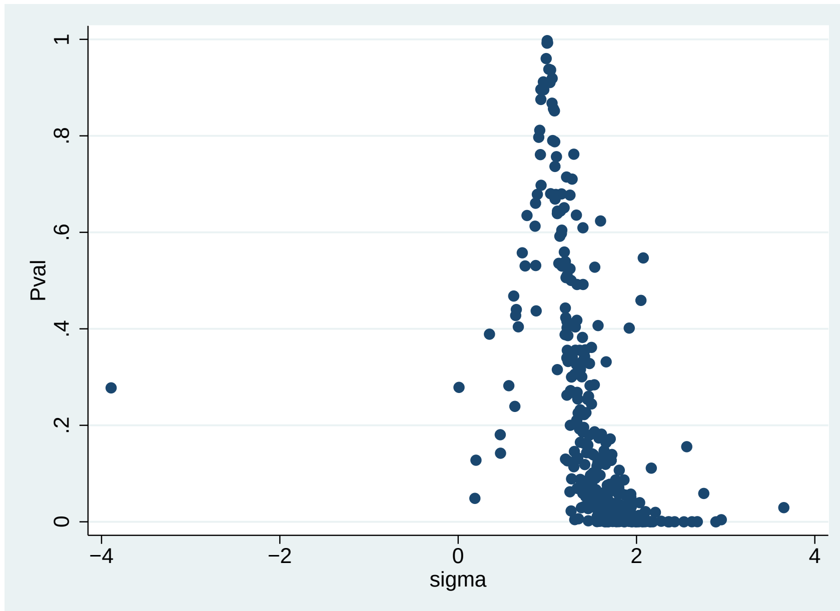

Figure 2: P-values vs. estimates for σ

Douglas ($\sigma = 0.188 < 1$). Otherwise, 168 sectors were set to be Cobb–Douglas, and the remaining 181 sectors were estimated to be meta-Cobb–Douglas ($\sigma > 1$). The accepted elasticities are shown in Figure 3. The sector-wise estimates are shown in Tables 2–8.

Further, for the subsequent analysis of structural propagation, we calibrated the sector-wise CES parameters δ_{ij} to agree with the latest technological structure (i.e., that revealed by the 2005 input–output coefficients) under the estimated marginal elasticity of substitution σ_j, while resetting the relative productivity gain z_j to unity. In other words, we set the parameters according to the latter equilibrium price p_j and cost shares a_{ij} (or input–output coefficients) for the reference period so that they satisfy the identity

$$\delta_{ij} = a_{ij} \left(p_j / p_i \right)^{1-\sigma_j} . \tag{30}$$

Note that because CES comprehends both Cobb–Douglas ($\sigma_j = 1$) and Leontief ($\sigma_j = 0$) functions with regard to the elasticities, δ_{ij} equals the monetary input–output coefficient (a_{ij}) for Cobb–Douglas functions, and the physical input–output coefficient

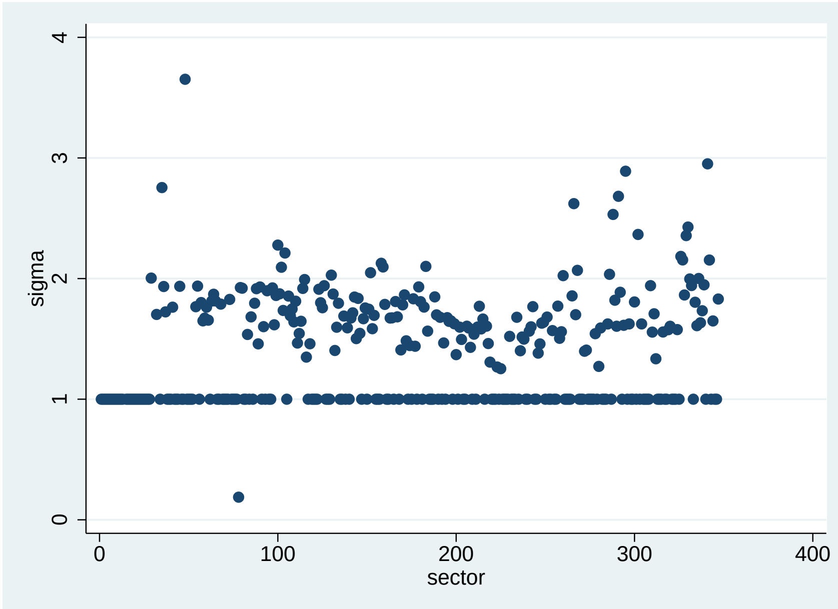

Figure 3: Estimates of CES marginal elasticity of substitution for various industrial sectors (σ_j), based on the 2000–2005 linked input–output table for Korea (BOK, 2015).

($\xi_{ij} = a_{ij}\left(p_j/p_i\right)$) for Leontief functions, in light of (30).[6]

3. Propagation Analysis

3.1. Technological structure

The unit-cost function for a multi-factor CES production function for an industrial sector (index j omitted) compatible with (24) is

$$h\left(p_0, p_1, \cdots, p_n; z\right) = \frac{1}{z}\left(\delta_0 p_0^{1-\sigma} + \delta_1 p_1^{1-\sigma} + \cdots + \delta_n p_n^{1-\sigma}\right)^{1/(1-\sigma)}.$$

We abbreviate the system of the above unit-cost functions as

$$\mathbf{h}\left(p_0, \mathbf{p}; \mathbf{z}\right) = \left(h_1\left(p_0, \mathbf{p}; z_1\right), \cdots, h_n\left(p_0, \mathbf{p}; z_n\right)\right). \tag{31}$$

[6]This is an alternative statement of the result obtained by Klein (1952–1953).

Applying Shephard's Lemma on $\mathbf{h}(p_0, \mathbf{p}; \mathbf{z})$, we have

$$\begin{bmatrix} \frac{\partial h_1(p_0,\mathbf{p};z_1)}{\partial p_0} & \frac{\partial h_2(p_0,\mathbf{p};z_2)}{\partial p_0} & \cdots & \frac{\partial h_n(p_0,\mathbf{p};z_n)}{\partial p_0} \\ \frac{\partial h_1(p_0,\mathbf{p};z_1)}{\partial p_1} & \frac{\partial h_2(p_0,\mathbf{p};z_2)}{\partial p_1} & \cdots & \frac{\partial h_n(p_0,\mathbf{p};z_n)}{\partial p_1} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial h_1(p_0,\mathbf{p};z_1)}{\partial p_n} & \frac{\partial h_2(p_0,\mathbf{p};z_2)}{\partial p_n} & \cdots & \frac{\partial h_n(p_0,\mathbf{p};z_n)}{\partial p_n} \end{bmatrix} = \begin{bmatrix} \nabla_0 \mathbf{h}(p_0, \mathbf{p}; \mathbf{z}) \\ \nabla \mathbf{h}(p_0, \mathbf{p}; \mathbf{z}) . \end{bmatrix} \tag{32}$$

Note that $\nabla_0 \mathbf{h}(p_0, \mathbf{p}; \mathbf{z})$ is the ex-post vector of physical primary input coefficients, and $\nabla \mathbf{h}(p_0, \mathbf{p}; \mathbf{z})$ is the ex-post matrix of physical input–output coefficients, which we otherwise call the technological structure. Moreover, note that according to (32), innovation (as represented by the productivity gain $\mathbf{z}$) has the influence of changing the technological structure. Structural propagation designates this influence in particular.

