

Technical change in a bubble economy: Japanese manufacturing firms in the 1990s

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Abstract An important economic policy issue is to ascertain when and if technical change (TC) is driving measured growth in productivity. Was this the case for Japan during the late 1980s when a massive financial bubble was being formed? This paper addresses this question, after first further developing methods needed for this purpose. The movement of firms' TC is of particular policy interest to Japan whose economy has been suffering from a prolonged recession for more than a decade since the burst of the bubble in 1990. In the period of time immediately prior to the burst of the bubble, our estimation results show a significant drop in technical progress. What we believe these results reflect is that Japanese manufacturing firms made excessive investments in production inputs in the years when the bubble was being formed. This excessive investment in inputs did not contribute positively to TC and hence the measured productivity and economic growth of the bubble period in the late 1980s was unsustainable.

Keywords Technical change · Total factor productivity · Economies of scale · Japan · Index number method

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1 Introduction

An important economic policy issue is to ascertain that technical change (TC) drives growth in productivity.¹ During the late 1980s, several years prior to the burst of the bubble, the Japanese economy was thought to be enjoying healthy growth and one of the most profitable periods in Japan's history.² Was this growth being driven by positive TC? This paper addresses this question.³ This is of particular policy interest to Japan whose economy suffered from a prolonged recession for more than a decade since 1990.⁴

Prior to the burst of the bubble in 1990, our estimation results show a significant drop in technical progress took place. This suggests that the Japanese manufacturing firms made excessive investment in production inputs in the years prior to 1990 while the bubble was being formed. (The bubble economy may have caused firms to make such incorrect investment decisions.) Such excessive investment in inputs did not contribute positively to TC. The growth which was not backed by TC could not last and the bubble burst in 1990, initiating the prolonged recession. Given the historically low economic growth rates Japan experienced in the 1990s, such estimates would be of considerable policy interest.⁵

¹ TC constitutes an integral part of total factor productivity growth (TFPG) but, as discussed below, TC is not identical to TFPG since the latter contains the effects due to economies of scale.

² A financial bubble is defined here to mean that massive increases in asset prices take place in a short while without being accompanied by the corresponding increases in their fundamental value. In the Japanese bubble in the late 1980s the prices of assets such as stocks, land and golf club memberships increased by several hundred percent or more just within a few years but the Japanese CPI stayed virtually unchanged during this period. For example, the Nikkei stock average went up from 11,543 in 1985 to 38,922 in January 1990. It collapsed following the burst of the bubble in that year and came down to as low as 7,907 in 2003. It is still around 16,000. Land prices in Japan followed similar patterns, and they are still below the 1985 level also. All Japanese banks provided loans using these assets with inflated prices as collateral to finance households and firms to buy the assets. As soon as the prices of the assets collapsed, the borrowers ended up with massive loans they could not repay and the Japanese banks ended up with hundreds of billions of dollars worth of bad (non-performing) loans. Many banks, firms and households went broke, and the non-performing loans are still troubling the Japanese banks and companies (particularly in construction and real estate industries) which managed to survive. Japanese manufacturers did their part in the formation of the bubble. They did not do so much regarding the purchase of inflated assets but they did borrow massive amounts of funds and this helped fuel the over-expansion of production capacity.

³ This question has not been studied in the literature yet, in part because of the difficulty in estimating TC while controlling for scale economies.

⁴ The fear of the revival of another financial bubble prevented Japanese government policy makers involved in both fiscal and monetary policy measures from injecting adequate amounts of cash into the economy to cope with the serious post-bubble recession. But the lack of their decisive stimulus measures is thought to have caused the prolonged deflationary trend and less than optimal investment in general.

⁵ For example, the knowledge of the presence of solidly positive TC and returns to scale for the Japanese manufacturing industries in the 1990s which we find in this paper might have led to a different (and more stimulating) policy regime than the one that was actually implemented in Japan for coping with the post-bubble recession.

In general firms' total factor productivity growth (TFPG) consists of TC and economies of scale (the returns to scale), and economies of scale often systematically vary with the firm characteristics. Our econometric specification allows estimation of TC and economies of scale separately and hence has some advantages in testing hypotheses about TC and economies of scale.

In estimating firms' TC it is important to control for the effects of economies of scale. But, as discussed below, estimating TC while controlling for scale economies typically suffers from sample multicollinearity problems.⁶ In order to avoid such multicollinearity problems in our estimation, we will use an empirical framework which takes advantage of certain properties of index numbers.

In this paper we first estimate the TC and scale elasticity (elasticity of scale) using data on firms in each of 18 Japanese manufacturing industries. TFPG, which is the sum of TC and economies of scale, is also estimated.

Throughout our estimation work we assume that firms in an industry and given 2-year time period share the same TC and economies of scale parameters. We first present some evidence that TC for Japanese manufacturing industries declined significantly in the late 1980s, during the few years prior to the burst of a financial bubble in 1990. This suggests the existence of massive investments in production inputs by Japanese manufacturers, where such a capacity expansion was not accompanied by positive TC. We interpret this to mean that Japanese manufacturers (like Japanese households and policy makers) were misguided by a financial bubble being formed in making their investment decisions.

The organization of the rest of the paper is as follows. In the next Sect. 2 we present our theoretical framework based on which we obtain our econometric specifications. In Sect. 3 we present our empirical model for estimating TC and economies of scale using data for firms in Japanese manufacturing industries. We discuss our data in Sect. 4. In Sect. 5 we present and discuss our estimation results. Section 6 concludes. Limitations and further extensions of our study are also discussed in Sect. 6.

2 Theoretical background

It is important to control for returns to scale in estimating TC. This is evidenced by many previous studies which have reported difficulties in estimating or controlling for returns of scale in a robust manner. Sample multicollinearity is the primary reason for such observed difficulties. A standard method to estimate these unknown parameters is to estimate a flexible cost function using cost share equations. However, estimating scale economies using a translog cost function,⁷ for example, requires estimation of the cost function itself as well as the share equation system. Since output, its squares and its cross products with input prices are all in the cost

⁶ This is because regression equations for isolating scale economies by definition require either output or cost variables on the right-hand side and such variables are often highly correlated with the time trend or price variables.

⁷ The translog functional form for a single output technology was introduced by Christensen et al. (1971, 1973). The multiple output case was defined by Burgess (1974) and Diewert (1974, p. 139).

function, multicollinearity can potentially cause serious estimation problems. (For example, Caves and Barton (1990, p. 34), Chan and Mountain (1983, p. 665) and Banker et al. (1988, p. 40) report such estimation problems.)

In this study we use an estimating framework that can accommodate a broad range of underlying production structures while limiting the number of unknown parameters to be estimated. Our final estimation model contains only a few explanatory variables which are not highly collinear in cross sections and over time. Our method, which is parsimonious in terms of the number of unknown parameters to be estimated, incorporates flexible production functions and provides a statistically consistent means for estimating scale economies and TC.

We begin by considering the concept of returns to scale in a cross section, and then go on to allow for disembodied TC over successive 2-year time periods.⁸ Although the forms of returns to scale and TC that we allow for are simplistic, estimation is carried out separately at the firm level for each of the eighteen industries and for each of the two successive years over the 1980s and 1990s. In this way, we are able to estimate potentially time-varying TC and economies of scale for manufacturing firms.

2.1 Modeling returns to scale

Our methodology presumes that panel data are available for one or more samples of production units (PUs, indexed for each sample by $i = 1, \dots, J$), where firms are the production units in this study. The PUs in each industry are assumed to have the same production structure for each successive pair of time periods of T years each (years denoted within each time period as $t = 1, \dots, T$) where T is at least 2.⁹ In this study, output for each PU is measured as real sales (denoted by the scalar, y^{it}). On the input side, data are required for the quantities for N inputs for each PU in each year (the column vectors $x^{i,t} = (x_1^{i,t}, \dots, x_N^{i,t})$), and we need unit prices for the inputs (the column vectors $w^{i,t} = (w_1^{i,t}, \dots, w_N^{i,t})$). Our firm data are described more fully in Sect. 4.

