Heterogeneity, trust, human capital and productivity growth: Decomposition analysis

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Running head: Heterogeneity, trust, human capital

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Abstract

This paper uses panel data from Japan to decompose productivity growth measured by the growth of output per labor unit into three components of efficiency improvement, capital accumulation and technological progress. It then examines their determinants through a dynamic panel model. In particular, this paper focuses on the question of how inequality, trust and humans affect the above components. The main findings derived from empirical estimations are: (1) Inequality impedes not only improvements in efficiency but also capital accumulation. (2) A degree of trust promotes efficiency improvements and capital accumulation at the same time. However, human capital merely enhances improvements in efficiency.

Keywords: Heterogeneity, Inequality, Trust, Data envelopment analysis

JEL classification: E25, O4, O15

1. Introduction

There has recently been increasing interest in the economic consequences of factors such as ethnic heterogeneity, social polarization, social trust, social network and social capital; factors that have been used to shed light in areas of sociology or political science (e.g., Coleman, 1990; Fukuyama, 1995; Granovetter, 1985; Putnam, 2000)[3]. Reflecting this trend, a growing number of researchers have examined how and to what extent socio-economic factors are related to economic growth (e.g., Easterly and Levine, 1997;Knack and Keefer, 1997; Montavo and Reynal-Querol, 2005; Zak and Knack, 2001)[4].

For example, social polarization is considered to reduce growth through various channels. It has been found that ethnic and religious polarization has a large and negative effect on economic development through a reduction of investment and an increase in governmental consumption (Montalvo and Reynal-Quarol, 2005). On the other hand, from the standpoint of economic polarization, opinions seem to vary as to the effects of income inequality, which is usually measured as the Gini coefficient for economic growth[5]. Some researchers have found inequality has negative effects on growth (e.g., Alesina and Perotti, 1996; Keefer and Knack, 2002; Mo, 2000; Perotti,

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[3] For instance, Spagnolo (1999) addresses the influence of social relations that are strengthened by social capital in cooperation with organization such as community. Not only interactions between trust and legal enforcement, but also those with social capital are examined when financial development is induced (Guiso et al., 2004). Alesina and La Ferrara (2000) investigated how heterogeneity affects participating behavior considered as collective action. Lassen (2007) attempts to investigate influences of ethnic heterogeneity and trust on the size of the informal sector.

[4] Hall and Jones (1999) investigate how socio-economic factors are related to output per worker.

[5] In general, a country's level of economic inequality has been viewed as an outcome of its economic performance, such as by economic growth. In recent years, there has been increasing interest in the opposite causality; that is to say, the question of how inequality affects economic growth.

1996; Persson and Tabellini, 1994; Sukiassyan, 2007). By contrast, positive effects have also been observed (e.g., Forbes, 2000; Li and Zou, 1998) [6]. There are also inconclusive results (e.g., Banerjee and Duflo,2003).

If socio-economic factors are profoundly associated with economic growth, it would be cogent to ask what are the channels through which socio-economic factors have an effect on growth. The classical analysis of Kaldor (1956) argued that income distribution has a critical effect upon capital accumulation, through which economic growth is affected. Recent studies show that low trust and heterogeneous societies reduce the rate of investment and therefore hamper capital accumulation, resulting in a decreasing growth rate (Zak and Knack, 2000; Montalvo and Reynal-Querol, 2005). Besides capital accumulation, as argued by Shcumpeter (1912), technological progress resulting from innovation generated by entrepreneurs involves diffusion of technology, leading to economic growth. Accordingly, economic growth can be attributed to several channels such as improvements in efficiency, technological progress, and capital accumulation (Kumar and Russell, 2002). The main purpose of this paper is to examine the determinants of efficiency improvement, capital accumulation and technological progress.

Previous reports (Yamamura and Shin 2007a, 2007b, 2008; Zheng et al., 1998, 2003) have used data envelopment analysis to construct a production frontier and decompose labor-productivity growth into three components of efficiency improvement, capital accumulation, and technological progress to more closely investigate economic growth. Through regression analysis such reports have examined how various key

[6] One of the explanations for such discordance is that a negative relationship is found for less developed countries and by contrast, a positive one is found for developed countries (Barro, 2000).

independent variables have an effect on these components. Applying the above approach, we attempt to decompose the effects of socio economic factors upon growth after controlling for unobservable fixed effects and endogeneity.

It is widely and generally acknowledged that post-war Japan has experienced the unprecedented economic growth. Some researchers point out that this economic growth is in part because of socio-economic features formed through long-term local interaction within organizations such as the community (Hayami, 2001). What is more, the industrial development of Japan was accelerated in part thanks to efficiency improvements in post-war Japan (Yamamura and Shin, 2008; Yamamura et al., 2005). We thus found it appropriate to deal with the labor-productivity growth of Japan to examine how socio-economic factors affect growth through efficiency improvement. Accordingly this paper is concerned with Japan's labor-productivity growth. The main findings here provide evidence as follows: Inequality impedes not only efficiency improvement but also capital accumulation. The degree of trust promotes both efficiency improvement and capital accumulation. However, human capital just enhances efficiency improvement.

The organization of this paper is as follows: Section 2 explains briefly the strategy of the method used in the present paper and describes data sources. Subsequently, regression functions are presented. Section 3 discusses the results of the estimations. The final section offers concluding observations. An explanation of data envelopment analysis and decomposition is in the appendix.

2. Methodology

2.1. Data

Table 1 includes the independent variable definitions, means, and the coefficient of variation of the analyzed data. Details of each variable are as follows. The Gini coefficient of income is represented as GINI, in 1979, 1984, 1989, 1994 and 1999 as collected from the Statistics Bureau of the Ministry of Internal Affairs and Communications (various years). Surveys were carried out in 1979 and 1996 by the Japan Broadcasting Corporation (Nihon Hoso Kyokai); respondents were asked, "Are there many persons whom you can trust in your neighborhood?" We use data from the Japan Broadcasting Corporation (1979, 1996) in which the rate of respondents who said "yes" was separately reported for males and females at the prefecture level. This rate is used as the indicator of trust. The proxy of human capital represented as HC is obtained from Hi-stat[7]. Apart from GINI, TRUST, and HC, all data were collected from the Index Corporation (2006).