3.2. Structural propagation

For obvious reasons, the ex-post equilibrium price under given $\mathbf{z}$ is needed, to examine the ex-post technological structure of (32). Because the equilibrium price will coincide with the unit cost under perfect competition, we have the identity

$$\mathbf{p} = \mathbf{h}(p_0, \mathbf{p}; \mathbf{z}) . \tag{33}$$

Let $\boldsymbol{\pi}(\mathbf{z}) = (\pi_1(\mathbf{z}), \cdots, \pi_n(\mathbf{z}))$ be the solution for (33), given the numéraire price p_0. The ex-post propagated equilibrium technological structure is the technological structure (32) evaluated at this equilibrium solution as

$$\boldsymbol{\xi}_0(\mathbf{z}) \equiv \nabla_0 \mathbf{h}(p_0, \mathbf{p}; \mathbf{z})|_{\mathbf{p}=\boldsymbol{\pi}(\mathbf{z})}, \qquad \boldsymbol{\Xi}(\mathbf{z}) \equiv \nabla_0 \mathbf{h}(p_0, \mathbf{p}; \mathbf{z})|_{\mathbf{p}=\boldsymbol{\pi}(\mathbf{z})} . \tag{34}$$

Also, note that ex-post element-wise physical input–output coefficients can be derived for CES production functions as

$$\xi_{ij}(\mathbf{z}) = \frac{\partial h_j\left(p_0, \mathbf{p}; z_j\right)}{\partial p_i}\Big|_{\mathbf{p}=\boldsymbol{\pi}(\mathbf{z})} = \delta_{ij} z_j^{\sigma_j - 1} \left(\frac{\pi_j(\mathbf{z})}{\pi_i(\mathbf{z})}\right)^{\sigma_j} = a_{ij}(\mathbf{z}) \frac{\pi_j(\mathbf{z})}{\pi_i(\mathbf{z})}. \tag{35}$$

We may then use (34) to perform ex-post input–output analysis, for example as

$$\mathbf{V}(\mathbf{z}) = p_0 \boldsymbol{\xi}_0(\mathbf{z}) \left\langle [\mathbf{I} - \boldsymbol{\Xi}(\mathbf{z})]^{-1} \bar{\mathbf{d}}' \right\rangle = \mathbf{a}_0(\mathbf{z}) \left\langle [\mathbf{I} - \mathbf{A}(\mathbf{z})]^{-1} \langle \boldsymbol{\pi}(\mathbf{z}) \rangle \bar{\mathbf{d}}' \right\rangle, \tag{36}$$

where $\mathbf{V}(\mathbf{z}) = (V_1(\mathbf{z}), \cdots, V_n(\mathbf{z}))$ denotes the sector-wise primary factor (in monetary terms) required for the economy to consume a fixed (vector) amount of final demand, which we denote by $\bar{\mathbf{d}} = \left(\bar{d}_1, \cdots, \bar{d}_n\right)$. Note that the second identity is due to the third identity for (35), and that angle brackets indicate diagonalization.

So the question is how to solve (33). Although we may have an analytical solution for specific cases, such as $\delta = 1$ (Cobb–Douglas) and $\delta = 0$ (Leontief), which we present in the Appendix, there is no general analytical solution. Yet, we can still use the recursive methodology, since the system of unit-cost functions (31) is strictly concave with respect to the entries $\mathbf{p}$. In other words, we may apply (33) recursively, iteratively feeding the output back as input, to eventually reach the equilibrium solution. That is,

$$\mathbf{p}^{t+1} = \mathbf{h}\left(p_0, \mathbf{p}^t; \mathbf{z}\right), \qquad \lim_{t\to\infty} \mathbf{p}^t = \boldsymbol{\pi}\left(\mathbf{z}\right), \tag{37}$$

where $\mathbf{p}^t$ denotes the price vector at the tth iteration.

Below we present the results obtained for calculating $\mathbf{V}(\mathbf{z})$, where we used $\mathbf{z} = \mathbf{z}_{\mathrm{MH}}$, or a doubling of "Medical and Health Services (Public)," the 327th sector's productivity ($\mathbf{z}_{327} = (1, \cdots, 1, z_{327}, 1, \cdots, 1)$, where $z_{327} = 2$), as the trigger of structural propagation. We have obtained an ex-post equilibrium price via (37) with 20 iterations.[7] Figures 6, 4, 5, and 7 respectively show the primary input saved, $\Delta\mathbf{V} = \mathbf{V}(\mathbf{1}) - \mathbf{V}(\mathbf{z}_{327})$, for CES, Cobb–Douglas, and Leontief productions. Naturally, we used the estimated sector-wise elasticity of substitution (Figure 3) for CES productions while setting all the elasticities to unity for Cobb–Douglas and zero for Leontief productions. The sum of the saved primary factor, $\Delta\mathbf{V}\mathbf{1}'$, is displayed in Table 1. The kurtosis, which measures the degree of polarization of the sector-wise distribution of the savings $\Delta\mathbf{V}$, is also displayed.

Table 1: Saved primary input by productivity doubling of Medical and Health Services (Public) (327th sector) in different functional forms (unit: Million KRW)

	Leontief	Cobb-Douglas	CES	msCES
$\Delta\mathbf{V}\mathbf{1}'$	871,089	891,347	900,227	638,842
kurtosis	(328)	(324)	(322)	(331)

.

As seen from the numbers in Table 1, the magnitude of propagation is relatively larger for Cobb–Douglas productions than for Leontief productions, whereas the sector-wise distribution is more polarized for Leontief productions than for Cobb–Douglas productions. It is possible that inflexibility of technology (zero elasticity) can consoli-

[7] Note that the final differential (difference in values between the 19th and 20th iterations) was negligibly small.

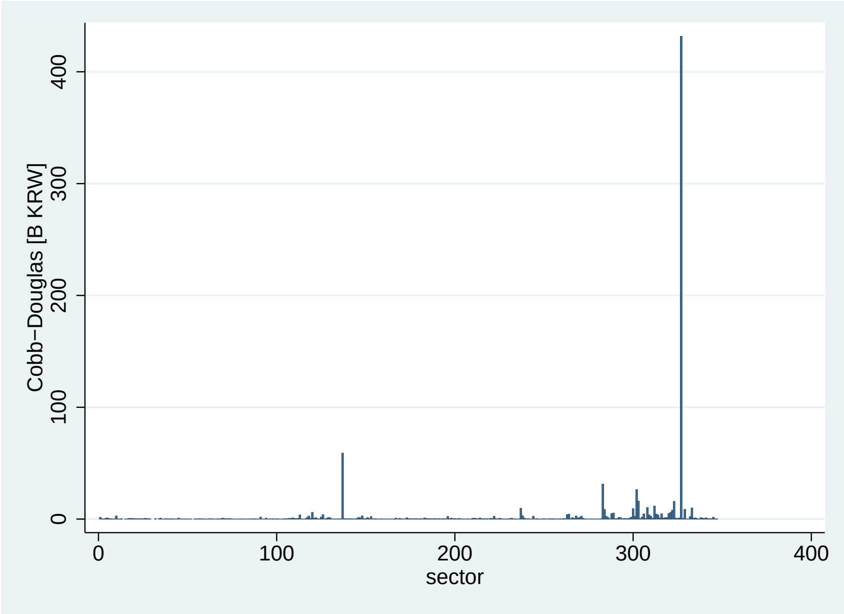

Figure 4: Propagation of the 327th sector productivity doubling under Cobb–Douglas production.

