Stanford
Center for International Development

**Working Paper No. 498**

# Measuring the Growth Rates of Multiple-Factor Productivity: Malmquist Index Approach

by

Jeong Yeon Lee

April 2014

Stanford University
John A. and Cynthia Fry Gunn Building
366 Galvez Street | Stanford, CA | 94305-6015

# Measuring the Growth Rates of Multi-Factor Productivity: Malmquist Index Approach

Jeong Yeon Lee*

**April 2014**

## Abstract

Lee (2014) provides the estimates of the Solow residual for 24 OECD countries. To complement these estimates in examining relative productivity of individual countries, this paper measures the growth rates of multi-factor productivity (MFP) for the same sample of 24 OECD countries using the Malmquist index approach. The Malmquist index approach is expected to address some of the limitations of the growth accounting approach by relying on the concept of the best-practice frontier. The best-practice frontier offers a common reference point against which relative productivity growth of all sample countries are measured. The use of the best-practice frontier in measurement also allows productivity growth to be broken down into technical change and efficiency change. When the same input-output variables are used, the time trends of MFP growth identified by both approaches are found to be more or less in sync, whereas there are noticeable differences in the relative standing among the sample countries between the two approaches.

***Keywords*:** Economic Growth; Multi-Factor Productivity; Malmquist Index; OECD

***JEL Classification Codes*:** O33; O47

* Graduate School of International Studies, Yonsei University, 50 Yonsei-ro, Seodaemun-gu, Seoul 120-749, Korea. Tel: +82-2-2123-4645. Fax: +82-2-2123-8653.
*E-mail address*: leejy@yonsei.ac.kr

## 1. Introduction

The neoclassical growth theory identifies multi-factor productivity (MFP) as an engine of long-term economic growth. According to the theory, economic growth unaccompanied by an improvement in MFP continues to slow down due to diminishing returns to capital until the growth eventually comes to a halt. Under the stagnant MFP, the optimum rate of investment also decreases over time as capital stocks accumulate, and any investment demand heated above or cooled below its optimal level is likely to generate temporary ups and downs around the declining path of economic growth while not being able to alter the path itself. As a result, an economy is able to resist the gravity of diminishing returns and achieve an accelerating pace of growth only if it manages to constantly improve its multi-factor productivity.

The key role of multi-factor productivity in economic growth is conceptually clear, but its empirical verification is more complicated due to the fact that MFP is not something directly observable and thus its growth has to be estimated in an indirect manner. Of such indirect ways, the most frequently used is an empirical methodology called growth accounting. The aim of growth accounting is to identify the portion of the growth rate in gross domestic product (GDP) that is not explained by growth in observable inputs such as capital and labor. Through growth accounting, therefore, a country's economic growth is divided into two parts, growth based on input accumulation and residual growth. This residual growth, also known as the Solow residual, is described as an estimate of MFP growth in the growth accounting approach.

The most obvious advantage of the Solow residual lies in the theoretical link that can be established between the production function and the index number approach behind its estimation.[1] Although this and other advantages have made the growth accounting approach the most widely used methodology for estimating MFP changes, the approach is not without limitations. In terms of the Solow residual, for example, it is possible for one country to show a more rapid productivity growth than the other simply because the former starts from a lower productivity level.[2] Growth accounting is subsequently more useful for understanding the historical trend of productivity growth in a single country than for gauging the standing of the country relative to productivity growth of other countries.

Lee (2014) provides the estimates of the Solow residual for 24 countries from the Organization for Economic Co-operation and Development (OECD). To complement these estimates in examining relative productivity of individual countries, this paper measures MFP growth rates for the same sample of 24 OECD countries by means of an alternative method of the Malmquist index approach. In the Malmquist index approach, a sample of countries is chosen to construct the best-practice frontier using input-output combinations of the sample countries, and MFP changes are estimated in reference to this best-practice frontier. As a result, the Malmquist index approach is expected to address the aforementioned limitation of the growth accounting approach by using a common reference point, the best-practice frontier, for all sample countries in estimating their MFP growth rates. The use of the best-practice frontier in measurement also allows for technical inefficiency, in contrast with the growth accounting approach that assumes all units of production are technically efficient.

[1] Hulten (2000), pp. 8-11.
[2] Hulten (2000), p. 26.

Accordingly, a measure of MFP change in the Malmquist index approach may reflect a progress in the available best practices as well as an improvement in the country's capacity to keep up with the prevailing best practices.

The next section defines the Malmquist index, and explains its breakdown into technical change and efficiency change. In Section 3, data and the estimation method are described. Section 4 reports the estimation results, and highlights some notable productivity trends in the OECD area. Section 5 concludes.

## 2. The Malmquist Index

The Malmquist index approach begins with constructing the best-practice frontier from data on input-output combinations of a sample of countries, followed by measuring the distance between any particular observation and the frontier. Following Shephard (1970) and Caves et al. (1982), the output distance function at *t*, $D_0^t$, is defined as follows:

$$D_0^t(X_t,Y_t) = \inf \{\theta: (X_t, Y_t/\theta) \in T^t\} \quad (1)$$

where $T^t$ represents the production technology which is defined as $T^t = \{ (X_t, Y_t) : X_t$ can produce $Y_t$ at time $t \}$. $X_t$ is a vector of inputs at *t*, ($K_t$, $L_t$), and $Y_t$ is aggregate output at *t*. In Eq. (1), $D_0^t \leq 1$ denotes $( X_t , Y_t ) \in T^t$, and $D_0^t=1$ in particular indicates that $(X_t , Y_t )$ lies on the best-practice frontier. Caves et al. (1982) define the output-based Malmquist index between period *t* and period $t+1$ as

$$M_o\left(X_{t+1}, Y_{t+1}, X_t, Y_t\right) = \left[\frac{D_0^t(X_{t+1}, Y_{t+1})}{D_0^t(X_t, Y_t)} \frac{D_0^{t+1}(X_{t+1}, Y_{t+1})}{D_0^{t+1}(X_t, Y_t)}\right]^{1/2} \quad (2)$$

A value of $M_o$ greater than 1 indicates positive growth of multi-factor productivity from period $t$ to period $t$+1, and a value less than 1 represents deterioration in multi-factor productivity.

It is well-documented that the Malmquist index allows for technical inefficiency by relying on the concept of the best-practice frontier, in contrast to the growth accounting approach. Following Färe et al. (1994), the Malmquist index in Eq. (2) can be rewritten as

$$M_o\left(X_{t+1}, Y_{t+1}, X_t, Y_t\right) = \frac{D_0^{t+1}(X_{t+1}, Y_{t+1})}{D_0^t(X_t, Y_t)} \times \left[\frac{D_0^t(X_{t+1}, Y_{t+1})}{D_0^{t+1}(X_{t+1}, Y_{t+1})} \frac{D_0^t(X_t, Y_t)}{D_0^{t+1}(X_t, Y_t)}\right]^{1/2} \quad (3)$$

Eq. (3) shows the decomposition of the Malmquist index into two basic components – "technical change" and "efficiency change". Technical change between period $t$ and period $t$+1 is denoted by the bracket on the right hand side of Eq. (3) that is the geometric mean of two ratios, each representing a shift in the best-practice frontier estimated at the input level in each of the two periods, $t$ and $t$+1. The value of technical change greater than 1 indicates an improvement in the prevailing best practice. Turning to efficiency change between period $t$ and period $t$+1, it is represented by the first ratio on the right hand side of Eq. (3) that measures the change in technical efficiency from period $t$ to period $t$+1. Subsequently, efficiency change determines whether production is moving closer to or away from the prevailing frontier, and captures the efficiency catch-up effect between the two periods $t$ and

*t*+1. The value of efficiency change greater than 1 implies that the country has closed the gap of its production method with the prevailing best practice.

## 3. Data and Estimation Method

The best-practice frontier is constructed using a sample of 24 OECD countries over the period of 1985-2011. The sample includes: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Japan, Korea, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, and the United States. These countries are chosen to facilitate comparisons with Lee (2014) that is based on the same sample of OECD countries. Germany represents unified Germany from 1991 and the whole of Germany before 1991. For the years up to 1990, the OECD estimates data for the whole of Germany based on data for West Germany. Among the current OECD member countries, 10 countries are not included in this study; they include Chile, Czech Republic, Estonia, Hungary, Luxembourg, Mexico, Poland, Slovak Republic, Slovenia, and Turkey.

The measure of aggregate output is constant price GDP adjusted in 2005 prices from the OECD Annual National Accounts database.[3] Total hours actually worked ('total hours' hereafter) and the productive capital stock are the two aggregate input proxies. Total hours are from the OECD Productivity database.[4] The measure covers total employment comprising wage and salary earners as well as the self-employed (including contributing family members), and it is corrected for paid holidays, sick leave and annual leave. During

[3] Data was extracted on Jan 17, 2013.
[4] Data was extracted on January 17, 2013.

1985-2011, there are missing values of total hours for Austria (1985-1994) and Portugal (1985) that were filled in using the estimated growth rates of total hours.[5] The second input proxy is the overall productive capital stock from the OECD Economic Outlook database.[6] The OECD Economic Outlook database has gaps in data for the productive capital stock of Germany (1985-1990), Greece (1985-1994), and Ireland (1985-1989) over the study period of 1985-2011. Subsequently, those missing observations were filled in by assuming the perpetual inventory model with a constant scrapping rate.[7]

For estimation of the best-practice frontiers, several methods have been developed since Farrell (1957). This paper uses the data envelopment analysis (DEA) approach to estimate the frontiers and calculate Malmquist indexes. In the DEA approach, the best-practice frontiers are estimated by non-parametric linear programming methods. We assume constant returns to scale (CRS) as underlying technology and calculate multi-factor productivity growth employing the DEA approach. Variable returns to scale (VRS) may be an alternative specification of technology, but the Malmquist index is equivalent to the traditional notion of multi-factor productivity under a CRS benchmark (Färe et al., 1997; and Ray and Desli, 1997). For calculation of indexes, we use DEAP version 2.1 (Coelli, 1996).

## 4. Estimation Results

### 4.1. Multi-Factor Productivity

Table 1 presents the estimated growth rates of multi-factor productivity based on the

[5] See Lee (2014) for details.
[6] Data was extracted from OECD Economic Outlook No. 92 on May 20, 2013.
[7] See Lee (2014) for details.

Malmquist index approach.[8] According to these estimates, multi-factor productivity in the 24 sample countries increased on average by 0.6 percent per year over the period 1986-2011. In terms of the Solow residual, Lee (2014) finds the corresponding growth rate to be about 1 percent using the same input-output variables.[9] The correlation between the Malmquist index and the Solow residual is found to be statistically significant; the correlation coefficient and the rank correlation coefficient are respectively 0.69 and 0.66. In theory, the Malmquist index is equivalent to the Törnqvist index from the growth accounting approach under certain conditions including the translog technology.