Data related to these variables are unavailable for some years. As set out above, data of the Gini coefficient and the indicator of trust are insufficient to construct as panel data. Therefore additional data were generated by interpolation based on the assumption of constant changes in rates to make up for this deficiency[8].

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[7] Data of human capital is available from the Hi-stat HP: http://21coe.ier.hit-u.ac.jp/research/database.
See http://www.ier.hit-u.ac.jp/~fukao/japanese/data/fuken2000/datamaking.pdf for a full account of the method of calculation.

[8] It must be noted that these data might suffer from measurement errors when interpolation is conducted. Caution should thus be exercised when interpreting the estimation results.

2.2. Methods

We analyze the extent of efficiency improvement, capital accumulation and technological progress by data envelopment analysis (abbreviated hereafter as DEA) using prefecture level panel data from 1979 to 1997. First, we estimate the labor-productivity in each prefecture by DEA (Banker et al., 1984). Labor-productivity growth can be decomposed into efficiency improvement, capital accumulation and technological progress. This approach has an advantage over the growth accounting approach in that we can further decompose total factor productivity growth, thereby obtaining more detailed information. Second, we take these variables as dependent variables and estimate their determinants by controlling unobservable individual and time effects through dynamic panel model[9]. This method allows us to investigate how and to what extent inequality and additional key factors have an effect upon productivity growth through efficiency improvement and capital accumulation. We can examine whether and to what degree various factors determining productivity growth affect efficiency improvement and capital accumulation. See appendix for details about DEA.

2.3. Specification of the Regression Function

We would now like to formulate a regression function which takes

[9] Some prior research has used panel data to employ a fixed effects model (Banerjee and Duflo, 1996; Forbes, 2000; Li and Zou, 1998) and a dynamic panel model (Banerjee and Duflo, 1996; Forbes, 2000; Skiassyan, 2007).

labor-productivity, the level of efficiency, the level of per capita capital, and the level of technology as dependent variables denoted as LY_{it}, respectively. To estimate their determinants, the following equation is postulated:

$$LY_{it} = \alpha_1 LY_{it0} + \alpha_2 LGINI_{it0} + \alpha_3 GHET_{it0} + \alpha_4 LTRUS_{it0} + \alpha_5 LHC_{it0} + \alpha_6 LDY_{it0} + \alpha_7 LRAIN_{it0} + \alpha_8 LSNOW_{it0} + \varepsilon_t + \nu_i + u_{it},$$

$\varepsilon_t, \nu_i, u_{it}$ represent the following unobservable effects; t's year-specific effects, the i 's prefecture-specific effects, and the error term, respectively. $t0$ is the lagged year of the t's year. ν_i includes the time-invariant feature. The structure of the data set used in this study is a panel. We incorporate a lagged dependent variable, LY_{it0}, to control for the initial level. We employed a dynamic panel model to reduce the omitted variable bias caused by time invariant individual specific features (Banerjee and Duflo, 2003; Forbes, 2000; Li and Zou, 1998). Development stages are considered to be covered in ε_t, and each year's dummy variables are included to restrain the time-specific effects (Forbes, 2000; Li and Zou, 1998). The stage of development seems to be correlated with growth and inequality at the same time, causing the spurious correlation problem. Inclusion of year dummies is thought to alleviate this problem. In addition to year dummies, human capital that is accounted for later appears to control for possible sources of spurious correlation since it stands for the stage of development[10]. What is more, to address potential endogenous problems with lagged

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[10] Previous researches include variables used in this research and additionally control for various factors concerning institutional and economic conditions (e.g., Barro, 2000; Banerjee and Duflo, 2003; Forbes, 2000; Hall and Jones, 1999; Keefer and Knack, 2002; Knack, 2003; Knack and Keefer, 1997; Perotti, 1996; Persson and Tabellini, 1994; Zak and Knack, 2001).

Institutional and geographical features can be controlled by the fixed effects independent variables, We carry out dynamic panel estimation as developed by Arellano-bond (Baltagi, 2005) since dynamic panel models allow past realizations of the dependent variable to affect its current level.

Additional key independent variables, regarded as socio-economic ones, are explained in the sections that follow[11]. Combined expectations about efficiency improvement, capital accumulation, and technological progress lead us to predictions about productivity growth since, as explained in the subsection *2.2*, efficiency improvement, capital accumulation, and technological progress can be obtained from the decomposition of productivity growth.

2.4. Gini coefficient and generational heterogeneity

LGINI represents the Gini coefficient of per capita income in logform, *LGINI* is incorporated into the function to capture income inequality effects in the base year *t0.* In conjecture based upon political economy arguments, redistribution of resources from the rich to the poor is more apt to be called for if income is unequally distributed. In this case, income inequality is the cause of a reduction in economic growth since the incentive for workers to work harder and for entrepreneurs to generate innovation is reduced. Consequently, there is a decline in the impetus to obtain more advanced technology than that presently existing, leading to a retardation of efficiency improvement. As well, technology would not be progressed very much if there is a

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estimation. Also, there is little difference among institutions of the prefectures of Japan. This is why that we use only the important variables that are frequently used in the literature.

[11] Besides of socio-economic independent variables, indicators of a natural environment such as day hours, annual precipitation, and quantity of snowfall are added as a control variable.

scarcity of innovation. Another point to be borne in mind is that if there imperfect conditions related to the credit market, investors will have limited access to credit leading to reduced investment and thus capital accumulation will be hampered[12]. Thus, the signs of *LGINI* are predicted to be negative in each of the estimations.

The function includes the log of the index of generational fractionalization represented as *LGHET* with the aim of capturing the effects of the generational heterogeneity[13]. Recently researchers have draw attention to the structure of society from the view point of heterogeneity. It is increasing acknowledged that people are unwilling to contribute to public goods benefiting other ethnic groups. Findings reported, for instance, show that ethnic heterogeneity reduces the incentive for collective action (Alesina and La Ferrara, 2000) so decreasing voluntary tax compliance (Lassen, 2007) and reducing investment, thus hampering economic growth (Easterly and Levine, 1997; Montavo and Reynal-Querol, 2005). From the above an inference that capital accumulation is not promoted, because of social heterogeneity impeding collective action calling for the provision of public goods, can be derived. On the other hand, intuitively worker homogeneity is required for the smooth transmission of knowledge by economizing transaction costs. Social heterogeneity thus hampers knowledge spillover resulting in deteriorating efficiency. Nevertheless, little speculation has, with the exception of Vigdor (2004), taken place concerning the effects

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[12] Besides the discussion as above, polarization such as inequality is thought to reduce the security of property and contractual rights, and through this channel polarization is inversely associated with economic growth.