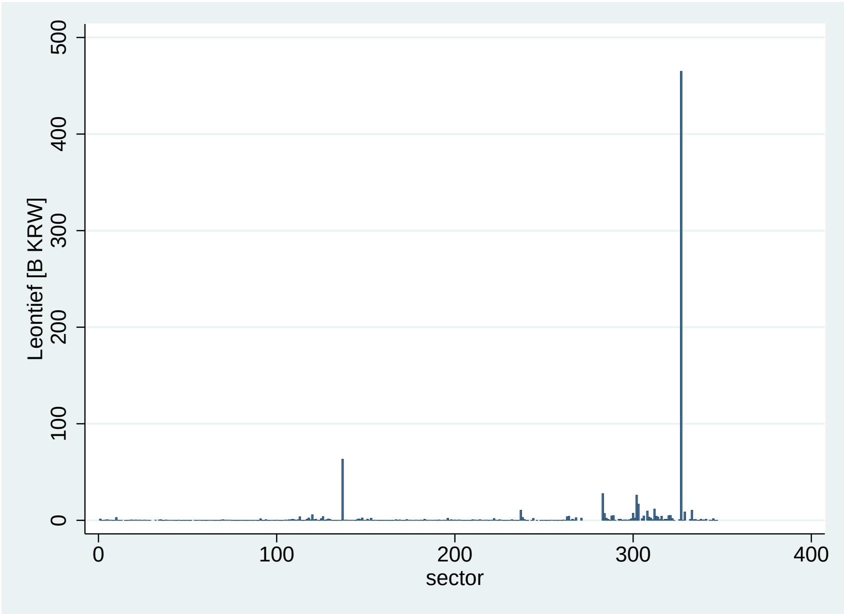

Figure 5: Propagation of the 327th sector productivity doubling under Leontief production.

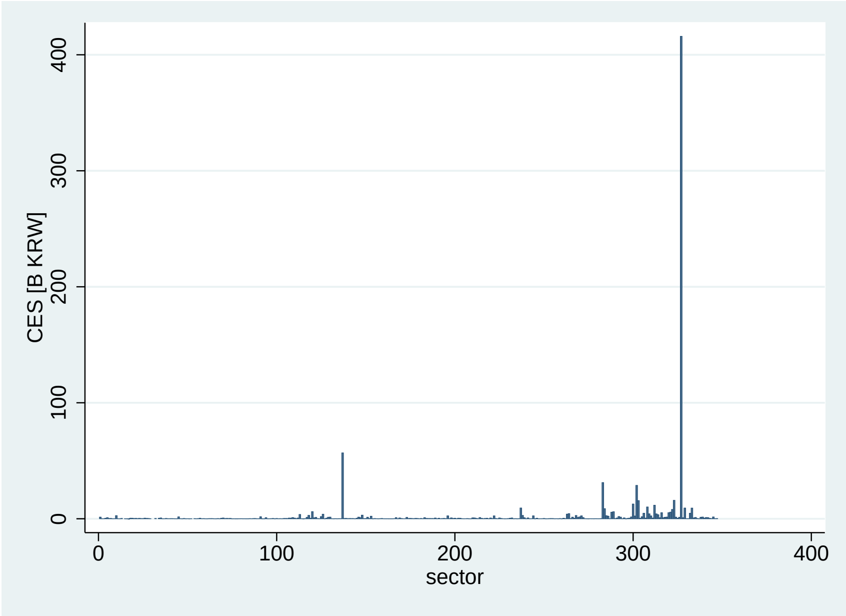

Figure 6: Propagation of the 327th sector productivity doubling under CES production.

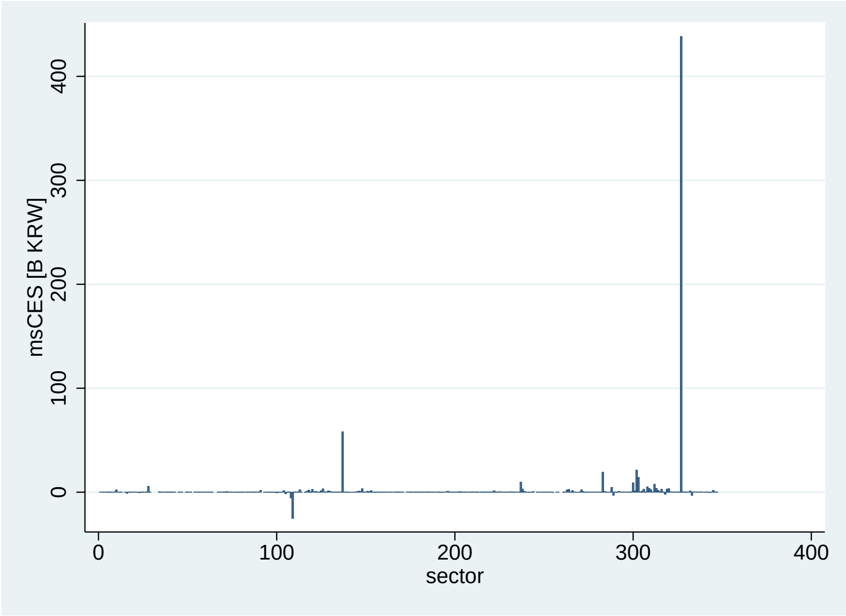

Figure 7: Propagation of the 327th sector productivity doubling under multi-stage CES production.

date the potential propagation effects while flexibility of technology (non-zero elasticity) can do the opposite. Our estimates on CES production indicate that the propagation effects of Cobb-Douglas production, both in terms of magnitude and distribution, lie in-between those for Leontief and CES productions. This result is closely related to our estimates on the elasticities, whose sector-wide average was 1.39, which is meta-Cobb–Douglas, on average.

4. Concluding Remarks

To date, input–output analysis has been extensively used for assessing the costs and benefits of new goods and new innovations. These studies implicitly rely upon the non-substitution theorem, which allows investigators to study effects under a fixed technological structure, while restricting the subjects of analysis to transformations within the final demand. Nevertheless, substitution of technology will prevail in any industry when a new technology or innovation is introduced into any component (industry) of the economy. Stronger influence is typically foreseeable for intermediate-industry technologies, as they have much stronger and wider feedback within the economy-wide system of production.

In order to take the full set of technology substitution possibilities into account, we proposed in this study a methodology to measure the sector-wise elasticity of substitution for CES production functions, instead of using uniform a priori elasticities of substitution (such as zeros and ones) in modeling economy-wide, multi-sector, multi-factor production systems. A recursive method in the dual (unit-cost functions) was used to evaluate influences on the general equilibrium technological substitutions and eventually on the social costs and benefits (so-called structural propagation) initiated by the introduction of new technology or innovation, which we treat as a gain in productivity.

We have found that more elastic production functions (here, CES production functions) have more significant and wider propagation effects, whereas those for inelastic production functions (here, Leontief production functions) were relatively smaller and more polarized; effects for the Cobb–Douglas production functions were in-between. In the end, the reliability of this analytical framework depends on the measurement of sector-wise technological elasticities, which we obtained in this study as the maximizer of the correlation between the two observation-consistent share parameters. Naturally, different metrics (e.g., Euclidean distances or cosine similarity) can be tested for vector similarity evaluation. Applications and extensions of structural propagation analysis are potentially immense, including internationalization, dynamicalization, quality consideration, and structural viability assessment, which are all left to future investigations.

