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Measuring energy intensity in Japan: A new method

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A R T I C L E I N F O

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A B S T R A C T

Energy intensity and energy conservation have been important pillars of energy policies in Japan. Recently, the government has introduced new initiatives to enhance energy efficiency and reduce energy intensity. We analyze the energy intensity in Japan for the period 1973–2006 by proposing a new method which takes into account all other inputs used in production and corrects for the bias in the traditional energy intensity measure. We show that the traditional energy intensity measure has serious flaws. The traditional measure overestimates actual energy intensity before the mid-1980s and largely underestimates afterwards. It is found that aggregate energy intensity has risen remarkably from 1991 to 2001. The main cause of this rise is the rapid rise in energy intensity in manufacturing and energy sectors.

1. Introduction

Japan has been praised for her success in enhancing energy efficiency during the last three decades. Conventionally measured energy efficiency, real GDP divided by total energy consumption, has declined by about 30% over three decades while slowing down since the early 1990s (OECD & International Energy Agency, 2012, p. 75). In international comparisons, Japan earned the status of the most energy-efficient economy (OECD & International Energy Agency, 2008, p. 53).

Most studies in the energy intensity and energy policy literature have praised Japanese energy policies, energy conservation and efficiency policies in particular, for the decline in energy intensity during the last three decades when compared with other OECD countries (e.g., Fukasaku, 1995; Geller, Harrington, Rosenfeld, Tanishima, & Unander, 2006; Zhao et al., 2014). Among the earlier studies, Schipper and Meyers (1992, p. 96) showed that those Japanese industries with high energy-intensity (ferrous metals, paper and pulp, building materials, chemicals, and non-ferrous metals) have exhibited significant reduction in energy intensities from the mid-1970s to the late 1980s. They also argued that Japan stood out as the most successful of the major advanced economies. Other studies comparing Japan and the US (e.g., McDonald, 1990; Nagata, 1993) pointed out similar trends in declining energy intensities in Japanese industries. However, energy intensity increased a little during the 1990s. It is generally argued that this was due to low oil prices in the 1990s which discouraged costly energy conservation technologies (Smil, 2007). Okajima and Okajima (2013), on the other hand, argued that the structural changes in energy consumption in the industrial and commercial sectors starting from the early 1990s was the primary cause of the increase in overall energy efficiency.

Energy intensity is an important measure whose changes are followed very seriously by policy-makers in Japan. The government emphasizes the importance of enhancing energy efficiency and reducing energy intensity at the industry and enterprise levels. Therefore, it is important to calculate energy intensity accurately. To evaluate the success of the energy conservation policies, economists generally look at the conventional energy consumption to GDP ratio, or energy intensity. The inverse of this ratio implies energy efficiency. The government in Japan has reported energy intensity over the years and developed targets to reduce this ratio. The usefulness of this ratio comes from its simplicity and easiness in interpretation. However, researchers soon realized that this ratio is far from revealing the progress in real energy efficiency, since it is a composite indicator which also embodies improvements that may have been occurring due to structural effects, where the relative contribution of less energy-intensive sectors (such as services) to GDP increase over time.

Motivated by the prospect of measuring real efficiency improvements, the energy economics literature witnessed an influx of studies that decompose changes in aggregate energy intensity into structural and sectoral intensity effects. The methodological approach adopted in most of these studies was either an Index Decomposition Approach (IDA) or Structural Decomposition Approach (SDA). The idea behind the IDA is akin to decomposing a value change index to price and quantity change

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indices[1], while SDA relies on input–output analysis with more demanding data requirements.

In a comprehensive review of IDA, Ang (1995) surveys 51 studies published between 1987 and 1994 and Ang and Zhang (2000) survey an additional 124 studies conducted between 1995 and 1999, to conclude that the main drive behind the declining aggregate intensities is the declining sectoral intensity effect. Some more recent works (see for example, Huntington, 2010; Mulder & de Groot, 2012) however, provided contrary evidence showing that the main drive behind declining aggregate energy intensity is the structural change. Finally, Ang, Mu, and Zhou (2010) recommend common adoption of the Logaritmic Mean Divisia Index (LMDI) with its desirable properties, after comparing accounting frameworks used for tracking energy efficiency trends.

As for the SDA, Rose and Casler (1996) in their review of earlier studies, compare IDA and SDA to offer a critical perspective. Hoekstra and van den Bergh (2003), conducting a more comprehensive comparison of two methods, show how IDA and SDA can be translated to one other. They also suggest a more careful assessment of the axiomatic properties of the indices generated. In a more recent study, Su and Ang (2012) provide a review of latest methodological developments along with 43 applied studies conducted between 1999 and 2010.

More recently, researchers inspired by the decomposition of Malmquist productivity index first proposed by Färe, Grosskopf, Norris, and Zhang (1994), have also adopted production-theoretical approach to decompose energy intensity changes over time into their subcomponents. These studies can be viewed as the extensions of Kumar and Russell (2002) and Zhou and Ang (2008) who respectively decomposed labor productivity and aggregate CO_2 emissions into their subcomponents. Realizing the need for multilateral comparisons of energy intensity levels across different energy consuming entities, Zhou and Ang (2008) resort to data envelopment analysis techniques (DEA) to compare average energy utilization performance of the OECD countries. The DEA approach, which accounts for possible substitution effects among capital, labor and energy inputs as well as for the possible substitution effect among different energy inputs also allows for inclusion of the undesirable outputs as a by-product of desirable outputs. After comparing different contraction methods (radial versus non-radial) and existence of slacks (slack-based versus non-slack-based), they conclude that the slack-based DEA model has a higher discriminatory power. Their results indicate that nine countries (Australia, France, Ireland, Italy, Norway, Portugal, Sweden, Switzerland, and USA) are perfectly energy-efficient among the OECD countries and that remaining inefficient countries had a potential to reduce energy consumption by 86 quadrillion Btu over a five-year period 1997–2001. In a more recent study using Shephard output distance functions, Wang (2013) decomposes energy intensity changes overtime into five components: change in technical efficiency; technological progress; change in capital energy ratio; change in labor energy ratio and changes in output structure.

Although these studies immensely contributed to our knowledge base on the evolution of energy efficiency trends *over time*, there are some considerable challenges in performing informative and fair comparisons between the energy *efficiency levels* of units considered. Even cross-country studies conducted by Mulder and de Groot (2012), and Voigt, de Cian, Schymura, and Verdolini (2014) were limited to the comparison of efficiency trends over time as the authors proceed first by decomposing energy intensity trends within individual countries, and only then do comparisons across countries. The only exceptions are the work of Duro, Alcantara, and Padilla (2010) and Zhou and Ang (2008) where the authors analyze the inequality of energy intensity among OECD countries.