The estimation results reported in Table 1 indicate that annual MFP growth measured by the Malmquist index tends to differ considerably from country to country. Moreover, consistently growing productivity is not something to be taken for granted, as negative growth over a one-year period was often observed in most countries. Over the entire period 1986-2011, the average annual growth rate of multi-factor productivity was negative in one-third of the 24 sample countries – Canada, Greece, Israel, Italy, Korea, New Zealand, Portugal, and Spain – in terms of the Malmquist index. Of these eight countries, six countries – Canada, Greece, Israel, Italy, New Zealand, and Spain – also show relatively slow MFP growth in terms of growth accounting with their Solow residual being on average fairly close to zero during 1986-2011. In contrast, Korea and Portugal show relatively strong MFP growth in terms of the Solow residual. Korea in particular registers the average growth rate of MFP that is considerably higher than those of any other OECD countries. In the Malmquist approach, however, Japan – followed by Austria and Ireland – was found to show the most robust growth of MFP during 1986-2011. Both approaches find particularly strong

[8] An annual growth rate of multi-factor productivity is represented by (Malmquist index – 1).
[9] The growth rate is obtained from Lee (2014), Table 6.

productivity growth in Ireland, whereas the pace of MFP growth in Japan and Austria only hovers around the OECD average growth rate in terms of the Solow residual.

It is also clear from Table 1 that annual MFP growth exhibits substantial variation over time within a single country. The average annual growth rate of MFP for the 24 sample countries ranges from 2 percent in 2000 to -2.3 percent in 2009. There was an OECD-wide deterioration in multi-factor productivity in 2008 as well. These results are highly comparable to those based on the growth accounting approach. In terms of the Solow residual, Lee (2014) finds that the pace of MFP growth in the same sample of OECD countries was the most robust in 2000 with its average growth rate of 2.3 percent while it became negative in 2009 (-2 percent) and also in 2008 (-1.4 percent).

In line with Lee (2014), this study also divides the entire study period 1986-2011 into five sub-periods, each half-decade-long, and estimates the average growth rates of multi-factor productivity for each sub-period by calculating the geometric mean of Malmquist indexes. The results, reported in Table 2, clearly show considerable variation in the pace of OECD-wide productivity growth over time. They also suggest that the MFP growth trend in terms of the Malmquist index moves closely in steps with the trend suggested by Lee (2014) based on the Solow residual. The relatively strong OECD-wide productivity growth during the second half of the 1980s was followed by a considerable slowdown in MFP growth in the next half-decade. Then OECD countries as a whole were found to achieve the highest pace of MFP growth in the second half of the 1990s, but this strong productivity growth sharply decelerated in the two subsequent sub-periods. The pace of MFP growth in the sub-period of 2006-2011 was found to be particularly weak as the Malmquist index and the Solow residual respectively indicate negative growth and virtual stagnation in this sub-period.

In terms of the Malmquist index, Ireland showed strong MFP growth in the first three sub-periods spanning the second half of the 1980s and the entire 1990s. A relatively high pace of productivity growth was also found in Portugal and Japan (in 1986-1990), in Belgium and Germany (in 1991-1995), and in Finland (in 1996-2000). In the two subsequent sub-periods, Iceland and Sweden achieved relatively sound growth during 2001-2005, and Japan during 2006-2011. In contrast, Korea continued to suffer negative growth of multi-factor productivity in all five sub-periods. Other OECD countries that registered a negative rate of MFP growth in each sub-period include: Canada, Denmark, and Sweden (in 1986-1990); Canada, Finland, Iceland, Israel, Italy, Portugal, Spain, and Switzerland (in 1991-1995); Israel and Portugal (in 1996-2000); Canada, Denmark, Greece, Israel, Italy, Portugal, and Spain (in 2001-2005); and Canada, Denmark, Greece, Iceland, Ireland, Israel, Italy, New Zealand, Norway, Portugal, and the United Kingdom (in 2006-2011).

The productivity growth trend for three major economies – the United States, the Eurozone, and Japan – is presented in Figure 1. The growth rate of MFP in the Eurozone is constructed using a real GDP weighted geometric mean of Malmquist indexes for 11 of its member countries. The 11 Eurozone countries include: Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal, and Spain. Subsequently, seven other Eurozone members as of March 2014 – Cyprus, Estonia, Latvia, Luxembourg, Malta, Slovakia, and Slovenia – are not included in the construction of MFP growth rates for the Eurozone. The trend for the Eurozone is shown for the entire study period of 1986-2011 even though the euro was officially introduced only in 1999.

During 1987-1991, Japan showed relatively strong MFP growth, consistently outpacing productivity growth in the Eurozone and the United States. Lee (2014) also finds a similar

trend for this half decade using the Solow residual. Japan continued to achieve a relatively high pace of MFP growth in the 1990s in terms of the Malmquist index, whereas the country was found to be lagging behind the Eurozone and the United States in terms of the Solow residual. Between the United States and the Eurozone, the Malmquist index and the Solow residual both find that MFP growth in the United States tended to consistently outstrip the Eurozone from 1992. Both approaches also find that MFP growth in the Eurozone was relatively weak, constantly trailing behind Japan and the United States, after the official launch of the common currency.

In Figures 2 through 4, the trend of MFP growth based on the Malmquist index is presented with the trend of the Solow residual for each of the three major economies. The figures clearly show that the time trends of MFP growth identified by both approaches are more or less in sync. However, there are noticeable differences in the relative standing among these economies between the two approaches. Compared with the Malmquist index, the Solow residual tends to consistently underestimate MFP growth for Japan, and also, to a lesser extent, that for the United States. In contrast, the Solow residual tends to present overestimated rates of MFP growth – in comparison with the Malmquist index – for the Eurozone in most years. Particularly in the 1990s, there was a clear and relatively wide gap between the two measures observed for all three economies.

### 4.2. Decomposition of Multi-Factor Productivity

One clear advantage of the Malmquist index approach vis-à-vis the Solow residual is the former allows for technical inefficiency in measurement of multi-factor productivity by

relying on the concept of the best-practice frontier. Eq. (3) allows the estimated growth rates of multi-factor productivity to be broken down into two components: a shift in the best-practice frontier (technical change) and a catch-up with the best-practice frontier (efficiency change). Accordingly, technical change represents an improvement in potential productive capacity, and efficiency change captures the extent of moving closer to (or away from) the prevailing potential capacity. The estimates of technical change and efficiency change thus help us to identify a major driver of MFP growth between potential productive capacity and technical efficiency.

The estimates of technical change for the 24 sample countries are reported in Table 3. The average rate of technical change for the 24 sample countries was found to be 1 percent per year, surpassing the average annual growth rate of MFP of 0.6 percent, during 1986-2011. Since the estimates of technical change can be viewed to gauge the degree of improvements in potential productive capacity, this gap between MFP growth and technical change suggests that actual productivity growth in the OECD area fell short of an increase in the area's potential productive capacity during 1986-2011. Table 3 clearly shows that potential productive capacity improved on average in most of the sample countries over the 26 year period. In particular, Australia, Austria, Belgium, France, Germany, Japan and the Netherlands were found to achieve relatively strong improvements in their potential productive capacity with their average rates of technical change all above 1.6 percent. In contrast, the average rate of technical change was found to be close to virtual stagnation in Israel and Portugal, and it was negative in Greece and Korea.

As in the previous section, the entire period of 1986-2011 was divided into five sub-periods, each half-decade long, and the average rates of technical change for individual sub-

periods were estimated. The results presented in Table 4 show a noticeable trend in the pace of OECD-wide growth in potential productive capacity over time. The average rate of technical change was found to reach 2.7 percent in the sub-period of 1996-2000 after gradually increasing in the two previous sub-periods. However, the rate of technical change declined sharply in the two subsequent sub-periods – falling by more than one-half during 2001-2005, and becoming even negative during 2006-2011. In the sub-period of 1996-2000, Iceland, Ireland, New Zealand, and the United Kingdom achieved a particularly strong improvement in their potential productive capacity with their average rates of technical change exceeding 4 percent, whereas the same countries showed a relatively slow pace of technical change, less than 1 percent, in the previous sub-period. On the other hand, all sample countries exhibited a negative rate of technical change during 2006-2011, suggesting an across-the-board fall in potential productive capacity in the OECD area. The decline in potential capacity was found to be relatively large in Greece, Israel, Korea, New Zealand, and Portugal.

Figure 5 follows technical change for the three major economies – the United States, the Eurozone, and Japan. Technical change for the Eurozone was measured by the real GDP-weighted geometric mean of technical change for 11 Eurozone countries in the sample. In the figure, technical change for the three major economies clearly moves in sync, suggesting that these three economies were facing largely the same changes in their potential productive capacity over 1986-2011. In particular, the three economies experienced a relatively brisk pace of improvement in potential productive capacity throughout the 1990s except for a brief setback in 1998, but the increase in potential capacity began to sharply lose speed from 2003 and eventually turned into deterioration from 2006. The rate of technical change in the three

major economies remained largely negative until 2011.

Since the average rate of technical change was found to be greater than the average rate of MFP growth during 1986-2011, it is sensible to expect an overall increase in technical inefficiency among the sample countries over the 26 year period. Table 5 shows that the geometric mean of efficiency change for the sample countries over 1986-2011 is indeed slightly less than 1. The cross-country difference in the average rate of efficiency change was not found to be large as the average rate ranges between 0.8 percent (in Ireland) and -1.2 percent (in Canada, Iceland, and Korea). Only six countries – Austria, Germany, Ireland, Japan, Sweden, and the United States – were found to improve technical efficiency on average over the period 1986-2011.

Efficiency change exhibited considerable variation over time, even though its cross-country variation was somewhat limited as described above. Over the entire 1986-2011 period, the average annual rate of efficiency change for the sample countries ranges from more than 2.7 percent (in 2008) to less than -3.1 percent (in 1991). The OECD countries in the sample were found to significantly improve technical efficiency in 1988, then production in the OECD area continued to drift away from the prevailing potential capacity for the next fifteen years, and finally the sample countries swung back to the path of rising technical efficiency from 2004. The OECD countries as a whole showed particularly strong improvement in technical efficiency during 2006-2008.

When the entire period 1986-2011 was divided into five sub-periods as summarized in Table 6, the average rate of efficiency change was negative for the first four sub-periods. The sample countries were found to suffer a widening gap with the best-practice frontier at a relatively rapid pace especially in the 1990s. A widening of technical inefficiency was

particularly rapid in Korea, Spain and Switzerland in the first half of the 1990s, and in Iceland, Israel, Korea, and Portugal in the second half of the 1990s. In contrast, most OECD countries managed to improve technical efficiency in the sub-period of 2006-2011 except for Greece, Iceland, and the United Kingdom.[10] Israel and Korea achieved a particularly robust rise in technical efficiency in this sub-period.

Figure 6 shows the trend of technical efficiency in the Eurozone reflected in the real GDP-weighted geometric mean of efficiency change for individual member countries, as well as technical efficiency in the United States and Japan. According to this figure, technical inefficiency in the future Eurozone countries as a whole continued to widen before the creation of the euro in 1999. Technical inefficiency also widened constantly in the United States and Japan in most of the 1990s, although Japan showed relatively strong improvement in technical efficiency in the second half of the 1980s. All three major economies were found to improve technical efficiency at a robust pace from 2006, except for a brief setback in the Eurozone and Japan in 2009.