For now we ignore the time dimension (and omit the time superscript) so as to focus on the measure of returns to scale.

To recap, we assume that the structure of production can be described by a production function f which is homogeneous of degree k , where the constant term and the returns to scale and technical change parameters are constant for all individual micro units (firms) in the same industry but are allowed to vary over industries and from one 2-year time interval to the next.

Thus, for firms in each of our industry, 2-year data samples, we assume that the structure of production can be described by a homogeneous of degree k production function denoted by

⁸ The methodology here can be easily extended to the case where more than two time periods of cross-sectional data are available.

⁹ In order to allow for the possibility of changing production structures over time, our panels consist of just two years each (i.e. $T = 2$); “rolling” 2-year panels. It is not necessary to have a longer panel length.

$$y^i = f(x^i) \quad (2.1)$$

It follows from the homogeneity assumption for the production function that if the input vector for the j^{th} PU equals λ times the input vector for PU i , then the level of output for the j^{th} PU is given by λ to the k^{th} power times the output quantity for the PU i ; i.e.,

$$\begin{aligned} y^j &= f(x^j) \\ &= f(\lambda x^i) \\ &= \lambda^k f(x^i) \\ &= \lambda^k y^i. \end{aligned} \quad (2.2)$$

Taking natural logarithms (denoted by \ln), from (2.2) we have

$$\ln y^j - \ln y^i = k \ln \lambda. \quad (2.3)$$

Expression (2.3) can be solved for k , yielding

$$k = (\ln y^j - \ln y^i) / \ln \lambda. \quad (2.4)$$

This is the elasticity of returns to scale with respect to output for the degree k homogenous production function f .

For a pair of PUs i and j that have the production structure described by (2.2), λ is the factor by which the input quantities for PU i must be inflated in order to move from the PU i to the PU j production surface. This is the definition of a Malmquist input quantity index¹⁰ for comparing the inputs of PU i with those of PU j using the technology of PU i . We denote this Malmquist input quantity index by $Q_{M|i}^{*ij}$ where the star indicates that this is an input index, the superscripts following the star indicate which PUs are being compared, the subscript M indicates that this is a Malmquist index (the notation $M(t)$ will be used instead when we also wish to note the time period for the index), and the subscript i indicates that the comparison is based on the technology of PU i . Similarly, $(1/\lambda)$ is the factor by which the input quantities for PU j must be equi-proportionately reduced in order to move from the PU j to the PU i production surface. We also define the Malmquist input quantity index for comparing the inputs of PU j with those of PU i using the technology of PU j . We denote this Malmquist input quantity index by $Q_{M|j}^{*ji}$.

There is no obvious reason for preferring either $Q_{M|i}^{*ij}$ or $Q_{M|j}^{*ji}$. Thus it is customary to define the geometric average of these two Malmquist input indexes to be *the* Malmquist index¹¹ for comparing the inputs of firms i and j , with this Malmquist

¹⁰ Diewert and Nakamura (2007) define and discuss the Malmquist output quantity indexes.

¹¹ Diewert and Nakamura (2007) explain that the Malmquist output quantity indexes correspond to the two output indexes defined in Caves et al. (1982, p. 1400) and referred to by them as Malmquist indexes because Malmquist (1953) proposed indexes similar to these in concept, though his were for the consumer rather than the producer context. They then go on in the next section to present and discuss Malmquist input quantity indexes. For more on Malmquist indexes, see Balk (2001), Grosskopf (2003), and Färe et al. (1994).

input index denoted equivalently by $Q_M^{*i,j}$ or $Q_M^{*j,i}$. Thus, what we will refer to as the Malmquist input index is given by

$$\begin{aligned} Q_M^{*i,j} &= (Q_{M_i}^{*i,j} Q_{M_j}^{*j,i})^{(1/2)} \\ &= Q_M^{*j,i}. \end{aligned} \tag{2.5}$$

In the following we present our measurement method, using translog functions, an important class of flexible production functions.

2.2 Application to a translog production function

In general, Malmquist indexes are theoretical constructs that cannot be evaluated using observable price data. However, it is well known (e.g., OECD (2001)) that under certain conditions the Malmquist input index equals the Törnqvist input quantity index (Theil (1965), Törnqvist (1936) and Fisher (1922)) denoted by $Q_T^{*i,j} (= Q_T^{*j,i})$.¹² One of the conditions under which this will be true is when the PUs have the same translog production function.¹³ Thus, if f is translog, then we have

$$\lambda = Q_M^{*i,j} = Q_T^{*i,j} \tag{2.6}$$

where

$$\ln Q_T^{*i,j} = (1/2)(s^i + s^j)'(\ln x^j - \ln x^i) \tag{2.7}$$

Under the additional assumption that the PUs minimize costs, then $s^i = (s_1^i, \dots, s_N^i)$ and $s^j = (s_1^j, \dots, s_N^j)$ are the cost share vectors for the N input factors for the two PUs. The input price vectors for the PUs i and j are denoted by $w^i = (w_1^i, \dots, w_N^i)$ and $w^j = (w_1^j, \dots, w_N^j)$, and the elements of the cost share vectors are given by

$$s_n^i = (w_n^i x_n^i) / (w^i x^i) \quad \text{and} \quad s_n^j = (w_n^j x_n^j) / (w^j x^j) \tag{2.8}$$

where a prime denotes a transpose.^{14, 15} The Törnqvist input quantity index defined in (2.7) can be evaluated from the data available to us for firms.

¹² Törnqvist indexes are also known as translog indexes following Jorgenson and Nishimizu (1978) who introduced this terminology because Diewert (1976, p. 120) related the indexes to a translog production function.

¹³ Using the exact index number approach, Caves et al. (1982, pp. 1395–1401) give conditions under which the Malmquist output and input volume indexes equal Törnqvist indexes, as noted also in the OECD (2001) manual on productivity measurement authored by Paul Schreyer, and also in Diewert and Nakamura (1993).

¹⁴ Note that the PU specific price vectors are treated as being given exogenously and are assumed not to depend on the level of production for a PU, though they can vary over the PUs.

¹⁵ Yoshioka et al. (1994) and Nakajima et al. (1998) presented an alternative proof of (2.6)–(2.8). Their proof is more indirect than the one given in this paper.

Suppose that the production function is a homogeneous of degree k translog function (Christensen, Jorgenson and Lau (1973)) given by

$$k^{-1} \ln f(x^i) = \beta_0 + \beta_1' \ln x^i + (1/2) \ln x^{i'} R \ln x^i. \tag{2.9}$$

In our setting the unknown parameters in (2.9) are β_0 , a scalar, β_1 , a column vector of coefficients with column sum 1, and k , which is a scalar representing the degree of homogeneity. R is a non-positive definite matrix with column sums equal to 0. The dimensions of β_1 and R conform to that of x^i .

For a given time period, if the technology of the PUs i and j can be represented by the translog production function given in (2.9), then under the assumptions that have been made and using (2.6), the returns to scale in the cross-section can be represented as

$$\begin{aligned} k &= (\ln y^j - \ln y^i) / \ln Q_T^{*i,j} \\ &= [\ln f(x^j) - \ln f(x^i)] / \ln Q_T^{*i,j} \end{aligned} \tag{2.10}$$

where $\ln Q_T^{*i,j}$ is given by (2.7).