[13] Following the general index of fragmentation (Alesina and La Ferra, 2002; Alesina et al., 2003), fragmentation can be written as

$$FRA = 1 - \sum_{i=1}^{I} \left(\frac{n_i}{N}\right)^2 ,$$

where n_i is the number of people in the i th group, N is the population, and I is the number of groups in the prefecture.

of generational heterogeneity on economic growth or collective action. On the assumption that generational and ethnic heterogeneity have the same influence upon economic growth, it would be expected that generational heterogeneity impedes efficiency improvement and capital accumulation. This leads us to expect *LGHET* to take the negative sign in the estimation of capital accumulation, efficiency improvement and therefore productivity growth.

2.5. Trust

LTRUS stands for the log of the indicator of trust explained earlier. Social trust, which is one of the elements of social capital, is thought to facilitate coordination and cooperation (Putnam, 2000). That is to say, as presented in Knack and Keefer (1997), a high degree of mutual trust among people is a cause economizing transaction costs. This feature of trust enables technology to diffuse more smoothly and effectively, resulting in efficiency improvement.

With respect to the association of trust and capital accumulation, Zak and Knack (2002) present an economic model said to underlie the positive effect of trust upon investment and present evidence coinciding with the model. In this model, assuming that a principal-agent relationship holds between investors regarded as principals and brokers as agents, the principal is subject to moral hazard by the agent. They show, in this setting, that the amount of investment is higher when trust is higher and therefore cheating by a broker is less likely to take place. Considering this discussion of trust, leads us to a prediction that the signs of *LTRUS* become positive in estimations of efficiency improvement, capital accumulation and thereby productivity growth.

2.6. Human capital

HC is the indicator of human capital. It is generally and widely acknowledged that human capital makes a contribution to economic growth. For this, higher education is likely to promote economic growth through various easily understandable channels. For instance, more educated people make better use of expertise in generating new technology leading to technological progress. They also can get an advantage over less educated ones by learning from others so that information spillover becomes more facile and effectively. As a result, efficiency is improved. Nevertheless, the relationship between capital accumulation and *HC* seems to be equivocal. Taking the above considerations together, *HC* is expected to take a positive sign for efficiency improvement and technological progress.

3. Estimation results

The estimation results of the dynamic panel model with a year dummy for productivity growth, efficiency improvement, capital accumulation, and technological progress are reported in *Tables 2, 3*, *4* and *5,* respectively. Economic inequality is associated with the extent of economic development (Barro, 2000) and therefore seems to be under the influence of economic growth. If this is the case, the coefficients of *GINI* would suffer from an endogeneity bias. Therefore, in columns (2), (4), (6), and (8) in each of the tables, *GINI* is treated as endogenous explanatory variables, and we use the levels for two periods or more as additional instruments (Arellano, 2003). In addition, results when second-order lags of an independent variable is included are reported in columns (3), (4), (7), and (8) in each table. Other socio-economic factors captured by the independent variables, *LGHET, LTRUS* and *LHC,* are treated as exogenous variables in this paper. Peoples' birth year was decided before the current period, leading to generation heterogeneity, *LGHET*, being given. The decision to invest in human capital was also determined before the current period and so the level of human capital, *LHC*, is considered the predetermined exogenous variable. The magnitude of trust, *LTRUS,* is thought to be based on a non-economic background such as culture or history. A non-economic background can be regarded as an unobservable fixed feature and therefore is controlled for by dynamic panel estimations. That is, dynamic panel estimation allows correlations to be made between unobservable fixed features (non-economic background) and *LTRUS.* Estimation results do not suffer from endogenous bias even if the non-economic background is correlated with *LTRUS*[14].

Sargan's over-identification test and second-order serial correlation test are available to check the validity of the estimation results in the dynamic panel model. Above all, a test for the hypothesis that there is no second-order serial correlation for the disturbance of the first-differenced equation is important because the consistency of the estimator relies upon no second-order serial correlation.

Before discussing the results, it is worth noting that because all variables incorporated in the estimation function are in log form, the coefficients can be interpreted as elasticities.

3.1. Productivity growth

[14] Despite these reasons, there seems the possibility that *LGHET, LTRUS* and *LHC* cause endogenous biases. It is, however, beyond the scope of this paper to consider the possibility.

We begin by discussing *Table 2* that shows results concerning the determinants of labor-productivity growth. Barro and Sala-i-Martin (1992), uses Japanese prefecture level data to investigate convergence of incomes using Barro regression. They found that the Japanese economy supports β -convergence of neoclassical theory. In contrast to their results, however, the initial level of output, *LY_1,* yields positive signs at the 1 % level in all estimations. This does not support the convergence hypothesis[15]. This paper controls for unobservable time invariant specific features using a dynamic panel model. In addition, year specific macro shocks are captured by year dummies. Most previous works have not controlled for these factors and so suffer from estimation bias. That is, an omitted variable bias is thought to account for the inconsistencies. That income inequality and generational heterogeneity have a negative influence upon productivity growth is expressed clearly in the third and forth rows since all signs of the coefficients of *LGINI* and *LGHET* are negative and significant at the 1 % level. It is worth noting that the magnitude of *LGHET* is greater than 4, being far larger than those of other variables; suggesting that productivity growth decreases by more than 4 % if generational heterogeneity rises by 1 %. From this, we derive the argument that generational structure plays a more significant role in productivity growth than does income distribution.

The fact that the signs of *LTRUS* are positive despite being statistically

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[15] Barro regression has been widely applied in analyses of the convergence hypothesis. But Quah (1993) criticizes approaches using Barro regression and proposes an analysis using a Markov transition matrix, as an alternative way to test the convergence hypothesis. Kawagoe (1999) uses data for per capita gross prefectural production and adopts this method. He concludes that there is no regional income convergence hypothesis in Japan. Fujita and Tabuchi (1997) also shows that there is no regional income convergence hypothesis in Japan using Theil's measure.

insignificant in some specifications coincided with the anticipation that trust is positively related to productivity growth. We found it evident that human capital represented as *LHC* made a tremendous contribution to productivity growth because *LHC* takes the expected positive and significant signs, and its magnitude is far larger than *LTRUS*.