Furthermore, regarding the IDA and SDA approaches, even after accounting for the effect of structural change, the resultant measure of energy intensity is still the inverse of a partial factor productivity measure (PFP) i.e., energy productivity, that does not take into consideration compositional differences between inputs of the units being compared (which are also subject to change over time) and that ignore the type of substitution among inputs and hence, make it a measure that disguises rather than illuminates. Hence, the objective of this paper is to address the issues above by constructing an alternative multi-factor input intensity index (an inverse of Multi-factor Productivity Index (MFP)) that accommodates level comparisons as well as over-time multilateral comparisons and to show that special cases of this measure not only generates the traditional single input intensity measure (i.e., aggregate energy intensity as the inverse of PFP measure), but also leads to an energy intensity index that overcomes the shortcomings of the traditional measure. Unlike our predecessors, our productivity measure (or energy intensity measure) overcomes the shortcomings of the partial productivity measure by not only controlling for the compositional differences in outputs (both across the units being observed and over-time) but also by accounting for the compositional differences in inputs (both across the units being observed and over-time). Hence, this study can be viewed as the extension of the production-theoretical approaches, where DEA techniques are used to develop Malmquist quantity indices, a novel approach first introduced into the measurement of factor intensities (factor productivities). Furthermore, provision of an alternative decomposition approach is yet another novelty of the study.

All our measures will rely on computation of directional distance functions, first introduced by Chambers, Chung, and Färe (1996), which provide a valuable framework in modeling a technology with multiple outputs and inputs. Directional distance functions have recently been used utilized by researchers to analyze various issues (e.g., Cheng & Zervopoulos, 2014; Fukuyama & Weber, 2005; Halkos & Tzeremes, 2013). An empirical application on the energy intensity of Japanese manufacturing sectors, further complements existing studies.

The rest of the paper proceeds as follows. In Section 2, we discuss energy efficiency and energy conservation policies and strategies in Japan since the 1970s. We review the literature on energy efficiency and energy intensity in Japan in Section 2. In Section 3, we discuss in detail the method of analysis. The data used in the analysis are explained in Section 4. The results and policy implications of the results are presented in Section 5. Finally, Section 6 concludes the paper.

2. Energy efficiency and energy intensity in Japan

2.1. Energy efficiency policies in Japan

Energy conservation and enhancing energy efficiency have been major policy priorities in Japan since the early 1970s. Two oil crises in the 1970s revealed high energy dependency of Japanese industries. As a response, to boost research and development in energy-saving technologies especially in manufacturing, the government passed the *Law Concerning the Rational Use of Energy* in 1979. The law introduced obligations for firms in various economic activities as well as for residential consumers to reduce energy consumption and improve efficiency in energy use. The law was amended due to regulatory needs in 1983, 1993, 1999, 2003, 2005, and 2009.

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[1] Denoting energy intensity, energy consumption, and output as EI, E, and Y, respectively, EI can be decomposed as follows: $EI = \frac{E}{Y} = \sum_i \frac{E_i}{Y_i} \cdot \frac{Y_i}{Y}$, where i denotes individual sectors. Technological improvement or the efficiency component is captured by the first term, which implies pure sectoral level of energy intensity, and the structural change component is captured by the second term, which implies structural changes in the sectoral shares in output.

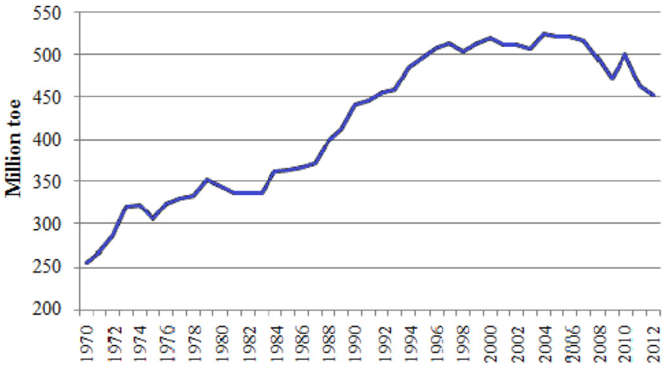

Fig. 1. Japan's total energy use (1970–2012).
Source: World Bank World Development Indicators Database.

In the 1993 revision, the law obligated large enterprises to designate energy conservation managers and submit reports about energy conservation. In the 1999 amendment, the government introduced the *Top Runner Program* whereby energy efficiency standards are set for specific products which account for a large share of energy consumption (e.g., air conditioner, computer, automobile, TV, etc.). The set of products was expanded over the years.

The government formulated the *Basic Energy Plan* in 2003, which was revised in 2007 and 2010, to specify energy supply and demand policies. In 2007 revision, the government introduced a target to improve energy efficiency by 30% by 2030 (OECD & International Energy Agency, 2008, p. 59). Concurrently in 2006, the government launched the *New National Energy Strategy* with the same target (Energy Conservation Center Japan, 2011, p. 6). To achieve energy efficiency targets, the new strategy launched the *Energy Conservation Frontrunner Plan*. In addition, the government introduced various support schemes in the *Energy Conservation Technology Strategy* in 2007 to promote the development of energy conservation technologies (Energy Conservation Center Japan, 2011, p. 7).

In 2010, the Ministry of Economy, Trade and Industry (METI) launched the revised version of the *Basic Energy Plan* (Ministry of Economy, Trade & Industry, 2010). Along with doubling the energy self-sufficiency ratio and the energy independence ratio by 2030, the plan also targeted "maintaining and enhancing energy efficiency in the industrial sector at the highest level in the world" by introducing innovative technologies. A turning point in energy policies was the Great East Japan Earthquake and the subsequent nuclear power plant disaster in 2011. The disaster triggered a national campaign to save energy due to the substantial decline in electricity generation after the earthquake. In addition, new measures to enhance nuclear safety were introduced.

2.2. Review of the studies on energy intensity and energy efficiency in Japan

Fig. 1 reveals that total energy consumption in Japan has increased from about 250 million tons of oil equivalent (toe) in 1970 to 500 million toe in the mid-1990s. The increase was especially remarkable during the second half of the 1980s, at a time when the Japanese economy was experiencing a boom. Since the mid-1990s, the rise in energy consumption has halted and has been on a declining trend since 2006.[2] In 2012, Japan successfully reduced its total energy consumption below the 1992 level.

Conventionally measured energy intensity, energy consumption divided by real output, has declined over the years as well. Energy intensity can be measured using data from the Japan Industrial Productivity Database.[3] On average, energy intensity has increased slightly by 0.4% per annum from 1990 to 1999 but declined remarkably by 0.8% per annum between 2000 and 2010.

It is customary to decompose the change in traditional energy intensity into technological improvement and structural change components.[4] Various studies in the literature have employed modified versions of this decomposition technique by assigning different weights to each component such as the arithmetic mean Divisia index, log mean Divisia index, LMDI (e.g., Mulder & de Groot, 2011; Voigt et al., 2014), and Laspeyres index (e.g., Zhang, 2003). Some recent studies examining Japan and comparing with other countries are noteworthy. Zhao et al. (2014) compared and decomposed the energy efficiency in manufacturing industries in Japan and China. They showed that energy intensity recently decreased remarkably in both countries and this resulted from efficiency improvement by use of new technologies thanks to governments' energy efficiency policies and structural changes played a significant role in Japan. Mulder and de Groot (2011) found using the LMDI method that, at the aggregate economy level, efficiency effect and structural change effect accounted for 59% and 41% of the decline in energy intensity, respectively, for the 1980–2005 period. Using the same method and data from the World Input–Output Database, Voigt et al. (2014) found that structural changes were the main driver behind declining energy intensity in Japan. Finally, Honma and Hu (2008) used data envelopment analysis using 14 inputs, 11 energy sources, and one output (GDP) to compute total-factor energy efficiency for regions in Japan. They found U-shaped relationship between energy efficiency and per capita income. In particular, they emphasized that energy efficiency is much lower than that of the efficiency levels of other production factors in the manufacturing sector and hence calculation of energy intensity should go beyond a partial productivity measure and take into account the use of all inputs other than energy as well.

