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Measurement of Sectoral Technological Progress in Japan

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Measurement of Sectoral Technological Progress in Japan Revisited*

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Abstract. This paper examines the direction and the magnitude of bias in the technological progress measurement due to imperfect competition and short-run fixed costs. We show that, if capital growth exceeds non-capital input growth, the traditional measure underestimates the true technological growth if the pure profit is on the average positive. We then measure the actual magnitude of this bias by re-estimating sectoral technological progress in the Japanese industries. We find that the traditional measurement *under*estimates the technological progress by about one third between 1962 and 1974.

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1. Introduction

Phenomenal success of East Asian economies has attracted much attention to the source of their economic growth. Especially, recent studies based on neoclassical theory produced controversial results: the most important source of economic growth of the East Asian countries (except Japan) is capital accumulation, and the estimated rate of technological progress is very small and in some cases substantially negative (see Tsao [18], Kim and Lau [6], Young [19], and Park and Kwon [14]). Based on these results, it is often argued that economic growth in this area cannot be sustained for a long period of time (see Krugman [7]).

Here, Japan is an interesting exception. A series of studies has shown that technological progress contributes substantially to her economic growth (see Kuroda and Jorgenson [8]). Thus, it is an interesting research agenda to investigate the difference between the Japanese and other East Asian economies.

There are, however, theoretical and resulting measurement problems in the above-mentioned analyses of productivity growth, which must be solved before pursuing this agenda. Most of the studies in this field assume perfect competition, constant returns to scale, and full factor utilization, although many sectors in East Asian economies are considered to be imperfectly competitive and their short-run production entails substantial fixity. Presence of imperfect competition and short-run fixed costs may bias the measurement of technological progress, and the results reported in the previous studies may be misleading.

The first purpose of this paper is to examine the direction and the magnitude of bias in the technological progress measurement due to imperfect competition and short-run fixed costs. We show that imperfect competition coupled with short-run fixed costs is likely to make the traditional measurement of technological progress biased. The direction of bias depends, firstly, on the relative magnitude of growth between capital stocks and non-capital inputs, and secondly, whether firms enjoy a pure profit in the "long run" or not. Here we use the "long run" for a period long enough to cover at least one business cycle but not long enough to allow entry and exit to drive the pure profit equal to zero.[1] Thus, if capital growth exceeds non-capital input growth (which is the case in many industries in Japan), then the traditional measure underestimates the true technological growth if the pure profit is on the average positive. On the contrary, however, if the pure profit is negative on the average, then the traditional measure overstates the true rate. Since the Japanese (and other East Asian countries') economic growth in the high growth era is accompanied by rapid accumulation of capital stocks and positive pure profits, this result suggests that the traditional measurement may understate the true productivity growth if the market is imperfectly competitive and there are fixed costs in the short run.

The second purpose of this paper is to measure the actual magnitude of this bias by re-estimating sectoral technological progress in the Japanese industries. We take the oft-mentioned Keio Economic Observatory (hereafter abbreviated as KEO) series of sectoral technological progress, which have been focal in the discussion of sectoral technological progress in the Japanese economy (Kuroda and Jorgenson [8] and Kuroda [10]). The data set is particularly suited for our purpose, since (a) it has

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[1] In this sense, the "medium run" might be more appropriate, but we stick to this popular word just for convenience.

information about material and energy inputs in addition to labor and capital so as to avoid nagging problems plaguing analysis based on value-added production functions, and (b) it meticulously excludes the effect of quality change in capital and non-capital inputs from the calculation of technological progress. Thus, the KEO data set is relatively free from the quality-change criticism which might undermines the productivity-growth measurement. We use the Kuroda [10] version of this data set, since it has been widely discussed in the literature. Comparing our results assuming imperfect competition and short-run fixed costs with his results assuming perfect competition and constant returns to scale, we immediately gain insights about the possible direction and magnitude of biases.[2] We in fact found a substantial downward bias in the traditional measurement of technological growth in the high growth era with rapid capital accumulation: the traditional measurement *under*estimates the technological progress by about one third between 1962 and 1974. However, the result also shows a very sharp decline in the productivity growth (except for Electric Machinery) in the period after the oil crisis (1975-1984). In this period, traditional measurement overestimates the productivity growth since the pure profit is negative in many industries. Thus, the traditional measurement substantially underestimates the productivity decline experienced by the Japanese economy.

The plan of this paper is as follows. In section 2, we specify production technology with short-run fixed costs and variable utilization, and derive the formula to relate the "true" rate of technological progress to its traditional measure that assumes perfect competition, constant returns to scale, and full factor utilization. We examine the

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[2] The data are explained in Kuroda et al [9].

direction and magnitude of bias in the traditional measurement of technological bias. In Section 3, we first estimate mark-up and the magnitude of short-run fixed costs, and then use them to re-estimate technological progress in the thirty Japanese sectors in the KEO data set. In Section 4, we discuss implications of the empirical results on the Japanese economy and present a concluding remark on the debate over Asian productivity growth.

2. Imperfect Competition, Short-Run Fixed Costs and Measurement of Technological Progress

For expository self-consistency, we briefly explain the properties of the traditional (neoclassical) measurement of technological progress, which has been an essential building block of the recent attempts to analyze Asian economic growth. We then discuss the combined effect of imperfect competition and short-run fixed costs on the measurement.

2.1. The Rate of Technological Progress

Let us consider the following general form of multiple-input-one-output technology

$$y_t = f\left(x_{1t}, ..., x_{nt}, k_t; A_t\right). \tag{2.1}$$

Here y_t is the output, x_{it} is the ith input, k_t is capital stocks,[3] and A_t is the shift parameter representing the level of technology, all of which are evaluated at time t.

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[3] Here we treat capital stocks as a scaler variable, but it may be a vector of many kinds of capital goods. Extension to multi-capital-good cases is straightforward. By the same token, it is also straightforward (though cumbersome) to extend our analysis to the multi-output case.

We hereafter denote the partial derivative of a variable z with respect to time t as $\dot{z}$.

The *rate of technological progress* θ_t at time t is defined as the rate of output growth for given inputs x_{it} and k_t, which is

$$\theta_t = \frac{\partial f}{\partial A_t} \frac{\dot{A}_t}{y_t} \tag{2.2}$$

2.2. Traditional Approach

Perfect competition and constant returns to scale. In the traditional approach, the production technology is assumed to exhibit constant returns to scale, and the market is perfectly competitive. In particular, f is assumed to be linear homogeneous in x_{it} and k_t.

The firm maximizes profits such that

$$\underset{y_t}{Max} \;\; p_t y_t - C(y_t; q_{1t}, ..., q_{nt}, r_t).$$

where the cost function is determined by:

$$C(y_t; q_{1t}, ..., q_{nt}, r_t) \equiv \underset{x_{it}, k_t}{Min} \left(\sum_{i=1}^{n} q_{it} x_{it} + r_t k_t \right) \text{ s.t. (2.1).}$$

Then, equilibrium conditions are

$$\frac{q_{it}}{\lambda_t} = \frac{\partial f}{\partial x_{it}}; \; \frac{r_t}{\lambda_t} = \frac{\partial f}{\partial k_t}; \tag{2.3}$$

and

$$p_t = \lambda_t \tag{2.4}$$

where λ_t is the marginal cost: $\lambda_t = \partial C / \partial y_t$.

Measuring technological progress. We have, from (2.4) and (2.3),

$$\frac{\dot{y}_t}{y_t} = \frac{1}{y_t}\left(\sum_{i=1}^{n} \frac{\partial f}{\partial x_{it}} \dot{x}_{it} + \frac{\partial f}{\partial k_t} \dot{k}_t\right) + \frac{\partial f}{\partial A_t} \frac{\dot{A}_t}{y_t} = \left(\sum_{i=1}^{n} \frac{q_{it} x_{it}}{\lambda_t y_t} \frac{\dot{x}_{it}}{x_{it}} + \frac{r_t k_t}{\lambda_t y_t} \frac{\dot{k}_t}{k_t}\right) + \theta_t$$

where (2.3) is utilized. Accordingly, we get

$$\theta_t = \frac{\dot{y}_t}{y_t} - \left(\sum_{i=1}^{n} \frac{q_{it} x_{it}}{\lambda_t y_t} \frac{\dot{x}_{it}}{x_{it}} + \frac{r_t k_t}{\lambda_t y_t} \frac{\dot{k}_t}{k_t}\right). \tag{2.5}$$

Measurement in practice. In practice, the rate of technological progress is measured from a convenient formula based of perfect competition and constant returns to scale. Since perfect competition and constant returns imply $p_t y_t = \sum_{i=1}^{n} q_{it} x_{it} + r_t k_t$, we have

$$\frac{r_t k_t}{\sum_{j=1}^{n} q_{jt} x_{jt} + r_t k_t} = \frac{r_t k_t}{p_t y_t} = 1 - \frac{\sum_{j=1}^{n} q_{jt} x_{jt}}{p_t y_t}.$$

Thus, the share of capital in total factor payments is derived from the share of the other factors. This property is almost always used in the literature. The estimated rate of growth in the total factor productivity is then

$$\theta_t^{est} = \frac{\dot{y}_t}{y_t} - \left(\sum_{i=1}^{n} \frac{q_{it} x_{it}}{p_t y_t} \frac{\dot{x}_{it}}{x_{it}} + \left(1 - \frac{\sum_{j=1}^{n} q_{jt} x_{jt}}{p_t y_t}\right) \frac{\dot{k}_t}{k_t}\right). \tag{2.6}$$

2.3. Short-Run Fixed Cost and Short-Run Production Function.

As is well known, there are two problems in this simple framework. First, production facilities and corresponding worker organization are usually designed for a specific range of output, and they are not readily adjustable in the short run. This suggests that there may be non-negligible fixed costs in the short run. Second, because of these short-run fixed costs, productivity is generally procyclical over the business cycle, going up in booms and down in recessions (see Hall [4]).