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Appendix

Cobb–Douglas Production

We present the ex-post and benchmark Cobb–Douglas unit-cost functions for the jth industry. That is,

$$\pi_j(\mathbf{z}) = \frac{1}{z_j}\prod_{i=0}^{n}\left(\frac{\pi_i(\mathbf{z})}{a_{ij}}\right)^{a_{ij}}, \qquad \bar{p}_j = \prod_{i=0}^{n}\left(\frac{\bar{p}_i}{a_{ij}}\right)^{a_{ij}}. \tag{38}$$

Here, a_{ij} denotes the jth industry's output elasticity for the ith input, which is assumed to be constant under Cobb–Douglas production. Note that a_{ij} is also identical to the benchmark cost share of ith input for the jth industry's output (or the benchmark monetary input–output coefficient). Also, note that $\bar{p}_i$ denotes benchmark (i.e., $\pi_i(\mathbf{1}) = \bar{p}_i$) equilibrium price.

By taking the log and subtraction on (38), we obtain

$$\ln\pi_j(\mathbf{z}) - \ln\bar{p}_j = \sum_{i=0}^{n} a_{ij}\left(\ln\pi_j(\mathbf{z}) - \ln\bar{p}_j - \ln z_i\right). \tag{39}$$

Rewriting (39) for an $n \times n$ multiple-industry setting, we have

$$\ln\boldsymbol{\pi}(\mathbf{z}) - \ln\bar{\mathbf{p}} = \left[\ln\boldsymbol{\pi}(\mathbf{z}) - \ln\bar{\mathbf{p}} - \ln\mathbf{z}\right]\mathbf{A}, \tag{40}$$

where we abbreviate, for example, $\ln\boldsymbol{\pi} = (\ln\pi_1, \cdots, \ln\pi_n)$. Then, we can solve (40) for $\boldsymbol{\pi}(\mathbf{z})$ to obtain the analytical solution to (33). That is,

$$\boldsymbol{\pi}(\mathbf{z}) = \bar{\mathbf{p}}\left\langle\exp\left(-(\ln\mathbf{z})\left[\mathbf{I} - \mathbf{A}\right]^{-1}\right)\right\rangle. \tag{41}$$

Furthermore, the following identities must hold for $\sigma_j = 1$ and $\mathbf{z} = \mathbf{1}$ in regard to (35):

$$\delta_{ij} = a_{ij}(\mathbf{z}), \qquad \delta_{ij} = a_{ij}(\mathbf{1}) = a_{ij}. \tag{42}$$

Thus, we see that $a_{ij}(\mathbf{z})$ will remain unchanged. In other words, we may substitute ex-post input–output coefficients with those of the benchmark, that is,

$$\mathbf{a}_0(\mathbf{z}) = \mathbf{a}_0, \qquad \mathbf{A}(\mathbf{z}) = \mathbf{A}. \tag{43}$$

Hence, for Cobb–Douglas production, (36) can be evaluated as follows:

$$\mathbf{V}(\mathbf{z}) = \mathbf{a}_0 \left\langle [\mathbf{I} - \mathbf{A}]^{-1} \left\langle \exp\left(- (\ln \mathbf{z}) [\mathbf{I} - \mathbf{A}]^{-1} \right) \right\rangle \langle \bar{\mathbf{p}} \rangle \, \bar{\mathbf{d}}' \right\rangle . \tag{44}$$

Leontief Production

The ex-post equilibrium monetary balance for the j th industry is

$$y_j \pi_j (\mathbf{z}) = \pi_0 (\mathbf{z}) \, x_{0j} + \pi_1 (\mathbf{z}) \, x_{1j} + \cdots + \pi_n (\mathbf{z}) \, x_{nj} .$$

Rearranging this formula for further investigation gives

$$\begin{aligned} \pi_j (\mathbf{z}) &= \pi_0 (\mathbf{z}) \frac{x_{0j}}{y_j} + \pi_1 (\mathbf{z}) \frac{x_{1j}}{y_j} + \cdots + \pi_n (\mathbf{z}) \frac{x_{nj}}{y_j} \\ &= \pi_0 (\mathbf{z}) \, \xi_{0j} (\mathbf{z}) + \pi_1 (\mathbf{z}) \, \xi_{1j} (\mathbf{z}) + \cdots + \pi_n (\mathbf{z}) \, \xi_{nj} (\mathbf{z}) \\ &= \pi_0 (\mathbf{z}) \frac{\xi_{0j}}{z_0} + \pi_1 (\mathbf{z}) \frac{\xi_{1j}}{z_1} + \cdots + \pi_n (\mathbf{z}) \frac{\xi_{nj}}{z_n} . \end{aligned} \tag{45}$$

Note that the last identity can be derived by applying $\sigma_j = 0$ and $\mathbf{z} = \mathbf{1}$ in (35), giving

$$\xi_{ij} (\mathbf{z}) = \delta_{ij} z_j^{-1}, \qquad \xi_{ij} (\mathbf{1}) = \xi_{ij} = \delta_{ij} .$$

Thus, (45) can be reduced to

$$\boldsymbol{\pi} (\mathbf{z}) \langle \mathbf{z} \rangle = \boldsymbol{\xi}_0 + \boldsymbol{\pi} (\mathbf{z}) \, \boldsymbol{\Xi} = \mathbf{a}_0 \bar{\mathbf{p}} + \boldsymbol{\pi} (\mathbf{z}) \langle \bar{\mathbf{p}} \rangle^{-1} \mathbf{A} \langle \bar{\mathbf{p}} \rangle , \tag{46}$$

where we normalized prices using $\pi_0 = \bar{p}_0 = 1$. For the second identity, we used $\xi_{ij} = a_{ij} \bar{p}_j / \bar{p}_i$. Now, (46) can be solved for $\boldsymbol{\pi} (\mathbf{z})$ as follows:

$$\boldsymbol{\pi} (\mathbf{z}) = \mathbf{a}_0 [\mathbf{z} - \mathbf{A}]^{-1} \langle \bar{\mathbf{p}} \rangle . \tag{47}$$

Hence, for Leontief production, (36) can be evaluated as

$$\mathbf{V}(\mathbf{z}) = \mathbf{a}_0 \left\langle [\mathbf{z} - \mathbf{A}]^{-1} \langle \bar{\mathbf{p}} \rangle \, \bar{\mathbf{d}}' \right\rangle . \tag{48}$$