Even though only columns (4) and (8) pass both Sargan's test and the second-order correlation test, they do not affect the validity of the estimation results since the results are not affected by specifications.

3.2. Efficiency improvement

We now discuss the results of *Table 3*. The significant negative signs of the coefficients on *LGNI,* which persist under different specifications, indicate that economic inequality hampers efficiency improvement, as expected earlier. Corresponding with that anticipation, *LGHET* produces negative signs in all estimations even though no statistical significance is found. The results shown above tell us that socio-economic polarization and fractionalization such as economic inequality and generational heterogeneity cause efficiency improvement to decline. It is noteworthy that *LGHET* is far larger in magnitude than *LGNI*, which coincides with the results shown in *Table 2*. The combined results of *LGNI* and *LGHET* appear in *Tables 2* and *3* lead us to argue that economic inequality and generational heterogeneity have a detrimental effect upon productivity growth, partly though their negative impact upon efficiency.

We see from the fifth row that *LTRUS* yields a positive sign and is statistically significant at the 1 % level in all specifications. This reflects that trust is positively associated with efficiency improvement and therefore endorses the expectation. That is to say, learning from others is an easily facilitated route resulting in efficiency improvement because of the lower transaction cost where people have a tendency to trust each other. The coefficients on *LHC* take the anticipated positive signs and are statistically significant at the 1 % level, which persists in all estimations. The magnitude of *LHC* is from 3 to 7 times larger than that of *LTRUS*. This implies that the individual ability captured by human capital makes a greater contribution to facilitating learning from others and then improves the efficiency than does the closeness of interpersonal relationships captured by trust. In addition, as is later discussed in the following subsections, human capital hardly affects capital accumulation and technological progress. We found it interesting that the predominant positive effect of human capital on productivity growth is not from its effect on capital accumulation and technological progress, but from its effect on efficiency improvement. During the high growth post-war period, Japan was thought to be an example of a newly industrializing economy on track to catch up with the advanced economies by borrowing technology (Hayami, 2001). According to the evidence provided above, this catch-up mechanism seemed to persist even long after Japan became a developed country in that less developed prefectures learnt from developed ones, thereby improving efficiency. What is more, a high degree of human capital has promoted this catch up mechanism among prefectures during Japan's modern period.

3.3. Capital accumulation

Looking at the results presented in *Table 5* reveals that income inequality reduces capital accumulation, which is consistent with the expectation since the coefficients on *LGINI* are consistently negative. In contrast to this, generational heterogeneity produces positive signs, despite being statistically insignificant, which does not correspondent to the prediction. One plausible explanation is as follows. The larger the size of a generation, the larger the number of rivals within it. People are more likely to become rivals in various situations if they belong to the same generation, resulting in a hampering of collective action. Therefore, generational heterogeneity is less likely to impede collective action (Yamamura, 2008) and so capital accumulation does not decline.

The significantly positive signs of *LTRUS* in most of the estimations tells us that higher trust is apt to stimulate investment and therefore increase capital. The expectation about the effects of trust on capital accumulation is borne out in the results of the estimations, which coincide with the findings of Zak and Knack (2001).

LHC yields negative signs despite statistical insignificance in all estimations. Taking the results of the efficiency improvement estimations together, this can be interpreted as that higher human capital allocates more resources to enhance technological catch-up instead of capital accumulation, presumably because returns from physical capital are lower than those from technological catch-up in a developed country such as Japan. This presumption seems to be in line with the evidence provided by Yamamura and Shin (2008) that technological catch-up is three times as effective as capital accumulation, but that both have worked to cause economic convergence among Japanese prefectures.

Overall, the estimation results as discussed above are valid not only because they are robust to the choice of specifications, but also because they pass the second order correlation test in columns (3), (4), (7), and (8), even though no estimation results pass Sargan's tests.

3.4. Technological progress

Table 5 shows the results of technology improvement. The signs of *LGINI* and *LGHET* are not stable and are statistically insignificant. Contrary to the expectation, the coefficients of *LH* produce negative signs. Furthermore, none of the results of the estimations pass Sargan's and second-serial correlation tests. Taking this together, the factors included in the function hardly affect technology progress. Therefore, those factors have effects on the labor-productivity growth not through technological progress but through efficiency improvement and capital accumulation.

We have so far examined the determinants of productivity growth, efficiency improvement, capital accumulation and technological progress. The combined results presented above make the following evident. Inequality impedes not only efficiency improvement but also capital accumulation. The degree of trust simultaneously promotes efficiency improvement and capital accumulation. On the other hand, results that do not coincide with the anticipation raised earlier and the estimations results do not pass any tests that check their validity when technology progress is examined. This is why findings are not presented regarding technological progress. Overall, the results of productivity growth and efficiency improvement, to a large extent, share similarities regarding the effects of income inequality, trust, and human capital. It follows from this that productivity growth is in the large part attributable to efficiency improvement although capital accumulation has some important effects upon productivity growth.

4. Conclusion

In response to an upsurge in interest in ethnic heterogeneity, social capital, and general trust from a interdisciplinary point of view, increasing research has recently been devoted to accounting for how socio-economic factors affect economic growth. It thus seems to be open to question whether the influences of socio-economic factors on capital accumulation and diffusion of technology are different. There have been, however, few attempts to examine the channels through which socio-economic factors have an effect upon productivity growth. Accordingly, this paper, rather than putting an emphasis on just productivity growth, decomposes it into some components and then carefully investigates them. To this end, using panel data from Japan, which is characterized by a homogenous society, this paper employs the DEA method and a dynamic panel model.

Key findings derived from empirical estimations that are invariant to alternative specifications are as follows.

(1) Inequality impedes not only efficiency improvement but also capital accumulation. Furthermore, the magnitude of the elasticity of efficiency improvement with respect to inequality, which is -0.06, is about three times larger than that of capital accumulation.

(2) The degree of trust promotes efficiency improvement and capital accumulation at the same time. On the other hand, human capital only enhances

efficiency improvement. The elasticity of efficiency improvement with respect to human capital is about 0.64, which is eight times larger than that with respect to trust. This means that human capital has a larger impact on technological catch-up, although both trust and human capital make contributions.