## 5. Concluding Remarks

Lee (2014) provides the estimates of the Solow residual for 24 OECD countries. To complement these estimates in examining relative productivity of individual countries, this paper measures the growth rates of multi-factor productivity for the same sample of 24 OECD countries using the Malmquist index approach. The Malmquist index approach is expected to address some of the limitations of the growth accounting approach by relying on

[10] The rate of efficiency change for Ireland and Norway was 0 in all years during 2006-2011.

the concept of the best-practice frontier. For example, the best-practice frontier offers a common reference point against which relative productivity growth of all sample countries are measured.

In theory, the Malmquist index may become equivalent to the Törnqvist index from the growth accounting approach, but only under some restrictive conditions. The Malmquist index developed in this study is found to be significantly correlated with the Solow residual in Lee (2014), and the correlation coefficients range around 70 percent. The examination of OECD averages reveals that the time trends of multi-factor productivity growth identified by both approaches are more or less in sync. The investigation of the three major economies – the United States, the Eurozone, and Japan – also finds comparable time trends for both approaches. However, there are noticeable differences in the relative standing among the three economies between the two approaches.

The use of the best-practice frontier in measurement allows productivity growth to be broken down into technical change and efficiency change. Technical change represents an improvement in potential productive capacity, and efficiency change captures the extent of moving closer to (or away from) the prevailing potential capacity. The breakdown suggests that actual productivity growth in the OECD area fell short of an increase in the area's potential productive capacity during 1986-2011. Accordingly, the estimates of efficiency change indicate an overall increase in technical inefficiency among the sample OECD countries over the 26 year period. Finally, technical change for the three major economies was found to move clearly in sync, suggesting that these three economies were facing largely the same changes in their potential productive capacity over 1986-2011.

**References**

Caves, D.W., L.R. Christensen, and W.E. Diewert. 1982. "The Economic Theory of Index Numbers and the Measurement of Input, Output and Productivity." *Econometrica*, Vol. 50, pp. 1393-1414.

Coelli, T. 1996. *A Guide to DEAP Version 2.1: A Data Envelopment Analysis (Computer) Program*. CEPA (Centre for Efficiency and Productivity Analysis) Working Paper 96/08, Department of Econometrics, University of New England, Australia.

Färe, R., S. Grosskopf, and M. Norris. 1997. "Productivity Growth, Technical Change, and Efficiency Change in Industrialized Countries: Reply." *American Economic Review*, Vol. 87, No. 5, pp. 1040-1043.

Färe, R., S. Grosskopf, M. Norris, and Z. Zhang. 1994. "Productivity Growth, Technical Change, and Efficiency Change in Industrialized Countries." *American Economic Review*, Vol. 84, pp. 66-83.

Farrell, M. 1957. "The Measurement of Productive Efficiency." *Journal of the Royal Statistical Society Series A General*, Vol. 120, pp. 253-281.

Hulten, C. R. (2000), "Total Factor Productivity: A Short Biography," National Bureau of Economic Research, Working Paper 7471.

Lee, J. Y. (2014), "Global trends of multi-factor productivity," East-West Center Working Papers, Economics Series No. 136.

Ray, S.C. and E. Desli. 1997. "Productivity Growth, Technical Change, and Efficiency Change in Industrialized Countries: Comment. *American Economic Review*, Vol. 87, No.

5, pp. 1033-1039.

Shephard, R. 1970. *Theory of Cost and Production Functions*. Princeton: Princeton University Press.

Table 1. Growth Rate of Multi-factor Productivity

| | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 1986-2011 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Australia** | 0.003 | 0.02 | -0.004 | 0.004 | 0.017 | 0.015 | 0.043 | 0.015 | -0.004 | 0.017 | 0.033 | 0.031 | 0.037 | 0.005 | 0.017 | 0.041 | 0.005 | 0.022 | 0.008 | 0.007 | 0.009 | 0.008 | 0.003 | 0.022 | -0.011 | 0.008 | -0.986 |
| **Austria** | 0.038 | 0.028 | 0.016 | 0.033 | 0.023 | 0.029 | 0.014 | 0.011 | 0.009 | 0.032 | 0.002 | 0.011 | 0.04 | 0.017 | 0.027 | 0.009 | 0.019 | 0.007 | 0.016 | 0.022 | 0.033 | 0.022 | 0.005 | -0.002 | 0.022 | 0.004 | 0.019 |
| **Belgium** | 0.024 | 0.025 | 0.035 | 0.024 | 0.012 | 0.038 | 0.031 | 0.025 | 0.037 | -0.009 | 0.029 | 0.022 | -0.005 | 0.019 | 0.04 | -0.026 | 0.013 | 0.012 | 0.039 | -0.007 | 0.015 | 0.016 | -0.013 | -0.015 | 0.017 | -0.012 | 0.015 |
| **Canada** | -0.018 | -0.003 | 0.001 | -0.017 | -0.03 | -0.038 | -0.01 | 0 | 0.018 | 0 | -0.01 | 0.009 | 0.008 | 0.019 | 0.021 | -0.005 | 0.005 | -0.006 | -0.002 | 0.003 | -0.003 | -0.01 | -0.018 | -0.017 | 0.004 | 0.003 | -0.004 |
| **Denmark** | 0.015 | -0.017 | -0.016 | -0.011 | 0 | -0.001 | 0.005 | -0.008 | 0.043 | 0.011 | 0.009 | 0.007 | -0.005 | 0.004 | 0.013 | -0.012 | -0.006 | 0 | 0.012 | 0.003 | 0.007 | -0.006 | -0.028 | -0.038 | 0.028 | 0.01 | 0.001 |
| **Finland** | 0.004 | 0.006 | 0.019 | 0.016 | -0.016 | -0.055 | -0.024 | 0.004 | 0.038 | 0.032 | 0.024 | 0.044 | 0.033 | 0.019 | 0.037 | 0.009 | 0.007 | 0.014 | 0.029 | 0.015 | 0.027 | 0.029 | -0.018 | -0.07 | 0.028 | 0.014 | 0.01 |
| **France** | 0.02 | 0.008 | 0.031 | 0.033 | 0.02 | 0.015 | 0.02 | 0.013 | 0.024 | 0.026 | 0.004 | 0.021 | 0.025 | 0.016 | 0.035 | 0.009 | 0.03 | 0.01 | 0.005 | 0.015 | 0.029 | 0.001 | -0.01 | -0.006 | 0.014 | 0.014 | 0.016 |
| **Germany** | 0.015 | 0.014 | 0.026 | 0.035 | 0.035 | 0.035 | 0.025 | 0.014 | 0.027 | 0.024 | 0.02 | 0.023 | 0.011 | 0.009 | 0.027 | 0.025 | 0.014 | 0.009 | 0.008 | 0.012 | 0.036 | 0.017 | -0.001 | -0.026 | 0.02 | 0.017 | 0.018 |
| **Greece** | 0.005 | -0.005 | 0.062 | 0.05 | 0.005 | 0.036 | 0.005 | -0.028 | 0.004 | 0.002 | 0.003 | 0.012 | 0.001 | -0.008 | -0.008 | -0.011 | -0.019 | 0.002 | -0.011 | -0.019 | 0.018 | -0.042 | -0.065 | -0.079 | -0.082 | -0.087 | -0.011 |
| **Iceland** | 0.028 | 0.035 | -0.017 | -0.011 | -0.002 | -0.023 | -0.05 | 0.009 | 0.029 | -0.016 | 0.024 | 0.026 | 0.01 | -0.019 | -0.001 | 0.019 | 0.008 | 0.01 | 0.054 | 0.017 | -0.025 | 0.012 | -0.011 | -0.017 | -0.035 | 0.024 | 0.003 |
| **Ireland** | -0.019 | 0.039 | 0.044 | 0.046 | 0.053 | 0.012 | 0.028 | 0.015 | 0.035 | 0.064 | 0.055 | 0.069 | 0.032 | 0.045 | 0.045 | 0.003 | 0.014 | 0.003 | -0.004 | 0.004 | 0.001 | -0.003 | -0.05 | -0.04 | -0.005 | 0.018 | 0.019 |
| **Israel** | 0.013 | 0.034 | -0.003 | -0.021 | 0.037 | 0.026 | 0.013 | -0.03 | -0.011 | -0.011 | -0.024 | -0.039 | -0.019 | -0.026 | 0.034 | -0.054 | -0.041 | -0.019 | 0.019 | 0.019 | 0.02 | 0.012 | -0.007 | -0.028 | 0.007 | -0.007 | -0.004 |
| **Italy** | 0.004 | 0.007 | 0.015 | 0.011 | -0.006 | -0.01 | -0.009 | -0.014 | 0.013 | 0.013 | -0.007 | 0.003 | -0.006 | -0.004 | 0.016 | -0.001 | -0.015 | -0.018 | 0.003 | -0.004 | 0.001 | -0.002 | -0.017 | -0.038 | 0.019 | 0.001 | -0.002 |
| **Japan** | -0.004 | 0.029 | 0.058 | 0.043 | 0.058 | 0.029 | 0.014 | 0.029 | 0.011 | 0.024 | 0.021 | 0.024 | 0.004 | 0.03 | 0.023 | 0.018 | 0.021 | 0.016 | 0.025 | 0.013 | 0.007 | 0.017 | 0.002 | -0.008 | 0.038 | 0.042 | 0.022 |
| **Korea** | 0.019 | 0.006 | -0.001 | -0.05 | -0.036 | -0.034 | -0.051 | -0.038 | -0.024 | -0.026 | -0.036 | -0.029 | -0.089 | 0.058 | 0.023 | -0.012 | 0.017 | -0.021 | 0 | -0.004 | 0.006 | 0.004 | -0.015 | -0.029 | 0.023 | 0 | -0.013 |
| **Netherlands** | 0.014 | 0.012 | 0.018 | 0.02 | 0.014 | 0.011 | -0.001 | 0.015 | 0.018 | 0.001 | 0.009 | 0.018 | 0.021 | 0.023 | 0.018 | 0.006 | 0.007 | 0.013 | 0.033 | 0.02 | 0.017 | 0.016 | 0 | -0.024 | 0.021 | 0.008 | 0.013 |
| **New Zealand** | 0.006 | -0.015 | 0.017 | 0.001 | -0.007 | -0.004 | 0.006 | 0.037 | 0.027 | 0.012 | 0.005 | 0.007 | -0.007 | 0.028 | 0 | 0.007 | 0.019 | 0.002 | -0.007 | -0.016 | -0.021 | -0.017 | -0.047 | -0.014 | -0.016 | -0.02 | -0.001 |
| **Norway** | 0.011 | 0.006 | -0.008 | 0.024 | 0.024 | 0.034 | 0.028 | 0.021 | 0.038 | 0.029 | 0.031 | 0.026 | -0.002 | 0.004 | 0.029 | 0.022 | 0.012 | 0.019 | 0.019 | 0.006 | -0.011 | -0.019 | -0.036 | -0.008 | -0.006 | -0.004 | 0.011 |
| **Portugal** | 0.049 | 0.059 | 0.051 | 0.037 | 0.005 | 0.01 | -0.025 | -0.048 | -0.019 | 0.01 | 0.003 | -0.001 | -0.002 | -0.015 | -0.015 | -0.029 | -0.032 | -0.039 | -0.016 | -0.017 | -0.01 | -0.005 | -0.03 | -0.05 | 0.002 | -0.024 | -0.006 |
| **Spain** | 0.001 | 0.016 | 0.008 | 0.001 | -0.011 | -0.016 | -0.021 | -0.031 | -0.005 | -0.008 | 0.003 | 0.003 | -0.002 | 0 | -0.001 | -0.008 | -0.01 | -0.006 | -0.007 | -0.006 | -0.003 | -0.004 | -0.012 | 0.015 | 0.02 | 0.014 | -0.003 |
| **Sweden** | 0.005 | 0.008 | -0.003 | -0.003 | -0.016 | -0.022 | -0.013 | 0.016 | 0.026 | 0.02 | 0.016 | 0.037 | 0.026 | 0.02 | 0.034 | 0.002 | 0.03 | 0.029 | 0.029 | 0.021 | 0.026 | 0.002 | -0.021 | -0.029 | 0.037 | 0.014 | 0.011 |
| **Switzerland** | 0.001 | -0.008 | 0.007 | 0.019 | 0.006 | -0.054 | -0.016 | -0.015 | -0.007 | 0.011 | 0.022 | 0.028 | 0.009 | -0.007 | 0.029 | 0.02 | 0.007 | -0.007 | 0.005 | 0.014 | 0.018 | 0.015 | 0 | -0.026 | 0.012 | 0.015 | 0.004 |
| **UK** | 0.026 | 0.027 | 0.011 | -0.005 | -0.011 | -0.024 | 0.009 | 0.018 | 0.024 | 0.009 | 0.008 | 0.012 | 0.007 | 0.006 | 0.022 | 0.006 | 0.011 | 0.022 | 0.009 | 0.007 | 0.006 | 0.011 | -0.023 | -0.053 | -0.009 | -0.013 | 0.004 |
| **US** | 0.022 | 0.004 | 0.011 | 0.008 | 0.01 | 0.006 | 0.033 | 0.005 | 0.01 | 0.001 | 0.025 | 0.015 | 0.022 | 0.025 | 0.02 | 0.009 | 0.022 | 0.023 | 0.016 | 0.011 | 0.003 | 0.008 | 0.007 | 0.023 | 0.024 | 0.003 | 0.014 |
| **Geometric Mean** | 0.012 | 0.014 | 0.016 | 0.012 | 0.007 | 0 | 0.002 | 0.001 | 0.015 | 0.011 | 0.011 | 0.016 | 0.006 | 0.011 | 0.02 | 0.002 | 0.006 | 0.004 | 0.012 | 0.006 | 0.008 | 0.003 | -0.017 | -0.023 | 0.007 | 0.001 | 0.006 |