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Table 2: Estimated elasticities for all sectors ($i = 1 \cdots 50$)

no.	sector	$\hat{\sigma}$	s.e.	t value	P value	σ	obs.
1	Unmilled rice	0.645	0.445	−0.797	0.428	1.000	78
2	Barley	1.399	0.778	0.514	0.609	1.000	59
3	Wheat	0.351	0.740	−0.877	0.389	1.000	25
4	Misc. cereals	0.010	0.903	−1.096	0.279	1.000	46
5	Vegetables	1.326	0.686	0.475	0.636	1.000	101
6	Fruits	1.660	0.676	0.976	0.332	1.000	90
7	Pulses	1.532	0.837	0.636	0.528	1.000	49
8	Potatoes	1.278	0.745	0.374	0.710	1.000	46
9	Oleaginous crops	1.254	0.607	0.419	0.677	1.000	46
10	Cultivated medicinal herbs	1.297	0.976	0.304	0.762	1.000	58
11	Other edible crops	2.166	0.720	1.619	0.111	1.000	54
12	Cotton and hemp	0.928	0.456	−0.159	0.875	1.000	22
13	Horticultural specialities	1.807	0.496	1.626	0.107	1.000	101
14	Natural rubber					1.000	
15	Seeds and seedlings	0.200	0.521	−1.537	0.128	1.000	95
16	Other Inedible crops	2.564	1.050	1.490	0.156	1.000	16
17	Dairy farming	0.568	0.400	−1.080	0.282	1.000	117
18	Beef cattle	1.342	0.225	1.515	0.132	1.000	119
19	Pigs	1.272	0.261	1.041	0.300	1.000	120
20	Poultry and birds	1.372	0.369	1.007	0.316	1.000	122
21	Other animals	1.224	0.241	0.928	0.356	1.000	102
22	Operation of timber tracts	0.475	0.355	−1.480	0.142	1.000	92
23	Raw timber	0.751	0.394	−0.632	0.530	1.000	46
24	Edible forest products	0.915	0.356	−0.239	0.811	1.000	74
25	Misc. forest products	1.469	0.346	1.357	0.179	1.000	68
26	Fishing	1.307	0.299	1.027	0.306	1.000	160
27	Aquaculture	1.147	0.319	0.463	0.644	1.000	126
28	Agriculture, forestry and fishing related services	1.037	0.464	0.080	0.937	1.000	131
29	Anthracite	2.004	0.350	2.872	0.005	2.004	128
30	Bituminous coal					1.000	
31	Crude petroleum and Natural gas					1.000	
32	Iron ores	1.703	0.372	1.887	0.063	1.703	78
33	Copper ores					1.000	
34	Lead and zinc ores	2.076	1.700	0.633	0.547	1.000	7
35	Misc. non-ferrous metal ores	2.755	0.907	1.936	0.059	2.755	48
36	Sand and gravel	1.934	0.289	3.236	0.002	1.934	109
37	Crushed and broken stone abd Other bulk stones	1.724	0.346	2.092	0.039	1.724	116
38	Limestone	1.557	0.352	1.585	0.116	1.000	122
39	Materials for ceramics	1.495	0.423	1.170	0.244	1.000	113
40	Crude salt	1.527	0.489	1.078	0.284	1.000	91
41	Misc. non-metallic minerals	1.763	0.302	2.525	0.013	1.763	104
42	Slaughtering and meat processing	1.393	0.404	0.974	0.332	1.000	101
43	Poultry slaughtering and processing	1.569	0.683	0.833	0.407	1.000	91
44	Prepared meat products	1.633	0.422	1.498	0.136	1.000	138
45	Dairy products	1.936	0.489	1.916	0.057	1.936	140
46	Canned seafoods	1.597	1.213	0.492	0.624	1.000	106
47	Frozen fish and seafoods	2.050	1.412	0.743	0.459	1.000	98
48	Salted, dried and smoked seafoods	3.652	1.199	2.212	0.029	3.652	94
49	Misc. processed seafoods	1.919	1.091	0.842	0.402	1.000	109
50	Polished rice	0.955	0.401	−0.111	0.912	1.000	92

Table 3: Estimated elasticities for all sectors ($i = 51 \cdots 100$)

no.	sector	$\hat{\sigma}$	s.e.	t value	P value	σ	obs.
51	Polished barley	1.216	0.588	0.367	0.715	1.000	69
52	Flour and cereal preparations	0.772	0.478	−0.476	0.635	1.000	98
53	Raw sugar					1.000	
54	Refined sugar	1.767	0.443	1.730	0.087	1.767	97
55	Starches	1.938	0.472	1.987	0.050	1.938	98
56	Glucose, glucose syrup and maltose	1.607	0.452	1.344	0.182	1.000	106
57	Bakery and confectionery products	1.801	0.442	1.814	0.071	1.801	170
58	Noodles	1.650	0.266	2.444	0.016	1.650	131
59	Seasonings	1.672	0.376	1.789	0.076	1.672	149
60	Soy sauce ad bean paste	1.763	0.284	2.688	0.008	1.763	123
61	Animal and marine fats and oils	1.655	0.340	1.927	0.057	1.655	103
62	Vegetable fats and oils, and processed edible refined oil	1.495	0.541	0.916	0.362	1.000	123
63	Canned or cured fruits and vegetables	1.814	0.384	2.122	0.036	1.814	135
64	Coffee and tea	1.870	0.343	2.540	0.012	1.870	125
65	Ginseng products	1.815	0.347	2.349	0.021	1.815	100
66	Malt and yeast	1.706	0.512	1.378	0.172	1.000	86
67	Bean curd and Misc. foodstuffs	1.451	0.394	1.146	0.254	1.000	158
68	Ethyl alcohol for beverages	1.788	0.267	2.956	0.004	1.788	104
69	Blended and distilled sojoo	1.652	0.415	1.570	0.119	1.000	117
70	Beer	0.652	0.449	−0.775	0.440	1.000	106
71	Other liquors	1.717	0.467	1.535	0.127	1.000	124
72	Soft drinks and Manufactured ice	1.054	0.533	0.102	0.919	1.000	137
73	Prepared livestock feeds	1.827	0.325	2.549	0.012	1.827	150
74	Tobacco products	0.904	0.373	−0.258	0.797	1.000	98
75	Woolen yarn	1.578	0.422	1.369	0.174	1.000	109
76	Cotton yarn	1.053	0.317	0.167	0.868	1.000	123
77	Silk and hempen yarn	0.961	0.299	−0.132	0.896	1.000	82
78	Regenerated fiber yarn	0.188	0.406	−2.002	0.049	0.188	82
79	Synthetic fiber yarn	1.926	0.433	2.136	0.035	1.926	120
80	Thread and other fiber yarns	1.920	0.287	3.205	0.002	1.920	110
81	Woolen fabrics	1.433	0.356	1.217	0.226	1.000	110
82	Cotton fabrics	1.159	0.385	0.414	0.680	1.000	123
83	Silk and hempen fabrics	1.537	0.289	1.860	0.066	1.537	106
84	Regenerated fiber fabrics	1.164	0.261	0.630	0.530	1.000	100
85	Synthetic fiber fabrics	1.683	0.326	2.094	0.038	1.683	124
86	Other fiber fabrics	1.473	0.482	0.982	0.328	1.000	116
87	Knitted fabrics	1.796	0.268	2.972	0.004	1.796	107
88	Fiber bleaching and dyeing	1.916	0.449	2.041	0.044	1.916	115
89	Knitted wearing apparels	1.459	0.230	1.998	0.048	1.459	124
90	Knitted clothing accessories	1.930	0.402	2.316	0.022	1.930	112
91	Textile wearing apparels and Clothing accessories	1.069	0.378	0.182	0.856	1.000	137
92	Leather wearing apparels	1.601	0.306	1.964	0.052	1.601	104
93	Fur and Fur wearing apparels	1.345	0.284	1.218	0.226	1.000	121
94	Textile products and Misc. textile products	1.899	0.358	2.509	0.013	1.899	154
95	Cordage, rope, and fishing nets	1.425	0.459	0.926	0.356	1.000	111
96	Leather	1.368	0.307	1.200	0.232	1.000	125
97	Luggage and handbags	1.923	0.338	2.729	0.007	1.923	114
98	Footwear	1.617	0.258	2.396	0.018	1.617	127
99	Other leather products	1.860	0.497	1.732	0.087	1.860	87
100	Lumber	2.278	0.384	3.331	0.001	2.278	101