Based upon the findings indicated above, it can be plausibly pointed out that the effect of trust on productivity growth through diffusion of technology is larger than through the increase in investment, although both diffusion of technology and capital accumulation are attributable to a high degree of trust. Furthermore, the impact of human capital on productivity growth arises not from enhancing investment and technological progress but from promoting diffusion of technology. Contrarily, economic polarization such as inequality hampers investment and diffusion of technology.

It seems appropriate that socio-economic factors such as generation heterogeneity, human capital, and trust cause endogenous biases. However, this paper does not consider this problem. It should be noted that the present paper is limited to an empirical analysis of Japan in which institutional conditions such as the legal system do not vary and therefore cannot be considered as institutional factors. These are the major issues remaining to be addressed in our future study.

Appendix: Data Envelopment Analysis and Tripartite Decomposition

DEA is a nonparametric method to construct a production frontier and associated productive efficiency indexes for a whole data set. The approach for obtaining the production function is to envelop all scattered data on the dimension of input and output factors in a convex cone. Then, the upper boundary of this set represents the production frontier as the best practice. This method has advantages over other methods as it requires no specification of functional forms, except that it needs to assume returns to scale of technology. In this case, we assume constant-returns-to-scale (CRS) technology with three variables: capital stock (K) and labor (L) as aggregate inputs and output (Y) as the aggregate output. We can now express the production function in two dimensions by modifying a linear homogeneous production process where output per labor $(y = Y/L)$ can be produced by capital per labor $(k = K/L)$. Then (k_t^i, y_t^i), $t = 1,\ldots,T$, $i = 1,\ldots,I$, represents observations on these two variables of i prefecture for time t.

The concept of the DEA method is briefly described in Figure A1 without a specific mathematical explanation. In this $\langle k, y\rangle$ space of scalar input and output, there are 12 scattered points of (k_t^i, y_t^i) that represent observations in a given period for a certain hypothetical economy. The best-practice production frontier under CRS technology can be constituted by enveloping the upper boundary of these observations corresponding with each level of inputs (4 points in this case) including the origin to make a convex cone. Therefore, it represents the maximum feasible outputs given each level of input. Let $\bar{y}_t(k_t)$ denote the maximum output that we can produce with capital stock k_t in period t.

We utilize the output-based efficiency index to measure the distance between the observed output level and the level on the frontier for a given input level. Such an index for i prefectures at time t is defined by

$$e(k_t^i, y_t^i) = \min\{\theta \mid (k_t^i, y_t^i/\theta) \in S_t\} \tag{A1}$$

where S_t indicates the CRS production set. For example, the output-based efficiency level of one observation $e(k_t, y_t)$ at point A in Figure A1 is the ratio of the actual output y_t to the production frontier level $\bar{y}_t(k_t)$, that is, $e(k_t, y_t) = y_t / \bar{y}_t(k_t)$=a/b. Output-based efficiency is always less than or equal to 1, which indicates the relative efficiency for the best practice of observations at a given period. It has the advantage of measuring productivity shortfall and catch-up relative to the best-practice frontier.

Figure A1. Data Envelopment Analysis Method

We now explain the tripartite decomposition method. If each of the production frontiers is constructed for any two years, we can then decompose productivity growth between two periods into three components. The tripartite decomposition method is conceptually described between two period technologies in Figure A2. We consider the two periods as the base period t and in the current period $t+1$. y_t and k_t represent output and capital stock per capita, respectively, in period t. Thus, the ratio of actual outputs between two years can be arranged as,

$$\frac{y_{t+1}}{y_t} = \frac{e_{t+1} \times \bar{y}_{t+1}(k_{t+1})}{e_t \times \bar{y}_t(k_t)}. \tag{A2}$$

There are two ways to modify this ratio. One way is to multiply the top and bottom by $\bar{y}_t(k_{t+1})$, the potential output at current capital stock under the base year technology, in the equation (A3). The other way is to multiply by $\bar{y}_{t+1}(k_t)$, the potential output at base capital stock under the current year technology, in the equation (A4).

$$\frac{y_{t+1}}{y_t} = \frac{e_{t+1}}{e_t} \times \frac{\bar{y}_{t+1}(k_{t+1})}{\bar{y}_t(k_{t+1})} \times \frac{\bar{y}_t(k_{t+1})}{\bar{y}_t(k_t)} \tag{A3}$$

$$\frac{y_{t+1}}{y_t} = \frac{e_{t+1}}{e_t} \times \frac{\bar{y}_{t+1}(k_t)}{\bar{y}_t(k_t)} \times \frac{\bar{y}_{t+1}(k_{t+1})}{\bar{y}_{t+1}(k_t)} \tag{A4}$$

To adjust the differences of (A3) and (A4), we take the geometric average of both decompositions as follows.

$$\frac{y_{t+1}}{y_t} = \frac{e_{t+1}}{e_t} \times \left(\frac{\bar{y}_{t+1}(k_{t+1})}{\bar{y}_t(k_{t+1})} \times \frac{\bar{y}_{t+1}(k_t)}{\bar{y}_t(k_t)} \right)^{\frac{1}{2}} \times \left(\frac{\bar{y}_t(k_{t+1})}{\bar{y}_t(k_t)} \times \frac{\bar{y}_{t+1}(k_{t+1})}{\bar{y}_{t+1}(k_t)} \right)^{\frac{1}{2}} = \mathrm{E} \times \mathrm{T} \times \mathrm{K} \tag{A5}$$

where E stands for the contribution of the efficiency changes, T is the contribution of the technological changes and K is the contribution of the capital accumulation between two periods. Output changes for the two periods can be decomposed by efficiency, technological and capital accumulation changes. An efficiency change is the change in the distance from the frontier. The technological change is the shift in the frontier. The capital accumulation change is the movement along the frontier.