Note: Malmquist index - 1

Table 2. Growth Rate of Multi-factor Productivity (Sub-period Average)

| | 1986-1990 | 1991-1995 | 1996-2000 | 2001-2005 | 2006-2011 |
|---|---|---|---|---|---|
| **Australia** | 0.00796 | 0.01709 | 0.02453 | 0.01651 | 0.00645 |
| **Austria** | 0.02757 | 0.01896 | 0.01932 | 0.01458 | 0.01392 |
| **Belgium** | 0.02397 | 0.02425 | 0.02089 | 0.00596 | 0.00123 |
| **Canada** | -0.01346 | -0.00617 | 0.00934 | -0.00101 | -0.00687 |
| **Denmark** | -0.00587 | 0.00985 | 0.00558 | -0.00063 | -0.00476 |
| **Finland** | 0.00572 | -0.00161 | 0.03136 | 0.01477 | 0.001 |
| **France** | 0.02236 | 0.01959 | 0.02015 | 0.01376 | 0.00691 |
| **Germany** | 0.02496 | 0.02498 | 0.01798 | 0.01358 | 0.01031 |
| **Greece** | 0.02304 | 0.0036 | -3E-05 | -0.01163 | -0.05685 |
| **Iceland** | 0.00638 | -0.01057 | 0.00786 | 0.02147 | -0.00888 |
| **Ireland** | 0.03226 | 0.03063 | 0.04913 | 0.00398 | -0.01346 |
| **Israel** | 0.01176 | -0.0028 | -0.01512 | -0.01566 | -0.00062 |
| **Italy** | 0.00617 | -0.00147 | 0.00036 | -0.00703 | -0.00616 |
| **Japan** | 0.03654 | 0.02137 | 0.02036 | 0.01859 | 0.01617 |
| **Korea** | -0.01275 | -0.03465 | -0.01591 | -0.00408 | -0.00197 |
| **Netherlands** | 0.0156 | 0.00877 | 0.01779 | 0.01575 | 0.00622 |
| **New Zealand** | 0.00034 | 0.01549 | 0.00653 | 0.00093 | -0.02257 |
| **Norway** | 0.01133 | 0.02998 | 0.01751 | 0.01558 | -0.01406 |
| **Portugal** | 0.04003 | -0.01465 | -0.00603 | -0.02664 | -0.01966 |
| **Spain** | 0.00296 | -0.01624 | 0.0006 | -0.0074 | 0.00493 |
| **Sweden** | -0.00183 | 0.00522 | 0.02657 | 0.02214 | 0.00455 |
| **Switzerland** | 0.00496 | -0.01643 | 0.01611 | 0.00776 | 0.00555 |
| **United Kingdom** | 0.00948 | 0.00706 | 0.01098 | 0.01098 | -0.01373 |
| **United States** | 0.01098 | 0.01094 | 0.02139 | 0.01618 | 0.0113 |
| **Geometric Mean** | **0.012** | **0.00583** | **0.0127** | **0.00569** | **-0.00349** |