We have shown that when the production functions have flexible translog forms, the returns to scale parameter k can be described simply as the difference between the logs of output observed for two sample points divided by the log of the Törnqvist input quantity index. We will use this fact below for devising econometric specifications which are parsimonious in the number of unknown parameters to be estimated.

2.3 Modeling disembodied technical change

In this study, we do not allow for within-industry cross section differences in the rate of TC and returns to scale (k). In the time dimension, however, we allow both TC and k to vary from one year to the next for firms in an industry. More specifically, when modeling the production activities of firms in the same industry over multiple time periods, we assume a production function that incorporates time as a separable variable:

$$y^{i,t} = f(x^{i,t}, t) = \lambda^{-k} f(\lambda x^{i,t}, t). \tag{2.11}$$

In this equation, $y^{i,t}$ and $x^{i,t}$ are, respectively, the scalar output quantity and the production input vector for the i^{th} PU in period t , and λ is a positive constant as before.

We assume that for one time period forward at a time, the technical change of the PUs can be described, as a first order approximation, by

$$\partial \ln y^{i,t} / \partial t = \partial \ln f(x^{i,t}, t) / \partial t = r \tag{2.12}$$

where r is a constant. With this assumption, (2.11) can be expressed as

$$y^{i,t} = f(x^{i,t})e^{rt} \quad (2.13)$$

so that we have

$$k^{-1} \ln y^{i,t} = k^{-1} \ln f(x^{i,t}) + (k^{-1})rt. \quad (2.14)$$

In (2–14), $k^{-1} \ln f(x^{i,t})$ is assumed to obey the translog function given in (2-9).

3 Empirical methodology

3.1 A basic estimating equation

We assume in the rest of this paper that the translog homogeneous of degree k production function characterizes the production environment for firms in an industry. Suppose that production for the PUs in an industry is described by (2.13), or

$$\ln y^{i,t} = \ln f(x^{i,t}) + rt. \quad (3.1)$$

For some reference PU, say A , in some given time period s ($1 \leq s \leq T - 1$) from (3.1) we have

$$\ln y^{A,s} = \ln f(x^{A,s}) + rs. \quad (3.2)$$

Now, consider any other PU in time period s , say i . From (3.1) we have

$$\ln y^{i,s} = \ln f(x^{i,s}) + rs. \quad (3.3)$$

Subtracting (3.3) from (3.2) we have

$$\ln y^{A,s} - \ln y^{i,s} = \ln f(x^{A,s}) - \ln f(x^{i,s}). \quad (3.4)$$

Using (2.10), we have the result that

$$\ln f(x^{A,s}) - \ln f(x^{i,s}) = k \ln Q_{T(s)}^{*A,i} \quad (3.5)$$

where the Törnqvist index on the right compares the inputs for firm i with those for the reference firm in period s .

For period $s+1$, the appropriate reference PU for our purposes is A in period $s+1$, but with the same input vector as in period s ; that is, we use

$$\begin{aligned} \ln y^{A,s+1} &= \ln f(x^{A,s}) + r(s+1) \\ &= \ln y^{A,s} + r. \end{aligned} \quad (3.6)$$

Thus for any given period s ($1 \leq s \leq T - 1$), from (3.4) and (3.5) we see that the period s output for the i^{th} PU is related to the period s output of the reference PU by

$$\ln y^{i,s} = \ln y^{A,s} + k \ln Q_{T(s)}^{*A,i} \tag{3.7}$$

And for period $s+1$ we have

$$\begin{aligned} \ln y^{i,s+1} &= \ln y^{A,s+1} + k \ln Q_{T(s+1)}^{*A,i} \\ &= \ln y^{A,s} + r + k \ln Q_{T(s+1)}^{*A,i} \end{aligned} \tag{3.8}$$

where $\ln y^{A,s+1}$ is the hypothetical expected output of the reference PU in period $s+1$ given by (3-6).

Our basic estimating equation is obtained by combining (3.7) and (3.8) as

$$\ln y^{i,t} = \beta_0 + \beta_1 D_{i,t} + \beta_2 \ln Q_{T(t)}^{*A,i} + u^{i,t} \tag{3.9}$$

where $\beta_0 = \ln f(x^{A,s})$, $\beta_1 = r$, $\beta_2 = k$ and where the time dummy is defined by

$$\begin{aligned} D^{i,t} &= 1 \quad \text{if } t = s + 1 \\ &= 0 \quad \text{if } t = s. \end{aligned} \tag{3.10}$$

The error term u has been added in (3.9) because it is assumed that the derived estimating equation holds with error for the observed data. In estimation, we treat the error term $u^{i,t}$ as randomly distributed in the annual cross sections with zero mean and constant variance σ_u^2 and over time (for $t = s, s + 1$) as autocorrelated with ρ as the first order autocorrelation for the PUs in each of our industry and 2-year subsamples of data for plants and for firms.

There are only three unknown parameters to estimate in our econometric specification (3.9)¹⁶.

In general, year dummy D_{it} and translog input quantity chain index number $Q_{T(s)}^{*A,i}$ in (3.9) are not expected to be highly correlated.¹⁷ Thus, the proposed specification will allow us to estimate both $r(S)$ and $k(S)$ with minimal problems from sample multicollinearity. Since we allow the error term ε_{it} in (3.9) to obey a first-order autoregressive process, we estimate b_0 , b_1 and b_2 using generalized least squares (GLS).^{18, 19}

¹⁶ In estimating scale economies and TC using aggregate time series, Chan and Mountain (1983), for example, had to estimate 22 unknown parameters using 25 annual observations.

¹⁷ For the particular data sets used, the correlation coefficients calculated for the 18 manufacturing industries are quite small and range between .009 and .025.

¹⁸ We carried out the estimation using both OLS and GLS. Since both estimates are similar, only GLS estimates are presented.

¹⁹ To estimate (3-9), a reference PU must be selected or created, and then the values must be calculated for the Törnqvist index for comparing the input quantities of each of the estimation sample PUs with the input quantities for the reference PU. In this study we have followed the standard method of using as the reference PU a construct (a hypothetical firm) possessing sample average firm characteristics. (See Diewert (1999) for more on this sort of approach and the alternatives.) We also used Törnqvist-type input index values.

4 Our data and estimation strategy

The primary source of our firm data is the financial statements filed with the Ministry of Finance and compiled by the Japan Development Bank for manufacturing firms listed in the first section of the Tokyo Stock Exchange.²⁰ We use the following four production inputs: the number of workers (x_1) as labor, the fixed assets at the beginning of each year (x_2) as capital, raw material (x_3), and other input goods (x_4),²¹ all measured per firm. Capital (x_2) is adjusted for by the industry-specific capital utilization rate reported by the Japanese Ministry of Economy, Trade and Industry (METI).

The corresponding input prices used are: the average annual cash earnings per worker (w_1) for x_1 ; the depreciation rate for fixed assets plus the average interest rate for one-year term-deposit (w_2) for x_2 ; the Bank of Japan input price index for the price of raw materials (w_3); and the GDP deflator for the price of other inputs (w_4). Firms' net sales is used as output (y) and Bank of Japan's industry output price index is used as the deflator of output (1988 = 100).