The observation of the existence of non-negligible fixed costs leads some economists to a recent approach in which capital stocks are assumed to be a quasi-fixed factor: that is, an approach where all capital stocks are fixed in the short run though they change through investment. Moreover, in response to the apparent deviation from the constant returns to scale, the non-constant-returns property is often incorporated in the quasi-fixed capital approach (see, for example, Morrison [11]).

These studies, however, ignore the fact that *not all capital inputs are literally fixed* in the short run, and that *not all labor inputs are perfectly flexible* in the short run. On the one hand, firms can purchase machine tools to produce output in the present period, and they customarily do so if possible. On the other hand, they cannot get rid of some of managerial labor in the short run, even if they decide not to produce output temporarily. Thus, both capital and labor are *partially sticky* in the sense that it is difficult to adjust them completely at once, but *neither is completely rigid* even in the short run. Because of this partially sticky adjustment, these inputs are often described as being under-utilized, compared with full utilization when adjustment is completed.

Moreover, recent studies (see, for example, Basu [1]) show that if *short-run adjustments of production organization are completed,* then the production function exhibits constant returns to scale for a given technology, as in the neoclassical framework. This suggests that apparent increasing returns are short-run phenomenon. If the partial stickiness in inputs is properly accounted for, then production is still described reasonably well by the neoclassical production function of the type (2.1).

Based on the discussion above, we depart from the neoclassical framework in a different way from the quasi-fixed capital approach. Our approach can be considered as one of *quasi-fixed production-organization*, since we assume production organization (including production facility and corresponding worker organization) is fixed in the short run. This leads to short-run fixed costs and short-run decreasing average costs. However, as explained above, the quasi-fixity of production organization does not imply that capital and labor are also fixed. For given production organization, it is always possible to realign equipments and machine tools as well as to reorganize worker organization, and thus capital and labor are variable in the short run. In the long-run steady state where adjustment is completed and there is no uncertainty, we require constant returns and that the input-output relationship should coincide with the neoclassical one (2.1).[4]

Let us now specify *short-run production function*, which incorporates the characteristics of quasi-fixed production-organization in the simplest way.

Let y^*_{t-1} represent the maximum production capacity of the firm's current production organization, which is determined in the previous period. On the one hand, the firm cannot produce more than this capacity, and production facility and worker organization are designed for the best use at this capacity. On the other hand, the current production organization need inputs just to maintain the facility and orga-

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[4] It should be noted that the quasi-fixed capital approach and our approach are not mutually exclusive. It is possible to incorporate the short-run immobility of capital stocks in our framework.

nization even though no output is produced. The maximum capacity y^*_{t-1} is fixed in the short run because of the sticky production organization. The firm has to determine period t's capacity y^*_{t-1} in period $t-1$.

Specifically, we assume the following short-run production function

$$y_t = \{1+\gamma\} f\left(x_{1t}, ..., x_{nt}, k_t; A_t\right) - \gamma y^*_{t-1}, \tag{2.7}$$

which is, of course, defined only for y_t such that $y^*_{t-1} \geq y_t \geq 0$, where f is the same as (2.1) and γ is a technologically-determined parameter.[5]

This formulation satisfies our requirement. First, in order to produce non-negative output, at least inputs $(x_{1\,\min t}, ..., x_{n\,\min t}, k_{i\,\min t})$ satisfying

$$0 = \{1+\gamma\} f\left(x_{1\,\min t}, ..., x_{n\,\min t}, k_{i\,\min t}; A_t\right) - \gamma y^*_{t-1}$$

are needed. Thus, we have short run fixed costs. It should be noted that this formulation allows substitution between "fixed inputs" $(x_{1\,\min t}, ..., x_{n\,\min t}, k_{i\,\min t})$. Second, in the *long-run steady state* where adjustment is complete and there is no uncertainty, the actual output and the maximum capacity coincide with each other $y^*_{t-1} = y_t$. Therefore, the long run steady-state production function is implicitly defined by

$$y_t \mid_{\text{steady state}} = \{1+\gamma\} f\left(x_{1t}, ..., x_{nt}, k_t; A_t\right) - \gamma \left(y_t \mid_{\text{steady state}}\right),$$

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[5] A similar form is used in Rotemberg and Woodford [16] in their study of cyclical mark-ups.

where $y_t \mid_{\text{long run}}$ is the long-run steady-state output. The relation (2.8) leads to the *long-run steady-state production function*

$$y_t \mid_{\text{steady state}} = f\left(x_{1t}, ..., x_{nt}, k_t; A_t\right) \tag{2.8}$$

which is exactly the same as (2.1).

In the short run, however, there is uncertainty in the future. Since capacity must be determined one period earlier than actual production, it is not always possible to set the maximum capacity equal to the actual output. There may be possibility of over-capacity on the one hand and of under-capacity on the other. The firm determines the next period's capacity by comparing the opportunity cost of under-utilization in the case of overcapacity with the opportunity cost of lost sales in the case of under-capacity.

The maximum capacity is generally not observable. Therefore, to make analysis empirical operational, we have to make an additional assumption on the relation between the maximum capacity and the observable variables. In this paper, we assume that the maximum capacity y_{t-1}^{*} is proportional to the "normal" output y_t^N, of which we use the trend output as a proxy:

$$y_{t-1}^{*} = \zeta y_t^N. \tag{2.9}$$

Then, the short-run production function is now

$$y_t = f^{*}\left(x_{1t}, ..., x_{nt}, k_t; A_t, y_t^N\right) \equiv \{1+\gamma\} f\left(x_{1t}, ..., x_{nt}, k_t; A_t\right) - \gamma_0 y_t^N \tag{2.10}$$

where $\gamma_0 = \gamma\zeta$.

2.4. Imperfect Competition, Short-run Fixed Costs and Bias in Measuring Technological Change.

Let us now consider implications of the quasi-fixed production organization and the resulting short-run fixed costs on the measurement of technological progress. Since output depends not only on inputs but also on the maximum capacity, the simple definition of the technological progress, namely, the rate of output growth not attributable to input growth, is not an appropriate one. It is dependent on the change of the maximum capacity.

In the long run, however, the maximum capacity grows on the average by the same rate as output, so long as production exhibits long-run constant returns (which we have assumed in the previous section). Taking this property in mind, we define the *long-run* rate of technological progress as the rate of output growth not attributable to input growth *in the long run in which capacity growth coincides output growth.*

Differentiating the short run production function (2.10) with time, and taking the average over T periods, we get

$$\frac{1}{T}\sum_{t=0}^{T}\frac{\dot{y}_t}{y_t} = \frac{1}{T}\sum_{t=0}^{T}\left[\sum_{i=1}^{n}\frac{\partial f^*}{\partial x_{it}}\frac{\dot{x}_{it}}{y_t} + \frac{\partial f^*}{\partial k_t}\frac{\dot{k}_t}{y_t}\right] + \frac{1}{T}\sum_{t=0}^{T}\frac{\partial f^*}{\partial A_t}\frac{\dot{A}_t}{y_t} - \gamma_0\frac{1}{T}\sum_{t=0}^{T}\frac{\dot{y}_t^N}{y_t} \qquad (2.11)$$

since we know $\partial f^*/\partial y_t^N = -\gamma_0$. The second term is the factor affecting output growth which is not attributable to input growth. The third term represents the effect of long-run capacity adjustment. It is on the average approximately equal to output growth, since the normal-output growth is on the average equal to the actual-output growth:

$$\frac{1}{T}\sum_{t=0}^{T}\frac{\dot{y}_t^N}{y_t}=\frac{1}{T}\sum_{t=0}^{T}\frac{y_t^N}{y_t}\frac{\dot{y}_t^N}{y_t^N}\approx\frac{1}{T}\sum_{t=0}^{T}\frac{\dot{y}_t}{y_t}. \tag{2.12}$$

Substituting (2.12) into (2.11) and rearranging terms, we get

$$\frac{1}{T}\sum_{t=0}^{T}\frac{\dot{y}_t}{y_t}=\left(\frac{1}{1+\gamma_0}\right)\frac{1}{T}\sum_{t=0}^{T}\left[\sum_{i=1}^{n}\frac{\partial f^*}{\partial x_{it}}\frac{\dot{x}_{it}}{y_t}+\frac{\partial f^*}{\partial k_t}\frac{\dot{k}_t}{y_t}\right]+\left(\frac{1}{1+\gamma_0}\right)\frac{1}{T}\sum_{t=0}^{T}\frac{\dot{A}_t}{y_t}\frac{\partial f^*}{\partial A_t} \tag{2.13}$$

Consequently, the third term represents the long-run output growth not attributable to input growth. Thus, the long-run rate of technological progress $\theta\mid_{\text{Long Run}}$ is defined in the following way:

$$\theta\mid_{\text{Long Run}}=\left(\frac{1}{1+\gamma_0}\right)\frac{1}{T}\sum_{t=0}^{T}\frac{\dot{A}_t}{y_t}\frac{\partial f^*}{\partial A_t}. \tag{2.14}$$

This definition has an intuitive interpretation. Consider a long-run steady-state growth path, in which output growth is constant and completely predictable (no uncertainty). Since the rate of technological growth is the same for all periods, we have

$$\theta\mid_{\text{Long Run}}=\left(\frac{1}{1+\gamma_0}\right)\frac{\dot{A}_t}{y_t}\frac{\partial\left(1+\gamma\right)f}{\partial A_t}. \tag{2.15}$$

Moreover, in the long-run steady-state growth path, the capacity y_{t-1}^* is always equal to the actual output y_t. This implies $\zeta=1$ in (2.9), so that we have $\gamma_0=\gamma$. Since we get $y_t=(1+\gamma)f-\gamma y_t$ in this case, we get $y_t=f$. Substituting these relations into (2.15), we have

$$\theta\mid_{\text{Long Run}}=\frac{\dot{A}_t}{f}\frac{\partial f}{\partial A_t}$$

This is the "rate of technological progress" based on the long-run steady-state production function (2.8).