Note: Malmquist index -1

Table 3. Rate of Technical Change

| | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 1986-2011 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Australia** | 0.01 | 0.016 | 0.002 | 0.042 | 0.034 | 0.043 | 0.031 | 0.023 | 0.038 | 0.032 | 0.034 | 0.027 | 0.002 | 0.012 | 0.04 | 0.035 | 0.022 | 0.031 | 0.02 | 0.011 | -0.009 | -0.018 | -0.033 | 0.001 | -0.003 | -0.004 | 0.017 |
| **Austria** | 0.01 | 0.016 | 0.002 | 0.042 | 0.034 | 0.043 | 0.031 | 0.023 | 0.038 | 0.032 | 0.034 | 0.027 | 0.002 | 0.012 | 0.04 | 0.035 | 0.022 | 0.031 | 0.02 | 0.011 | -0.009 | -0.018 | -0.033 | 0.001 | -0.003 | -0.004 | 0.017 |
| **Belgium** | 0.01 | 0.016 | 0.002 | 0.042 | 0.034 | 0.043 | 0.031 | 0.023 | 0.038 | 0.032 | 0.034 | 0.027 | 0.002 | 0.012 | 0.04 | 0.035 | 0.022 | 0.031 | 0.02 | 0.011 | -0.009 | -0.018 | -0.033 | 0.001 | -0.003 | -0.004 | 0.017 |
| **Canada** | 0.012 | 0.008 | -0.011 | -0.002 | 0.023 | 0.026 | 0.022 | 0.012 | 0.03 | 0.02 | 0.033 | 0.034 | 0.002 | 0.006 | 0.026 | 0.01 | 0.009 | 0.009 | 0.012 | 0.004 | -0.007 | -0.013 | -0.035 | -0.01 | -0.001 | 0.006 | 0.009 |
| **Denmark** | 0.012 | 0.007 | -0.013 | 0.001 | 0.02 | 0.026 | 0.023 | 0.013 | 0.033 | 0.021 | 0.031 | 0.031 | 0 | 0.005 | 0.025 | 0.01 | 0.009 | 0.009 | 0.012 | 0.004 | -0.006 | -0.011 | -0.033 | -0.003 | 0.005 | 0.013 | 0.009 |
| **Finland** | 0.013 | 0.01 | -0.01 | -0.003 | 0.023 | 0.026 | 0.024 | 0.016 | 0.037 | 0.023 | 0.03 | 0.03 | 0 | 0.005 | 0.026 | 0.01 | 0.01 | 0.01 | 0.011 | 0.005 | -0.004 | -0.007 | -0.031 | 0.003 | 0.012 | 0.024 | 0.011 |
| **France** | 0.01 | 0.016 | 0.002 | 0.042 | 0.034 | 0.043 | 0.031 | 0.023 | 0.038 | 0.032 | 0.034 | 0.027 | 0.002 | 0.012 | 0.04 | 0.035 | 0.022 | 0.031 | 0.02 | 0.011 | -0.009 | -0.018 | -0.033 | 0.001 | -0.003 | -0.004 | 0.017 |
| **Germany** | 0.01 | 0.016 | 0.002 | 0.042 | 0.034 | 0.043 | 0.031 | 0.023 | 0.038 | 0.032 | 0.034 | 0.027 | 0.002 | 0.012 | 0.04 | 0.035 | 0.022 | 0.031 | 0.02 | 0.011 | -0.009 | -0.018 | -0.033 | 0 | -0.005 | -0.003 | 0.017 |
| **Greece** | 0.011 | 0.031 | -0.007 | 0.007 | 0.005 | 0.036 | 0.005 | -0.028 | 0.004 | 0.002 | 0.003 | 0.045 | 0.029 | 0.042 | 0.039 | -0.005 | 0.002 | -0.01 | -0.01 | -0.001 | -0.005 | -0.014 | -0.076 | -0.087 | -0.025 | 0.009 | -0.001 |
| **Iceland** | 0.015 | 0.032 | 0.001 | -0.015 | 0.036 | 0.026 | 0.014 | -0.011 | 0.006 | 0.002 | 0.055 | 0.069 | 0.031 | 0.045 | 0.049 | 0.011 | 0.025 | 0.015 | 0.004 | 0.008 | 0.002 | 0 | -0.027 | -0.012 | 0.011 | 0.009 | 0.015 |
| **Ireland** | 0.014 | 0.023 | -0.003 | -0.012 | 0.034 | 0.026 | 0.014 | -0.009 | 0.006 | 0.002 | 0.055 | 0.069 | 0.032 | 0.045 | 0.045 | 0.003 | 0.014 | 0.003 | -0.004 | 0.004 | 0.001 | -0.003 | -0.05 | -0.04 | -0.005 | 0.018 | 0.01 |
| **Israel** | 0.013 | 0.034 | -0.003 | -0.021 | 0.037 | 0.026 | 0.013 | -0.03 | -0.011 | -0.011 | 0.027 | 0.06 | 0.029 | 0.042 | 0.039 | -0.005 | 0.002 | -0.01 | -0.01 | -0.001 | -0.005 | -0.014 | -0.076 | -0.087 | -0.025 | 0.009 | 0 |
| **Italy** | 0.012 | 0.001 | -0.015 | 0.002 | 0.019 | 0.026 | 0.024 | 0.015 | 0.035 | 0.023 | 0.029 | 0.027 | -0.005 | -0.002 | 0.021 | 0.009 | 0.006 | 0.008 | 0.014 | 0.003 | -0.008 | -0.013 | -0.035 | -0.009 | 0.002 | 0.01 | 0.008 |
| **Japan** | 0.011 | 0.008 | -0.001 | 0.035 | 0.034 | 0.043 | 0.031 | 0.023 | 0.038 | 0.032 | 0.034 | 0.027 | 0.002 | 0.012 | 0.04 | 0.035 | 0.022 | 0.031 | 0.02 | 0.011 | -0.009 | -0.018 | -0.033 | 0.001 | -0.003 | -0.004 | 0.016 |
| **Korea** | 0.019 | 0.006 | -0.001 | 0.001 | 0.005 | 0.036 | 0.006 | -0.028 | 0.004 | 0.001 | 0 | 0.044 | 0.029 | 0.042 | 0.039 | -0.005 | 0.002 | -0.01 | -0.01 | -0.001 | -0.005 | -0.014 | -0.076 | -0.087 | -0.025 | 0.009 | -0.001 |
| **Netherlands** | 0.01 | 0.016 | 0.002 | 0.042 | 0.034 | 0.043 | 0.031 | 0.023 | 0.038 | 0.032 | 0.034 | 0.027 | 0.002 | 0.012 | 0.04 | 0.035 | 0.022 | 0.031 | 0.02 | 0.011 | -0.009 | -0.018 | -0.033 | 0.001 | -0.003 | -0.004 | 0.017 |
| **New Zealand** | 0.015 | 0.03 | -0.001 | -0.013 | 0.034 | 0.026 | 0.014 | -0.012 | 0 | -0.003 | 0.044 | 0.064 | 0.029 | 0.042 | 0.039 | -0.005 | 0.002 | -0.01 | -0.01 | -0.001 | -0.005 | -0.014 | -0.076 | -0.087 | -0.025 | 0.009 | 0.003 |
| **Norway** | 0.011 | 0.006 | -0.008 | 0.024 | 0.024 | 0.034 | 0.028 | 0.021 | 0.038 | 0.029 | 0.031 | 0.026 | -0.002 | 0.004 | 0.029 | 0.022 | 0.012 | 0.019 | 0.019 | 0.006 | -0.011 | -0.019 | -0.036 | -0.008 | -0.006 | -0.004 | 0.011 |
| **Portugal** | 0.011 | 0.03 | -0.007 | 0.01 | 0.005 | 0.035 | 0.011 | -0.033 | -0.007 | -0.008 | 0.022 | 0.058 | 0.029 | 0.042 | 0.039 | -0.005 | 0.002 | -0.01 | -0.01 | -0.001 | -0.005 | -0.014 | -0.076 | -0.087 | -0.025 | 0.009 | 0 |
| **Spain** | 0.012 | 0.007 | -0.012 | -0.001 | 0.023 | 0.026 | 0.023 | 0.014 | 0.036 | 0.026 | 0.031 | 0.027 | 0.002 | 0 | 0.02 | 0.009 | 0.005 | 0.008 | 0.015 | 0.003 | -0.01 | -0.017 | -0.036 | -0.008 | -0.003 | -0.004 | 0.007 |
| **Sweden** | 0.011 | -0.003 | -0.017 | 0.005 | 0.017 | 0.026 | 0.026 | 0.021 | 0.038 | 0.032 | 0.034 | 0.027 | 0.002 | 0.012 | 0.04 | 0.03 | 0.013 | 0.016 | 0.017 | 0.005 | -0.011 | -0.018 | -0.036 | -0.008 | -0.008 | 0 | 0.01 |
| **Switzerland** | 0.01 | 0.016 | 0.002 | 0.035 | 0.021 | 0.026 | 0.025 | 0.018 | 0.038 | 0.029 | 0.034 | 0.027 | 0.002 | 0.012 | 0.04 | 0.035 | 0.021 | 0.021 | 0.017 | 0.002 | -0.011 | -0.019 | -0.039 | -0.015 | -0.003 | 0.003 | 0.013 |
| **UK** | 0.015 | 0.026 | -0.001 | -0.015 | 0.037 | 0.026 | 0.014 | -0.008 | 0.01 | 0.005 | 0.049 | 0.061 | 0.026 | 0.037 | 0.043 | 0.011 | 0.022 | 0.014 | 0.005 | 0.008 | 0.003 | 0.003 | -0.025 | -0.03 | -0.025 | 0.009 | 0.012 |
| **US** | 0.01 | 0.016 | 0.002 | 0.042 | 0.027 | 0.037 | 0.031 | 0.023 | 0.038 | 0.032 | 0.034 | 0.027 | 0.002 | 0.009 | 0.03 | 0.022 | 0.012 | 0.017 | 0.018 | 0.003 | -0.012 | -0.019 | -0.033 | -0.002 | -0.003 | -0.004 | 0.014 |
| **Geometric Mean** | 0.012 | 0.016 | -0.004 | 0.013 | 0.026 | 0.033 | 0.022 | 0.006 | 0.025 | 0.019 | 0.032 | 0.038 | 0.01 | 0.019 | 0.036 | 0.017 | 0.013 | 0.013 | 0.01 | 0.005 | -0.007 | -0.014 | -0.043 | -0.024 | -0.007 | 0.004 | 0.01 |

Note: Technical change - 1

Table 4. Rate of Technical Change (Sub-period Average)

| | 1986-1990 | 1991-1995 | 1996-2000 | 2001-2005 | 2006-2011 |
|---|---|---|---|---|---|
| **Australia** | 0.020691 | 0.03338 | 0.0229 | 0.02376 | -0.01107 |
| **Austria** | 0.020691 | 0.03338 | 0.0229 | 0.02376 | -0.01107 |
| **Belgium** | 0.020691 | 0.03338 | 0.0229 | 0.02376 | -0.01107 |
| **Canada** | 0.005932 | 0.02198 | 0.02011 | 0.0088 | -0.01008 |
| **Denmark** | 0.005338 | 0.02318 | 0.01831 | 0.0088 | -0.00594 |
| **Finland** | 0.00653 | 0.02518 | 0.01812 | 0.0092 | -0.00065 |
| **France** | 0.020691 | 0.03338 | 0.0229 | 0.02376 | -0.01107 |
| **Germany** | 0.020691 | 0.03338 | 0.0229 | 0.02376 | -0.0114 |
| **Greece** | 0.009325 | 0.0036 | 0.03149 | -0.00481 | -0.03368 |
| **Iceland** | 0.01362 | 0.00732 | 0.04973 | 0.01257 | -0.00292 |
| **Ireland** | 0.011061 | 0.00773 | 0.04913 | 0.00398 | -0.01346 |
| **Israel** | 0.01176 | -0.0028 | 0.03933 | -0.00481 | -0.03368 |
| **Italy** | 0.003734 | 0.02458 | 0.0139 | 0.00799 | -0.00893 |
| **Japan** | 0.017297 | 0.03338 | 0.0229 | 0.02376 | -0.01107 |
| **Korea** | 0.005976 | 0.00359 | 0.03067 | -0.00481 | -0.03368 |
| **Netherlands** | 0.020691 | 0.03338 | 0.0229 | 0.02376 | -0.01107 |
| **New Zealand** | 0.012841 | 0.00491 | 0.04354 | -0.00481 | -0.03368 |
| **Norway** | 0.011328 | 0.02998 | 0.01751 | 0.01558 | -0.01406 |
| **Portugal** | 0.009729 | -0.00065 | 0.03793 | -0.00481 | -0.03368 |
| **Spain** | 0.00573 | 0.02498 | 0.01592 | 0.00799 | -0.01306 |
| **Sweden** | 0.00253 | 0.02858 | 0.0229 | 0.01617 | -0.01357 |
| **Switzerland** | 0.01674 | 0.02718 | 0.0229 | 0.01915 | -0.01409 |
| **United Kingdom** | 0.012229 | 0.00934 | 0.04313 | 0.01198 | -0.01096 |
| **United States** | 0.019305 | 0.03219 | 0.02032 | 0.01438 | -0.01223 |
| **Geometric Mean** | **0.012696** | **0.02094** | **0.02725** | **0.01157** | **-0.01531** |