In computing the capital stock x_2 , new investment in fixed assets is deflated using the investment goods deflator by industry published by the Economic Planning Agency. The input price of capital (w_2) is also adjusted by the investment goods deflator. Estimation of (3.9) requires firm output ($\ln y^{i,t}$) and the Törnqvist input quantity index ($\ln Q_{T(s)}^{*A,i}$) which is calculated by (2.7). Descriptive statistics for these variables are presented for firms in selected industries in Table A1 in Appendix A.²²

Since we are interested in the movement of TC over time it is important that our data set does not suffer from certain sample selectivity problems which might seriously bias estimation of TC. For example, the movement of R&D expenditures for our sample firms over time should not be affected due to firms' entry or exit. Fortunately our sample consists of large established manufacturers listed in the first section of the Tokyo Stock Exchange and these firms experienced relatively little change (in terms of their corporate identity) over our sample time period (1988–1998). There were only a few major mergers involving firms in this section (particularly in the petroleum sector), and there were only a few exits of failed firms which were bought out by other firms and counted as acquisitions. In addition all our sample firms have positive R&D expenditures.²³ For these reasons sample

²⁰ The first section of the Tokyo Stock Exchange lists all established Japanese companies which are generally much larger than those listed in the second section (for smaller and less established firms) or the Jasdac security exchange (for newly created enterprises).

²¹ This is measured on a cost basis and includes all expenses other than the expenses for labor, raw material and depreciation.

²² The numbers of manufacturing firms in our sample for the period 1997–1998 for the industries included in our study are: food (74), pulp (29), printing (19), chemicals (151), plastic products (28), rubber products (16), pottery and ceramics (47), steel and iron (47), nonferrous metals (36), metals (72), general machinery (a) (65), general machinery (b) (108), electric machinery (a) (114), electric machinery (b) (54), transportation machinery (112), precision (35), textile (41) and petroleum and coal products (5). The total number of firms in the sample is 1053.

²³ Also the database we use updates all figures at source so that it contains updated income-statement and balance-sheet items as well as other financial information items for the firms involved in the acquisitions that took place in this section during our sample period.

selection bias does not seem to be a potentially serious problem for our sample and hence we do not correct for possible selectivity bias in this study.²⁴ Nevertheless we have done some additional estimation work to verify this. (This is discussed in the section below on sample selection bias.)

5 Estimation results

5.1 Results using data on firms

Our estimation results for TFPG, TC and the elasticity of scale were derived by the instrumental variables (IV) method²⁵ for firms in Japanese manufacturing industries for the period 1988–1998 and are summarized in Tables 1–3, respectively. TC and the elasticity of scale estimates are also illustrated in Fig. 1. All of the Japanese manufacturing industries recorded significant reductions in TFP between the 1964–1988 period and the 1988–1998 period, showing the drastic negative impact of the burst of the financial bubble in the 1990–1991 period and the subsequent economic problems on the Japanese manufacturing industries.²⁶ Seven manufacturing industries (petroleum/coal products, rubber products, steel/iron, electrical machinery (a) and (b), transportation machinery and precision) registered average TFPG rates above 4% during the 1964–1988 period, with the highest growth rate registered by electrical machinery (Table 1). Only electrical machinery industries achieved TFPG of above 2% (i.e., 2.9% and 2.8%) for the period 1988–1998. Of the remaining industries only textile and plastics registered TFPG above 1% (Table 4). This is consistent with estimates for Japanese TFP growth using macro series (Kuroda et al. (2003)).²⁷

Since a relatively large portion of the long-run variation over time in Japanese TFPG is explained by TC,²⁸ TC and TFPG behave similarly to some extent.²⁹ TC declined for most of the reported manufacturing industries from the 1964–1988 period to the 1988–1998 period (Table 2). Twelve manufacturing industries registered the average rates of TC above 1% over the period 1964–1988. Chemicals, electrical machinery, transportation machinery and precision registered TC above

²⁴ There were a considerable number of corporate identity changes in the other stock exchanges in Japan where smaller and newer firms concentrate. We have not used these smaller firms because information required for this study is often missing for these firms.

²⁵ This method is discussed below in this section.

²⁶ The financial bubble burst in December 1990 (the period 1990–1991 in our tables).

²⁷ OECD also reports the following business sector TFP growth rates for the periods 1960–1973, 1973–1979 and 1979–1997: 4.9%, 0.7% and 0.9% for Japan; 1.9%, 0.1% and 0.7% for the U.S.; and 3.7%, 1.6% and 1.3% for France.

²⁸ See Tables B1 in Appendix B for decompositions of TFPG for establishments for 1988–1998.

²⁹ A number of papers have pointed out that a rapid growth of output is possible over a period of years even though TFP growth during those years is negative. For example, Park and Kwon (1995) attribute the rapid growth of the South Korean economy for the period 1966–1989 to the effects of scale economies in particular while the TFP growth during the same period is often non-existent or negative. Their findings seem to be consistent with Kim and Lau's (1995) findings that the rapid economic growth of newly industrialized countries in East Asia was accompanied by little indigenously generated TC.

Table 1 TFP growth (TFPG) for firms in manufacturing industries, 1988–1998^a

| | 1964–1988 ^b | 1988–1991 | 1991–1995 | 1995–1998 | 1988–1998 |
|----------------------------|------------------------|-----------|-----------|-----------|-----------|
| Food | 0.02167 | -0.00464 | 0.00876 | 0.00394 | 0.00329 |
| Textile | 0.02281 | 0.01259 | 0.03168 | 0.00753 | 0.01871 |
| Pulp | 0.02961 | -0.01245 | 0.01307 | -0.00914 | -0.00125 |
| Printing | - | -0.01051 | -0.00802 | -0.00340 | -0.00738 |
| Chemicals | 0.02956 | -0.00313 | 0.00786 | 0.01186 | 0.00576 |
| Petroleum/coal products | 0.05489 | -0.02890 | -0.02270 | -0.01255 | -0.02151 |
| Plastic products | - | 0.00418 | 0.03010 | 0.00200 | 0.01389 |
| Rubber products | 0.04627 | 0.02911 | 0.01085 | -0.01718 | 0.00792 |
| Pottery | 0.03192 | -0.01140 | 0.00850 | 0.00345 | 0.00102 |
| Steel | 0.0448 | -0.01210 | 0.00780 | 0.00091 | -0.00024 |
| Non-ferrous metals | 0.03759 | -0.00416 | -0.00191 | -0.00443 | -0.00334 |
| Metal products | 0.03218 | -0.04026 | 0.01868 | -0.01084 | -0.00786 |
| Gen mach (a) ^c | 0.02707 | -0.01506 | 0.00215 | 0.01075 | -0.00044 |
| Gen mach (b) ^d | 0.02707 | -0.00097 | -0.00097 | -0.00097 | -0.00097 |
| Elec mach (a) ^e | 0.05186 | 0.02690 | 0.04323 | 0.01348 | 0.02941 |
| Elec mach (b) ^f | 0.05186 | 0.02767 | 0.02767 | 0.02767 | 0.02767 |
| Transp mach | 0.04332 | 0.00645 | 0.01010 | -0.01884 | 0.00032 |
| Precision | 0.04324 | -0.00583 | 0.01187 | -0.01053 | -0.00016 |

^a This table is based on year-by-year IV regression estimates (available from the authors on request). The figures given here are the averages calculated for the specified periods

^b See Nakajima et al. (1998) for year-by-year regression estimates

^c This category includes boilers, engines, metal processing machinery and general machinery parts

^d This category includes general machinery groupings which are not included in General Machinery (a)

^e This category includes industrial electrical equipment, industrial electronic applications equipment and other electrical machinery

^f This category includes industrial communication equipment and civilian communication equipment

2%. For the 1988–1998 period only electrical machinery achieved the average rate of TC above 2%. We also note that 12 out of 18 industries registered higher levels of TC than TFPG for 1988–1998 (Tables 1, 2). This suggests that Japanese manufacturing firms' relatively heavier reliance on TC than scale economies in achieving their TFPG is quite robust. This behavior in TC of Japanese manufacturing may provide partial explanations for Japan's continuing strengths in exports of manufacturing goods in the 1990s and 2000s. This may deserve further investigation.