The long-run rate of technological progress can be estimated from observable variables. From (2.14) and (2.13), we have

$$\theta \,|_{\text{Long Run}} = \frac{1}{T} \sum_{t=0}^{T} \left[\frac{\dot{y}_t}{y_t} - \left(\frac{1}{1+\gamma_0} \right) \left\{ \sum_{i=1}^{n} \frac{\partial f^*}{\partial x_{it}} \frac{\dot{x}_{it}}{y_t} + \frac{\partial f^*}{\partial k_t} \frac{\dot{k}_t}{y_t} \right\} \right] \tag{2.16}$$

We replace the above expression's second term on the right hand side with market variables.

Since firms are still assumed to be price-takers in input markets, (short-run) cost minimization yields the following relations.

$$\frac{q_{it}}{\lambda_t} = \frac{\partial f^*}{\partial x_{it}}; \; \frac{r_t}{\lambda_t} = \frac{\partial f^*}{\partial k_t} \tag{2.17}$$

where λ_t is the marginal cost. Output markets may be imperfectly competitive. We have

$$p_t = \mu_t \lambda_t . \tag{2.18}$$

Here μ_t is the mark-up rate over the marginal cost λ_t. We treat the mark up rate as a *parameter* to be estimated from the data, and do not make any specific assumptions on its determination.[6]

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[6] The mark-up rate μ_t must be equal to or greater than unity in the long run for the firm to be profitable, but it may be smaller than unity in the short run.

Substituting (2.17) and (2.18) into (2.16), we have [7]

$$\theta\mid_{\text{Long Run}}=\frac{1}{T}\sum_{t=0}^{T}\left[\frac{\dot{y}_t}{y_t}-\frac{\mu_t}{1+\gamma_0}\left(\sum_{i=1}^{n}\frac{q_{it}x_{it}}{p_t y_t}\frac{\dot{x}_{it}}{x_{it}}+\frac{r_t k_t}{p_t y_t}\frac{\dot{k}_t}{k_t}\right)\right] \tag{2.19}$$

2.5. Direction and Magnitude of Bias in the Measurement of Technological Progress.

Comparing (2.6) and (2.19), we have the following relation (see Appendix).

$$\theta\mid_{\text{Long Run}}-\frac{1}{T}\sum_{t=0}^{T}\theta_t^{est}=\frac{1}{T}\sum_{t=0}^{T}\left(\frac{\mu_t}{1+\gamma_0}-1\right)\left\{\left(\sum_{i=1}^{n}w_{it}\right)\frac{\dot{k}_t}{k_t}-\sum_{i=1}^{n}w_{it}\frac{\dot{x}_{it}}{x_{it}}\right\}. \tag{2.20}$$

where w_{it} is the factor share such that

$$w_{it}=\frac{q_{it}x_{it}}{p_t y_t}.$$

The equation (2.20) shows that if there is no pure profit so as to have $\mu_t=1+\gamma_0$, then the traditional technological-growth measurement is *not* biased. In other words, *if there is no entry barrier and free entry leads to zero pure profit, then the traditional approach, assuming perfect competition and constant returns, produces the correct figure of technological progress even if competition is imperfect and there are short-run fixed costs.* However, pure profits are not always equal to zero. Then, the

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[7] This immediately follows the transformation of (2.16) below:

$$\theta\mid_{\text{Long Run}}=\frac{1}{T}\sum_{t=0}^{T}\left[\frac{\dot{y}_t}{y_t}-\frac{1}{1+\gamma_0}\left(\sum_{i=1}^{n}\frac{q_{it}}{\lambda_t}\frac{\dot{x}_{it}}{y_t}+\frac{r_t}{\lambda_t}\frac{\dot{k}_t}{y_t}\right)\right]$$

traditional approach entails bias, and (2.20) determines the direction and magnitude of the bias in the estimated technological progress.

The direction and the magnitude of bias depend on (1) whether the market is competitive or not, (2) whether there are substantial fixed costs, and (3) whether capital growth exceeds non-capital input growth.

Suppose that $\mu_t > 1 + \gamma_0$, which ensures non-negative profits in the long run. Then, if capital input growth exceeds non-capital input growth $((\sum w_{it})\left(\dot{k}_t\ /k_t\right) > \sum w_{ij}\left(\dot{x}_{it}\ /x_{it}\right))$, which is often found in the process of actual economic growth, the traditional measure *underestimates* the true technological progress. The magnitude of the bias is greater if the price-marginal-cost margin μ_t is greater, while it is smaller when the magnitude of fixed costs γ_0 is greater. If, on the contrary, the non-capital input growth is greater than capital growth, the conclusion is reversed.

In reality, the firm may not earn a positive profit for a long period. Then, the conclusion of the bias just presented may be reversed in such a case. Thus, the direction of the bias and its magnitude are empirical questions.

It should be noted here that we have not made any specific assumption with respect to the firm's pricing behavior. Imperfect competition may be Cournot quantity competition, differentiated-product Bertrand one, bilateral monopoly, or repeated-game implicit-cartel. What we have assumed are only (1) firms are input-price takers minimizing cost, and (2) production function incorporates short-run fixed costs in the form of (2.10). In this sense, this formulation is quite general.

3. Re-Assessment of Sectoral Technological Progress in Japan

3.1. Data

In this section, we take the oft-cited work of Kuroda and his group on the sectoral technological progress[8], and examine the effect of imperfect competition and short-run increasing returns due to fixed costs on the measurement of technological progress using this data set. The data base we use is the Keio Economic Observatory Data Base (see Kuroda et al.[9] for detail), reported in [10].

The KEO Data consist of thirty SNA-based sectors excluding Government Service between 1960 and 1985[9]. Table 1 reports the sector classification. In each sector, the Divisia price and quantity index of output, and the Divisia price and quantity index of labor, capital service, energy and material as well as constant-price capital stocks are reported. The distinctive characteristics of this data set is its adjustment of quality change in inputs. Thus, we are relatively free from confusing quality change as technological progress. Also, we postulate production function whose inputs include material and energy, as well as labor and capital service. In this way, we avoid problems in using industry-wide value-added production function.

This data set is derived from the assumption of perfect competition and constant returns to scale. However, it can easily be seen that the Divisia price and quantity indexes for inputs other than capital service calculated by the KEO group are still valid in our approach, because of our specific formulation (2.10). See Appendix ??.

The oft-cited traditional estimates of technological progress based this data set

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[8] An earlier version of this work is the basis of the oft-cited Kuroda and Jorgensen [8].

[9] See the Appendix of Nishimura and Kuninori [13] for a concise description of this data set.

is obtained from the formula (2.6) under the assumption of perfect competition and constant returns to scale as in the traditional approach. In particular, it assumes that the capital service's share in the value-added is equal to the rental payments to capital, in order to get the rental price of capital service (or from a slightly different perspective, the cost of capital).

Since we do not impose perfect competition, we have to estimate the rental price of capital stocks independently. We follow the standard procedure of constructing cost of capital and assume that the rental price is equal to the cost of capital.[10]

3.2. Estimating Mark-up under Variable Utilization

Methodology. In estimating the mark up under variable factor utilization, we utilize the method developed in Nishimura, Ariga and Ohkusa [12]. We hereafter briefly discuss the procedure.

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[10] The rental price of capital goods r_t is constructed by the following standard formula correcting for corporate tax, depreciation allowance, and capital gains from inflation in capital goods:

$$r = (\rho + \delta - \pi_K^e) \times \frac{1 - k - \tau d}{1 - \tau} p_K$$

where r is the firm's rental price of capital, ρ its cost of fund, δ the economic rate of depreciation, π_K^e the expected rate of inflation of capital goods, p_K the real price of capital goods, k the effective rate of investment tax credit (which is *zero* in Japan), τ the effective rate of corporate income tax, and d the present discounted value of tax deductions for depreciation.

For the cost of fund ρ, we use the nominal interest rate of Rituki Denden Sai (Telephone and Telegraph Bond). The economic depreciation rate δ is industry-specific and is taken from the KEO Data Base. (The KEO group estimates the rate of depreciation using only quantity data in the version we use, so that their depreciation rate does not depend on their assumption of perfect competition.) The price of capital stocks p_K is also taken from the KEO Data Base. The expected rate π_K^e is approximated by the moving average of the current and preceding rate of change in the price of capital stocks. The effective corporate tax rate τ is computed in the usual way in which

$$\tau = \frac{(u + v)(1 + i)}{1 + i + v} \text{ where } u = u_c(1 + u_\ell)$$

where u is the overall corporate income tax rate, u_c the national corporate income tax rate, u_ℓ the local corporate tax surcharge rate, v the enterprise tax rate (ignoring the progressive part), i the interest rate of Telephone and Telegraph Bonds. Here u_c, u_ℓ and v are common to all industries and taken from various tax publications. All of these data are available from the authors upon request.

We use the framework of the previous section. Long-run steady-state production function f is a function $f(K_t, L_t, J_t, E_t; A_t)$ of K_t, L_t, J_t, and E_t, which are, respectively, labor input, capital service input, material input and energy input in the t-th period. A_t represents the state of technology. The short-run production function f^* is

$$Q_t = f^*(K_t, L_t, J_t, E_t; A_t) = (1+\gamma)\, f(K_t, L_t, J_t, E_t; A_t) - \gamma_0 Q_t^N,$$

where γ_0 depends on the magnitude of fixed costs and Q_t^N is the normal output.

Let us define the elasticity of output with respect to capital, labor, material and energy such that

$$\varepsilon_Q \equiv \frac{K_t}{Q_t}[f_K^*]_t + \frac{L_t}{Q_t}[f_L^*]_t + \frac{J_t}{Q_t}[f_J^*]_t + \frac{E_t}{Q_t}[f_E^*]_t$$

where $[g]_t$ is the value of function g evaluated at t. Then, we have

$$\mu_t[\alpha_K]_t = \varepsilon_Q - \mu_t([\alpha_L]_t + [\alpha_J]_t + [\alpha_E]_t) \tag{3.1}$$

Using the above relations, we obtain (see Appendix ??)

$$([\alpha_K]_t + [\alpha_L]_t + [\alpha_J]_t + [\alpha_E]_t) = \frac{1}{\mu_t}\left(1 + \gamma_0 \frac{Q_t^N}{Q_t}\right) \tag{3.2}$$

We use the trend output as a proxy of normal output Q_t^N.