Figure A2. Illustration of Tripartite Decomposition

We diagrammatically explain decomposition identity (A5) in Figure A2. Points B and G represent feasible input-output combinations in period t and $t+1$, respectively. Multiplying the top and bottom by $\bar{y}_t(k_{t+1})$ or $\bar{y}_{t+1}(k_t)$, we obtain

$$\frac{\mathrm{EG}}{\mathrm{AB}} = \frac{\mathrm{EG/EH}}{\mathrm{AB/AC}} \times \frac{\mathrm{EH}}{\mathrm{EF}} \times \frac{\mathrm{EF}}{\mathrm{AC}} \tag{A6}$$

or

$$\frac{\mathrm{EG}}{\mathrm{AB}} = \frac{\mathrm{EG/EH}}{\mathrm{AB/AC}} \times \frac{\mathrm{AD}}{\mathrm{AC}} \times \frac{\mathrm{EH}}{\mathrm{AD}}, \tag{A7}$$

respectively. The geometric average of (A4) and (A5) is

$$\frac{\mathrm{EG}}{\mathrm{AB}} \approx \frac{\mathrm{EG/EH}}{\mathrm{AB/AC}} \times \left(\frac{\mathrm{EH}}{\mathrm{EF}} \times \frac{\mathrm{AD}}{\mathrm{AC}} \right)^{\frac{1}{2}} \times \left(\frac{\mathrm{EF}}{\mathrm{AC}} \times \frac{\mathrm{EH}}{\mathrm{AD}} \right)^{\frac{1}{2}}. \tag{A8}$$

Let $E \equiv \frac{EG/EH}{AB/AC}$, $T \equiv \left(\frac{EH}{EF} \times \frac{AD}{AC}\right)^{\frac{1}{2}}$ and $K \equiv \left(\frac{EF}{AC} \times \frac{EH}{AD}\right)^{\frac{1}{2}}$, then (A8) is equal to (A5).

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Table 1

Descriptive statistics

Variables	Definition	Mean	Coefficient of variation
LY	Output per worker in log form	1.183	0.552
LE	Level of efficiency in log form	-0.241	-0.560
LK	Level of capital in log form	1.285	0.789
LT	Level of technology in log form	1.424	0.450
LGINI	Gini coefficients in log form	-1.275	-0.044
LGHET	Generation heterogeneity in log form	-0.067	-0.052
LTRUS	Magnitude of trust in log form	-0.752	-0.129
LHC	Human capital index in log form	-0.002	-22.423
LDAY	Day hours in log form	7.585	0.016
LRAIN	Annual precipitation in log form	7.315	0.045
LSNOW	Quantity of snowfall in log form	3.083	0.328

Table 2
Determinants of productivity growth (Dynamic Panel Model)

	(1)L Y	(2)L Y	(3) LY	(4) LY	(5) LY	(6) LY	(7) LY	(8) LY
LY_1	0.71**	0.71**	0.74**	0.71**	0.72**	0.73**	0.75**	0.75**
	(26.1)	(26.8)	(19.3)	(26.8)	(27.27)	(28.1)	(19.6)	(19.9)
LY_2			-0.04	-0.03			-0.03	-0.02
			(-1.10)	(-0.96)			(-0.94)	(-0.78)
LGINI	-0.09**	-0.07**	-0.08**	-0.07**	-0.08**	-0.07**	-0.08**	-0.07**
	(-3.00)	(-2.67)	(-2.92)	(-2.67)	(-2.90)	(-2.52)	(-2.83)	(-2.46)
LGHET	-4.13*	-4.55**	-4.28*	-4.55**				
	(-2.27)	(-2.52)	(-2.32)	(-2.52)				
LTRUS	0.05*	0.03	0.05*	0.03	0.11*	0.08	0.11*	0.08
	(1.94)	(1.47)	(1.96)	(1.47)	(1.89)	(1.44)	(1.90)	(1.45)
LHC	0.64**	0.56**	0.65**	0.56**	0.76**	0.69**	0.77**	0.70**
	(3.39)	(3.05)	(3.40)	(3.05)	(4.18)	(3.91)	(4.19)	(3.92)
LDAY	-0.04**	-0.05**	-0.04**	-0.05**	-0.04**	-0.05**	-0.04**	-0.05**
	(-2.55)	(-3.33)	(-2.43)	(-3.33)	(-2.49)	(-3.27)	(-2.39)	(-3.17)
LRAIN	0.002	0.002	0.002	0.002	0.001	0.001	0.002	0.002
	(0.54)	(0.56)	(0.56)	(0.56)	(0.40)	(0.40)	(0.42)	(0.42)
LSNOW	-0.001	-0.001	-0.001	-0.001	-0.002	-0.002	-0.002	-0.002
	(-0.73)	(-0.67)	(-0.62)	(-0.67)	(-1.02)	(-1.01)	(-0.93)	(-0.93)
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sargan-test (P-value)	0.00	0.11	0.00	0.20	0.00	0.13	0.00	0.21
Serial correlation								
First order (P-value)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Second order (P-value)	0.07	0.09	0.14	0.15	0.08	0.10	0.14	0.14
Sample	719	719	719	719	719	719	719	719
Groups	46	46	46	46	46	46	46	46

Notes: Numbers in parentheses are t-statistics. * and ** indicate significance at 5 and 1 per cent levels, respectively (one-sided tests). In each of the estimates, year dummies are included but not reported to save space.

Table 3
Determinants of efficiency improvement (Dynamic Panel Model)