We have also found that the null hypothesis of constant returns to scale ($k = 1$) is decisively rejected for firms in most industries and many years in favor of the alternative hypothesis of decreasing returns to scale ($k < 1$) for the period 1988–1998. This is in contrast to the findings at the establishment level that factories in

Table 2 Technical change (TC) for firms in manufacturing industries, 1988–1998^a

| | 1964–1988 ^b | 1988–1991 | 1991–1995 | 1995–1998 | 1988–1998 |
|----------------------------|------------------------|-----------|-----------|-----------|-----------|
| Food | −0.0001 | −0.00376 | 0.00535 | 0.00376 | 0.00214 |
| Textile | 0.0164 | 0.01332 | 0.02542 | 0.00564 | 0.01585 |
| Pulp | 0.0118 | −0.01050 | 0.01442 | −0.00330 | 0.00163 |
| Printing | − | −0.00902 | −0.00826 | −0.00255 | −0.00677 |
| Chemicals | 0.0206 | 0.00447 | 0.00791 | 0.01038 | 0.00762 |
| Petroleum/coal products | 0.0088 | −0.03092 | −0.02805 | −0.01919 | −0.02625 |
| Plastic products | − | 0.01146 | 0.02048 | −0.00074 | 0.01141 |
| Rubber products | 0.0124 | 0.02949 | 0.01362 | −0.01618 | 0.00944 |
| Pottery | 0.0135 | −0.00801 | 0.00917 | 0.00160 | 0.00174 |
| Steel | 0.0036 | −0.01109 | 0.00603 | −0.00012 | −0.00095 |
| Non-ferrous metals | −0.0014 | −0.00984 | −0.00220 | −0.00389 | −0.00500 |
| Metal products | 0.0147 | −0.02635 | 0.01979 | −0.01699 | −0.00509 |
| Gen mach (a) ^c | 0.0187 | −0.00734 | 0.00242 | 0.01128 | 0.00215 |
| Gen mach (b) ^d | 0.0187 | 0.00108 | 0.00108 | 0.00108 | 0.00108 |
| Elec mach (a) ^e | 0.026 | 0.03391 | 0.04799 | 0.01842 | 0.03489 |
| Elec mach (b) ^f | 0.026 | 0.03480 | 0.03480 | 0.03480 | 0.03480 |
| Transp mach | 0.0245 | 0.00907 | 0.00842 | −0.01876 | 0.00046 |
| Precision | 0.0316 | 0.00159 | 0.01664 | 0.00034 | 0.00724 |

^a This table is based on year-by-year IV regression estimates (available from the authors on request). The figures given here are the averages calculated for the specified periods

^b See Nakajima et al. (1998) for year-by-year regression estimates

^c This category includes boilers, engines, metal processing machinery and general machinery parts

^d This category includes general machinery groupings which are not included in General Machinery (a)

^e This category includes industrial electrical equipment, industrial electronic applications equipment and other electrical machinery

^f This category includes industrial communication equipment and civilian communication equipment

Japanese manufacturing industries exhibit increasing returns to scale for the period 1968–1998.³⁰ Our findings that the effects of scale economies exist at the establishment level but disappear at the aggregate level (i.e., firm and industry levels) imply, among other things, that establishment size does not adjust rapidly within the time period we consider.

That is, large establishments do not grow at the expense of small establishments. It is the slowly increasing technical level that explains most of the gains in aggregate TFP in the Japanese manufacturing sector. Our empirical results suggest the presence of slow but steady positive TC for the Japanese manufacturing sector.³¹

³⁰ Year-by-year estimates for the elasticity of scale for establishments tend to be one (constant returns to scale) or greater than one (i.e., increasing returns to scale) for most Japanese manufacturing industries for the period 1963–1998 (see, for example, Nakajima et al. (1998, 2001)).

³¹ Using aggregate time series data for the period 1961–1980 Tsurumi et al. (1986) also find that Japanese manufacturers spend relatively long periods of time (up to ten years) to adjust their production methods to incorporate new technological requirements. Their findings are consistent with ours.

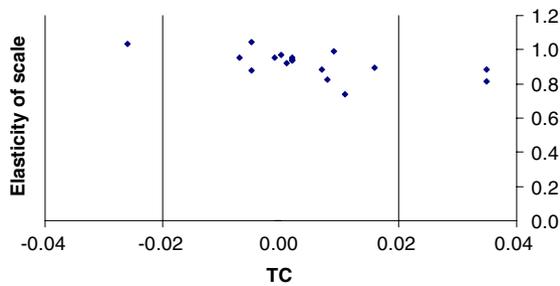


Fig. 1 Firms, 1988–1998. *Notes:* actual estimates for TC and elasticity of scale are given in the last columns of Tables 2 and 3, respectively. All scale elasticity estimates are around or below one. Most estimates for TC are positive but they range from the lowest (−0.026 for petroleum/coal) to the highest (0.035 for electrical machinery (a) and (b))

Another reason for the decreasing returns to scale at the firm level is that, while scale production is still important at the level of individual plants for lowering production cost, it is becoming increasingly less important in the overall operations of typical Japanese manufacturing firms. Restructuring and internationalization of Japanese manufacturers in the 1980s and 1990s resulted in the massive hollow out of production facilities and their much heavier reliance on revenues from developments of technologies and new management and manufacturing methods. Production operations now constitute less than 70% of the total cost of many Japanese manufacturing firms.³²

5.2 Potential endogeneity and IV estimation

In our estimating Eq. (3.9) $\ln Q_{T(t)}^{*A,i}$ may be correlated with the equation error term $u^{i,t}$. To the extent that $\ln Q_{T(t)}^{*A,i}$ is an index of production inputs, it is less likely to have such a correlation with the error term than the raw inputs themselves. Nevertheless, if such a correlation exists and is statistically significant, our OLS estimates of the equation parameters may be biased. OLS estimates are unbiased and efficient only if the null hypothesis of no such correlation holds. On the other hand, IV estimates are consistent even if the null hypothesis does not hold. For this reason we have estimated Eq. (3.9) using both OLS and IV.³³ Since IV estimates are not efficient, it would be helpful to keep OLS estimates for those cases for which there is no endogeneity problem. Using standard specification tests³⁴ we have tested

³² This means that the cost of operation associated with a firm's establishments including wage bills and the cost of materials and equipment is about 70% or less of the total budget of the firm. It used to be close to 90% in the 1980s.

³³ As instruments we have used the average annual cash earnings per worker and the depreciation rate for fixed assets plus the average interest rate for one-year term-deposit. Both of these variables vary significantly from one firm to another. We have also used some additional firm-specific instruments including lagged variables and found the results to be robust with respect to the choice of IV instruments.

³⁴ Hausman test and also a Lagrange multiplier test (e.g., Nakamura and Nakamura (1981), Godfrey (1988, § 4.8)).