3. Method of analysis

Two productivity measures, namely partial factor productivity (PFP) and multi (total) factor productivity (MFP), have been used widely in various fields. These measures are distinctive in their treatment of inputs. PFP is a simple ratio of the output to a single input while MFP is the ratio of output to all inputs combined in production. The inverse of productivity ratio is called intensity. Hence, there are two intensity measures, single input intensity and multi-factor input intensity. When there are multiple outputs, there is then a need to construct a quantity index of output for both intensity measures and a quantity index of inputs for the MFP measure (Caves, Christensen, & Diewert, 1982a, b; Diewert, 1992).

The most widely used productivity measure for its ease is PFP, but its shortcomings are also well established (Windle & Dresner, 1992). In multilateral comparisons of producing units at a point in time, what passes for difference in productivity may in fact represent a different mix of input use. For overtime comparisons, on the other hand, when the proportion in which factors of production undergoes a change, PFP provides a distorted view of the contribution made by these factors in changing the level of production.

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[2] Energy Conservation Center Japan (2011, pp. 41–42) outlays the history of energy conservation measures for the industrial sector.

[3] This database is available at: http://www.rieti.go.jp/en/database/JIP2013/index.html (accessed May 1, 2016).

[4] Denoting energy intensity, energy consumption, and output as EI, E, and Q, respectively, EI can be decomposed as follows: $EI = \frac{E}{Q} = \sum_i \frac{E_i}{Q_i} \cdot \frac{Q_i}{Q}$, where i denotes individual sectors. Technological improvement or the efficiency component is captured by the first term, which implies pure sectoral level of energy intensity, and the structural change component is captured by the second term, which implies structural changes in the sectoral shares in output.

Therefore, partial productivity may be a useful index if the input in question constitutes a dominant fraction of total input use or if the amount of other inputs remain unchanged. In what follows, a method will be provided to overcome the shortcomings of PFP measure.

To construct a new PFP measure, we build on the techniques developed by Färe, Grosskopf, and Zaim (2000), Färe, Grosskopf, and Hernández-Sancho (2004), Zaim, Färe, and Grosskopf (2001) and Zaim (2004) which use output distance functions to construct quantity indices. We instead use the directional technology distance function which allows for the expansion of outputs and the contraction of inputs at the same time.

To introduce our methodology, we start with the general case of MFP and demonstrate that PFP is a special case of MFP before we correct for the bias in measuring PFP. At the outset, we construct a quantity index for outputs and a quantity index for inputs. The quantity index of output(s) shows the relative success of an observation, say *j*, in expanding its output(s) and simultaneously contracting its input(s) while using the same level of input(s) as another observation, say *i* (or using some arbitrary level of inputs common to both *i* and *j*). One should note that, in constructing an output index compositional differences in inputs are accounted for. The quantity index of input(s) on the other hand, measures the relative success of observation, say *j*, in expanding its output(s) and simultaneously contracting its input(s) while producing the same level of output(s) as another observation, say *i* (or producing some arbitrary level of output(s) common to both *i* and *j*). Note this time that, in constructing an input quantity index compositional differences in output(s) are accounted for.

Suppose there are K production units each using inputs $x = (x_1, \ldots, x_N) \in \mathbb{R}^N_+$ and producing outputs $y = (y_1, \ldots, y_M) \in \mathbb{R}^M_+$. Production technology is then defined as (x, y) i.e. $T = ((x, y) :$ x can produce $y)$ which satisfies the regularity conditions such as closedness and convexity (Färe & Primont, 1995). There are various alternatives to construct distance functions. We prefer the directional technology distance functions which satisfy these regularity conditions and also are perfect aggregator and performance measures. Accordingly, we can construct an MFP index using the directional technology distance function

$$\vec{D_T}(x, y; g_x, g_y) = \sup[\lambda : (x - \lambda g_x, y + \lambda g_y) \in T] \tag{1}$$

where T is the production technology and (g_x, g_y) is a non-zero direction in $\mathbb{R}^N_+ \times \mathbb{R}^M_+$ that determines the direction in which $\vec{D_T}(\bullet)$ is defined. To avoid preassigning any direction, the direction (g_x, g_y) can be chosen at the realized vector (x, y) as suggested by Chambers, Chung, and Färe (1998).

We construct the output quantity index by taking two directional distance functions with respect to a constant returns to scale (CRS) technology which show the successes of producing units (i.e., industries) j and i in the expansion of outputs and the contraction of a common arbitrary vector of inputs as follows:

$$\vec{D^j_{OT}}(y^j, x^0) = \max \lambda^j_0$$

subject to

$$\sum_{k=1}^{K} z_k y_{km} \geq y^j_m + \lambda^j_0 y^j_m,\ m = 1, \ldots, M$$

$$\sum_{k=1}^{K} z_k x_{kn} \leq x_n{}^0 - \lambda^j_0 x^0_n,\ n = 1, \ldots, N$$

$$z_k \geq 0,\ k = 1, \ldots, K$$

and (2)

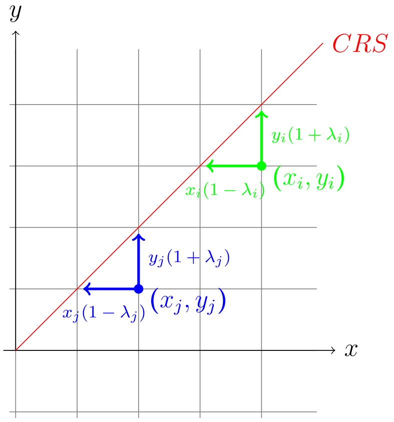

Fig. 2. Illustration of directional technology distance function.

$$\vec{D^i_{OT}}(y^i, x^0) = \max \lambda^i_0$$

subject to,

$$\sum_{k=1}^{K} z_k y_{km} \geq y^i_m + \lambda^i_0 y^i_m,\ m = 1, \ldots, M$$

$$\sum_{k=1}^{K} z_k x_{kn} \leq x^0_n - \lambda^i_0 x^0_n,\ n = 1, \ldots, N$$

$$z_k \geq 0,\ k = 1, \ldots, K \tag{3}$$

where the z_k terms are intensity variables.

Next, denoting the maximum attainable outputs as y^*_j and y^*_i and minimum attainable inputs as x^*_j and x^*_i, under the CRS assumption we obtain the following:

$$\frac{y^*_j}{y^*_i} = \frac{y_j(1 + \lambda^j_0)}{y_i(1 + \lambda^i_0)} = \frac{x_j(1 - \lambda^j_0)}{x_i(1 - \lambda^i_0)} = \frac{x^*_j}{x^*_i} \tag{4}$$

By restricting $x_j = x_i = x_0$, a quantity index of output (Q_y) is obtained as follows:

$$Q_y = \frac{y_j}{y_i} = \frac{(1 + \lambda^i_0)(1 - \lambda^j_0)}{(1 + \lambda^j_0)(1 - \lambda^i_0)} \tag{5}$$

Fig. 2 demonstrates the directional technology distance function. Consider for two industries (x_j, y_j) and (x_i, y_i) whose output we want compare as $\frac{y_j}{y_i}$. The first linear programing problem expands industry j's output vector y_j and simultaneously contracts an input vector common to both, i.e., $x_j = x_i = x_0$, and the second program does the same thing for industry i. Similar triangles allow one to write the last equation which allows for comparisons of outputs of two industries which have the same input composition and amounts.