Note: Technical change -1

Table 5. Rate of Efficiency Change

| | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 1986-2011 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Australia** | -0.007 | 0.004 | -0.006 | -0.036 | -0.016 | -0.027 | 0.012 | -0.008 | -0.04 | -0.015 | -0.001 | 0.003 | 0.035 | -0.007 | -0.022 | 0.006 | -0.017 | -0.009 | -0.012 | -0.004 | 0.018 | 0.026 | 0.038 | 0.021 | -0.007 | 0.011 | -0.002 |
| **Austria** | 0.028 | 0.012 | 0.014 | -0.008 | -0.01 | -0.014 | -0.016 | -0.011 | -0.027 | 0 | -0.031 | -0.016 | 0.038 | 0.005 | -0.013 | -0.025 | -0.003 | -0.023 | -0.004 | 0.011 | 0.043 | 0.041 | 0.039 | -0.003 | 0.025 | 0.008 | 0.002 |
| **Belgium** | 0.014 | 0.009 | 0.033 | -0.016 | -0.021 | -0.005 | 0.001 | 0.002 | -0.001 | -0.04 | -0.005 | -0.005 | -0.007 | 0.007 | 0 | -0.058 | -0.009 | -0.019 | 0.019 | -0.018 | 0.024 | 0.035 | 0.021 | -0.015 | 0.02 | -0.009 | -0.002 |
| **Canada** | -0.031 | -0.012 | 0.012 | -0.015 | -0.052 | -0.063 | -0.032 | -0.012 | -0.012 | -0.019 | -0.042 | -0.024 | 0.007 | 0.013 | -0.005 | -0.015 | -0.004 | -0.015 | -0.014 | -0.001 | 0.004 | 0.002 | 0.018 | -0.007 | 0.005 | -0.003 | -0.012 |
| **Denmark** | 0.003 | -0.023 | -0.004 | -0.012 | -0.02 | -0.026 | -0.017 | -0.021 | 0.01 | -0.01 | -0.021 | -0.023 | -0.006 | 0 | -0.012 | -0.021 | -0.015 | -0.009 | -0.001 | -0.001 | 0.014 | 0.005 | 0.005 | -0.034 | 0.023 | -0.003 | -0.009 |
| **Finland** | -0.009 | -0.005 | 0.03 | 0.018 | -0.038 | -0.079 | -0.047 | -0.012 | 0.001 | 0.008 | -0.006 | 0.014 | 0.034 | 0.014 | 0.01 | -0.001 | -0.003 | 0.004 | 0.018 | 0.01 | 0.031 | 0.036 | 0.013 | -0.072 | 0.016 | -0.01 | -0.001 |
| **France** | 0.01 | -0.008 | 0.029 | -0.008 | -0.014 | -0.027 | -0.01 | -0.009 | -0.013 | -0.006 | -0.029 | -0.007 | 0.023 | 0.004 | -0.004 | -0.024 | 0.008 | -0.021 | -0.015 | 0.004 | 0.038 | 0.019 | 0.024 | -0.007 | 0.017 | 0.017 | 0 |
| **Germany** | 0.005 | -0.002 | 0.024 | -0.006 | 0.002 | -0.008 | -0.005 | -0.009 | -0.01 | -0.008 | -0.013 | -0.004 | 0.01 | -0.003 | -0.012 | -0.009 | -0.008 | -0.022 | -0.012 | 0.001 | 0.046 | 0.036 | 0.033 | -0.026 | 0.025 | 0.021 | 0.001 |
| **Greece** | -0.005 | -0.035 | 0.07 | 0.042 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.031 | -0.027 | -0.048 | -0.045 | -0.007 | -0.021 | 0.013 | -0.001 | -0.017 | 0.023 | -0.028 | 0.012 | 0.009 | -0.058 | -0.095 | -0.01 |
| **Iceland** | 0.013 | 0.003 | -0.018 | 0.005 | -0.037 | -0.048 | -0.063 | 0.02 | 0.023 | -0.018 | -0.03 | -0.04 | -0.021 | -0.061 | -0.048 | 0.008 | -0.017 | -0.006 | 0.049 | 0.01 | -0.027 | 0.011 | 0.016 | -0.005 | -0.046 | 0.014 | -0.012 |
| **Ireland** | -0.033 | 0.016 | 0.048 | 0.059 | 0.018 | -0.014 | 0.014 | 0.025 | 0.029 | 0.062 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.008 |
| **Israel** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.049 | -0.093 | -0.046 | -0.065 | -0.005 | -0.05 | -0.042 | -0.009 | 0.029 | 0.02 | 0.025 | 0.026 | 0.076 | 0.065 | 0.034 | -0.016 | -0.005 |
| **Italy** | -0.007 | 0.005 | 0.031 | 0.008 | -0.025 | -0.035 | -0.032 | -0.028 | -0.021 | -0.01 | -0.035 | -0.023 | -0.001 | -0.002 | -0.005 | -0.01 | -0.021 | -0.026 | -0.011 | -0.007 | 0.009 | 0.012 | 0.019 | -0.029 | 0.017 | -0.009 | -0.009 |
| **Japan** | -0.014 | 0.022 | 0.059 | 0.008 | 0.024 | -0.013 | -0.016 | 0.006 | -0.026 | -0.008 | -0.013 | -0.004 | 0.002 | 0.017 | -0.016 | -0.016 | -0.001 | -0.015 | 0.004 | 0.002 | 0.017 | 0.036 | 0.036 | -0.009 | 0.041 | 0.046 | 0.006 |
| **Korea** | 0 | 0 | 0 | -0.051 | -0.041 | -0.067 | -0.056 | -0.01 | -0.028 | -0.027 | -0.036 | -0.07 | -0.114 | 0.016 | -0.015 | -0.008 | 0.016 | -0.011 | 0.01 | -0.003 | 0.011 | 0.019 | 0.067 | 0.064 | 0.049 | -0.009 | -0.012 |
| **Netherlands** | 0.003 | -0.003 | 0.016 | -0.02 | -0.019 | -0.031 | -0.031 | -0.007 | -0.019 | -0.031 | -0.024 | -0.009 | 0.019 | 0.011 | -0.021 | -0.027 | -0.015 | -0.017 | 0.012 | 0.009 | 0.027 | 0.035 | 0.035 | -0.025 | 0.025 | 0.012 | -0.004 |
| **New Zealand** | -0.01 | -0.043 | 0.018 | 0.015 | -0.04 | -0.029 | -0.008 | 0.051 | 0.027 | 0.015 | -0.037 | -0.054 | -0.035 | -0.013 | -0.037 | 0.011 | 0.018 | 0.012 | 0.002 | -0.015 | -0.017 | -0.002 | 0.032 | 0.08 | 0.009 | -0.029 | -0.004 |
| **Norway** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Portugal** | 0.037 | 0.028 | 0.059 | 0.027 | 0 | -0.024 | -0.035 | -0.015 | -0.012 | 0.018 | -0.018 | -0.056 | -0.03 | -0.054 | -0.052 | -0.024 | -0.034 | -0.029 | -0.006 | -0.015 | -0.005 | 0.009 | 0.051 | 0.041 | 0.028 | -0.032 | -0.006 |
| **Spain** | -0.012 | 0.009 | 0.02 | 0.002 | -0.033 | -0.041 | -0.042 | -0.044 | -0.039 | -0.033 | -0.027 | -0.024 | -0.003 | -0.001 | -0.02 | -0.017 | -0.015 | -0.013 | -0.021 | -0.009 | 0.006 | 0.013 | 0.024 | 0.024 | 0.023 | 0.017 | -0.01 |
| **Sweden** | -0.006 | 0.011 | 0.014 | -0.008 | -0.032 | -0.046 | -0.038 | -0.005 | -0.012 | -0.012 | -0.017 | 0.01 | 0.024 | 0.008 | -0.006 | -0.027 | 0.017 | 0.013 | 0.011 | 0.016 | 0.037 | 0.021 | 0.015 | -0.022 | 0.045 | 0.015 | 0.001 |
| **Switzerland** | -0.009 | -0.023 | 0.005 | -0.016 | -0.014 | -0.078 | -0.04 | -0.032 | -0.043 | -0.017 | -0.012 | 0 | 0.007 | -0.019 | -0.01 | -0.015 | -0.014 | -0.028 | -0.012 | 0.012 | 0.03 | 0.035 | 0.041 | -0.011 | 0.015 | 0.012 | -0.009 |
| **UK** | 0.012 | 0.001 | 0.013 | 0.011 | -0.046 | -0.049 | -0.005 | 0.026 | 0.014 | 0.003 | -0.039 | -0.047 | -0.019 | -0.029 | -0.02 | -0.005 | -0.01 | 0.008 | 0.004 | -0.001 | 0.003 | 0.008 | 0.003 | -0.023 | 0.017 | -0.022 | -0.008 |
| **US** | 0.012 | -0.011 | 0.009 | -0.032 | -0.016 | -0.03 | 0.003 | -0.017 | -0.027 | -0.03 | -0.009 | -0.012 | 0.02 | 0.016 | -0.01 | -0.012 | 0.009 | 0.006 | -0.001 | 0.008 | 0.015 | 0.028 | 0.042 | 0.025 | 0.027 | 0.007 | 0 |
| **Geometric Mean** | 0 | -0.002 | 0.02 | -0.002 | -0.018 | -0.032 | -0.02 | -0.005 | -0.01 | -0.008 | -0.021 | -0.022 | -0.004 | -0.008 | -0.015 | -0.015 | -0.008 | -0.009 | 0.002 | 0 | 0.015 | 0.018 | 0.027 | 0.001 | 0.014 | -0.003 | -0.004 |

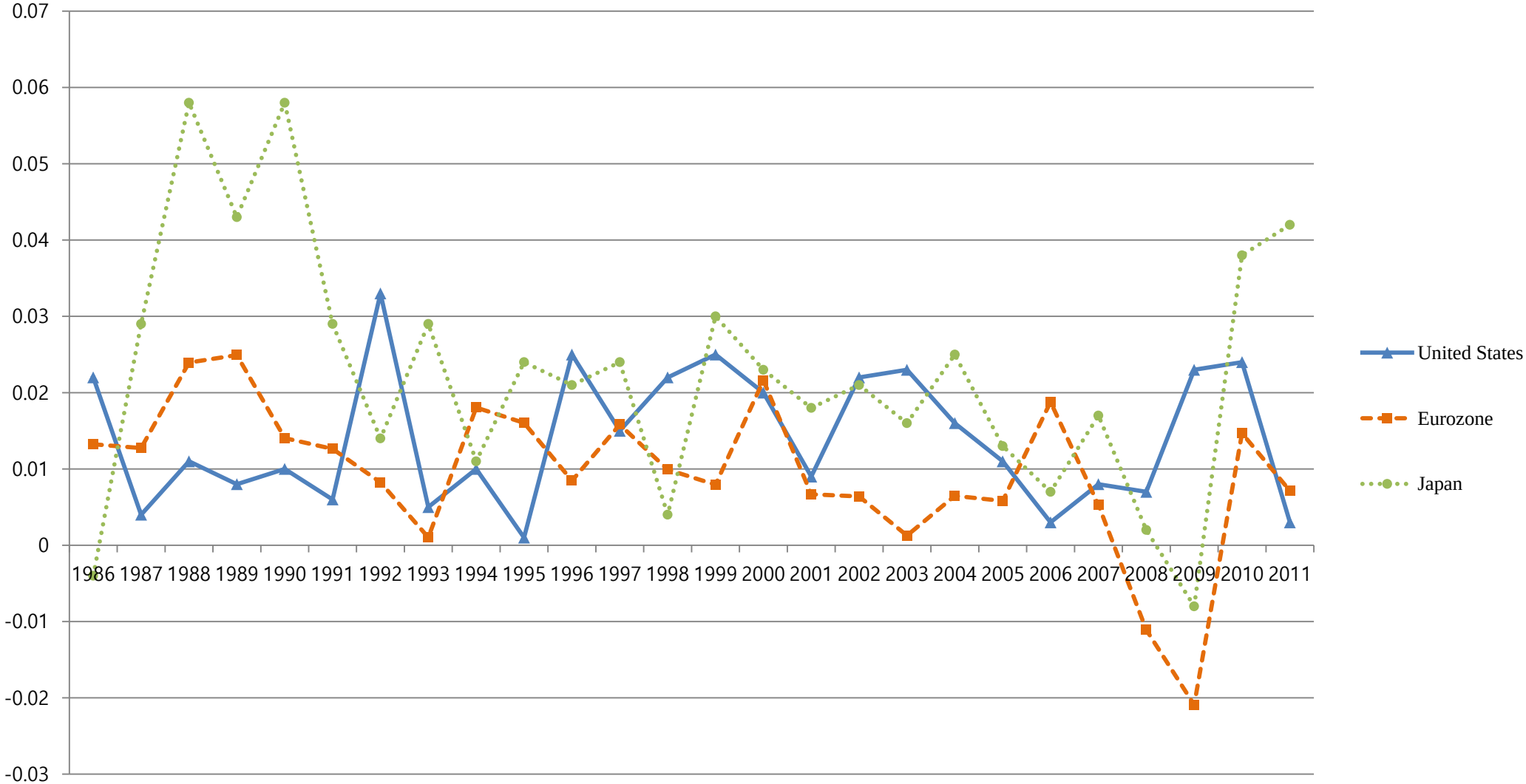
Note: Efficiency change - 1

Table 6. Rate of Efficiency Change (Sub-period Average)