	(1)L E	(2)L E	(3) LE	(4) LE	(5) LE	(6) LE	(7) LE	(8) LE
LE_1	0.80**	0.80**	0.85**	0.85**	0.80**	0.80**	0.85**	0.85**
	(34.4)	(35.4)	(22.6)	(22.9)	(34.4)	(35.4)	(22.6)	(23.2)
LE_2			-0.06*	-0.06*			-0.06*	-0.06*
			(-1.66)	(-1.86)			(-1.68)	(-1.89)
LGINI	-0.06*	-0.06*	-0.05*	-0.05*	-0.06*	-0.06*	-0.05*	-0.05*
	(-2.01)	(-1.96)	(-1.76)	(-1.71)	(-2.04)	(-2.00)	(-1.79)	(-1.74)
LGHET	-0.87	-1.46	-0.77	-1.34				
	(-0.48)	(-0.81)	(-0.42)	(-0.73)				
LTRUS	0.07**	0.08**	0.08**	0.08**	0.16**	0.16**	0.17**	0.18**
	(2.57)	(2.76)	(2.68)	(2.85)	(2.42)	(2.58)	(2.54)	(2.69)
LHC	0.52**	0.60**	0.56**	0.64**	0.53**	0.64**	0.57**	0.67**
	(2.46)	(3.01)	(2.57)	(3.09)	(2.69)	(3.39)	(2.79)	(3.45)
LDAY	-0.01	-0.02*	-0.01	-0.02	-0.01	-0.02*	-0.01	-0.02
	(-1.04)	(-1.67)	(-0.87)	(-1.43)	(-1.04)	(-1.70)	(-0.86)	(-1.45)
LRAIN	0.005	0.004	0.005	0.004	0.005	0.003	0.005	0.004
	(1.04)	(0.82)	(1.07)	(0.86)	(1.02)	(0.77)	(1.06)	(0.82)
LSNOW	-0.003	-0.002	-0.002	-0.002	-0.003	-0.002	-0.002	-0.002
	(-1.16)	(-1.02)	(-1.06)	(-0.93)	(-1.22)	(-1.12)	(-1.11)	(-1.01)
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sargan-test (P-value)	0.00	0.11	0.01	0.40	0.00	0.10	0.01	0.39
Serial correlation								
First order (P-value)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Second order (P-value)	0.07	0.08	0.21	0.26	0.08	0.09	0.22	0.27
Sample	719	719	719	719	719	719	719	719
Groups	46	46	46	46	46	46	46	46

Notes: Numbers in parentheses are t-statistics. * and ** indicate significance at 5 and 1 per cent levels, respectively (one-sided tests). In each of the estimates, year dummies are included but not reported to save space.

Table 4
Determinants of capital deepening (Dynamic Panel Model)

	(1)L K	(2)L K	(3) LK	(4) LK	(5) LK	(6) LK	(7) LK	(8) LK
LK_1	0.93**	0.93**	1.12**	1.11**	0.93**	0.93**	1.12**	1.11**
	(90.1)	(91.3)	(26.4)	(26.9)	(96.5)	(97.6)	(26.4)	(26.9)
LK_2			-0.18**	-0.18**			-0.18**	-0.18**
			(-4.63)	(-4.63)			(-4.64)	(-4.65)
LGINI	-0.02*	-0.02*	-0.02*	-0.02	-0.02*	-0.02	-0.02	-0.02
	(-1.88)	(-1.66)	(-1.66)	(-1.44)	(-1.82)	(-1.62)	(-1.61)	(-1.39)
LGHET	0.41	0.61	0.10	0.27				
	(0.43)	(0.81)	(0.10)	(0.27)				
LTRUS	0.03**	0.02*	0.02*	0.02	0.07**	0.06*	0.06*	0.04
	(2.35)	(1.96)	(1.78)	(1.49)	(2.52)	(2.12)	(1.90)	(1.60)
LHC	-0.09	-0.07	-0.08	-0.06	-0.10	-0.09	-0.08	-0.07
	(-1.02)	(-0.92)	(-0.84)	(-0.74)	(-1.29)	(-1.24)	(-0.97)	(-0.90)
LDAY	0.001	0.0002	-0.004	-0.005	0.001	-0.0001	-0.004	-0.005
	(0.11)	(0.00)	(-0.47)	(-0.59)	(0.12)	(-0.01)	(-0.46)	(-0.60)
LRAIN	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	(0.50)	(0.62)	(0.63)	(0.72)	(0.53)	(0.65)	(0.64)	(0.74)
LSNOW	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
	(-1.11)	(-1.28)	(-0.65)	(-0.81)	(-1.09)	(-1.23)	(-0.65)	(-0.80)
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sargan-test (P-value)	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
Serial correlation								
First order (P-value)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Second order (P-value)	0.14	0.15	0.95	0.96	0.15	0.15	0.95	0.96
Sample	719	719	719	719	719	719	719	719
Groups	46	46	46	46	46	46	46	46

Notes: Numbers in parentheses are t-statistics. * and ** indicate significance at 5 and 1 per cent levels, respectively (one-sided tests). In each of the estimates, year dummies are include, but not reported to save space.

Table 5
Determinants of technological progress (Dynamic Panel Model)

	(1)L T	(2)L T	(3) LT	(4) LT	(5) LT	(6) LT	(7) LT	(8) LT
LT_1	0.88**	0.89**	1.14**	1.15**	0.88**	0.89**	1.14**	1.15**
	(63.3)	(65.7)	(29.5)	(29.8)	(64.9)	(66.8)	(29.6)	(29.9)
LT_2			-0.27**	-0.27**			-0.27**	-0.27**
			(7.29)	(7.31)			(7.28)	(7.31)
LGINI	0.01	0.01	-0.003	-0.005	0.008	0.005	-0.003	-0.005
	(0.50)	(0.33)	(-0.19)	(-0.29)	(0.51)	(0.35)	(-0.19)	(-0.29)
LGHET	-0.27	0.21	-0.59	-0.11				
	(-0.26)	(0.21)	(-0.51)	(-0.10)				
LTRUS	-0.02	-0.02	-0.03*	-0.02	-0.04	-0.03	-0.06	-0.05
	(-1.42)	(-1.24)	(-1.81)	(-1.60)	(-1.17)	(-1.04)	(-1.64)	(-1.46)
LHC	-0.21*	-0.16	-0.24*	-0.18	-0.19*	-0.16*	-0.20*	-0.17
	(-1.93)	(-1.50)	(-1.94)	(-1.52)	(-1.94)	(-1.70)	(-1.86)	(-1.60)
LDAY	-0.005	-0.005	-0.007	-0.007	-0.005	-0.005	-0.007	-0.007
	(-0.63)	(-0.64)	(-0.71)	(-0.72)	(-0.61)	(-0.63)	(-0.69)	(-0.72)
LRAIN	0.001	0.002	0.001	0.002	0.001	0.002	0.001	0.002
	(0.58)	(0.85)	(0.54)	(0.77)	(0.58)	(0.86)	(0.53)	(0.76)
LSNOW	-0.003	-0.004	0.0003	0.0002	-0.004	-0.004	0.0002	0.0002
	(-0.23)	(-0.31)	(0.21)	(0.16)	(-0.30)	(-0.30)	(0.13)	(0.14)
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sargan-test (P-value)	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
Serial correlation								
First order (P-value)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Second order (P-value)	0.01	0.01	0.00	0.00	0.01	0.01	0.00	0.00
Sample	719	719	719	719	719	719	719	719
Groups	46	46	46	46	46	46	46	46