Next, we need to choose an input vector common to both i and j. We can choose industry i as a reference unit and calculate the difference between other industries and i. By normalizing this way, industry i's output equals 1 and all other industries' outputs can be expressed relative to i. To construct the input quantity index, we use the following directional distance functions which show the successes of industries j and i in the contraction of inputs and the expansion of a common vector of outputs as follows:

$$\vec{D^j_{iT}}(y^0, x^j) = \max \lambda^j_i$$

subject to

$$\sum_{k=1}^{K} z_k y_{km} \geq y^0_m + \lambda^j_i y^0_m,\ m = 1, \ldots, M$$

$$\sum_{k=1}^{K} z_k x_{kn} \le x_n^j - \lambda_i^j x_n^j, n = 1, \ldots, N$$
$$z_k \ge 0, k = 1, \ldots, K$$
and (6)

$$\vec{D_{iT}^{i}}(y^0, x^i) = \max \lambda_i^i$$
subject to
$$\sum_{k=1}^{K} z_k y_{km} \ge y_m^0 + \lambda_i^i y_m^0, m = 1, \ldots, M$$
$$\sum_{k=1}^{K} z_k x_{kn} \le x_n^i - \lambda_i^i x_n^i, n = 1, \ldots, N$$
$$z_k \ge 0, k = 1, \ldots, K \tag{7}$$

Denoting the minimum attainable inputs as x_j^* and x_i^*, we obtain the following:

$$\frac{x_j^*}{x_i^*} = \frac{x_j(1-\lambda_i^j)}{x_i(1-\lambda_i^i)} = \frac{y_j(1+\lambda_i^j)}{y_i(1+\lambda_i^i)} = \frac{y_j^*}{y_i^*} \tag{8}$$

Using the restriction $y_j = y_i = y_0$, a quantity index of inputs (Q_x) is obtained as follows:

$$Q_x = \frac{x_j}{x_i} = \frac{(1+\lambda_i^j)(1-\lambda_i^i)}{(1+\lambda_i^i)(1-\lambda_i^j)} \tag{9}$$

An output vector of a randomly selected industry then can be chosen as a reference unit and all other industries' input indices can be expressed relative to the selected reference industry.

Given all specifications above, MFP index is defined as follows:

$$MFP = \frac{\frac{(1+\lambda_0^i)(1-\lambda_0^j)}{(1+\lambda_0^j)(1-\lambda_0^i)}}{\frac{(1+\lambda_i^j)(1-\lambda_i^i)}{(1+\lambda_i^i)(1-\lambda_i^j)}} \tag{10}$$

Subsequently, the inverse of MFP, multi-factor input intensity index (MFII), is defined as follows:

$$MFII = \frac{\frac{(1+\lambda_i^j)(1-\lambda_i^i)}{(1+\lambda_i^i)(1-\lambda_i^j)}}{\frac{(1+\lambda_0^i)(1-\lambda_0^j)}{(1+\lambda_0^j)(1-\lambda_0^i)}} \tag{11}$$

Note that MFP and MFII satisfy the conditions of homogeneity, time reversal, transitivity, and dimensionality.

When there is only one output (Y) and only one input, energy (E), MFP boils down to a simple measure and allows for comparisons of PFP for energy (PFP_E) whose reciprocal is the aggregate energy intensity (AEI) as follows:

$$PFP_E = \frac{\frac{Y_j}{E_j}}{\frac{Y_i}{E_i}} = \frac{\frac{Y_j}{Y_i}}{\frac{E_j}{E_i}} \tag{12}$$

$$AEI = \frac{\frac{E_j}{E_i}}{\frac{Y_j}{Y_i}} \tag{13}$$

To compute PFP_E and AEI we need to solve four linear programing problems, two for each indices of input and output. Two problems below compare outputs of industries j and i given constant input levels at an arbitrary level common to both industries.

$$\vec{D_{OT}^{j}}(Y^j, E^0) = \max \gamma_0^j$$
subject to
$$\sum_{k=1}^{K} z_k Y_k \ge Y^j + \gamma_0^j Y^j$$
$$\sum_{k=1}^{K} z_k E_k \le E^0 - \gamma_0^j E^0$$
$$z_k \ge 0, k = 1, \ldots, K$$
and (14)

$$\vec{D_{OT}^{i}}(Y^i, E^0) = \max \gamma_0^i$$
subject to
$$\sum_{k=1}^{K} z_k Y_k \ge Y^i + \gamma_0^i Y^i$$
$$\sum_{k=1}^{K} z_k E_k \le E^0 - \gamma_0^i E^0$$
$$z_k \ge 0, k = 1, \ldots, K \tag{15}$$

Likewise, two problems below compare energy inputs of industries j and i given constant output levels at an arbitrary level common to both industries.

$$\vec{D_{iT}^{j}}(Y^0, E^j) = \max \gamma_i^j$$
subject to
$$\sum_{k=1}^{K} z_k Y_k \ge Y^0 + \gamma_i^j Y^0$$
$$\sum_{k=1}^{K} z_k E_k \le E^j - \gamma_i^j E^j$$
$$z_k \ge 0, k = 1, \ldots, K$$
and (16)

$$\vec{D_{iT}^{i}}(Y^0, E^i) = \max \gamma_i^i$$
subject to
$$\sum_{k=1}^{K} z_k Y_k \ge Y^0 + \gamma_i^i Y^0$$
$$\sum_{k=1}^{K} z_k E_k \le E^i - \gamma_i^i E^i$$
$$z_k \ge 0, k = 1, \ldots, K \tag{17}$$

For simplicity, we can choose the energy input and output which are constant at an arbitrary level to be equal to those for industry i thereby making the industry i the reference industry. Energy productivity for i then equals 1 and all other industries' productivities are expressed relative to i. Due to transitivity property of this index, multilateral comparisons are possible. Consequently, PFP_E and AEI are computed relative to industry i as follows:

$$PFP_E = \frac{\frac{(1+\gamma_0^i)(1-\gamma_0^j)}{(1+\gamma_0^j)(1-\gamma_0^i)}}{\frac{(1+\gamma_i^j)(1-\gamma_i^i)}{(1+\gamma_i^i)(1-\gamma_i^j)}} \tag{18}$$

$$AEI = \frac{\frac{(1+\gamma_i^j)(1-\gamma_i^i)}{(1+\gamma_i^i)(1-\gamma_i^j)}}{\frac{(1+\gamma_0^i)(1-\gamma_0^j)}{(1+\gamma_0^j)(1-\gamma_0^i)}} \tag{19}$$