Table 3 Elasticity of scale for firms in manufacturing industries, 1988–1998^a

| | 1988–1991 | 1991–1995 | 1995–1998 | 1988–1998 |
|----------------------------|-----------|-----------|-----------|-----------|
| Food | 0.94644 | 0.95800 | 0.95562 | 0.95382 |
| Textile | 0.85601 | 0.86565 | 0.96461 | 0.89245 |
| Pulp | 0.94909 | 0.93558 | 0.92639 | 0.93688 |
| Printing | 0.96767 | 0.95972 | 0.92865 | 0.95279 |
| Chemicals | 0.81330 | 0.82140 | 0.84037 | 0.82466 |
| Petroleum/coal products | 1.08564 | 1.08251 | 0.91830 | 1.03419 |
| Plastic products | 0.80694 | 0.59806 | 0.86831 | 0.74180 |
| Rubber products | 1.03629 | 0.99808 | 0.93392 | 0.99030 |
| Pottery | 0.91655 | 0.94152 | 0.94894 | 0.93626 |
| Steel | 0.95657 | 0.94493 | 0.96397 | 0.95413 |
| Non-ferrous metals | 1.05655 | 1.04309 | 1.03986 | 1.04616 |
| Metal products | 0.87618 | 0.93772 | 0.80643 | 0.87987 |
| Gen mach (a) ^b | 0.90680 | 0.98354 | 0.92392 | 0.94263 |
| Gen mach (b) ^c | 0.92280 | 0.92280 | 0.92280 | 0.92280 |
| Elec mach (a) ^d | 0.90188 | 0.88623 | 0.85437 | 0.88136 |
| Elec mach (b) ^e | 0.81585 | 0.81585 | 0.81585 | 0.81585 |
| Transp mach | 0.96718 | 0.96255 | 0.98696 | 0.97126 |
| Precision | 0.89488 | 0.91206 | 0.83426 | 0.88356 |

^a This table is based on year-by-year IV regression estimates (available from the authors on request). The figures given here are the averages calculated for the specified periods

^b This category includes boilers, engines, metal processing machinery and general machinery parts

^c This category include general machinery groupings which are not included in General Machinery (a)

^d This category includes industrial electrical equipment, industrial electronic applications equipment and other electrical machinery

^e This category includes industrial communication equipment and civilian communication equipment

the null hypothesis that there is no endogeneity. The Hausman test rejected the null hypothesis 9 out of 180 cases (=18 industries \times 10 time periods).³⁵ This suggests that endogeneity is not a serious problem in our sample. Nevertheless, all of our estimation results for TC presented are IV estimates except for those cases for which the specification error tests have accepted the null hypothesis of no endogeneity. IV estimates for TC and the elasticity of scale are summarized in Figure 1.³⁶ Summary statistics for the decomposition of TFPG into TC and returns to scale are given in Table B1 in Appendix B.

³⁵ Both specification tests provided essentially the same test results.

³⁶ Complete IV estimates are available from the authors on request.

5.3 Potential sample selection bias

One of the objectives of this study is to analyze the movement of TC characterizing large Japanese manufacturers. Because of its massive influence on the growth of the Japanese economy, the movement of TC for large manufacturers is of serious policy concern to government policy makers.³⁷ For this reason our sample firms consist of generally established large manufacturing firms listed in the first section of the Tokyo Stock Exchange. The sources of potential sample selection bias of the sorts Heckman (1976, 1979) considers include entry and exit into the sample of interest, corporate identity changes due to mergers and acquisitions, and a censored or truncated R&D variable. Because our sample firms are all large and established, they all conduct R&D and hence we have no truncation problem from this source. It is also the case that, because of the prevalence of Japanese corporate governance and management practices,³⁸ very few mergers, acquisitions and takeovers (hostile or friendly) take place between large Japanese firms.³⁹ In addition new entries to or exits from the first section of the Tokyo Stock Exchange have been a relatively rare event.⁴⁰ For these reasons, the composition of firms in the included industries over our sample period (1988–1998) changed relatively little.⁴¹ The actual variation over ten time periods in the number of firms included in our sample is reported for some selected industries in Table B1; this information can be summarized as follows: food (minimum size = 73, maximum size = 98); pulp (26, 31), printing (9, 19), chemicals (144, 160), plastic (144, 160), rubber (16, 19), pottery and ceramic (48, 59), steel and iron (47, 52), non-ferrous metals (35, 39), metals (49, 72), general machinery (a) (63, 71), general machinery (b) (96, 109), electrical machinery (a) (107, 120), electrical machinery (b) (50, 59), transportation machinery (99, 114), precision instruments (32, 38), textiles (38, 49) and petro and coal (5, 10).⁴²

Our estimation method (3.9) allows us to use as many firms for each 2-year estimating panel as we have data for. This characteristic of our estimation method is

³⁷ Many policy makers believe, correctly or incorrectly, that these large firms drive Japan's economic growth.

³⁸ See, for example, Morck and Nakamura (1999) and Morck et al. (2000).

³⁹ For example, after having agreed to merge on friendly terms in order to gain international competitiveness, the Mitsui Chemical and Sumitomo Chemical Companies (Japan's second and third largest chemical firms) decided not to merge last year. Their reason was the incompatibility of the firm-specific management methods of the respective companies.

⁴⁰ Permission to be listed on this stock exchange requires a significant amount of accomplishment on the part of the applicant firm. Few firms, once listed, exit from it.

⁴¹ Also the sample size varies only slightly from one period to another for most industries (Table B1).

⁴² The variation in the sample size comes primarily from the occasional lack of relevant data for a few companies in each of the industries. The major exceptions are: the petroleum industry in which, because of the substantial rise in oil price in recent years, major mergers took place; the printing industry in which some large firms listed their former divisions involved in printed circuit-related business lines; and the food industry in which some existing firms also separated and listed some of their divisions for new products.

particularly useful for one of the objectives of our study: to measure the over time evolution of TC with reasonable efficiency. Nevertheless, in order to access the potential impact of this variation in sample size over time on our empirical results, we have also estimated (3.9) using a panel of firms which appear in each of the ten time periods. (By definition the number of firms in the panel for each industry is the minimum of the two numbers given for that industry above.) The results using this panel data are almost identical to those we obtained earlier. This suggests that the type of variation we have in the number of firms included in the 2-year panel is not a serious source of sample bias.⁴³

5.4 The bubble

In the late 1980s when a financial bubble was being formed, the Japanese economy was thought to be enjoying the best prosperity ever in its history, with virtually no inflation observed in the consumer price index. However, during this period the prices of assets of all kinds (e.g., stock and land prices, and even assets like golf club memberships) were appreciating at a rapid rate. During this pre-bubble-burst period, Japanese households as well as businesses and government agencies all revised upward their expected rates of return in every type of investment. Consequently Japanese manufacturers increased their output by investing massively in production inputs.

Table 4 shows, respectively, OLS and IV estimates for TC for firms in some selected industries right before and after the burst of the Japanese financial bubble in the late 1990. Figure 2a and b, respectively, show these OLS and IV estimates also. We see from Table 4 and Fig. 2b that even the industries, electrical and transportation machinery and precision industries, which are among Japan's most valued and highly efficient industries, experienced a significant drop in the rate of TC in the few years prior to the bubble (1986–1989).⁴⁴ The expansion of their production facilities was not accompanied by TC. It was inevitable that these firms were going to suffer from a significant amount of excess production capacity. This over-investment situation was much worse in certain non-manufacturing sectors (e.g., real estate development and construction sectors) than manufacturing sectors. In fact the excess capacity which was caused by the excessive and misguided investment in the late 1980s, along with the non-performing loans that financed it, is still plaguing the Japanese economy.

One of the current policy issues of interest in Japan is to ascertain the degree to which TC is determined by the forces exogenous to the firms. For example, how much of firms' TC can be created by the firms' own efforts and how much is due to outside factors such as the spillovers from other firms? While there are no publicly

⁴³ This suggests that the type of variation we have is not correlated with the error terms of our estimating equations.

⁴⁴ We observe essentially the same phenomena from the OLS estimates (Table 4 and Fig. 2a).

