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A SECTORAL PERSPECTIVE: EMPIRICAL EVIDENCE FROM WIOD OVER 1995 TO 2009

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Structural decompositions of energy consumption, energy intensity, emissions and emission intensity A sectoral perspective: empirical evidence from WIOD over 1995 to 2009

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Table of Contents

List of Figures

List of Tables

Abstract

Using more than 68 million data points from the newly introduced World Input-Output Database (WIOD) over 1995 to 2009, this study investigates the historical dynamics of energy consumption, aggregate energy intensity, total emissions and total emission intensity at sectoral level by decomposing their relative changes in the input-output framework into five influencing factors: intensity effect, inter-industry structural effect, trade effect in intermediate inputs, structural change effect in final demand and total final demand effect. It identifies crucial empirical patterns that support UNIDO's ISID initiative: increases in energy consumption and total emissions at sectoral level driven by economic growth can be partially or even largely offset by the efficiency technology related intensity effect and the intensity effect within sectors contributes the most to reductions in aggregate energy intensity and total emission intensity.

Keywords: Structural decomposition, input-output model, energy, emissions, sustainable development.

1. Introduction

Development faces a fundamental dilemma. The development initiative proposed by many governments and international organizations across the globe has pledged to provide better living standards to people without discrimination or exclusion, for instance, the United Nations Millennium Development Goals (United Nations, 2000). The process of improving living standards is closely associated with material well-being, which in turn necessitates continuous improvements and expansion in industrial production, resulting in increasing energy consumption and high externalities such as emissions that lead to climate change and environmental pressures (Allcott & Greenstone, 2012), particularly in developing countries. Global energy consumption and CO_2 emissions were expected to rise by 27.86 per cent and 35.51 per cent from 2000 to 2010, respectively. Meanwhile, the growth rate in China was 116.71 per cent and 143.36 per cent, respectively[1]. If—given that the market share of clean energy is still very small—the relationship we currently observe between energy consumption, emissions and material well-being persists, developing less developed countries implies a trend in energy demand that is unsustainable and environmental degradation.

In practice, notable efforts have been made by policymakers in this regard. The European Commission (2010) announced the new EU 2020 strategy focusing on smart, sustainable and inclusive growth. More importantly, the recent concept of "Inclusive and Sustainable Industrial Development (ISID)" proposed by UNIDO represents a possible solution to the development dilemma, because this concept explicitly focuses on the link between industrialization and economic sustainability, a fundamental link if less developed countries are to catch up. Consequently, the answer to the question whether there is any empirical evidence that the ISID concept has been implemented is crucial for long-term policymaking.

This article quantitatively investigates this question by applying the Structural Decomposition Analysis (SDA) approach. In the input-output framework, the relative change of global energy consumption, aggregate energy intensity, total emissions and emission intensity during the period 1995 to 2009 are decomposed into five contributing factors: intensity effect, inter-industry structural effect, trade effect in intermediate inputs, structural change effect in final demand and total final demand effect. We consider two dimensions—energy consumption and total emissions—to answer the research question because (1) emissions are inseparably linked with the sources of

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[1] Data source: the World Development Indicators, the World Bank.

energy consumed in production[2], and (2) more importantly, as already mentioned above, development entails two aspects: (i) material well-being and (ii) externalities, such as emissions generated in the development process (Allcott & Greenstone, 2012). Decomposing energy consumption is only one aspect of development, namely the efforts of improving material well-being, but does not directly reflect the externalities aspect. Decomposing total emissions due to its easily quantifiable property and its association with environmental problems can contribute to a well-rounded understanding of the entire development process. Additionally, the concept of intensity is introduced. Energy intensity measures how efficient energy is consumed to produce useful outputs (Patterson, 1996) while emission intensity reflects the externality embodied in one unit of gross output.

This paper does not aim to accurately predict the future dynamics of energy consumption, aggregate energy intensity, total emissions or emission intensity for the entire world or for a specific country, but seeks to comprehensively map the history of global dynamics at sectoral level and explore common patterns which may be of value for policymaking by implying a possible scenario in which improvements in material well-being are more sustainable and equally distributed. Most decomposition studies perform an Index Decomposition Analysis (IDA) for specific industries or economies. Taking advantage of the newly introduced World Input-Output Database (WIOD) and using similar decomposition equations developed by Zhong (2014) to carry out analyses at the level of economies, our study does not focus on one specific economy, but is one of the first studies[3] to provide results at sectoral level for the entire world by considering trade transactions between sectors within and across the major economies in the world. This paper is structured as follows. The next section provides a brief literature review. The methodology and results are presented in Section 3 and Section 4. Finally, Section 5 concludes and discusses policy implications.

2. Literature review

The link between economic development and environmental quality has been heatedly debated in the literature. One of the leading debates focuses on the link between income per capita and environmental quality at per capita level, i.e. the Environmental Kuznets Curve (EKC). According to the EKC, the environmental quality deteriorates in the early stage of development with the

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[2] To avoid the problem of double counting, energy consumption is defined in this study as the sum of primary energy consumption covering 12 types of primary energy (see Section 3.1). The major composition of primary energy is fossil fuels.