A special form of these measures yields a PFP index which removes the bias in the traditional PFP measure. To construct this special form we reconstruct the output and input quantity indices in a separate form as follows. The following two problems compare the output quantity indices of two industries *j* and *i* which expand output and contract energy input common to both industries *while holding all other inputs at a constant level common to both industries.*

$$\vec{D_{OT}^{j}}(y^j, x^0, E^0) = \max \beta_0^j$$

subject to

$$\sum_{k=1}^{K} z_k y_{km} \geq y_m^j + \beta_0^j y_m^j,\ m = 1, \ldots, M$$

$$\sum_{k=1}^{K} z_k E_k \leq E^0 - \beta_0^j E^0$$

$$\sum_{k=1}^{K} z_k x_{kn_{-E}} \leq x_{n_{-E}}^0,\ n_{-E} = 1, \ldots, N-1$$

$$z_k \geq 0,\ k = 1, \ldots, K$$

and (20)

$$\vec{D_{OT}^{i}}(y^i, x^0, E^0) = \max \beta_0^i$$

subject to

$$\sum_{k=1}^{K} z_k y_{km} \geq y_m^i + \beta_0^i y_m^i,\ m = 1, \ldots, M$$

$$\sum_{k=1}^{K} z_k E_k \leq E^0 - \beta_0^i E^0$$

$$\sum_{k=1}^{K} z_k x_{kn_{-E}} \leq x_{n_{-E}}^0,\ n_{-E} = 1, \ldots, N-1$$

$$z_k \geq 0,\ k = 1, \ldots, K \tag{21}$$

Similarly, the following two problems compare the energy inputs of industries *j* and *i* with their output held constant at an arbitrary level common to both industries *while holding all inputs other than energy as fixed inputs.*

$$\vec{D_{iT}^{j}}(y^0, x^j, E^j) = \max \beta_i^j$$

subject to

$$\sum_{k=1}^{K} z_k y_{km} \geq y_m^0 + \beta_i^j y_m^0,\ m = 1, \ldots, M$$

$$\sum_{k=1}^{K} z_k E_k \leq E^j - \beta_i^j E^j$$

$$\sum_{k=1}^{K} z_k x_{kn_{-E}} \leq x_{n_{-E}}^j,\ n_{-E} = 1, \ldots, N-1$$

$$z_k \geq 0,\ k = 1, \ldots, K$$

and (22)

Table 1
List of sectors.

Abbreviation	Description	EUKLEMS codes
AGR	Agriculture, hunting, forestry, and fishing	A, B
MIN	Mining and quarrying	10–12
FBT	Food and beverages and tobacco	15.16
TEX	Textiles, textile, leather and footwear	17–19
WOO	Wood and cork	20
PAP	Pulp, paper, printing and publishing	21–22
PET	Coke, refined petroleum and nuclear fuel	23
CHE	Chemicals and chemical products	24
RUB	Rubber and plastics	25
NMM	Other non-metallic minerals	26
MET	Basic metals and fabricated metal products	27–28
MAC	Machinery, nec	29
ELC	Electrical and optical equipment	30–33
TRN	Transport equipment	34–35
MNF	Manufacturing, nec and recycling	36–37
ENE	Electricity, gas and water supply (energy)	E
CON	Construction	F
MOT	Sale and repair of motor vehicles	50
WHL	Wholesale trade	51
RET	Retail trade	52
HOT	Hotels and restaurants	H
TRA	Transport and storage	60–63
TLC	Post and telecommunications	64
FIN	Financial intermediation	J
RES	Real estate activities	K
BUS	Other business activities	71–74
PUB	Public admin and defense	L
EDU	Education	M
HLT	Health and social work	N
SOC	Other community, social and personal services	O

$$\vec{D_{iT}^{i}}(y^0, x^i, E^i) = \max \beta_i^i$$

subject to

$$\sum_{k=1}^{K} z_k y_{km} \geq y_m^0 + \beta_i^i y_m^0,\ m = 1, \ldots, M$$

$$\sum_{k=1}^{K} z_k E_k \leq E^i - \beta_i^i E^i$$

$$\sum_{k=1}^{K} z_k x_{kn_{-E}} \leq x_{n_{-E}}^i,\ n_{-E} = 1, \ldots, N-1$$

$$z_k \geq 0,\ k = 1, \ldots, K \tag{23}$$

We choose to equate the energy input, other inputs, and output which are held constant at an arbitrary level in the problems above to those of industry *i*, which serves as the reference (benchmark) industry. Subsequently, the corrected partial factor productivity for energy (*CPFP$_E$*) is equal to 1 and all other industries' indices are expressed relative to this industry. This index is also transitive. Finally, we obtain *CPFP$_E$* and the corrected energy intensity (*CEI*) as follows:

$$CPFP_E = \frac{\dfrac{(1+\beta_0^i)(1-\beta_0^j)}{(1+\beta_0^j)(1-\beta_0^i)}}{\dfrac{(1+\beta_i^j)(1-\beta_i^i)}{(1+\beta_i^i)(1-\beta_i^j)}} \tag{24}$$

$$CEI = \frac{\dfrac{(1+\beta_i^j)(1-\beta_i^i)}{(1+\beta_i^i)(1-\beta_i^j)}}{\dfrac{(1+\beta_0^i)(1-\beta_0^j)}{(1+\beta_0^j)(1-\beta_0^i)}} \tag{25}$$

4. Data

The data are obtained from November 2009 release of EU KLEMS Database (EU KLEMS, 2009).[5] EU KLEMS data are constructed in conjunction with national accounts. Our panel data cover the period 1973–2006 and 30 sectors. The complete list of 30 sectors is presented in Table 1. All variables in the database are expressed in constant 1995 prices in Japanese yen. Unavailability of data after 2006 is a shortcoming of the database as it

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[5] The EU KLEMS database is available at http://www.euklems.net. For a detailed description of the database construction, see O'Mahony and Timmer (2009).

Table 2
Summary statistics.

Variable	Obs.	Mean	Std. dev.	Min	Max
Capital	1020	40.50	81.30	1.61	693.40
Labor	1020	8.25	7.68	0.14	42.40
Energy	1020	0.44	0.42	0.01	2.30
Materials	1020	6.60	6.77	0.16	36.40
Services	1020	4.69	4.40	0.28	22.30
Output	1020	25.50	18.50	1.47	93.60

does not allow to track energy efficiency and intensity for the last 10 years.

Gross output (Y) expressed in basic prices are converted to 1995 constant prices in Japanese yen using gross output price index series. The input vector (X) is made up of capital (K), labor (L), energy (E), materials (M), and services (S). Capital input (K) refers to real fixed capital stock which is the sum of information and communication technologies (ICT) assets and non-ICT assets. EU KLEMS database also provides the components of both ICT and Non-ICT as follows: $K_{ICT} = K_{IT} + K_{CT} + K_{Soft}$ and $K_{Non-ICT} = K_{TraEq} + K_{OMach} + K_{OCon} + K_{Other}$, where K_{IT}, K_{CT}, K_{Soft}, K_{TraEq}, K_{OMach}, K_{OCon}, K_{Other} represent computing equipment, communications equipment, software, transport equipment, other machinery and equipment, total non-residential investment, and other assets, respectively. Labor input (L) is measured as total labor compensation for all persons engaged. The nominal figures are deflated by the price indices for the labor services to obtain the real figures in 1995 prices. Energy input (E) is measured as the nominal cost of intermediate energy inputs at current purchasers' prices and then converted to 1995 prices using the price indices for intermediate inputs. Similarly, materials (M) and services (S) are measured as intermediate material inputs and service inputs at current purchasers' prices, and then converted to constant 1995 prices using the intermediate input price indices. The descriptive statistics of all variables are reported in Table 2. All figures in Table 2 are expressed in trillions of Japanese yen.