| | 1986-1990 | 1991-1995 | 1996-2000 | 2001-2005 | 2006-2011 |
|---|---|---|---|---|---|
| **Australia** | -0.012293 | -0.015757 | 0.001426 | -0.007231 | 0.017739 |
| **Austria** | 0.007098 | -0.013638 | -0.003678 | -0.008892 | 0.025349 |
| **Belgium** | 0.003602 | -0.008729 | -0.002013 | -0.017312 | 0.012502 |
| **Canada** | -0.019831 | -0.027791 | -0.01041 | -0.009818 | 0.003136 |
| **Denmark** | -0.011248 | -0.012879 | -0.012439 | -0.009431 | 0.001505 |
| **Finland** | -0.001078 | -0.026355 | 0.01312 | 0.005571 | 0.001653 |
| **France** | 0.001676 | -0.013028 | -0.002742 | -0.009687 | 0.017912 |
| **Germany** | 0.004547 | -0.008001 | -0.004434 | -0.010028 | 0.022233 |
| **Greece** | 0.013726 | 0 | -0.030349 | -0.006673 | -0.02377 |
| **Iceland** | -0.006969 | -0.017816 | -0.040101 | 0.008555 | -0.006439 |
| **Ireland** | 0.021092 | 0.022906 | 0 | 0 | 0 |
| **Israel** | 0 | 0 | -0.052031 | -0.01091 | 0.034566 |
| **Italy** | 0.002231 | -0.025241 | -0.013293 | -0.015027 | 0.003021 |
| **Japan** | 0.019523 | -0.011456 | -0.002869 | -0.005237 | 0.02766 |
| **Korea** | -0.018666 | -0.037826 | -0.044865 | 0.000745 | 0.03311 |
| **Netherlands** | -0.004693 | -0.023847 | -0.004947 | -0.007719 | 0.017951 |
| **New Zealand** | -0.012342 | 0.01082 | -0.035288 | 0.005534 | 0.01154 |
| **Norway** | 0 | 0 | 0 | 0 | 0 |
| **Portugal** | 0.030025 | -0.013758 | -0.04212 | -0.021651 | 0.014938 |
| **Spain** | -0.002969 | -0.039807 | -0.01506 | -0.015008 | 0.017811 |
| **Sweden** | -0.004337 | -0.022736 | 0.003701 | 0.00586 | 0.018275 |
| **Switzerland** | -0.011444 | -0.042214 | -0.006843 | -0.011485 | 0.020184 |
| **United Kingdom** | -0.002059 | -0.002534 | -0.030861 | -0.00082 | -0.002447 |
| **United States** | -0.007735 | -0.02028 | 0.000903 | 0.001969 | 0.023941 |
| **Geometric Mean** | **-0.00058** | **-0.0147** | **-0.01413** | **-0.00581** | **0.01209** |

Note: Efficiency change -1

Figure 1. Growth Rate of Multi-factor Productivity




Note: Malmquist index - 1

Figure 2. Growth Rate of Multi-factor Productivity (United States)

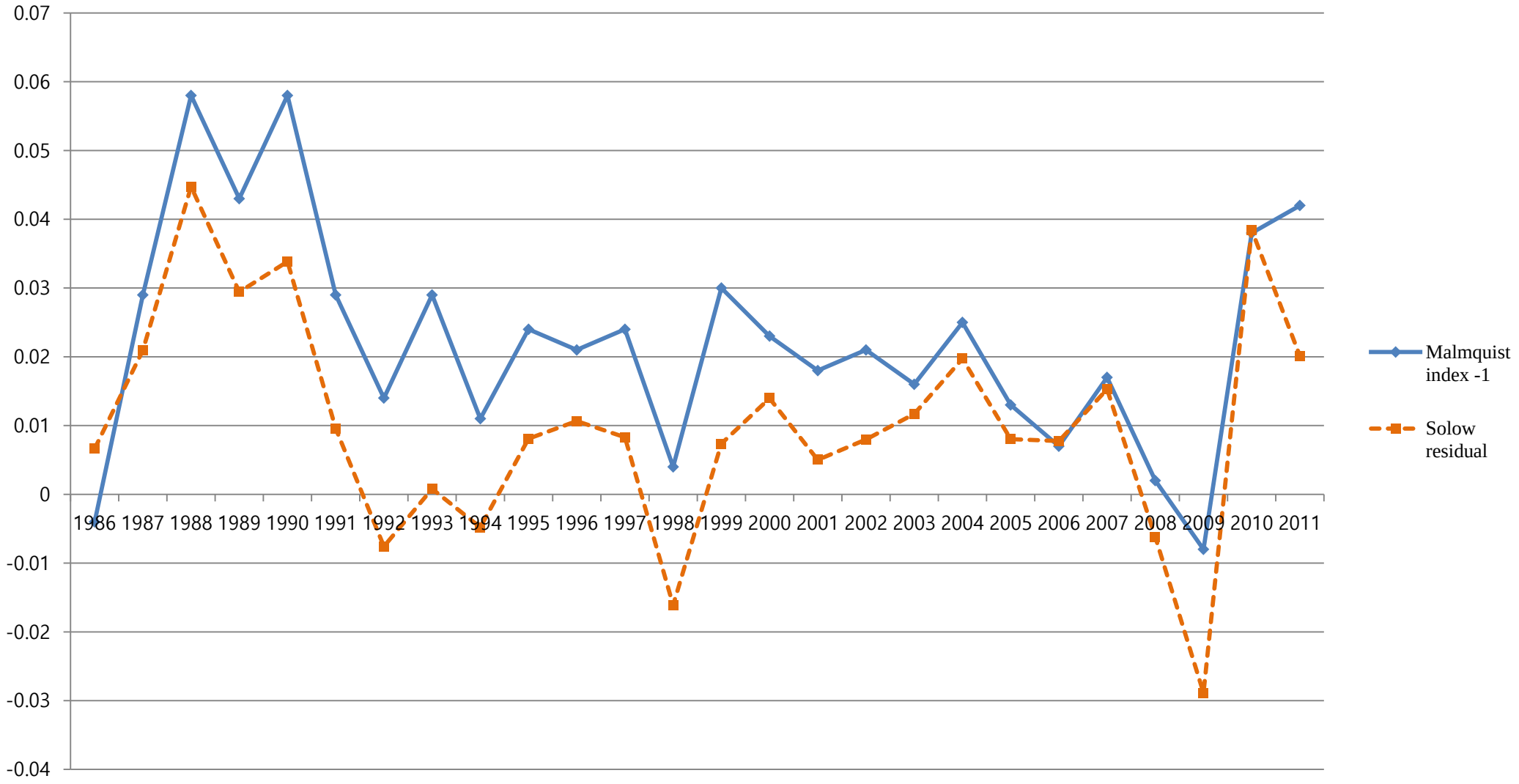


Figure 3. Growth Rate of Multi-factor Productivity (Eurozone)

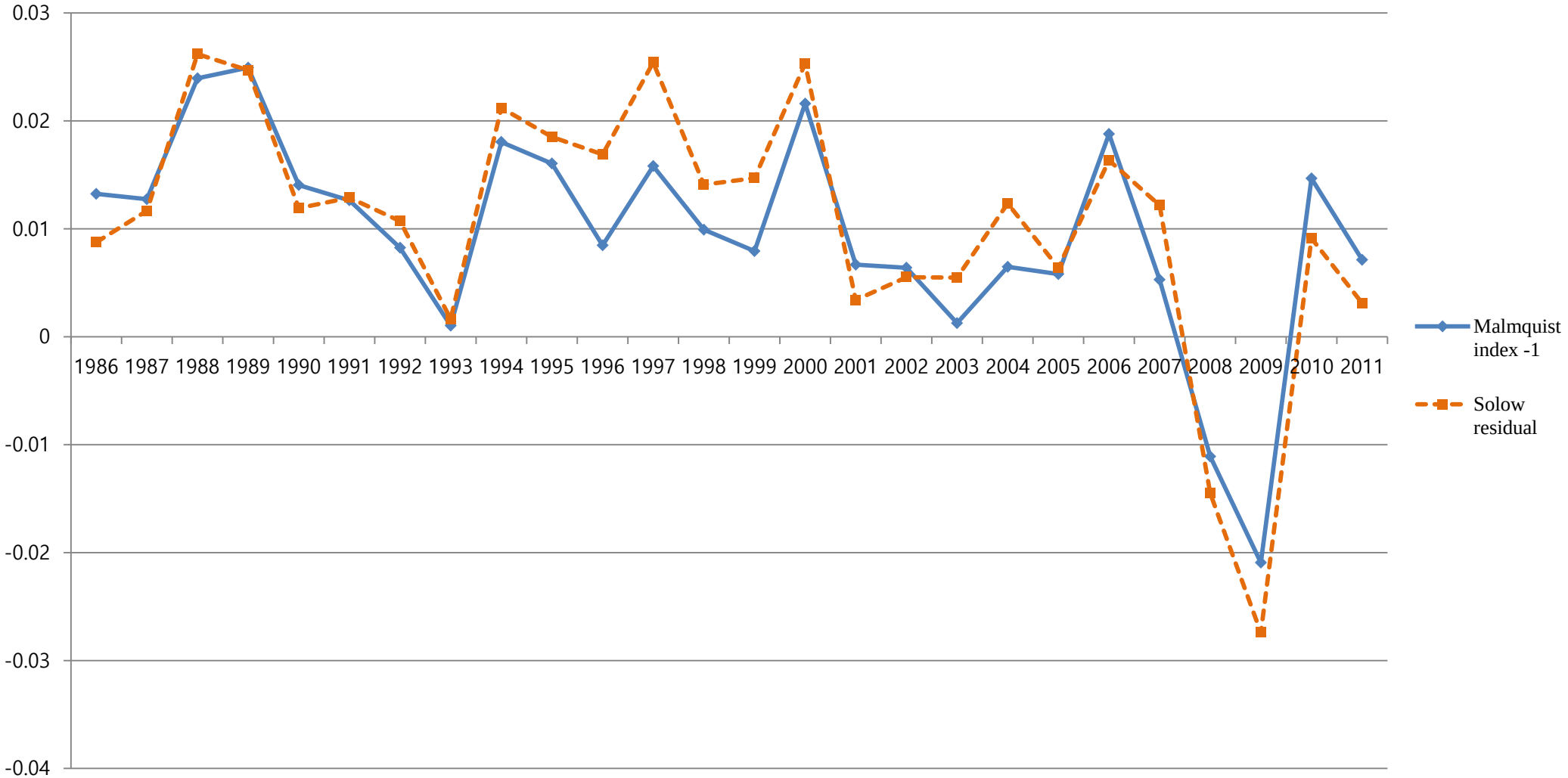


Figure 4. Growth Rate of Multi-factor Productivity (Japan)