Taking log of both sides of (3.2), and then applying the first-order Taylor expansion of $\log(1+x)$ around $x=0$ on $\log\left[1+\gamma_0\left(Q_t^N/Q_t\right)\right]$,[11] we get

$$\log([\alpha_K]_t+[\alpha_L]_t+[\alpha_J]_t+[\alpha_E]_t) = -\log\mu_t+\gamma_0\frac{Q_t^N}{Q_t} \tag{3.3}$$

where α_L is the labor's share, α_J the material's share and α_E the energy's share, in total sales such that

$$[\alpha_L]_t=\frac{w_tL_t}{p_tQ_t},\quad [\alpha_J]_t=\frac{p_t^JJ_t}{p_tQ_t},\quad [\alpha_E]_t=\frac{p_t^EE_t}{p_tQ_t}. \tag{3.4}$$

Procedure In our sample period of 1962-1984,[12] the Japanese economy experienced two oil crises (1973-74 and 1978-79), which might have significant effects on the sectoral mark-up μ_t and the sectoral normal output Q_t^*, the latter of which is approximated by the time-trend of output in our analysis. Thus, we postulate the following regression equation

$$\log([\alpha_K]_t+[\alpha_L]_t+[\alpha_J]_t+[\alpha_E]_t)$$

$$= -\left(\log\mu+d_1MarkupDUMMY1+d_2MarkupDUMMY2\right)+\gamma_0\tfrac{Q_t^N}{Q_t}+u_{1t} \tag{3.5}$$

where $MarkupDUMMY1$ is the dummy for structural change at the first oil crisis, $MarkupDUMMY2$ for that at the second crisis, and u_{1t} is the markup disturbance.

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[11] This procedure is justified if γ is sufficiently small. It is in fact shown to be small in empirical analysis.

[12] Since (1) the interest rate series (Telephone and Telegraph Bond) used in constructing the rental price of capital is available after 1962 and (2) the moving average of the current and preceding rate of change is used in approximating expected capital price change, the sample period in the estimation of mark-up and increasing returns is 1962-1984 although the KEO data span between 1960 and 1985.

Moreover, for the auxiliary trend-output estimation, we have

$$
\begin{aligned}
Q_t = {} & (Q_0 + m_2 TrendDUMMY1 + m_2 TrendDUMMY2) \\
& + (h_1 + h_2 TrendDUMMY1 + h_2 TrendDUMMY2)\, t + u_{2t},
\end{aligned}
\tag{3.6}
$$

where Q_0 is the constant, $TrendDUMMY1$ is the dummy for the structural change at the first oil crisis, $TrendDUMMY2$ for that at the second crisis and u_{2t} is the trend disturbance. Here we consider a structural change altering not only the slope but also the intercept. Consequently, there are four possible trend specifications: no change, one change in 1973, one change in 1979, and two changes in 1973 and 1979.

We proceed with the following two-step method. First, we estimate (3.5) for each of the four possible trend specifications, and determine whether there is a structural change in mark up in 1973, in 1979 or in both years by evaluating the t value of $MarkupDUMMY$. We then pick up, for each trend specification, an equation in which only statistically significant dummies are retained. Since there is no guarantee that the markup disturbance (which may stem from measurement errors in constructing variables) is not correlated with the explanatory variables, we use the instrumental variable method in which the instruments are the constant, dummy and the lagged variable of Q_t^N/Q_t. Finally, among four trend specifications, we choose the best specification according to the AIC criterion.

Result. The result of the estimation of mark-up is summarized in Table 2 and depicted in Figure 1, of which underlying information is found in Table 3. Table 3 reports (a) whether there is a permanent change in the mark-up due to two oil crises, (b) the mark-up rate, μ_t, of each sub-period with its confidence interval, and (c) the estimate of the magnitude of short-run fixed costs, γ_0, as well as information of structural change in output trend.[13] In most industries we have declining mark-up rates, which suggest across-the-board increase in competition in the Japanese economy throughout this sample period.

We have three groups in our thirty sectors. The first group, which we hereafter call IR ("Short-run" Increasing Returns) Industries, has a statistically significant γ_0, showing substantial short-run fixed costs. This group is shown in Figure 1, and consists of sixteen industries. As expected, it includes "Heavy/Chemical Industries" such as Iron and Steel, Fabricated Metal Products, Chemical and Allied Products, Petroleum and Coal, and Stone and Clay Products (Ceramics). Moreover, it includes "light" industries such as Food and Kindred Products, Textile Mill Products, Apparel and Other Fabricated Textile, Paper and Allied Products, Lumber and Wood Products, Furniture, and Leather Products, reflecting change in these industries toward capital-intensive mode of production. In addition, Construction and Transportation and Communication show substantial short-run fixed costs. As expected, an industry with a large fixed cost (large γ_0) tends to have a high markup (large μ).

The second group is called CR (Constant Returns) Industries, in which the hypothesis of $\gamma_0 = 0$ (*i.e.*, constant returns) is not rejected. This group consists of eleven industries. Interestingly, it includes "machinery" industries (General Ma-

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[13] If γ_0 is statistically significant, then the markup is computed from the result of the estimation of (3.5). If γ_0 is not statistically significant, (3.5) implies that

$$\mu = \frac{1}{[\alpha_K]_t + [\alpha_L]_t + [\alpha_J]_t + [\alpha_E]_t} + u_{1t}^{'}.$$

Thus, μ is the average of the reciprocal of the sum of factor shares in this case. We use this relation to estimate μ reported in Table 3.

chinery, Electric Machinery, and Precision Instruments) and "assembly" industries (Motor Vehicle and Equipment). They are all most successful industries in the Japanese manufacturing after 1973. This group also includes Rubber Products and Nonferrous Metal Products, as well as Agriculture-Forestry-Fisheries, Finance and Insurance, and Service.

The importance of this group in Japanese sectors is in sharp contrast with (West) Germany and the United States. Flaig and Steiner [2] and Morrison [11] found that most industries in both countries exhibit non-negligible increasing returns to scale, although their methodology is different from ours. However, this is broadly consistent with the result of Nishimura, Ariga, and Ohkusa [12], who, based on the analysis of a panel of Japanese firms for about twenty years, found that General Machinery and Electric Machinery industries show only small fixed costs.

The third group may be called "PROBLEMATIC," which consists of Mining, Real Estate and Utilities. The first two show unbelievably high mark-up throughout the sample period. However, this strange result is of no surprise because it is likely the artificial effect of governmental support in the case of Mining[14], and of artificial imputation procedure in Real Estate.[15] In the case of Utilities, the assumption that firms can choose their price (which is implicit in the derivation of the bias equation (2.20)) is not appropriate, since the price is completely regulated by the government.

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[14] Mining was once an important industry in Japan, but its share in GDP dwindled quite sharply. The government adopted a slow-death policy in which the industry was gradaually fading away. Meanwhile the government supported the industry directly, which distorted price and marginal cost figures in this industry.

[15] In the KEO data following the SNA procedure, the Real Estate industry is not really the real estate industry in the usual sense. It is constructed under the assumption that home-owners are landlords renting their home to themselves, and the imputed rents are included as output in this "industry". Since home-owners' labor in maintaining their home is unaccounted, the total cost corresponding to output (imputed rents) is likely to be substantially underestimated, resulting in extremely high mark-up rate.

Thus, they are not shown in Figure 1.

Figure 1 and Table 3 reveal that mark-up over marginal cost varies substantially among industries, and in general greater than unity, suggesting ubiquitous imperfect competition. However, the deviation from perfect competition is far less pronounced than the one found in several studies of U. S. industries, for example, Hall [4].

Table 2 shows the aggregate picture of imperfect competition in Japan. Industry-wide mark-up figures are aggregated with industries' value-added weight. We use two weights: one is the beginning of the sample period, 1962 and the other is the end year, 1984. Two figures show almost the same picture, in which the aggregate markup declines steadily, and the market becomes more competitive. Moreover, this table shows that industries with constant returns to scale are dominant in Japan in terms of value-added (excluding problematic ones).

3.3. The Revised Rate of Technological Progress

Using the results obtained in the previous section, we estimate the "revised" rate of technological progress based on (2.20) and compare it with the "traditional" estimate based on (2.6). The revised rate is shown alongside with the traditional one in Table 5, and illustrated in Figures 2 to 4. The resulting aggregate picture is depicted in Table 4.

In Figure 2, the average productivity growth over the entire sample period (1962-1984) is shown, while Figures 3 and 4 exhibit the rate in each sub-period. We juxtapose the traditional estimate to the revised one in order to highlight the effect of imperfect competition. Figure 2 also shows the share in GDP (at factor costs) in the two ends of the sample period: 1962 and 1984.

As expected, Figure 2 shows that the revised estimate is generally greater than the traditional estimate, except for a few industries. Food, which shows negative productivity growth in the traditional estimate, now posits a positive rate. Overall picture depicted in Table 4 reveals that the value-added weighted average of technological progress in the relevant twenty-seven industries is greater in the revised estimate than in the traditional estimate approximately by one third. This is the case regardless of particular choice of the reference year (1962 or 1984). Thus, this result shows that failure in recognizing imperfect competition makes traditional estimates substantially downward-biased with respect to the underlying rate in the entire sample period between 1962 and 1984. This is due to the fact that in most industries capital-input growth dominates non-capital-input growth and the firms' pure profit is positive over the entire sample period.

However, Figure 2 conceals striking difference between two sub-periods (1962-1973 and 1974-1984) depicted in Figures 3 and 4. In fact, although the traditional measurement of productivity growth is downward-biased in the sub-period of 1962-1973, it is upward-biased in the sub-period of 1974-1984. This result stems from the sharp decline in the mark-up reported in Table 2. Between 1974 and 1984, many industries suffer from negative pure profits ($\mu < 1 + \gamma_0$), so that the traditional measurement overestimates the true rate according to (2.20). Therefore, the traditional measurement substantially underestimates productivity slowdown experienced between the two sub-periods.