5. Empirical findings

5.1. Comparison of traditional and corrected measures

Fig. 3 presents two measures of aggregate energy intensity, the traditional measure (energy consumption divided by total output) which we named *AEI* (calculated using Eq. (19)), and the new corrected measure which we named *CEI* (calculated using Eq. (25)), for the period 1973–2006. For both of the measures, energy intensity at the economy level are the weighted geometric means of the sectoral energy intensity levels, weights being the respective shares of sectors in total output. Akin to the decomposition analysis studies, *AEI* can be thought of as the product of *CEI* (pure energy intensity, as the previous studies name it) and the effect of the structural differences among units compared at a point in time (or structural change for comparisons over time). *CEI* computes pure energy intensity by taking into account all factors of production and removes the effect of structural differences/changes off energy intensity. Therefore, it is closer to the pure energy intensity effect (or efficiency component) in the traditional decomposition of energy intensity which uses LMDI method. However, while only the changes in the levels of a specific industry can be traced in the traditional approach to decompose energy intensity, *CEI* allows us to do level comparisons across industries.

We compute both *AEI* and *CEI* using the energy intensity of MNF (manufacturing not elsewhere classified, including recycling) industry in 1995 as the benchmark level. To illustrate, in Fig. 3, the levels of *AEI* and *CEI* in 1985 are 1.23 and 1.14, respectively. These figures imply that aggregate energy intensity and corrected energy intensity in the Japanese economy in 1985 were 1.23 and 1.14 times of the respective energy intensity levels of the MNF industry in 1995.

Furthermore, in the years where $CEI > AEI$ ($CEI < AEI$) this indicates a structure of production where combinations of inputs and outputs use less (more) energy when compared to MNF industry in 1995. Thus, for the year 1985, this implies that on the average the economy must have had *higher* energy consuming combinations of inputs and outputs than that of the reference sector/year.

On the other hand, relative movements of the *AEI* and *CEI* measures with respect to each other over time will provide information on the nature of structural change. If for example, $AEI > CEI$ and diverge (converge) from each other overtime, this implies that the structural change is towards more (less) energy using combination of inputs and outputs. On the contrary, if $CEI > AEI$ and diverge (converge) over time, this is an indication that the structural change is towards less (more) energy using combination of inputs and outputs.

Fig. 3 demonstrates four distinct periods. The period 1976–1982 is a period where increasing *AEI* due to a structural change towards more energy using combination of inputs and outputs has been offset by declining *CEI*. This period overlaps with the oil shock in 1979 and the policy responses of the government in the aftermath to increase energy efficiency. During the period 1982–1986 however, increasing *CEI* concurrently with high energy prices has led Japanese government to put in place rationalization plans to induce structural changes towards less energy using sectors. The year 1986 coincides with the bubble economy (1986–1991) during which the rise in stock and real estate prices led industrial firms to increase investments largely. One should note that this is a period where $CEI > AEI$ and two measures converge indicating that structural change is towards more energy using combination of inputs and outputs. After the bubble in asset prices passed in 1991, from there on the Japanese economy was plagued by low economic growth rates and a deflationary spiral (lost decade), which led to decline in industrial activities and investments. This translates to our measures as a period where increasing *CEI* has been offset by a structural change towards less energy consuming sectors.

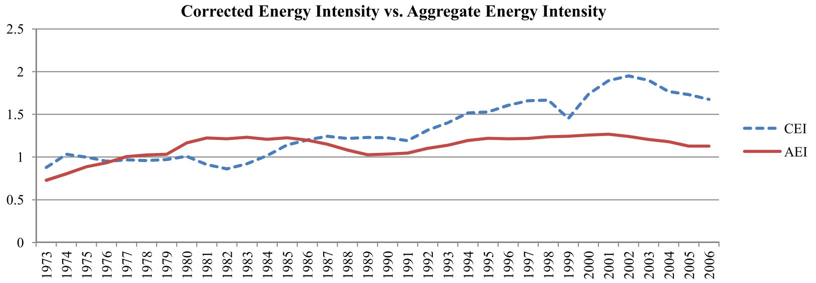

Fig. 3. Corrected vs. aggregate energy intensity measure (1973–2006).

Table 3
Corrected and aggregate energy intensities by sectors.

	1973–1979		1980–1984		1985–1991		1992–1999		2000–2006	
	CEI	AEI	CEI	AEI	CEI	AEI	CEI	AEI	CEI	AEI
AGR	0.52	0.15	0.51	0.23	0.51	0.21	0.76	0.30	0.88	0.38
MIN	1.95	1.84	1.02	1.87	1.63	2.17	1.87	2.10	2.26	1.77
FBT	0.55	0.46	0.54	0.74	0.80	0.83	1.44	0.95	1.77	0.92
TEX	1.13	0.73	1.03	1.08	1.11	1.16	1.16	1.17	1.74	1.18
WOO	1.77	0.81	1.02	1.11	1.28	1.14	1.61	1.09	2.06	1.31
PAP	1.23	1.52	1.27	1.70	1.74	1.67	2.49	1.81	2.94	2.17
PET	0.56	11.08	0.66	12.21	0.69	11.03	0.74	11.39	0.86	13.95
CHE	0.57	3.66	0.66	3.63	1.61	2.96	2.24	2.82	3.84	2.73
RUB	1.50	1.20	0.87	1.69	0.86	1.66	1.20	2.01	1.50	2.13
NMM	1.17	4.59	1.00	5.27	1.04	4.31	1.22	4.81	1.37	4.57
MET	5.60	3.19	4.34	4.07	4.64	2.57	4.93	2.70	6.11	3.05
MAC	0.98	0.79	0.91	1.15	1.25	0.98	1.52	0.84	1.55	0.81
ELC	0.64	0.92	0.82	1.40	1.62	1.22	1.90	1.08	1.99	1.03
TRN	0.56	0.68	0.72	0.93	1.02	0.82	1.43	0.81	1.43	0.73
MNF	1.36	0.93	0.89	1.01	0.90	0.89	1.02	0.99	1.26	0.96
ENE	1.93	4.05	1.80	4.18	1.94	4.39	7.13	5.36	13.51	4.79
CON	1.12	0.57	0.80	0.74	0.92	0.56	0.96	0.59	0.95	0.53
MOT	1.82	0.16	1.00	0.39	1.34	0.60	1.44	0.78	1.44	0.83
WHL	0.68	0.57	0.71	0.59	0.76	0.41	0.72	0.41	0.85	0.44
RET	1.07	0.94	1.66	1.35	2.83	1.48	2.73	1.47	2.76	1.35
HOT	0.92	1.02	1.69	1.54	2.18	1.24	3.14	1.63	3.98	1.92
TRA	2.21	1.13	2.51	1.44	2.42	1.16	2.75	1.24	3.30	1.22
TLC	1.49	0.57	0.74	1.18	0.77	0.95	0.82	0.65	1.28	0.56
FIN	0.52	0.57	0.45	0.37	0.38	0.20	0.45	0.25	0.47	0.25
RES	0.35	0.08	0.35	0.12	0.35	0.16	0.42	0.17	0.44	0.14
BUS	0.66	0.41	0.74	0.63	1.00	0.55	1.10	0.59	1.35	0.62
PUB	0.67	0.62	1.60	1.26	2.62	1.33	3.36	1.61	3.99	1.50
EDU	0.56	1.30	0.54	1.23	0.60	1.06	0.77	1.52	0.76	1.44
HLT	0.61	0.78	1.06	1.37	2.13	1.39	2.53	1.34	2.75	1.34
SOC	0.67	1.08	1.01	1.22	2.06	1.11	2.86	1.52	3.40	1.65

Note: CEI: corrected energy intensity, AEI: aggregate energy intensity.