[3] The World Input-Output Database (WIOD) is the first public database that has data on time series trade transactions between all economic sectors and major economies in the world. It has been open to the public since April 2012.

increase in income per capita. Environmental quality starts improving when income per capita reaches a certain level or a turning point. Intuitively, the EKC is an inverted U-shaped curve. The pioneering work of Selden and Song (1994) substantiates the existence of the EKC and forecasts the increase in global emissions based on the EKC using a multi-national panel analysis to study the link between four air pollutants and GDP per capita. Grossman and Krueger (1995) empirically estimated the threshold per capita income of US$ 8,000 for several environmental indicators, demonstrating that economic growth would bring about improvements in environmental quality once this threshold is met. A theoretical explanation for this is that in a static growth model in which a social planner chooses the technologies, the EKC makes sense as dirty technologies are used below the turning point while clean ones are applied once the threshold has been reached (Stokey, 1998).

Recent studies have been questioning the existence of the EKC, which implies that environmental quality is likely to continue to degrade. de Bruyn, van den Bergh, and Opschoor (1998) assert that the time patterns of some emissions positively correlate with economic growth and that the reduction in emissions is a result of technological change. Stern and Common (2001) use a more globally representative dataset to explore the sulphur emissions-income per capita relationship and find that (1) the relationship is monotonic instead of inverted U-shaped, and (2) changes in emissions are time trend-related rather than income per capita-related. Many critics focus on the parametric econometric specifications employed by prior studies, which might be problematic for estimation (Millimet, List, & Stengos, 2003), and develop semi-parametric or nonparametric approaches, for example, flexible semi-parametric linear regression (Millimet et al., 2003), nonparametric kernel estimation with panel data (Azomahou, Laisney, & Van, 2006) and the quantile fixed effect regression technique (Flores, Flores-Lagunes, & Kapetanakis, 2014), pointing out that previous empirical findings about the EKC are extremely sensitive to parametric model specifications and that we are probably being too optimistic about the environmental quality improvements that can be achieved as income grows over time.

More importantly, Andreoni and Levinson (2001) present a theoretical static model with micro-foundations to study the environment-income relationship with a focus on technology. They ascertain that the reduction at per capita level of those pollutants following an inverted U-shaped relationship with income depends on increasing returns to scale in emission reduction technologies only. In other words, economic growth alone is not the solution to environmental deterioration. In fact, the environment-income relationship is not necessarily inverted U-shaped: it can assume an entirely different shape depending on technology.

The main reason for reviewing the literature on EKC is to demonstrate that the EKC does not necessarily apply globally, even though it holds in some cases, and that what determines the environment-income relationship is the given technology. There might be a risk that policymakers erroneously interpret such an inverted U-shaped relationship as prioritizing economic growth over the environment, i.e. to “grow first, and then clean up” (Dasgupta, Laplante, Wang, & Wheeler, 2002). Modern industrial societies which heavily rely on fossil fuels are constantly generating new types of emissions, resulting in an increase of environmental risks. Moreover, according to growth theory, continuous improvements in technology, especially in those that increase input efficiency (e.g. energy) are likely to help the global economy overcome limitations to growth in the face of scarce and unrenewable resources (Grossman & Helpman, 1994). More recently, Acemoglu, Aghion, Bursztyn, and Hemous (2012) demonstrated the crucial importance of directed technological change by developing a growth model with environmental constraints, and suggest that policy instruments (e.g. taxes and subsidies) should be intentionally designed to support innovations in clean inputs to achieve sustainable growth. All things considered, promoting or better yet implementing UNIDO’s new initiative Inclusive and Sustainable Industrial Development (ISID) with a special focus on technology and innovation is indispensable.

The literature on the EKC suggests that technology needs to be taken into account second to the environment-income relationship. Our study employs a backward-looking perspective that tries to empirically explore the historical dynamics of energy consumption, aggregate energy intensity, total emissions and emission intensity, and advocates the implementation of ISID. We decompose the relative change of the variable interest over a given period into several influencing factors with a focus on technology. The following section presents a brief literature review on energy decomposition. The primary reason for this is that despite the differences in terms of properties between energy and total emissions, they are mathematically equivalent in calculations: both are simply scalar elements attributed to a specific sector in a specific economy. Generally speaking, there are three different decomposition approaches: the Index Decomposition Analysis (IDA), the Structural Decomposition Analysis (SDA) and the production function-based econometric method.

The Index Decomposition Analysis (IDA) is the most commonly used method, probably because the data requirement for applying it is much lower: IDA only requires the aggregate data at sectoral level. To study the dynamics of the variable interest, despite the fact that there are additive and multiplicative forms of IDA and that the mathematical specification in each form may differ, the basic idea remains the same: the change of the variable interest over a period—regardless whether the additive or multiplicative version is used—is rewritten into a product of components based on identical algebraic transformations, changing one variable each time and simultaneously holding all other variables constant (Ang, 2005; Ang & Lee, 1996; Ang & Lee, 1994; Zhang, 2003). A simple example for illustration purposes is the following:

$$E = \sum_{i}^{n} E_i = \sum_{i}^{n} \frac{E_i}{Y_i} \frac{Y_i}{Y} Y$$

In an economy with n sectors, total energy consumption E can be described as a product of $\frac{E_i}{Y_i}$, the $i - th$ sector's energy intensity; $\frac{Y_i}{Y}$, the share of gross output of the $i - th$ sector in the whole economy (the measurement of structural change), and Y, the economy's gross output.