Table 4 Technical change before and after the financial bubble (a) OLS estimates and (b) IV estimates: Japanese manufacturing firms

| | 1988–1989 | 1989–1990 | 1990–1991 | 1991–1992 | 1992–1993 | 1993–1994 | 1994–1995 |
|----------------------------|-------------------------|------------|------------|------------|------------|------------|------------|
| OLS estimates | | | | | | | |
| Elec mach (a) ^b | 0.04069*** ^a | 0.02826*** | 0.03277*** | 0.02983*** | 0.04232*** | 0.05433*** | 0.06548*** |
| Elec mach (b) ^c | 0.04702** | 0.02147** | 0.02788*** | 0.07056*** | 0.05842*** | 0.02907** | 0.05883*** |
| Transp mach | 0.01045*** | 0.00778* | 0.00897*** | 0.00445 | 0.00665** | 0.01416** | 0.00842** |
| Precision | 0.02524*** | 0.00324 | -0.02372** | -0.01379 | 0.02419* | 0.01997* | 0.03620*** |
| IV estimates | | | | | | | |
| Elec mach (a) ^b | 0.04882*** ^a | 0.03957*** | 0.03926*** | 0.0089*** | 0.03254*** | 0.05685*** | 0.0721*** |
| Elec mach (b) ^c | 0.06029** | 0.02147** | 0.02788** | 0.07056*** | 0.05842*** | 0.02907** | 0.05883*** |
| Transp mach | 0.00760*** | 0.00778* | 0.00897*** | 0.00445 | 0.00665** | 0.01416** | 0.00842** |
| Precision | 0.03396** | 0.00324 | -0.02372** | -0.01379 | 0.02419* | 0.01997* | 0.03620*** |

^a *, **, and *** denote, respectively, significance levels at 10%, 5% and 1%

^b This category includes industrial electrical equipment, industrial electronic applications equipment and other electrical machinery

^c This category includes industrial communication equipment and civilian communication equipment

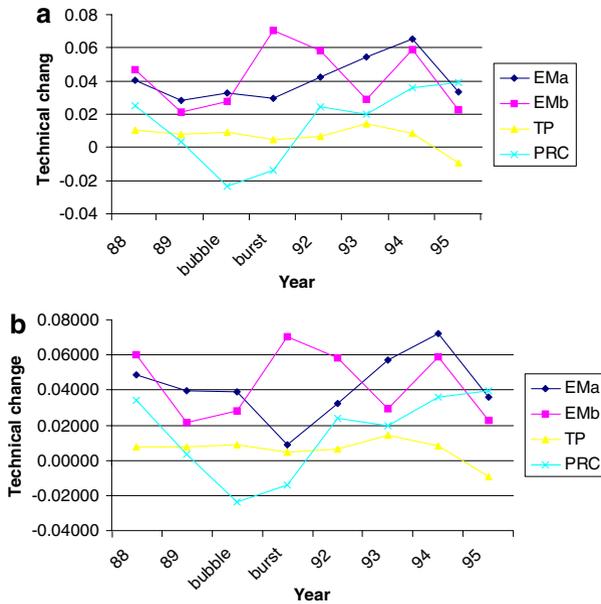


Fig. 2 (a) Technical change for firms (OLS), (b) Technical change for firms (IV)

Table 5 The Effects of Lagged Technical Change on Technical Change, 1988–98^a

| Constant | TC _{t-1} | R-squared | No. of obs. |
|---------------|-------------------|-----------|-------------|
| 0.0021 (1.04) | 0.2050 (2.87) | 0.040 | 180 |

^a Based on IV estimates for TC. Numbers in parentheses are absolute t-statistics based on heteroskedasticity-corrected standard errors

available data at the firm level yet to investigate these questions, we can test the hypothesis that TC is at least subject to some internal forces such as the firms’ own R&D by testing the autoregressiveness of TC over time. If TC (and hence TFPG) is at least in part endogenously determined at the firm level, then it in turn may imply that TC is not a random walk: it rather evolves over time with some positive autocorrelation. We ran an auto regression of TC on its immediate past to test this hypothesis. Table 5 shows that the coefficient of lagged TC is positive and statistically significant at a 1% level. This provides limited evidence that TC evolves with positive autocorrelation, suggesting the presence of endogenous elements that contribute to the evolution of the TC process.⁴⁵

⁴⁵ Such endogenous elements may be generated, for example, by firms’ investment in R&D and firm-specific training of their workers. (e.g., Romer (1990).)

6 Concluding remarks

In this paper we have presented an econometric method based on index number theory for estimating firms' TC and returns to scale using panel data. Our paper is a contribution to a substantial and growing literature on this methodological problem.⁴⁶ Then we have used the method to estimate TC, returns to scale and total factor productivity growth for Japanese manufacturing firms for the period 1988–1998. We have discussed the movement of these estimated quantities over time, particularly around the burst of the financial bubble in Japan. We have shown that a significant decline in TC, and, to a lesser extent, a decline in total factor productivity growth for many of the manufacturing industries was observed during the period when the bubble was being formed but prior to the burst of the bubble. This is consistent with the interpretation that massive investments in inputs were made by Japanese manufacturers in the late 1980s to increase their output, while such an expansion of the output was not accompanied by positive TC. This resulted in the observed excess capacity for Japanese manufacturing firms. Many Japanese manufacturers were suffering from excess capacity until recently. The excess capacity was also the main cause of Japanese banks' non-performing loans.⁴⁷

Another interesting finding of this paper is that the rate of TC in many Japanese manufacturing industries did recover to the pre-bubble level in the post-bubble period. This may explain why many parts of the Japanese manufacturing sector did not collapse in the 1990s after the burst of the bubble, despite the negative post-bubble circumstances and the lack of effective government and Bank of Japan policies to move Japan's economy out of the long-lasting recession. Some industries have managed to maintain (or regain) a certain level of global competitiveness.⁴⁸ One of the reasons for this may be the TC that continued to take place at the firm level.

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⁴⁶ See, for example, Balk (1993, 1998, 2001), Diewert et al. (2006), Diewert and Fox (2004, 2005), Diewert and Lawrence (2005), Diewert and Nakamura (2006), Grosskopf (2003), Färe et al. (1994), Hall (1990), and Milana (2005).

⁴⁷ Excessive investment in other sectors such as real estate and property development during the bubble period is another factor which has damaged the Japanese economy.

⁴⁸ For example, Japanese manufacturing industries ranging from what many regard as declining industries (e.g., shipbuilding, steel) to traditionally competitive industries (e.g., auto, electronics) have shown persistent resilience in their global competitiveness. Lau (2003), for example, cites as Japan's continuing comparative advantage the following: capital goods production, complex production processes and R&D capability.