5.2. Findings by sectors

5.2.1. Comparison of traditional and corrected measures

A comparison of traditional measure of energy intensity (*AEI*), based on Eq. (19), and the corrected measure (*CEI*), based on Eq. (25), by 30 sectors is presented in Table 3. The figures in the table are the annual geometric averages for each period and by each sector. The levels of energy intensity are expressed in the same manner, relative to the energy intensity level of MNF sector (manufacturing, not elsewhere classified) in 1995. The graphs for *AEI* and *CEI* by all sectors are also available in Fig. 4.

In most sectors, the trends are similar for both measures but the levels are divergent to varying degrees. During certain periods, *CEI* lies above *AEI*, such as in food, beverages and tobacco industry (FBT) during the period 1992–1999, and in some years the opposite is happening, such as during the period 1985–1991 in the same industry.

5.2.2. Trends in energy intensity

We do not aim to analyze energy intensity for all sectors here but energy intensities by major economic activities is worth noting. For this purpose, we classified economic activities into three major sectors as (i) primary sector (agriculture and mining), (ii) secondary sector (manufacturing industries and energy sector), and (iii) tertiary sector (services). We calculate the energy intensities as the weighted geometric average of the constituent sectors, the weights being the respective shares in output. Energy intensities measured using the corrected intensity (*CEI*) are presented in Fig. 5.

CEI in the primary sector did not change much until 1991 (around 0.59), from which point on there is an increasing trend until to 2001 (around 1.02) and it declines slightly afterwards. The tertiary sector's energy intensity, on the other hand, increased to some extent from the mid-1970s (around 0.82 in 1976) until 1986 (around 1.22) and then declined a little until 1991 to 1.03. From then on, it increased gradually to 1.50 in 2002 before declining slightly to 1.27 in 2006. On the other hand, while *CEI* in the secondary sector was successfully reduced during the 1970s (from 1.37 in 1974 to 1.02 in 1982), it increased with a secular rising trend over the years until 2002 except for the sharp decline in 1999. It hit 1.48 in 1988, 1.57 in 1991, 2.23 in 1998, and 2.73 in 2002. after 2002, it started falling and reached 2.09 in 2006. Therefore, the main driver of the increasing *CEI* at the economy level (in Fig. 3) seems to be the secondary sector, i.e. manufacturing and energy sectors. Overall, Fig. 4 demonstrates that *CEI* levels in all major sectors coped with the two oil shocks during the 1970s and have increased starting from the mid 1980s and throughout the 1990s, especially in the secondary sector. Hitting record levels in 2001, it then declined gradually in all three major sectors.

The sources of the increase in *CEI* at the economy level from 1990s onward can be traced from the energy intensities by subsectors reported in Table 3. The large increase in *CEI* in the secondary sector since the 1990s stem from the following industries: (i) paper and printing (PAP), (ii) industrial chemicals (CHE), and (iii) electricity, gas, and water (ENE). It is noteworthy that these are typically high-energy-intensive industries as well. Other sectors with large increases in energy intensity are hotels and restaurants (HOT), public services (PUB), health services (HLT), and other social services (SOC).

6. Conclusion

In this paper, we analyzed energy intensity in the Japanese economy and its sub-sectors for the period 1973–2006 by proposing a new method which takes into account all inputs used in production and corrects for the bias in the traditional energy

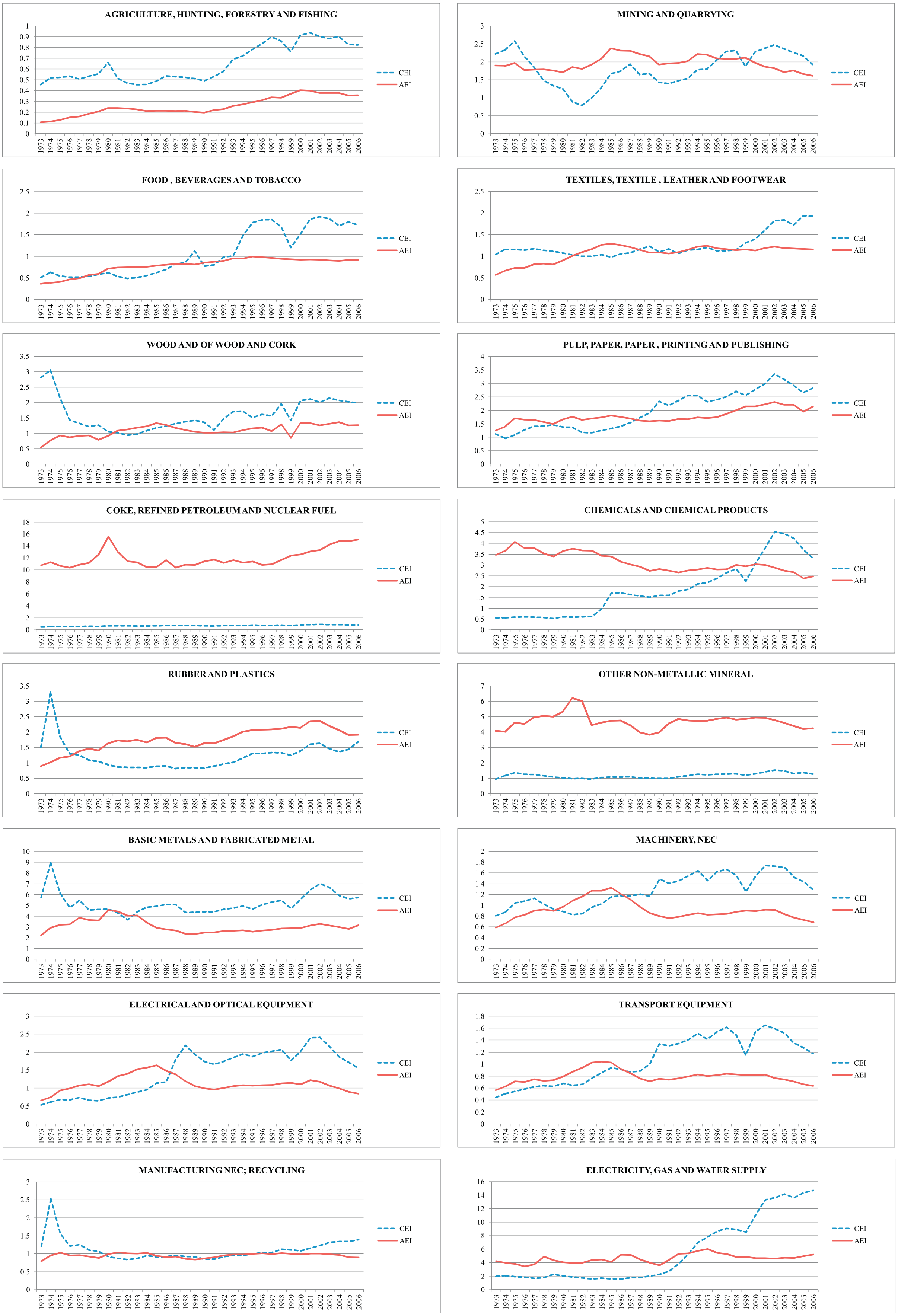

Fig. 4. Corrected vs. aggregate energy intensity for sectors.