Table 4: Estimated elasticities for all sectors ($i = 101 \cdots 150$)

no.	sector	$\hat{\sigma}$	s.e.	t value	P value	σ	obs.
101	Plywood	1.874	0.321	2.718	0.008	1.874	118
102	Reconstituted and densified wood	2.094	0.463	2.364	0.020	2.094	113
103	Wooden products for construction	1.736	0.312	2.360	0.020	1.736	110
104	Wooden containers and Other wooden products	2.212	0.512	2.366	0.020	2.212	120
105	Pulp	1.233	0.240	0.974	0.332	1.000	108
106	Newsprint	1.855	0.366	2.338	0.021	1.855	115
107	Printing paper	1.692	0.377	1.837	0.068	1.692	138
108	Other raw paper and paperboard	1.749	0.252	2.974	0.003	1.749	146
109	Corrugated paper and solid fiber boxes	1.641	0.284	2.253	0.026	1.641	115
110	Paper containers	1.812	0.296	2.742	0.007	1.812	128
111	Stationery paper and office paper	1.466	0.256	1.817	0.072	1.466	121
112	Other paper products	1.545	0.277	1.969	0.051	1.545	156
113	Printing	1.646	0.170	3.791	0.000	1.646	139
114	Reproduction of recorded media	1.919	0.267	3.435	0.001	1.919	132
115	Coal briquettes	1.992	0.176	5.649	0.000	1.992	74
116	Coke and other coal products	1.349	0.126	2.780	0.006	1.349	119
117	Naphtha	0.870	0.208	−0.628	0.531	1.000	117
118	Gasoline and Jet oil	1.460	0.146	3.139	0.002	1.460	123
119	Kerosene	1.267	0.394	0.676	0.500	1.000	122
120	Light oil	1.207	0.257	0.804	0.423	1.000	122
121	Heavy oil	1.191	0.326	0.586	0.559	1.000	121
122	Liquefied petroleum gas	1.394	0.449	0.877	0.382	1.000	121
123	Lubricants	1.912	0.370	2.462	0.015	1.912	127
124	Misc. petroleum refinery products	1.800	0.417	1.920	0.057	1.800	123
125	Petrochemical basic products	1.758	0.239	3.174	0.002	1.758	121
126	Petrochemical intermediate products and Other basic organic chemicals	1.941	0.273	3.442	0.001	1.941	159
127	Coal chemicals	0.997	0.314	−0.010	0.992	1.000	105
128	Industrial gases	1.724	0.487	1.487	0.140	1.000	120
129	Basic inorganic chemicals	1.162	0.313	0.519	0.604	1.000	157
130	Synthetic resins	2.029	0.410	2.506	0.013	2.029	151
131	Synthetic rubber	1.872	0.451	1.934	0.056	1.872	116
132	Regenerated cellulose fibers	1.404	0.225	1.795	0.076	1.404	95
133	Synthetic fibers	1.597	0.274	2.177	0.031	1.597	124
134	Nitrogen compounds	1.795	0.266	2.986	0.003	1.795	110
135	Fertilizers	1.653	0.425	1.538	0.126	1.000	138
136	Pesticides and other agricultural chemicals	1.363	0.392	0.927	0.356	1.000	130
137	Medicaments	1.689	0.279	2.467	0.015	1.689	171
138	Cosmetics and dentifrices	1.510	0.344	1.483	0.140	1.000	161
139	Soap and detergents	1.592	0.354	1.672	0.097	1.592	147
140	Dyes, pigments, and tanning materials	0.987	0.254	−0.050	0.960	1.000	141
141	Paints, varnishes, and allied products	1.673	0.337	1.999	0.047	1.673	151
142	Printing ink	1.716	0.288	2.489	0.014	1.716	123
143	Adhesives, gelatin and sealants	1.847	0.291	2.908	0.004	1.847	139
144	Explosives and fireworks products	1.502	0.300	1.675	0.096	1.502	135
145	Recording media and Photographic chemical products	1.836	0.315	2.654	0.009	1.836	138
146	Misc. chemical products	1.546	0.296	1.847	0.067	1.546	168
147	Primary plastic products	1.637	0.437	1.456	0.147	1.000	151
148	Industrial plastic products	1.667	0.319	2.095	0.038	1.667	163
149	Household articles of plastic material	1.756	0.316	2.395	0.018	1.756	120
150	Tires and tubes	1.412	0.336	1.226	0.222	1.000	140

Table 5: Estimated elasticities for all sectors ($i = 151 \cdots 200$)

no.	sector	$\hat{\sigma}$	s.e.	t value	P value	σ	obs.
151	Rubber products	1.746	0.257	2.900	0.004	1.746	150
152	Sheet glass and primary glass products	2.049	0.359	2.924	0.004	2.049	125
153	Industrial glass products	1.585	0.175	3.346	0.001	1.585	165
154	Household glass products and others	1.695	0.268	2.594	0.011	1.695	132
155	Pottery	1.440	0.299	1.472	0.143	1.000	151
156	Refractory ceramic products	1.361	0.276	1.310	0.192	1.000	142
157	Clay products for construction	1.341	0.298	1.144	0.255	1.000	136
158	Cement	2.127	0.336	3.359	0.001	2.127	150
159	Ready mixed concrete	2.096	0.288	3.806	0.000	2.096	128
160	Concrete blocks, bricks, and other concrete products	1.786	0.278	2.823	0.005	1.786	140
161	Lime, gypsum, and plaster products	1.530	0.399	1.328	0.187	1.000	130
162	Cut stone and stone products	1.255	0.399	0.638	0.525	1.000	130
163	Asbestos and mineral wool products	1.673	0.331	2.032	0.044	1.673	141
164	Abrasives	1.674	0.338	1.994	0.048	1.674	138
165	Asphalts	1.659	0.470	1.400	0.164	1.000	121
166	Misc. nonmetallic minerals products	1.810	0.359	2.258	0.026	1.810	136
167	Pig iron	1.683	0.147	4.647	0.000	1.683	134
168	Ferroalloys	1.335	0.301	1.113	0.268	1.000	108
169	Steel ingots and semifinished products	1.409	0.188	2.178	0.031	1.409	140
170	Steel rods and bars	1.782	0.210	3.717	0.000	1.782	124
171	Section steel	1.865	0.176	4.926	0.000	1.865	117
172	Rails and wires	1.484	0.289	1.675	0.096	1.484	127
173	Hot rolled steel plates and sheets	1.060	0.226	0.267	0.790	1.000	135
174	Steel pipe and tubes, except foundry iron pipe and tubes	1.445	0.235	1.894	0.060	1.445	138
175	Cold rolled steel sheet, strip, and bars	0.868	0.300	−0.440	0.660	1.000	143
176	Iron foundries and foundry iron pipe and tubes	1.833	0.263	3.160	0.002	1.833	148
177	Forgings	1.439	0.236	1.857	0.066	1.439	118
178	Coated steel plates	1.222	0.336	0.660	0.511	1.000	140
179	Misc. primary iron and steel products	1.931	0.288	3.236	0.002	1.931	113
180	Copper ingots	1.809	0.234	3.454	0.001	1.809	120
181	Aluminium ingots	0.719	0.477	−0.588	0.558	1.000	120
182	Lead and zinc ingots	1.764	0.252	3.031	0.003	1.764	132
183	Gold and silver ingots	2.101	0.470	2.341	0.021	2.101	108
184	Other nonferrous metal ingots	1.564	0.256	2.205	0.029	1.564	117
185	Primary copper products	1.455	0.321	1.416	0.159	1.000	130
186	Primary aluminium products	1.387	0.372	1.039	0.301	1.000	140
187	Other nonferrous metal casting and forgings, and primary nonferrous metals	1.479	0.444	1.080	0.282	1.000	125
188	Metal products for construction	1.848	0.341	2.485	0.014	1.848	130
189	Metal products for structure	1.699	0.394	1.776	0.078	1.699	146
190	Metal tanks and reservoirs for equipment	1.327	0.332	0.987	0.326	1.000	125
191	Metal cans, barrels, and drums	1.679	0.374	1.815	0.072	1.679	128
192	Handtools	1.102	0.330	0.310	0.757	1.000	141
193	Bolts, nuts, screws, rivets, and washers	1.466	0.234	1.990	0.049	1.466	135
194	Fabricated wire products	1.096	0.231	0.415	0.679	1.000	144
195	Fastening metal products	1.676	0.315	2.149	0.033	1.676	133
196	Treatment and coating of metals and Misc. fabricated metal products	1.646	0.285	2.263	0.025	1.646	167
197	Internal combustion engines and turbines	1.650	0.219	2.962	0.004	1.650	152
198	Parts of general-purposed machinery and equipment	1.398	0.299	1.329	0.186	1.000	154
199	Conveyors and conveying equipment	1.625	0.323	1.938	0.054	1.625	161
200	Air-conditioning equipment and industrial refrigeration equipment	1.370	0.215	1.717	0.088	1.370	159