Other than the bias explained above, the overall industrial characteristics are the same in the revised estimate as in the traditional estimate. In particular, Electric Machinery, Precision Instrument, and Financial Service in the CR category and Chemical Products in the IR category have consistently high rate of technological progress for the entire sample period, followed by General Machinery and Motor Vehicle, whose high productivity growth somewhat abated after the oil crisis of 1973. In contrast, heavy industries in the IR category, whose productivity growth is comparable to that of the above-mentioned CR industries before the oil crisis, suffer from substantial slowdown after the crisis.

Figures 2 reveals that industries still showing substantial negative productive growth in the revised estimate are all industries under competition-reducing regulation of the government and/or quasi-government. They are Construction, Agriculture, Forestry and Fishery, Printing (including Publishing), Petroleum and Coal, and Service. It is well-known that the construction industry has a strong cartel-prone characteristics, which is enhanced further by political consideration in public work projects. Politically powerful agricultural cooperative has dominant power in the agricultural industry. Publishing business enjoys legal exemption from resale price maintenance prohibition in the Anti-Monopoly Law. The government intervenes petroleum refinery and related industries in various ways, which tend to insulate incumbent firms from possible entry. Government intervention is also found in service industries. Thus, the result of this paper suggests that regulatory structure is an important determinant of technological progress.

Finally, let us consider correlation between market power and technological progress. There are two conflicting views with respect to the effect of market power on productivity growth. In the Schumpeterian perspective, profit from market power makes a firm to afford investment in technological advancement, so that there might be a positive correlation between markup and productivity growth. In contrast, one may argue that high market power implies low competitive pressure to cut costs so that productivity growth is lower in noncompetitive industries than competitive ones.

We calculate correlation between markup[16] and productivity growth for all twenty-seven industries for 1962-1984, 1962-73 and 1974-1984, and find that the correlation coefficient is 0.0353 ('62-'84), -0.0027 ('64-'73) and 0.1094 ('74-'84), which are negligible. We then restrict our attention in each category and calculate the correlation coefficient. In the case of IR, we find 0.3135 (62-84), 0.14582 ('62-'73) and 0.53931 ('74-'84), while 0.41203 ('62-'84), 0.43291 ('62-'73) and 0.3331 ('73-'84) in the case of CR. Thus, there is no clear-cut systematic relation between market power and technological progress.

4. Concluding Remarks

In this paper, we have examined the measurement of technological progress under imperfect competition and short-run fixed costs.

First, we find that mark-up over marginal cost varies substantially among industries, and differs from unity, suggesting ubiquitous imperfect competition. However, the deviation from perfect competition is small. Second, among industries we are concerned, the value-added share of industries exhibiting statistically significant

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[16] Since the mark-up changes over sub-periods in some industries, we use its weighted average over the relevant period in which the ratio of the sub-period to the whole period is used as the weight of the corresponding mark-up.

short-run fixed costs is about one third of real GDP (excluding government), while that of industries of constant-returns technology is more than half.

Although one might expect that rather small mark-up and narrow scope of short run fixed costs among Japanese industries lead to their insignificant effect on productivity-growth measurement, this is not the case. The average rate of technological progress incorporating imperfect competition and short-run fixed costs between 1962 and 1984 is higher than the traditional measurement approximately by one third.[17] Thus, imperfect competition matters in the estimation of productivity growth of a rapidly growing economy even though the degree of monopoly power is small. In addition, the paper also reveals that the traditional measurement substantially underestimates productivity slowdown after the first oil crisis.

Moreover, imperfect competition may influence productivity growth directly. We find a strong correlation between productivity growth and government regulation. In our sample of industries, five industries exhibit *negative* productivity growth between 1962 and 1984. They are Construction, Agriculture, Printing (including publishing), Petroleum, and Service, in all of which various government intervention is found[18]. In addition, the most successful industries in the recent Japanese economic history, notably Motor Vehicle, Machinery, Electric Machinery, and Precision Instruments, show no sign of substantial short-run fixed cost nor high markup. These results may suggest that the competitive factor has important implication in technological progress by affecting the way technological innovation and adaptation take place.

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[17] Using the value-added weight in 1984 for each sector, we find that the annual rate of 1.05% for these sectors as compared with 0.692% in the traditional measurement. It should be noted here that these figure are substantially lower than figures usually seen in the literature, since we control quality change in inputs. See Section 3.

[18] See Section 3.

Although the result is still sketchy, it has several implications for East Asian economic growth. First, rapid capital accumulation coupled with imperfect competition in these countries may lead to substantial downward bias in the traditional measurement of productivity growth. Thus, very low productivity growth found in earlier studies may in fact distort the true picture and misleading.

Second, however, difference between Japan and other East Asian countries properly taken into account. Low mark-up and constant-returns property of machinery and "assembly" industries in Japan is in sharp contrast with these industries in other East Asian countries. For example, Park and Kwon [14] found them having substantial increasing returns to scale and significant market power.

The engine of the growth of the Japanese economy was the "heavy/chemical" industries of large short-run fixed costs, which seriously limited effective competition within industries and resulted in high mark-up. Relatively light competitive pressure resulted in substantial slowdown after the initial high growth phase ended at the time of the first oil crisis when migration from rural to urban areas virtually halted. As Krugman [7] indicates, high economic growth solely based on increase in factor inputs (made possible by, for example, migration from rural to urban societies) is not likely to be sustained for a long period of time.

However, after the 1973 oil crisis, the leading block of the Japanese economy was shifted toward to machinery and "assembly" industries. Although these industries are generally considered as "heavy" industries with large fixed costs, Japanese firms succeeded in developing production methods in which the burden of fixed costs is somewhat mitigated[19], and competitive pressure further strengthened this tendency. In this way, the Japanese economy sustained her growth.

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[19] So-called "flexible production method" can be considered as one manifestation of this effort. Also, "multi-functioned" labor within a firm contributes to reduce rigidity in production process.

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Appendix

A.1. Derivation of (2.20)

Taking the T-period average of (2.6), subtracting the result from (2.19), and rearranging terms, we have

$$\begin{aligned}
\theta \quad & \Big|\ {}_{\text{Long Run}} - \frac{1}{T}\sum_{t=0}^{T}\theta_t^{est} \\
= \quad & \frac{1}{T}\sum_{t=0}^{T}\left(1-\frac{\mu_t}{1+\gamma_0}\right)\left(\sum_{i=1}^{n}\frac{q_{it}x_{it}}{p_t y_t}\frac{\dot{x}_{it}}{x_{it}}\right) \\
& +\frac{1}{T}\sum_{t=0}^{T}\left(\frac{p_t y_t-\sum_{j=1}^{n}q_{jt}x_{jt}}{p_t y_t}-\frac{\mu_t}{1+\gamma_0}\frac{r_t k_t}{p_t y_t}\right)\frac{\dot{k}_t}{k_t}
\end{aligned} \tag{A.1}$$

which is transformed into

$$\begin{aligned}
\theta \quad & \Big|\ {}_{\text{Long Run}} - \frac{1}{T}\sum_{t=0}^{T}\theta_t^{est} \\
= \quad & \frac{1}{T}\sum_{t=0}^{T}\left[\left(1-\frac{\mu_t}{1+\gamma_0}\right)\left(\sum_{i=1}^{n}\frac{q_{it}x_{it}}{p_t y_t}\left(\frac{\dot{x}_{it}}{x_{it}}-\frac{\dot{k}_t}{k_t}\right)\right)\right] \\
& +\frac{1}{T}\sum_{t=0}^{T}\left(1-\frac{\mu_t}{1+\gamma_0}\left(\sum_{i=1}^{n}\frac{q_{it}x_{it}}{p_t y_t}+\frac{r_t k_t}{p_t y_t}\right)\right)\frac{\dot{k}_t}{k_t} \\
= \quad & \frac{1}{T}\sum_{t=0}^{T}\left[\left(1-\frac{\mu_t}{1+\gamma_0}\right)\left(\sum_{i=1}^{n}\frac{q_{it}x_{it}}{p_t y_t}\left(\frac{\dot{x}_{it}}{x_{it}}-\frac{\dot{k}_t}{k_t}\right)\right)\right] \\
& +1-\frac{1}{1+\gamma_0}\frac{1}{T}\sum_{t=0}^{T}\left(\sum_{i=1}^{n}\frac{q_{it}x_{it}}{\lambda_t y_t}+\frac{r_t k_t}{\lambda_t y_t}\right)\frac{\dot{k}_t}{k_t}
\end{aligned} \tag{A.2}$$

where (2.18) is utilized in the last transformation.

Using analogous argument as in (2.3), we have

$$\frac{q_{it}}{\lambda_t} = \frac{\partial f^*}{\partial x_{it}}; \; \frac{r_t}{\lambda_t} = \frac{\partial f^*}{\partial k_t}$$

where f^* is defined in (2.10) under our framework of imperfect competition and short-run fixed costs. Then, the linear homogeneity of f in (2.10) and the rearrangement of the definition (2.10) imply

$$\begin{aligned}
\frac{1}{T}\sum_{t=0}^{T}\left[\sum_{i=1}^{n}\frac{q_{it}x_{it}}{\lambda_t y_t} + \frac{r_t k_t}{\lambda_t k_t}\right] &= \frac{1}{T}\sum_{t=0}^{T}\left[\frac{1}{y_t}\left\{\sum_{i=1}^{n}\frac{\partial f^*}{\partial x_{it}}x_{it} + \frac{\partial f^*}{\partial k_t}k_t\right\}\right] \\
&= \frac{1}{T}\sum_{t=0}^{T}\frac{(1+\gamma)}{y_t}\left[\sum_{i=1}^{n}\frac{\partial f}{\partial x_{it}}x_{it} + \frac{\partial f}{\partial k_t}k_t\right] \\
&= \frac{1}{T}\sum_{t=0}^{T}\frac{(1+\gamma)\,f_t}{y_t} = \frac{1}{T}\sum_{t=0}^{T}\frac{y_t + \gamma_0 y_t^N}{y_t} \\
&\approx 1 + \gamma_0 \qquad \text{(A.3)}
\end{aligned}$$

where the last transformation is due to the property that the actual average output coincides with the normal output.