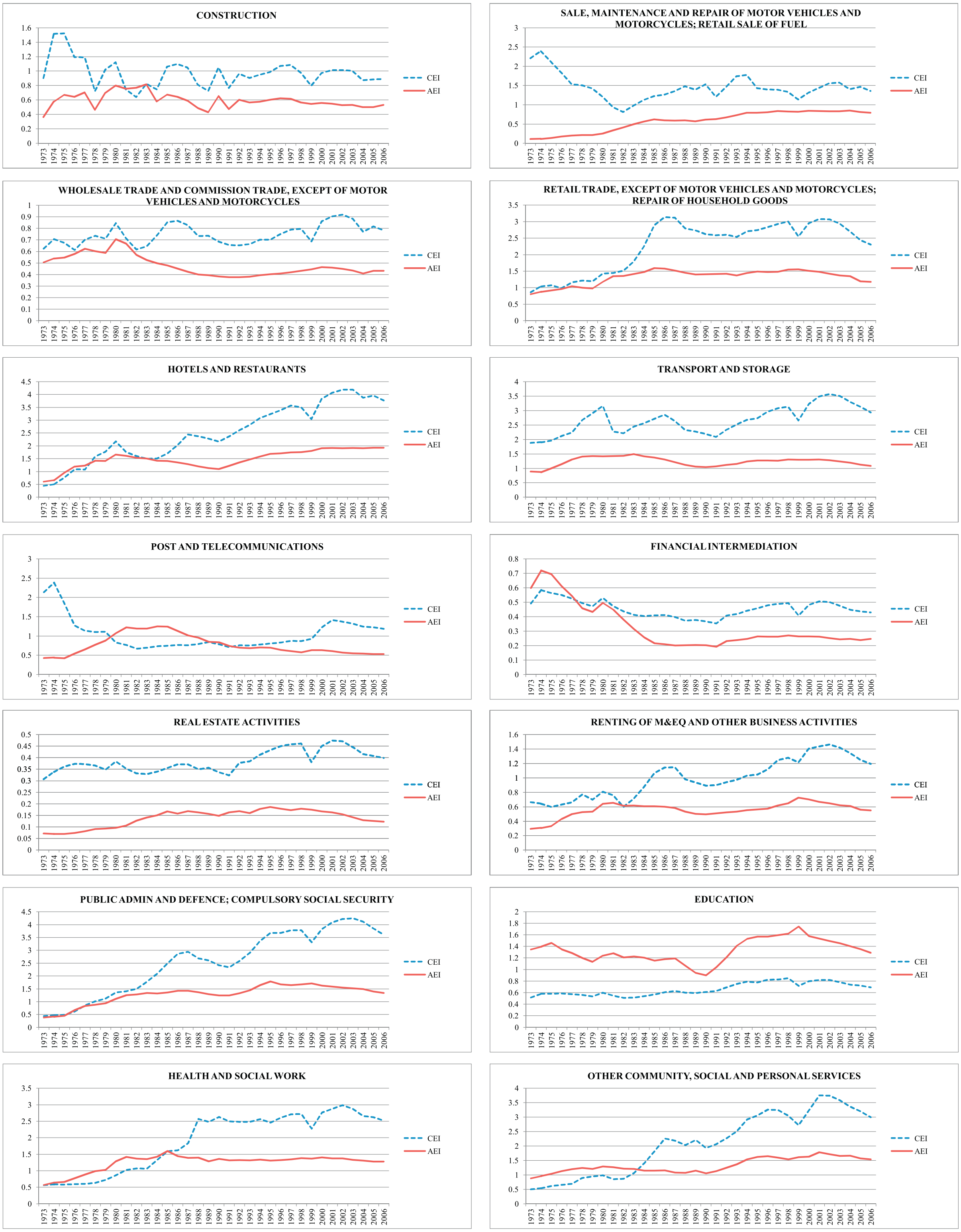

Fig. 4. Continued

intensity measure. It is noteworthy that the energy conservation policies of the Japanese government were based on the traditional energy intensity measure. We argue that this measure suffers from serious flaws. We found that while there is an upward trend in energy intensity for the three-decade period (1973–2006), the traditional measure overestimates aggregate energy intensity until 1986 and underestimates after 1986. Our findings using the corrected measure for the post-1990 period reveal that energy intensity at the economy level actually continued to rise, which confirms the general finding in the literature that energy intensity in Japan increased after the early 1990s.

The results of our analysis bear important policy implications. Our results using the corrected energy intensity measure imply notable reduction in energy intensity only during the 1970s and

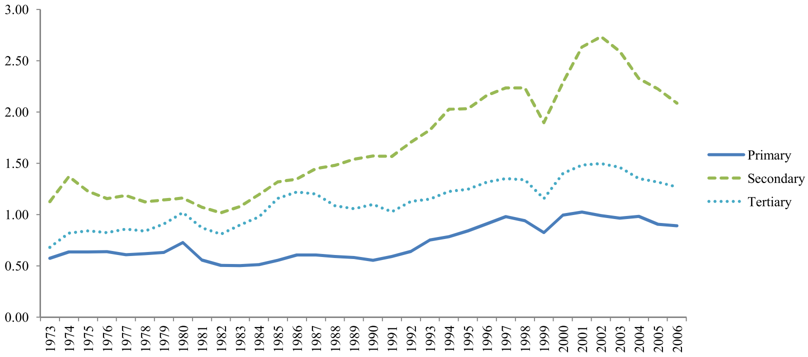

Fig. 5. Corrected energy intensity by major economic activities (1973–2006).

recently after 2001. While energy intensity was on the rise after 1990, the new policies after 1999, such as the *Top Runner Program* and the energy plan of the government after 2003 seems to have yielded some reduction in energy intensity after 2001. Structural changes in manufacturing and energy sectors, on the other hand, have worked to increase energy intensity after the mid-1980s. Hence, a major task for the Japanese government is to put in action the necessary measures to reduce energy intensity in the manufacturing and energy sectors. Zhao et al. (2014) argued that the change in energy consumption in Japan between 1975 and 1990 resulted from energy efficiency effect, and energy intensity change has resulted from efficiency effect after 1990. Based on our findings, we claim that the reverse of our corrected measure of energy intensity, i.e. energy efficiency, has worsened significantly especially during the 1990s. Therefore, the government's ambitious attempts to reduce energy conservation in industrial facilities during the 1990s seem to be a rational reaction.

We are bound by data availability in this study. Our data cover the period 1973–2006 and data for years after 2006 were not available at equal sectoral disaggregation. Therefore, it was not possible to evaluate the energy conservation and energy efficiency policies of the government after 2006. On the other hand, according to IEA's official statistics, aggregate energy efficiency in Japan, measured in the traditional fashion, has declined overall by about 7% between 2006 and 2011.

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