Appendix A. Descriptive statistics

Table A1 Descriptive statistics for manufacturing firms in selected industries^a

| Year | Var | Elec mach (a) | | | Elec mach (b) | | | Transp mach | | | Precision | | |
|-----------|-------|---------------|--------|-------------------|---------------|--------|-------------------|-------------|--------|-------------------|-----------|--------|-------------------|
| | | Mean | SD | Smpl ^b | Mean | SD | Smpl ^b | Mean | SD | Smpl ^b | Mean | SD | Smpl ^b |
| 1988–1989 | ln(y) | 10.73 | 1.2913 | 214 | 11.111 | 1.3564 | 100 | 11.276 | 1.3948 | 198 | 10.535 | 1.2065 | 64 |
| | ln(Q) | 0.0923 | 1.3534 | 214 | 0.0667 | 1.3529 | 100 | 0.1131 | 1.4208 | 198 | 0.1616 | 1.3123 | 64 |
| 1989–1990 | D | 0.5 | | 214 | 0.5 | | 100 | 0.5 | | 198 | 0.5 | | 64 |
| | ln(y) | 10.864 | 1.2849 | 228 | 11.209 | 1.3946 | 108 | 11.357 | 1.3988 | 214 | 10.602 | 1.2041 | 66 |
| 1990–1991 | ln(Q) | 0.1085 | 1.3282 | 228 | 0.1167 | 1.401 | 108 | 0.1116 | 1.4272 | 214 | 0.1776 | 1.3071 | 66 |
| | D | 0.5 | | 228 | 0.5 | | 108 | 0.5 | | 214 | 0.5 | | 66 |
| 1991–1992 | ln(y) | 10.923 | 1.2936 | 230 | 11.29 | 1.3663 | 114 | 11.342 | 1.3975 | 228 | 10.699 | 1.1916 | 70 |
| | ln(Q) | 0.0792 | 1.3338 | 230 | 0.0809 | 1.4025 | 114 | 0.0856 | 1.4366 | 228 | 0.1446 | 1.2898 | 70 |
| 1992–1993 | D | 0.5 | | 230 | 0.5 | | 114 | 0.5 | | 228 | 0.5 | | 70 |
| | ln(y) | 10.915 | 1.2959 | 232 | 11.318 | 1.3732 | 116 | 11.354 | 1.4086 | 226 | 10.657 | 1.2404 | 68 |
| 1993–1994 | ln(Q) | 0.0183 | 1.3486 | 232 | 0.0156 | 1.4465 | 116 | 0.0516 | 1.4469 | 226 | 0.0472 | 1.3225 | 68 |
| | D | 0.5 | | 232 | 0.5 | | 116 | 0.5 | | 226 | 0.5 | | 68 |
| 1994–1995 | ln(y) | 10.871 | 1.295 | 238 | 11.293 | 1.3802 | 118 | 11.303 | 1.4162 | 226 | 10.579 | 1.2692 | 68 |
| | ln(Q) | 0.0486 | 1.3519 | 238 | 0.057 | 1.5066 | 118 | 0.0324 | 1.4575 | 226 | 0.0694 | 1.343 | 68 |
| 1995–1996 | D | 0.5 | | 238 | 0.5 | | 118 | 0.5 | | 226 | 0.5 | | 68 |
| | ln(y) | 10.908 | 1.3019 | 236 | 11.378 | 1.3602 | 114 | 11.17 | 1.3189 | 218 | 10.528 | 1.2488 | 72 |
| 1996–1997 | ln(Q) | 0.0821 | 1.3669 | 236 | 0.1105 | 1.5174 | 114 | 0.078 | 1.3634 | 218 | 0.1013 | 1.3187 | 72 |
| | D | 0.5 | | 236 | 0.5 | | 114 | 0.5 | | 218 | 0.5 | | 72 |
| 1997–1998 | ln(y) | 10.977 | 1.3098 | 240 | 11.349 | 1.3543 | 114 | 11.184 | 1.2849 | 220 | 10.57 | 1.2016 | 76 |
| | ln(Q) | 0.0978 | 1.3922 | 240 | 0.1123 | 1.5192 | 114 | 0.0616 | 1.3106 | 220 | 0.1174 | 1.2781 | 76 |
| 1998–1999 | D | 0.5 | | 240 | 0.5 | | 114 | 0.5 | | 220 | 0.5 | | 76 |

Table A1 continued

| Year | Var | Elec mach (a) | | Elec mach (b) | | Transp mach | | Precision | |
|-----------|-------|---------------|--------|---------------|--------|-------------|--------|-----------|--------|
| | | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| 1995–1996 | ln(y) | 11.117 | 1.3517 | 11.379 | 1.4347 | 11.31 | 1.3995 | 10.599 | 0.9872 |
| | ln(Q) | 0.0831 | 1.4213 | 0.1536 | 1.5907 | 0.0896 | 1.4132 | 0.1244 | 1.0695 |
| | D | 0.5 | | 0.5 | | 0.5 | | 0.5 | |
| 1996–1997 | ln(y) | 11.176 | 1.371 | 11.469 | 1.4801 | 11.312 | 1.4119 | 10.646 | 1.0102 |
| | ln(Q) | 0.0783 | 1.4654 | 0.1107 | 1.637 | 0.0749 | 1.4199 | 0.1121 | 1.0954 |
| | D | 0.5 | | 0.5 | | 0.5 | | 0.5 | |
| 1997–1998 | ln(y) | 11.134 | 1.3773 | 11.447 | 1.4888 | 11.256 | 1.4077 | 10.612 | 1.0706 |
| | ln(Q) | 0.0446 | 1.4761 | 0.0867 | 1.6715 | 0.0415 | 1.4054 | 0.0777 | 1.1406 |
| | D | 0.5 | | 0.5 | | 0.5 | | 0.5 | |

^a To save space we present descriptive statistics for firms in the following manufacturing industries in this table: electric machinery (a) which includes industrial electrical equipment, industrial electronic applications equipment and other electrical machinery, electric machinery (b) which includes industrial communication equipment and civilian communication equipment; transportation machinery and precision. Descriptive statistics for all manufacturing industries are available from the authors on request

^b These sample sizes are for the sample firms pooled over two consecutive years and hence are twice the actual number of sample firms in each of the industries in the given time period. The numbers of manufacturing firms for the industries included in our study for the 1997–1998 period are: food (74), pulp (29), printing (19), chemicals (151), plastic products (28), rubber products (16), pottery and ceramics (47), steel and iron (47), nonferrous metals (36), metals (72), general machinery (a) (65), general machinery (b) (108), electric machinery (a) (114), electric machinery (b) (54), transportation machinery (112), precision (35), textile (41) and petroleum and coal products (5). The total number of firms in the sample is 1053. Descriptive statistics for all manufacturing industries for all time periods are available from the authors on request

Table A2 Descriptive statistics: auto-regression of TC^a

| Variables sample | Mean | SD | Min | Max |
|------------------|--------|--------|---------|--------|
| TC 180 | 0.0027 | 0.0283 | −0.1275 | 0.0811 |
| TC(−1) 180 | 0.0032 | 0.0277 | −0.1275 | 0.0811 |

Notes: IV estimates for TC which are available for firms in 18 industries were used in the auto-regression of TC reported in Table 6. The sample used consists of 18 industries and 10 time periods

7 Appendix B. Decomposition of TFP Growth

Table B1 Decomposition of average annual TFP growth at firms, 1988–1998

| Industry | TFP growth ^a | Technical change ^b | Scale economies ^b |
|---------------------------------------|-------------------------|-------------------------------|------------------------------|
| Food | 0.00329 | 0.00214 | 65 |
| Textile | 0.01871 | 0.01585 | 85 |
| Pulp | −0.00125 | 0.00163 | −130 |
| Printing | −0.00738 | −0.00677 | 92 |
| Chemicals | 0.00576 | 0.00762 | 132 |
| Petroleum/coal products | −0.02151 | −0.02625 | 122 |
| Plastic products | 0.01389 | 0.01141 | 82 |
| Rubber products | 0.00792 | 0.00944 | 119 |
| Pottery | 0.00102 | 0.00174 | 172 |
| Steel | −0.00024 | −0.00095 | 403 |
| Non-ferrous metals | −0.00334 | −0.00500 | 150 |
| Metal products | −0.00786 | −0.00509 | 65 |
| General machinery(a) ^c | −0.00044 | 0.00215 | −494 |
| General machinery(b) ^d | −0.00097 | 0.00108 | −111 |
| Electrical machinery(a) ^e | 0.02941 | 0.03489 | 119 |
| Electrical machinery (b) ^f | 0.02767 | 0.03480 | 126 |
| Transportation machinery | 0.00032 | 0.00046 | 144 |
| Precision | −0.00016 | 0.00724 | −4,522 |

^{a,b} Numbers in the second of the two columns labeled ‘Technical change’ and ‘Scale economies,’ respectively, represent percentage contributions

^c This category includes boilers, engines, metal processing machinery and general machinery parts

^d This category include general machinery which is not included in General Machinery (a)

^e This category includes industrial electrical equipment, industrial electronic applications equipment and other electrical machinery

^f This category includes industrial communication equipment and civilian communication equipment

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