Substituting (??) into (??), we get

$$\theta\mid_{\text{Long Run}} - \frac{1}{T}\sum_{t=0}^{T}\theta_t^{est} = \frac{1}{T}\sum_{t=0}^{T}\left[\left(1 - \frac{\mu_t}{1+\gamma_0}\right)\left\{\sum_{i=1}^{n}\frac{q_{it}x_{it}}{p_t y_t}\left(\frac{\dot{x}_{it}}{x_{it}} - \frac{\dot{k}_t}{k_t}\right)\right\}\right]$$

which is (2.20).

A.2. Derivation of (3.1)

First, the linear homogeneity of f implies

$$\frac{K_t}{[f]_t}[f_K]_t + \frac{L_t}{[f]_t}[f_L]_t + \frac{J_t}{[f]_t}[f_J]_t + \frac{E_t}{[f]_t}[f_E]_t = 1.$$

Second, since $[f_K^*]_t = (1+\gamma)\,[f_K]_t$, we have

$$\varepsilon_Q = \frac{(1+\gamma)\,[f]_t}{Q_t}\left(\frac{K_t}{[f]_t}[f_K]_t + \frac{L_t}{[f]_t}[f_L]_t + \frac{J_t}{[f]_t}[f_J]_t + \frac{E_t}{[f]_t}[f_E]_t\right) = 1 + \gamma_0\frac{Q_t^N}{Q_t} \tag{A.4}$$

On the one hand, from the definition of ε_Q and the marginal conditions such that $[f_L^*]_t = w_t/\lambda_t$, $[f_J^*]_t = p_t^J/\lambda_t$, $[f_E^*]_t = p_t^E/\lambda_t$, where w_t, p_t^J and p_t^E are the wage rate, the price of material and the price of energy, respectively, we have

$$\begin{aligned}\tfrac{K_t}{Q_t}[f_K^*]_t &= \varepsilon_Q - \tfrac{L_t}{Q_t}[f_L^*]_t - \tfrac{J_t}{Q_t}[f_J^*]_t - \tfrac{E_t}{Q_t}[f_E^*]_t \\ &= \varepsilon_Q - \tfrac{w_tL_t}{\lambda_tQ_t} - \tfrac{p_t^JJ_t}{\lambda_tQ_t} - \tfrac{p_t^EE_t}{\lambda_tQ_t} = \varepsilon_Q - \mu_t([\alpha_L]_t + [\alpha_J]_t + [\alpha_E]_t)\end{aligned} \tag{A.5}$$

where (3.4) is used.

On the other hand, we know that the marginal condition $[f_K^*]_t = r_t/\lambda_t$ together with the relation $p_t = \mu_t\lambda_t$, where μ_t is the mark-up rate and λ_t is the marginal cost as before, yields

$$[\alpha_K]_t = \frac{r_tK_t}{p_tQ_t} = \frac{1}{\mu_t}\frac{r_t}{\lambda_t}\frac{K_t}{Q_t} \Rightarrow \frac{r_t}{\lambda_t} = \mu_t[\alpha_K]_t\frac{Q_t}{K_t},$$

Consequently, we get

$$\frac{K_t}{Q_t}[f_K^*]_t = \mu_t[\alpha_K]_t \tag{A.6}$$

Combining (??) and (??), we have (3.1) in the text.

A.3. Heterogeneous Inputs and the Divisia Indexes

In the following discussion, we take labor as an example. Consider a generalized production function incorporating heterogeneous labor inputs, which has the form:

$$Q_t = (1+\gamma) f\left\{L\left(L_{1t}, ..., L_{nt}\right), k\right\} - \gamma_0 Q_t^N$$

where f is homogeneous of degree one in both L and k. Here $L\left(L_{1t}, ..., L_{nt}\right)$ is the labor-aggregator function which depends on n kinds of labor inputs $L_{1t}, ..., L_{nt}$, where L is homogeneous of degree one in the labor inputs. We show that, despite our assumption of imperfect competition in the product market, we still have the formula used by the KEO group,

$$\frac{\dot{L}_t}{L_t} = \sum_{i=1}^{n}\left(\frac{w_{it}L_{it}}{\sum_j w_{jt}L_{jt}}\right)$$

where w_{it} is the wage rate of the ith labor input..

Let us consider L_{it}. Cost minimization implies

$$w_{it} = \lambda_t\left(1+\gamma\right)\frac{\partial f}{\partial L}\frac{\partial L}{\partial L_{it}} \Rightarrow \frac{\partial L}{\partial L_{it}} = \frac{w_{it}}{\lambda_t\left(1+\gamma\right)\frac{\partial f}{\partial L}}$$

where λ_t is the marginal cost. This implies

$$\sum_{i=1}^{n} w_{it} L_{it} = \lambda_t \left(1+\gamma\right) \frac{\partial f}{\partial L} \sum_{i=1}^{n} \frac{\partial L}{\partial L_{it}} L_{it} = \lambda_t \left(1+\gamma\right) \frac{\partial f}{\partial L} L_t$$

since we have from the linear homogeneity of L

$$L_t = \sum_{i=1}^{n} \frac{\partial L}{\partial L_{it}} L_{it}.$$

Then, we have

$$\frac{\dot{L}_t}{L_t} = \frac{1}{L_t} \sum_{i=1}^{n} \frac{\partial L}{\partial L_{it}} \dot{L}_{it} = \sum_{i=1}^{n} \frac{w_{it} L_{it}}{\lambda_t \left(1+\gamma\right) \frac{\partial f}{\partial L} L_t} \frac{\dot{L}_{it}}{L_{it}} = \sum_{i=1}^{n} \left(\frac{w_{it} L_{it}}{\sum_j w_{jt} L_{jt}} \right) \frac{\dot{L}_{it}}{L_{it}}.$$

Thus, the Divisia quantity index is still appropriate aggregator in our framework. In the same vein, the corresponding Divisia price index is also appropriate one.

Table 1:
Industry Classification

	Sector Name	Abbreviation
1	Agriculture-Forestry-Fisheries	Agri.,Forest.,&Fish.
2	Mining	Mining
3	Construction	Construc.
4	Food and Kindred Products	Food
5	Textile Mill Products	Textile
6	Fabricated Textile and Apparel	Apparel
7	Lumber and Wood Products except Furniture	Lumber
8	Furniture and Fixture	Furniture
9	Paper and Allied Products	Paper & Pulp
10	Printing, Publishing and Allied Products	Printing
11	Chemical and Allied Products	Chemical
12	Petroleum Refinery and Related Products	Petroleum & Coal
13	Rubber	Rubber
14	Leather	Leather
15	Stone and Clay	Stone & Clay
16	Iron and Steel	Iron & Steel
17	Nonferrous Metal Products	Nonferrous
18	Fabricated Metal Products	Fab. Metal
19	Machinery	Gen. Machinery
20	Electric Machinery	Elec. Machinery
21	Motor Vehicles and Equipment	Motor Vehicle
22	Transportation Equipment except Motor	Trans. Equipment
23	Precision Instruments	Preci. Instrument
24	Miscellaneous Manufacturing	Misc. Manufac.
25	Transportation and Communication	Trans. & Commu.
26	Electric Utility and Gas Supply	Utilities
27	Wholesale and Retail Trade	Trade
28	Finance and Insurance	Finance
29	Real Estate	Real Estate
30	Service	Service

Table 2:
Weighted Average of Mark-Up

	IR+CR	IR	CR
1962 Weight			
1962-73	1.422	1.812	1.153
1974-79	1.249	1.595	1.009
1980-84	1.142	1.565	0.850
1984 Weight			
1962-73	1.380	1.825	1.145
1974-79	1.204	1.615	0.986
1980-84	1.156	1.588	0.928
Share in GDP (excluding Government)			
1962	0.879	0.359	0.520
1984	0.870	0.301	0.569

Note: IR means "short-run increasing returns" due to short-run fixed costs and variable factor utilization. CR denotes constant returns.

Table 3:
Mark-Up and Fixed Costs by Industry

	1	2	3	4	5	6	7	8	9	10
	Agri.,Forest.,& Fish.	Mining	Construc.	Food	Textile	Apparel	Lumber	Furniture	Paper & Pulp	Printing
Classification	CR	Problematic	IR	IR	IR	IR	IR	IR	IR	IR
Mark-Up(myu)										
Change at '74	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Change at '80	Yes	No	No	No	No	No	No	No	Yes	Yes
'62-'73	1.204	5.965	1.705	2.027	1.651	1.428	1.315	1.252	2.574	1.506
Upper bound (5%)	1.353	6.605	1.737	2.149	1.735	1.499	1.346	1.275	2.775	1.578
Lower bound (5%)	1.054	5.325	1.672	1.904	1.568	1.358	1.284	1.229	2.373	1.434
'74-'79	1.100	5.532	1.582	1.845	1.491	1.428	1.211	1.125	2.566	1.371
Upper bound (5%)	1.338	6.140	1.611	1.953	1.568	1.499	1.241	1.145	2.779	1.443
Lower bound (5%)	0.861	4.923	1.553	1.737	1.415	1.358	1.182	1.104	2.353	1.300
'80-'84	0.531	5.532	1.582	1.845	1.491	1.428	1.211	1.125	2.271	1.258
Upper bound (5%)	0.583	6.140	1.611	1.953	1.568	1.499	1.241	1.145	2.451	1.320
Lower bound (5%)	0.479	4.923	1.553	1.737	1.415	1.358	1.182	1.104	2.092	1.197
Fixed Costs (gamma)										
estimate	NA	1.766	0.484	0.569	0.492	0.383	0.246	0.093	0.902	0.310
t-value	NA	6.623	10.825	3.919	3.965	3.232	4.312	2.148	4.678	2.628
Trend										
Change at '74	NA	No	No	No	No	No	No	No	No	No
Change at '80	NA	No	No	No	No	No	No	No	Yes	Yes