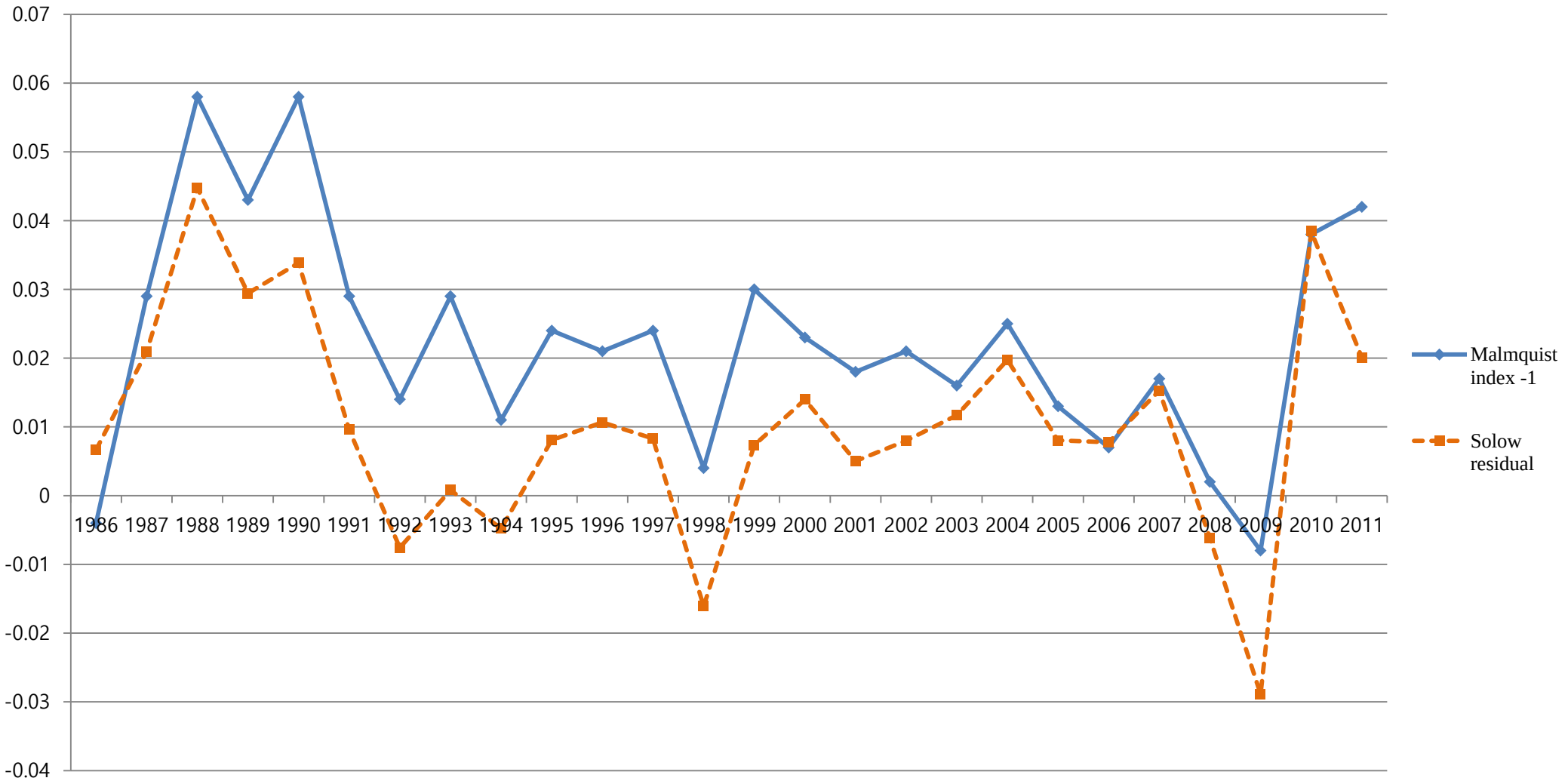
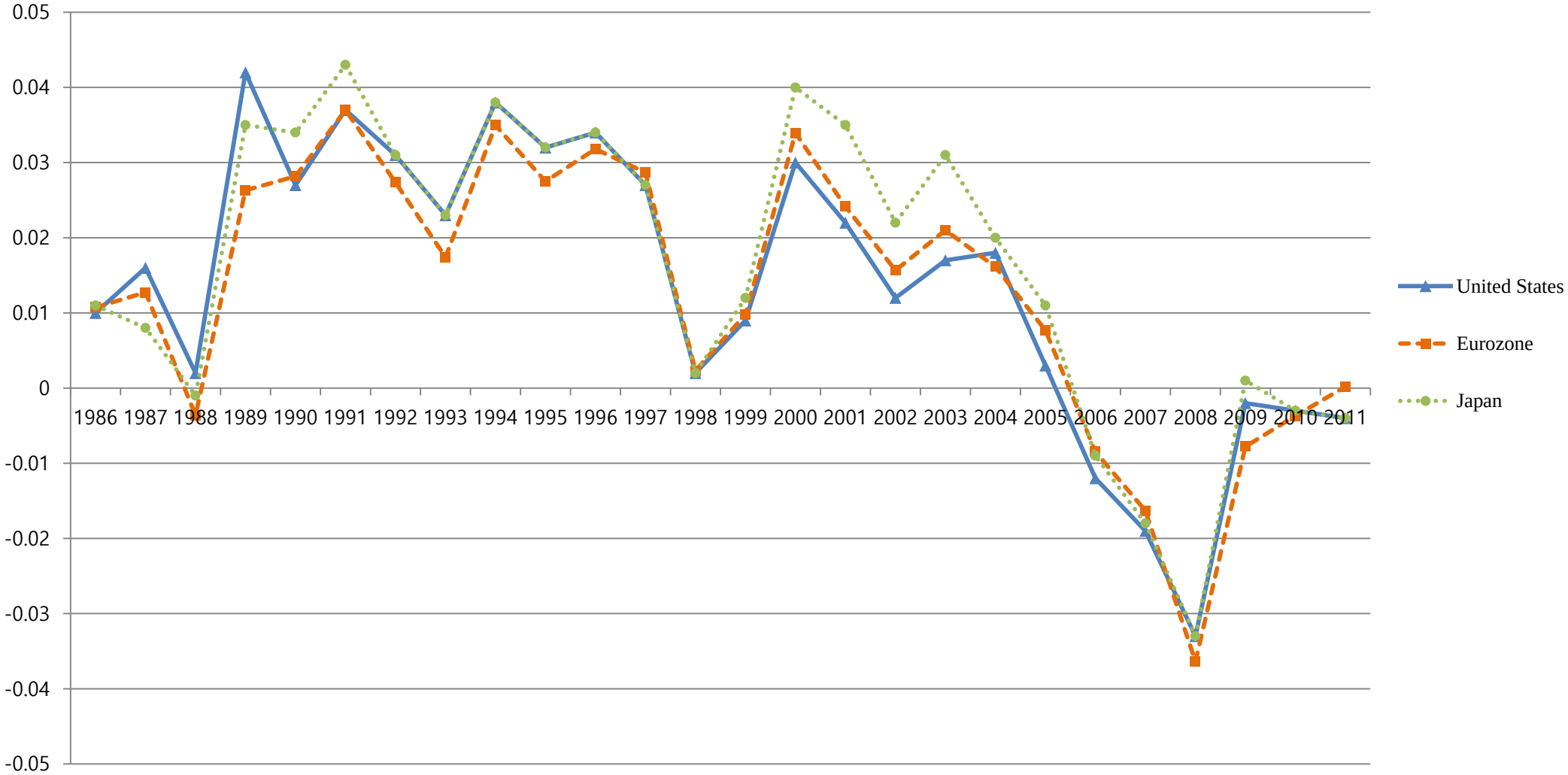
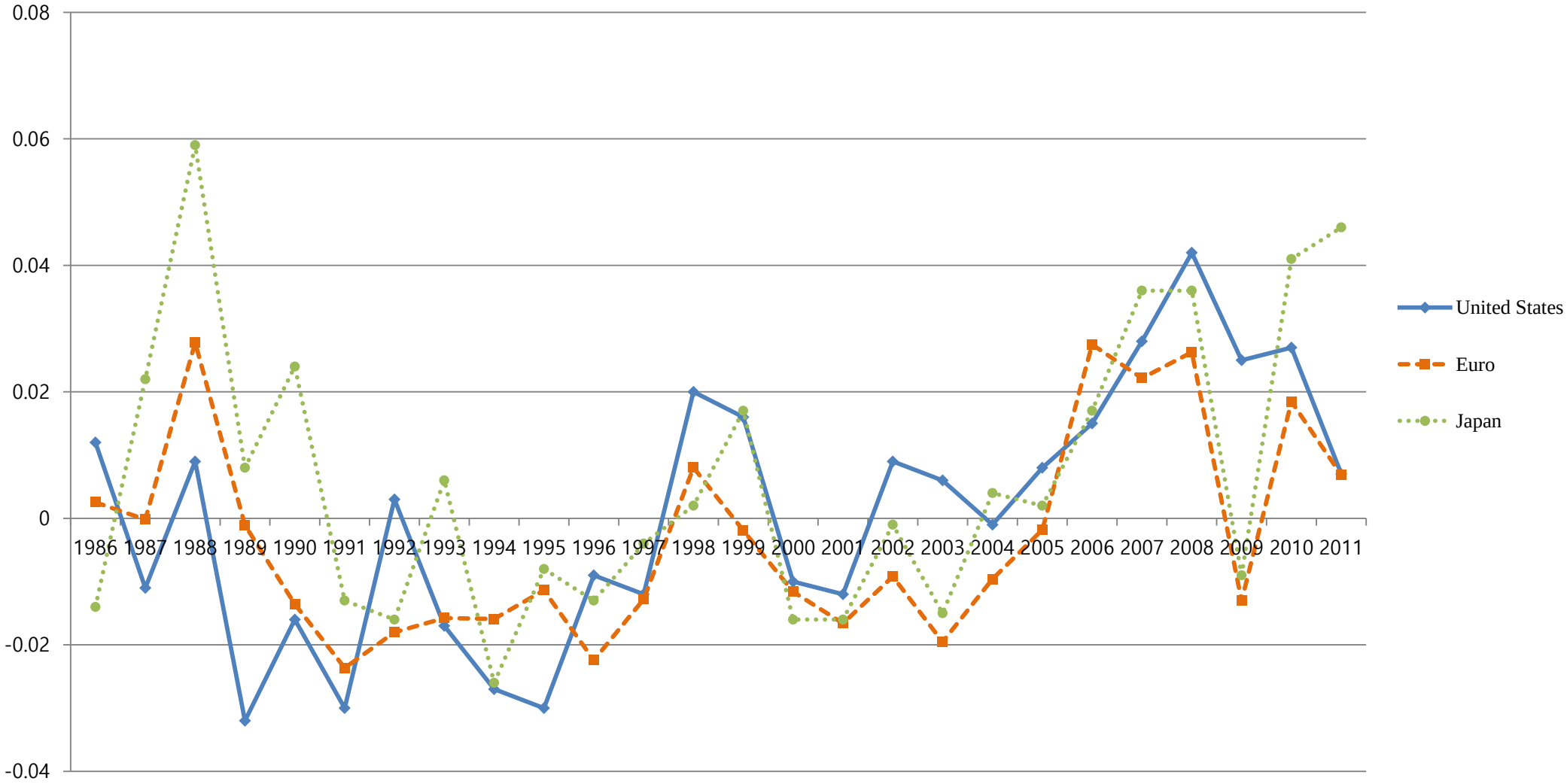


Figure 5. Rate of Technical Change




Note: Technical change - 1

Figure 6. Rate of Efficiency Change




Note: Efficiency change - 1