Table 6: Estimated elasticities for all sectors ($i = 201 \cdots 250$)

no.	sector	$\hat{\sigma}$	s.e.	t value	P value	σ	obs.
201	Boiler, Heating apparatus and cooking appliances	1.513	0.312	1.647	0.102	1.000	160
202	Pumps and compressors	1.597	0.291	2.051	0.042	1.597	154
203	Misc. machinery and equipment of general purpose	1.495	0.263	1.880	0.062	1.495	171
204	Metal cutting type machine tools	1.230	0.265	0.869	0.386	1.000	157
205	Metal forming machine tools	1.261	0.236	1.102	0.272	1.000	153
206	Agricultural implements and machinery	1.605	0.230	2.630	0.009	1.605	151
207	Construction and mining machinery	1.591	0.276	2.137	0.034	1.591	152
208	Food processing machinery	1.430	0.220	1.957	0.052	1.430	139
209	Textile machinery	1.327	0.214	1.525	0.129	1.000	161
210	Metal molds and industrial patterns	1.539	0.316	1.706	0.090	1.539	148
211	Misc. machinery and equipment of special purpose	0.863	0.271	−0.507	0.613	1.000	178
212	Motors and generators	1.598	0.214	2.790	0.006	1.598	157
213	Electric transformers	1.771	0.223	3.458	0.001	1.771	146
214	Capacitors and rectifiers, Electric transmission and distribution equipment	1.583	0.222	2.629	0.009	1.583	163
215	Insulated wires and cables	1.665	0.188	3.527	0.001	1.665	165
216	Batteries	1.220	0.195	1.125	0.263	1.000	147
217	Electric lamps and electric lighting fixtures	1.606	0.276	2.196	0.030	1.606	156
218	Misc. electric equipment and supplies	1.462	0.258	1.792	0.075	1.462	151
219	Electron tubes	1.307	0.107	2.876	0.005	1.307	155
220	Digital display	1.037	0.090	0.413	0.680	1.000	155
221	Semiconductor devices	1.226	0.147	1.536	0.126	1.000	158
222	Integrated circuits	1.112	0.111	1.007	0.315	1.000	163
223	Electric resistors and storage batteries	1.267	0.116	2.305	0.022	1.267	152
224	Electric coils, transformers	1.331	0.262	1.260	0.210	1.000	138
225	Printed circuit boards	1.253	0.135	1.878	0.062	1.253	156
226	Misc. electronic components	1.087	0.204	0.428	0.669	1.000	166
227	Television	0.875	0.161	−0.779	0.437	1.000	146
228	Electric household audio equipment	1.086	0.254	0.337	0.737	1.000	147
229	Other audio and visual equipment	1.219	0.228	0.958	0.340	1.000	160
230	Line telecommunication apparatuses	1.521	0.244	2.139	0.034	1.521	157
231	Wireless telecommunication and broadcasting apparatuses	0.930	0.179	−0.389	0.698	1.000	159
232	Computer and peripheral equipment	1.204	0.134	1.522	0.130	1.000	162
233	Office machines and devices	1.330	0.262	1.257	0.211	1.000	150
234	Household refrigerators	1.679	0.241	2.816	0.006	1.679	148
235	Household laundry equipment	1.258	0.200	1.287	0.200	1.000	141
236	Other household electrical appliances	1.402	0.232	1.735	0.085	1.402	156
237	Medical instruments and supplies	1.516	0.270	1.910	0.058	1.516	163
238	Regulators and Measuring and analytical instruments	1.498	0.279	1.786	0.076	1.498	163
239	Photographic and optical instruments	0.888	0.270	−0.415	0.679	1.000	161
240	Watches and clocks	1.220	0.269	0.817	0.415	1.000	143
241	Passenger automobiles	1.564	0.248	2.272	0.025	1.564	151
242	Buses and vans	1.600	0.215	2.797	0.006	1.600	148
243	Trucks and Motor vehicles with special equipment	1.767	0.216	3.555	0.001	1.767	150
244	Motor vehicle engines, chassis, bodies and parts	1.210	0.315	0.666	0.506	1.000	184
245	Trailers and containers	1.358	0.293	1.220	0.225	1.000	131
246	Steel ships	1.382	0.174	2.198	0.029	1.382	177
247	Other ships	1.458	0.206	2.225	0.027	1.458	162
248	Ship repairing and ship parts	1.631	0.209	3.019	0.003	1.631	147
249	Railroad vehicles and parts	1.638	0.205	3.113	0.002	1.638	153
250	Aircraft and parts	1.280	0.293	0.956	0.341	1.000	155

Table 7: Estimated elasticities for all sectors ($i = 251 \cdots 300$)