	11	12	13	14	15	16	17	18	19	20
	Chemical	Petroleum & Coal	Rubber	Leather	Stone & Clay	Iron & Steel	Nonferrous	Fab. Metal	Gen. Machinery	Elec. Machinery
Classification	IR	IR	CR	IR	IR	IR	CR	IR	CR	CR
Mark-Up(myu)										
Change at '74	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Change at '80	No	No	Yes	No	Yes	No	No	Yes	No	No
'62-'73	1.962	1.424	0.947	1.078	1.438	1.471	0.998	1.354	1.072	1.081
Upper bound (5%)	2.054	1.480	0.960	1.099	1.472	1.506	1.037	1.398	1.092	1.107
Lower bound (5%)	1.870	1.368	0.935	1.057	1.404	1.435	0.958	1.310	1.052	1.056
'74-'79	1.684	1.069	0.820	1.078	1.220	1.347	0.908	1.161	0.952	0.960
Upper bound (5%)	1.761	1.108	0.851	1.099	1.247	1.377	0.951	1.202	0.974	0.978
Lower bound (5%)	1.608	1.031	0.789	1.057	1.192	1.317	0.865	1.119	0.930	0.943
'80-'84	1.684	1.069	0.769	1.078	1.128	1.347	0.908	0.986	0.952	0.960
Upper bound (5%)	1.761	1.108	0.809	1.099	1.157	1.377	0.951	1.019	0.974	0.978
Lower bound (5%)	1.608	1.031	0.729	1.057	1.099	1.317	0.865	0.954	0.930	0.943
Fixed Costs (gamma)										
estimate	0.601	0.196	NA	0.165	0.280	0.351	NA	0.248	NA	NA
t-value	5.487	2.267	NA	3.438	5.229	6.505	NA	3.231	NA	NA
Trend										
Change at '74	No	No	NA	No	No	No	NA	No	NA	NA
Change at '80	No	No	NA	No	No	No	NA	Yes	NA	NA

	21	22	23	24	25	26	27	28	29	30
	Motor Vehicle	Trans. Equipment	Preci. Instrument	Misc. Manufac.	Trans. & Commu.	Utilities	Trade	Finance	Real Estate	Service
Classification	CR	IR	CR	CR	IR	Problematic	CR	CR	Problematic	CR
Mark-Up(myu)										
Change at '74	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Change at '80	Yes	Yes	Yes	Yes	No	No	Yes	No	Yes	No
'62-'73	1.079	1.158	1.005	1.048	2.305	0.902	1.126	1.358	4.453	1.136
Upper bound (5%)	1.106	1.189	1.018	1.056	2.534	1.021	1.189	1.441	4.889	1.161
Lower bound (5%)	1.052	1.127	0.992	1.039	2.075	0.783	1.064	1.275	4.017	1.111
'74-'79	0.985	1.058	0.868	0.931	1.887	0.713	0.976	1.179	4.453	0.940
Upper bound (5%)	1.013	1.090	0.910	0.956	2.066	0.764	1.045	1.213	4.889	0.960
Lower bound (5%)	0.958	1.026	0.825	0.907	1.709	0.663	0.907	1.144	4.017	0.920
'80-'84	0.926	0.905	0.790	0.878	1.887	0.713	0.901	1.179	3.316	0.940
Upper bound (5%)	0.955	0.929	0.831	0.896	2.066	0.764	0.941	1.213	3.642	0.960
Lower bound (5%)	0.897	0.880	0.749	0.860	1.709	0.663	0.861	1.144	2.991	0.920
Fixed Costs (gamma)										
estimate	NA	0.128	NA	NA	0.910	NA	NA	NA	NA	NA
t-value	NA	2.115	NA	NA	3.901	NA	NA	NA	NA	NA
Trend										
Change at '74	NA	No	NA	NA	No	NA	NA	NA	NA	NA
Change at '80	NA	Yes	NA	NA	No	NA	NA	NA	NA	NA

NA = Not Applicable

Note: IR means "short-run increasing returns" due to short-run fixed costs and variable utilization. CR denotes constant returns. See the Text for explanation of the "Problematic" category.

Table 4:
Weighted Average of Technological Progress (%)

	IR+CR	IR	CR
1962 Weight			
Total Sample Period			
Revised	0.825	0.766	0.866
Traditional	0.631	0.537	0.695
62-73			
Revised	1.678	1.591	1.739
Traditional	1.216	1.177	1.243
74-84			
Revised	-0.091	-0.114	-0.075
Traditional	0.002	-0.145	0.104
1984 Weight			
Total Sample Period			
Revised	1.090	0.738	1.276
Traditional	0.855	0.480	1.054
62-73			
Revised	1.978	1.507	2.226
Traditional	1.467	1.062	1.681
74-84			
Revised	0.137	-0.083	0.253
Traditional	0.198	-0.140	0.377
Share in GDP (excluding Government)			
1962	0.879	0.359	0.520
1984	0.870	0.301	0.569

Note: IR means "short-run increasing returns" due to short-run fixed costs and variable factor utilization. CR denotes constant returns.

Table 5:
Rate of Technological Progress by Industry

	1 gri.,Forest.,&Fish	2 Mining	3 Construc.	4 Food	5 Textile	6 Apparel	7 Lumber	8 Furniture	9 Paper & Pulp	10 Printing
Classification	CR	Problematic	IR	IR	IR	IR	IR	IR	IR	IR
Total Sample Period										
Revised	-1.676	4.952	-0.412	0.571	1.236	1.872	1.016	0.980	1.333	-1.270
Traditional	-1.703	1.806	-0.848	-0.289	1.080	1.837	1.111	0.804	0.479	-1.321
62-73										
Revised	-0.811	7.755	-0.638	0.935	1.788	2.578	0.847	0.474	1.111	-1.420
Traditional	-1.219	2.527	-1.298	-0.437	1.486	2.505	0.885	0.241	0.248	-1.578
74-84										
Revised	-2.611	1.976	-0.165	0.175	0.637	1.106	1.200	1.535	1.575	-1.106
Traditional	-2.228	1.026	-0.354	-0.127	0.639	1.114	1.358	1.422	0.732	-1.039
	11 Chemical	12 Petroleum & Coal	13 Rubber	14 Leather	15 Stone & Clay	16 Iron & Steel	17 Nonferrous	18 Fab. Metal	19 Gen. Machinery	20 Elec. Machinery
Classification	IR	IR	CR	IR	IR	IR	CR	IR	CR	CR
Total Sample Period										
Revised	2.657	-4.536	0.774	0.087	0.598	0.747	0.670	0.979	1.526	4.114
Traditional	2.391	-3.958	1.236	0.318	0.572	0.664	0.839	0.929	1.456	4.092
62-73										
Revised	3.640	-6.477	0.080	0.423	1.931	2.229	0.967	3.304	2.498	3.802
Traditional	3.242	-5.483	0.471	0.777	1.552	2.065	0.971	2.660	2.303	3.686
74-84										
Revised	1.594	-2.372	1.537	-0.278	-0.836	-0.846	0.347	-1.498	0.477	4.456
Traditional	1.470	-2.267	2.076	-0.180	-0.486	-0.842	0.695	-0.926	0.540	4.537
	21 Motor Vehicle	22 Trans. Equipment	23 Preci.Instrument	24 Misc. Manufac.	25 Trans. & Commu.	26 Utilities	27 Trade	28 Finance	29 Real Estate	30 Service
Classification	CR	IR	CR	CR	IR	Problematic	CR	CR	Problematic	CR
Total Sample Period										
Revised	1.755	1.004	2.663	0.832	1.779	-0.877	1.860	4.308	-0.658	-0.204
Traditional	1.705	1.197	3.128	0.816	1.722	-0.174	1.617	3.807	1.442	-0.512
62-73										
Revised	3.024	3.858	3.907	0.566	3.499	1.384	2.343	6.090	0.242	1.169
Traditional	2.767	3.796	3.886	0.318	3.385	1.382	1.775	5.058	3.599	0.501
74-84										
Revised	0.389	-2.021	1.323	1.123	-0.065	-3.287	1.335	2.398	-1.630	-1.681
Traditional	0.560	-1.564	2.306	1.362	-0.062	-1.844	1.444	2.459	-0.860	-1.606

NA = Not Applicable

Note: IR means "short-run increasing returns" due to short-run fixed costs and variable factor utilization.
CR denotes constant returns. See the text for the explanation of the "Problematic" category.