Notes: Numbers in parentheses are t-statistics. * and ** indicate significance at 5 and 1 per cent levels, respectively (one-sided tests). In each of the estimates, year dummies are included but not reported to save space

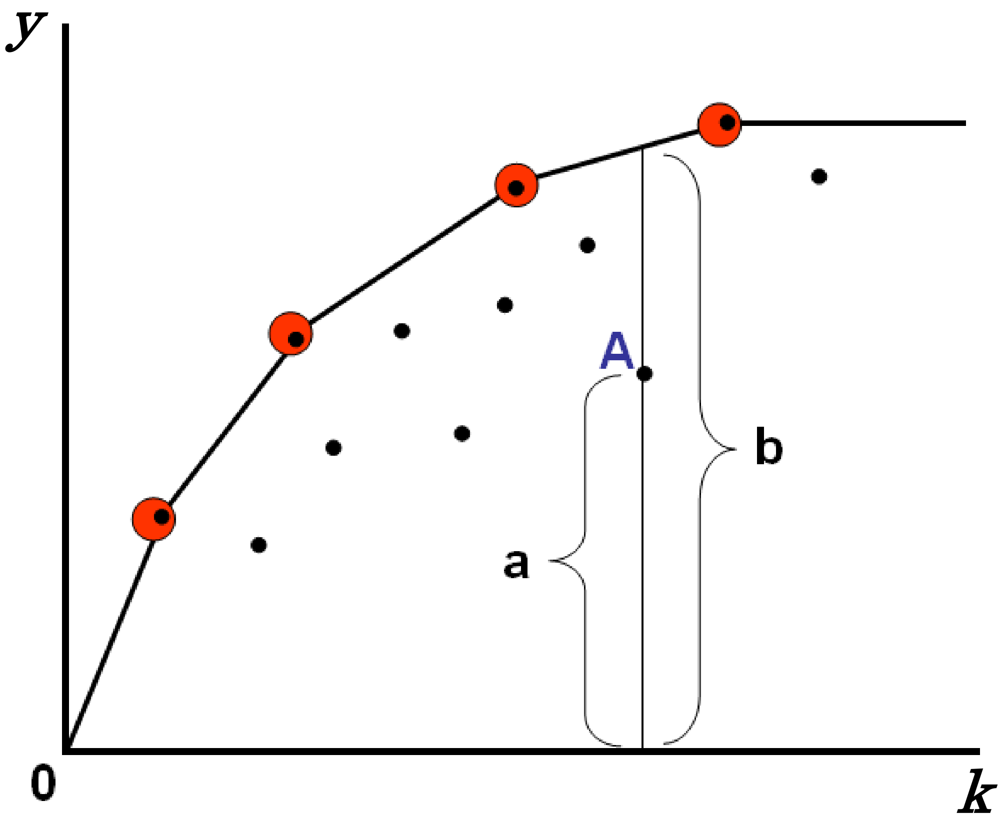

Figure A1. Data Envelopment Analysis Method

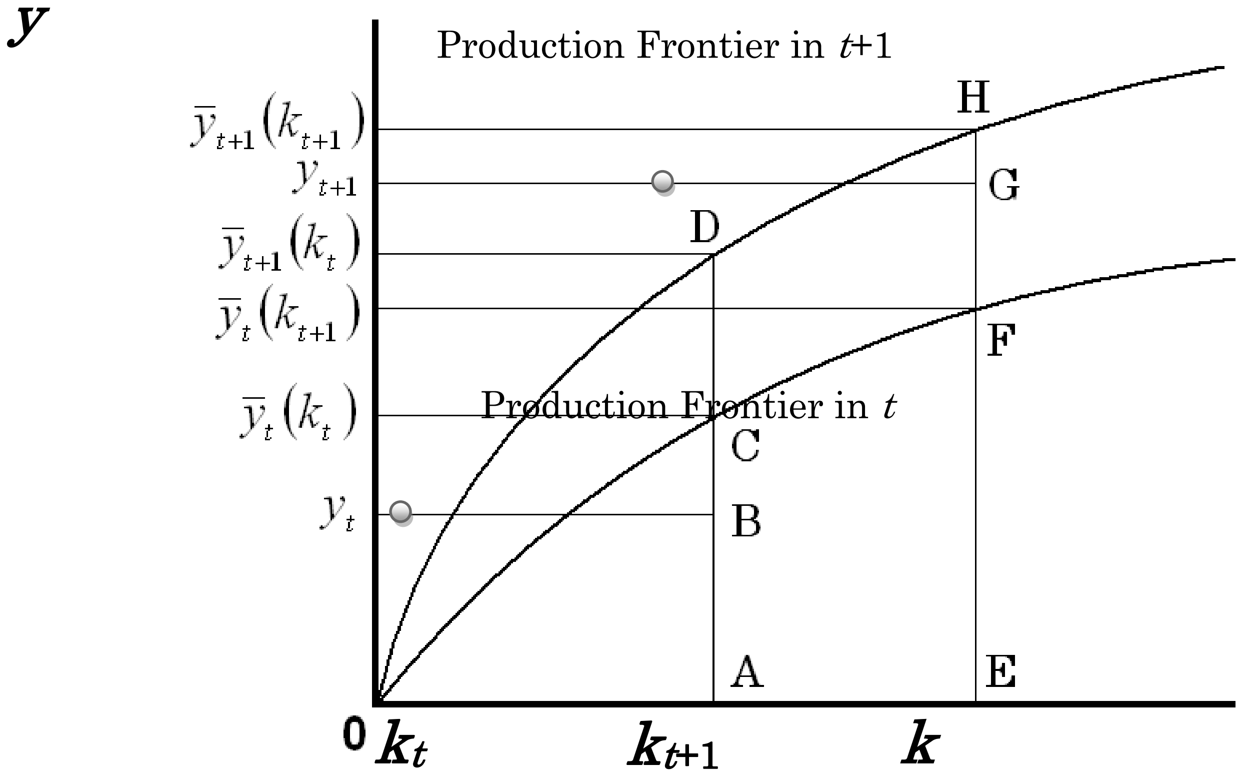

Figure A2. Illustration of Tripartite Decomposition