no.	sector	$\hat{\sigma}$	s.e.	t value	P value	σ	obs.
251	Motorcycles and parts	1.681	0.321	2.120	0.036	1.681	144
252	Bicycles and parts and misc. transportation equipment	1.202	0.262	0.769	0.443	1.000	128
253	Wood furniture	1.112	0.239	0.470	0.639	1.000	161
254	Metal furniture	1.569	0.224	2.544	0.012	1.569	142
255	Other furniture	1.083	0.307	0.270	0.788	1.000	162
256	Toys and games	1.199	0.230	0.866	0.388	1.000	157
257	Sporting and athletic goods	1.772	0.369	2.089	0.038	1.772	155
258	Musical instruments	1.505	0.244	2.066	0.041	1.505	151
259	Pens, pencils, and other artists' materials	1.559	0.217	2.575	0.011	1.559	141
260	Jewelry and plated ware	2.024	0.262	3.904	0.000	2.024	120
261	Misc. manufacturing products	1.417	0.297	1.403	0.162	1.000	192
262	Hydroelectric power generation	1.158	0.298	0.529	0.598	1.000	109
263	Fire power generation	0.636	0.308	−1.183	0.239	1.000	119
264	Nuclear power generation	1.644	0.424	1.519	0.131	1.000	122
265	Other generation	1.857	0.241	3.558	0.001	1.857	94
266	Manufactured gas supply	2.621	0.417	3.891	0.000	2.621	109
267	Steam and hot water supply	1.701	0.315	2.226	0.028	1.701	101
268	Water supply	2.068	0.201	5.302	0.000	2.068	120
269	Residential building construction	1.030	0.265	0.113	0.910	1.000	174
270	Non-residential building construction	1.129	0.208	0.620	0.536	1.000	178
271	Building repairs	1.140	0.261	0.537	0.592	1.000	164
272	Road construction	1.398	0.209	1.900	0.059	1.398	175
273	Railroad construction	1.407	0.214	1.902	0.059	1.407	166
274	Breakwater, pier, and harbor construction	1.114	0.246	0.463	0.644	1.000	156
275	Airport construction	1.163	0.262	0.623	0.534	1.000	154
276	Dam, levee, and flood control project construction	1.408	0.314	1.299	0.196	1.000	158
277	Water main line and drainage project construction	1.297	0.187	1.588	0.114	1.000	165
278	Land clearing and reclamation, and irrigation project construction	1.543	0.262	2.072	0.040	1.543	163
279	Land leveling and athletic field construction	1.303	0.208	1.461	0.146	1.000	169
280	Electric power plant construction	1.272	0.159	1.710	0.089	1.272	167
281	Communications line construction	1.591	0.240	2.460	0.015	1.591	155
282	Misc. construction	0.472	0.393	−1.345	0.181	1.000	170
283	Wholesale and Retail trade	0.675	0.389	−0.837	0.404	1.000	145
284	Restaurants	1.188	0.416	0.453	0.651	1.000	177
285	Accommodation	1.624	0.276	2.259	0.026	1.624	128
286	Railroad passenger transport	2.036	0.498	2.078	0.040	2.036	131
287	Railroad freight transport	0.922	0.255	−0.305	0.761	1.000	117
288	Road passenger transport	2.532	0.264	5.802	0.000	2.532	127
289	Road freight transport	1.821	0.433	1.896	0.060	1.821	127
290	Coastal and inland water transport	1.605	0.280	2.164	0.032	1.605	130
291	Oceangoing transport	2.682	0.450	3.735	0.000	2.682	136
292	Air transport	1.887	0.285	3.107	0.002	1.887	153
293	Supporting land transport activities	1.420	0.268	1.571	0.119	1.000	122
294	Supporting water transport activities	1.613	0.247	2.478	0.015	1.613	121
295	Supporting air transport activities	2.890	0.249	7.592	0.000	2.890	104
296	Cargo handling	1.202	0.329	0.616	0.539	1.000	118
297	Warehousing and storage	1.624	0.329	1.900	0.060	1.624	126
298	Other services incidental to transportation	1.080	0.426	0.187	0.852	1.000	117
299	Postal services	0.927	0.556	−0.131	0.896	1.000	112
300	Telecommunications	1.806	0.285	2.827	0.006	1.806	119

Table 8: Estimated elasticities for all sectors ($i = 301 \cdots 350$)

no.	sector	$\hat{\sigma}$	s.e.	t value	P value	σ	obs.
301	Broadcasting	0.965	0.306	−0.114	0.909	1.000	119
302	Central bank and banking institutions, Non-bank depository institutions	2.366	0.265	5.154	0.000	2.366	116
303	Other financial brokerage institutions	1.463	0.409	1.132	0.260	1.000	104
304	Life insurance	1.624	0.318	1.960	0.053	1.624	102
305	Non-life insurance	1.499	0.336	1.484	0.141	1.000	103
306	Services auxiliary to finance and insurance	1.585	0.375	1.561	0.121	1.000	105
307	Owner-occupied housing	−3.892	4.017	−1.218	0.278	1.000	5
308	Renting and subdividing of real estate	1.521	0.349	1.492	0.138	1.000	119
309	Services related to real estate	1.942	0.429	2.193	0.031	1.942	87
310	Research institutes(public)	1.556	0.250	2.224	0.027	1.556	178
311	Research institutes(private, non-profit, commercial)	1.708	0.265	2.677	0.008	1.708	148
312	Research and experiment in enterprise	1.335	0.184	1.825	0.069	1.335	221
313	Legal and accounting services	1.333	0.482	0.690	0.492	1.000	83
314	Market research and management consultancy	1.371	0.265	1.400	0.165	1.000	91
315	Advertising services	0.999	0.341	−0.003	0.997	1.000	121
316	Architectural engineering services	1.557	0.154	3.609	0.000	1.557	139
317	Computer softwares development and supply	1.331	0.407	0.813	0.418	1.000	111
318	Computer related services	1.315	0.340	0.928	0.356	1.000	107
319	Renting of machinery and goods	1.576	0.291	1.981	0.050	1.576	129
320	Cleaning and disinfection services	1.605	0.305	1.981	0.050	1.605	100
321	Misc. business services	1.003	0.355	0.009	0.993	1.000	125
322	Public government	0.623	0.518	−0.727	0.468	1.000	201
323	Local government	1.401	0.582	0.688	0.492	1.000	210
324	Education (public)	1.577	0.212	2.724	0.007	1.577	165
325	Education (private, non-profit)	1.017	0.218	0.078	0.938	1.000	144
326	Education (commercial)	2.184	0.290	4.076	0.000	2.184	123
327	Medical and health services(public)	2.155	0.225	5.140	0.000	2.155	134
328	Medical and health services(Private, non-profit)	1.864	0.282	3.060	0.003	1.864	137
329	Medical and health services (commercial)	2.357	0.321	4.223	0.000	2.357	156
330	Social work activities(public)	2.427	0.361	3.959	0.000	2.427	117
331	Social work activities(other)	1.997	0.328	3.042	0.003	1.997	133
332	Sanitary services(public)	1.942	0.303	3.106	0.002	1.942	126
333	Sanitary services(commercial)	1.418	0.439	0.953	0.343	1.000	125
334	Newspapers	1.804	0.225	3.566	0.001	1.804	114
335	Publishing	1.610	0.190	3.216	0.002	1.610	120
336	Library, museum and similar recreation related services(public)	2.001	0.265	3.781	0.000	2.001	129
337	Library, museum and similar recreation related services(other)	1.634	0.290	2.186	0.031	1.634	131
338	Motion picture, Theatrical producers, bands, and entertainers	1.733	0.209	3.509	0.001	1.733	147
339	Sports organizations and sports facility operation	1.948	0.173	5.492	0.000	1.948	140
340	Misc. amusement and recreation services	1.221	0.263	0.840	0.402	1.000	149
341	Business and professional organizations	2.951	0.667	2.924	0.004	2.951	91
342	Other membership organizations	2.154	0.324	3.560	0.001	2.154	110
343	Motor repair services	1.305	0.274	1.114	0.267	1.000	140
344	Other personal repair services	1.649	0.169	3.831	0.000	1.649	143
345	Laundry and cleaning services	1.314	0.374	0.839	0.404	1.000	87
346	Barber and beauty shops	1.567	0.364	1.557	0.123	1.000	89
347	Personal services	1.831	0.281	2.956	0.004	1.831	120
348	Office supplies					1.000	
349	Business consumption expenditures					1.000	
350	Nonclassifiable activities					1.000	