Figure 1: Mark-UP

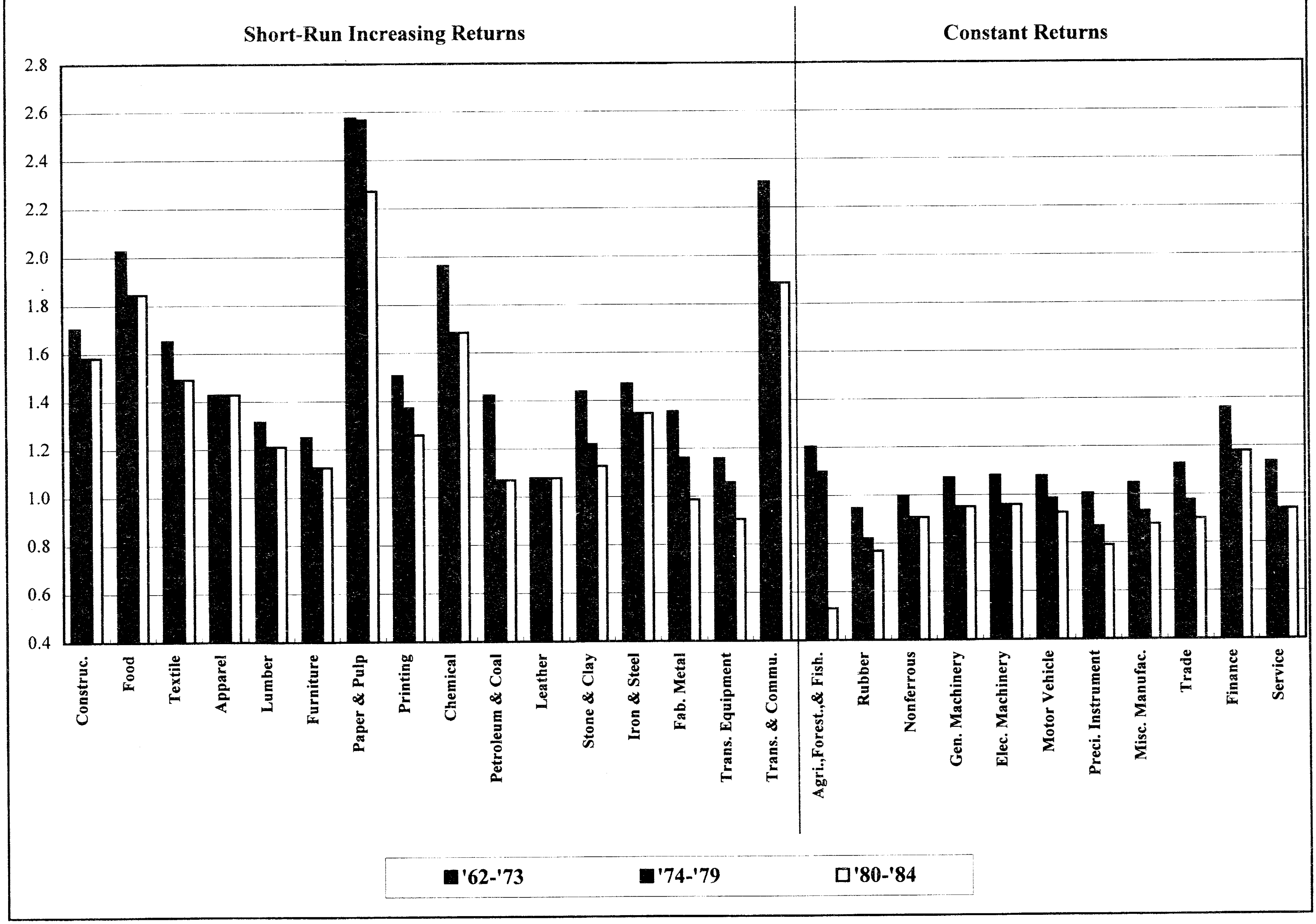

Figure 2: Rate of Technological Progress: Total Sample Period (62-84)

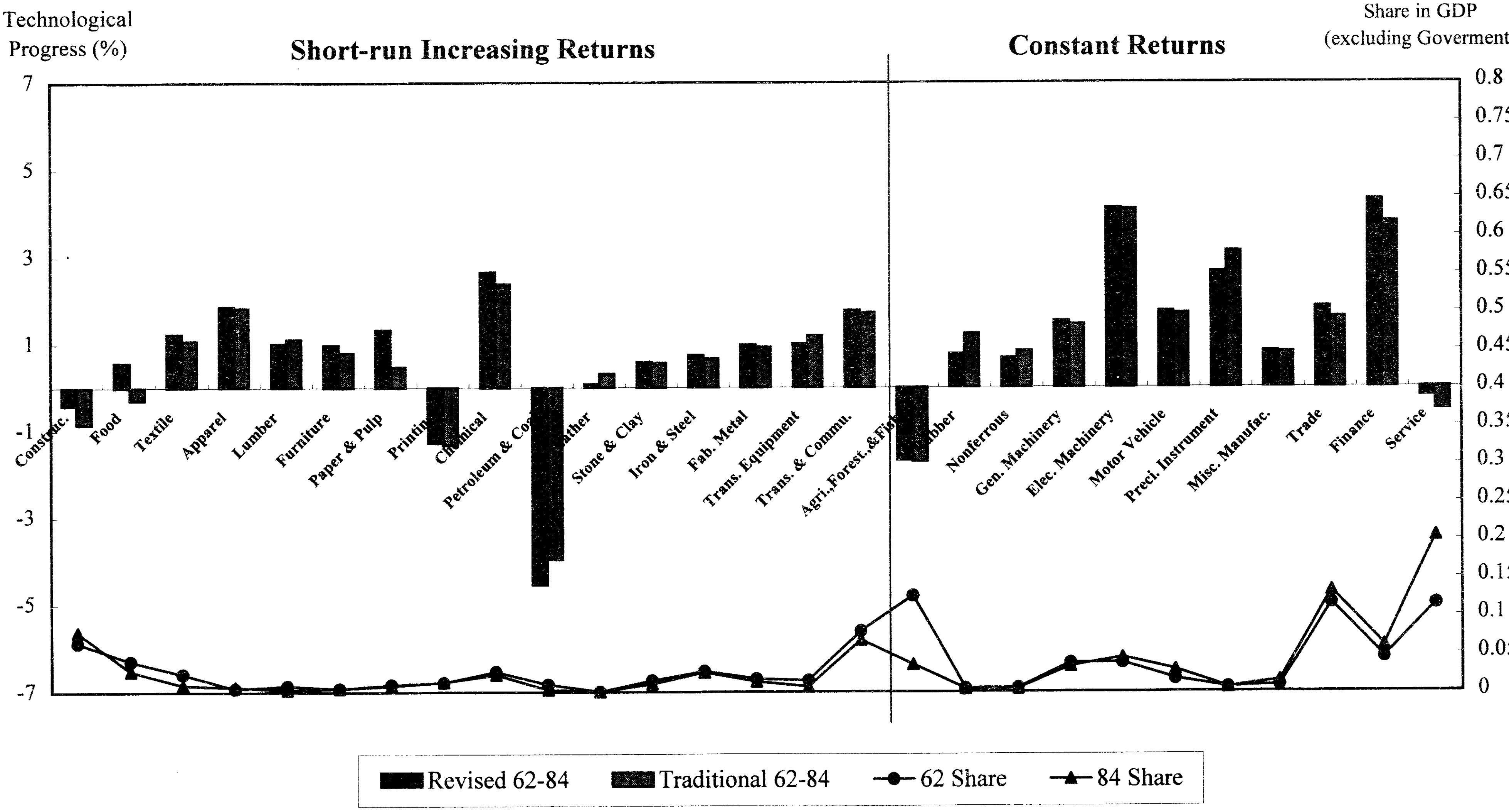

Figure 3: Rate of Technological Progress: Sub-Period 62-73

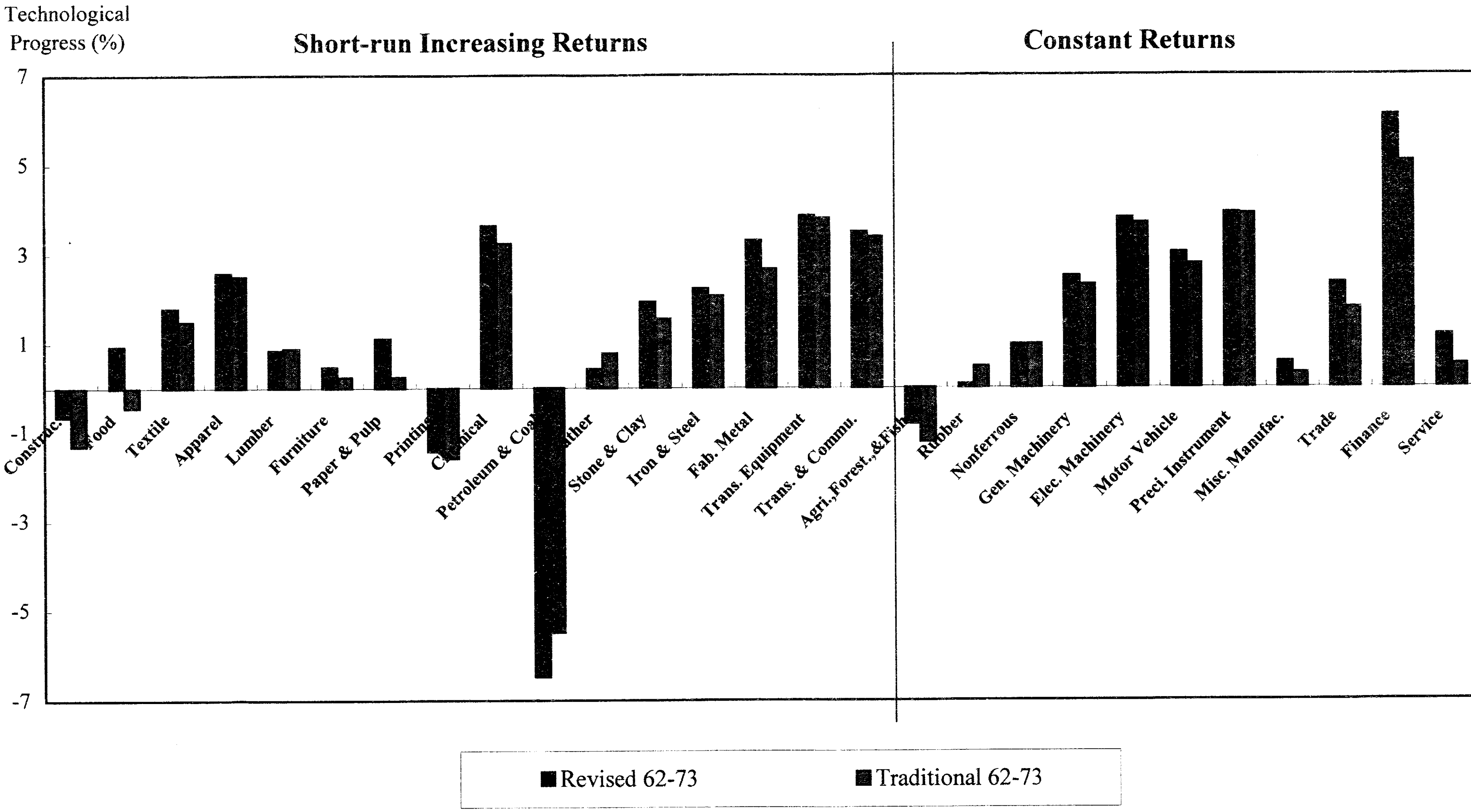

Figure 4: Rate of Technological Progress: Sub-Period 74-84