In Structural Decomposition Analysis (SDA), the basic idea behind performing decompositions is the same. The key difference is that SDA performs decompositions using a data-intensive matrix. In this sense, SDA can be viewed as an extension of the IDA in the context of linear algebra. In the input-output framework, a sector's gross output is consumed in two ways: intermediate inputs and final demand. The input-output dataset is a matrix that contains trade transaction information between any pair of sectors within the same economy and across economies. The number of data points of an input-output dataset can be substantial. Supposing there are m economies in the world and each economy has n sectors and k final demands, the total number of data points for one period only is $(m^2n^2 + mkn)$.

Although the input-output framework can describe the global economy in a perfectly reasonable way by detecting trade interactions between sectors, it is extremely expensive and time-consuming to construct the datasets, and it may sometimes even be impossible due to data unavailability. The input-output dataset did not cover the whole world for quite some time. Accordingly, much fewer studies adopted the SDA approach. Ang and Zhang (2000) conducted a survey of 124 decomposition studies and found that only 15 of these were SDA studies while the rest were IDA studies. Voigt, De Cian, Schymura and Verdolini (2014) apply the IDA technique to input-output data. Existing SDA studies generally focus on a specific economy or economies for which an input-output dataset exists. Recently, Xu and Dietzenbacher (2014) carried out a structural decomposition analysis of emissions relating to trade for 40 economies represented in the World Input-Output Database (WIOD), decomposing the dynamics of emissions into ten factors, with a special focus on the effects at national level and abroad. Zhong (2014) offers a structural decomposition study of energy consumption and energy intensity for 40 major economies in the world, the whole world, the EU and the new Member States[4].

The production function-based econometric method describes emissions (e.g., the total emissions of sulphur) using a Cobb-Douglas function with various inputs and technology (Stern, 2002, 2006). By deriving the per capita version of the Cobb-Douglas function, the changes in emissions can be decomposed into changes in input mix, output mix, scale and the state of technological change. Such an econometric decomposition specification can be estimated using panel data techniques, taking into account the country and time effects simultaneously.

This study uses the Structural Decomposition Analysis to answer the research question. The reasons are the following. First, in the context of globalization, international fragmentation of production is increasingly expanding, so that sectors within the same economy and across various economies are closely connected to each other through trade networks, which leads to many influencing factors like technological change, production substitution and enhanced production specialization based on labour and income level (Timmer, Erumban, Los, Stehrer, & de Vries, 2014). Growing international trade also stimulates the development of production offshoring, resulting in shared gains for all domestic factors (Grossman & Rossi-Hansberg, 2008). Such trade activities can only be included in the input-output dataset and taken into account by using the structural decomposition approach. Second, the production function-based econometric method requires a very strong assumption on the Cobb-Douglas form of production function. This study is particularly interested in the dynamics at sectoral level and manufacturing subgroups by technological level. For this purpose, as a follow-up study, we use a reduced form of decomposition equations following Zhong (2014), and neglect energy consumption of and total emissions generated by households.

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[4] The countries that joined the EU after the 2004 EU enlargement.

3. Methodology

3.1 Data

Our data source is the World Input-Output Database (WIOD)[5]. Funded by the European Commission, WIOD aims to provide researchers both a large-scale time series data source on international trade, energy consumption, emissions and socio-economic development and a deeper understanding of the dynamic globalization process (Timmer, 2012). To depict the global economy, WIOD collects official input-output data for 40 economies (including 27 EU Member States and 13 major economies in the world)[6] and uses a specific model to simulate the rest of the world (Dietzenbacher, Los, Stehrer, Timmer, & de Vries, 2013). Each of the economies listed in WIOD has 35 standardized economic sectors, which can be aggregated into primary industry, manufacturing and services. Manufacturing sectors in particular can be further grouped into low-tech manufacturing, medium-/low-tech manufacturing and medium-/high-tech manufacturing in accordance with their technological levels[7].

Three data-intensive datasets in WIOD are used in this study[8]. (1) The World Input-Output Tables (WIOT) over 1995 to 2009 at current prices provides monetary trade data for any pair of sectors within and across economies in terms of intermediate inputs and final demand. (2) The previous years' WIOT over 1996 to 2009 at current prices for deflating purposes. (3) The WIOD Environmental Accounts on energy consumption and emissions for each sector in each economy over 1995 to 2009, covering 27 categories[9] of energy by source (including 12 types of primary energy and 15 types of secondary energy) and 8 categories[10] of emissions by source.

The global economy can be viewed as a closed economic system where energy flows across sectors and economies and are partially embodied in the production process. The primary energy inputs of a sector might be transferred into secondary energy used by another sector, which implies that double counting might be an issue. Accordingly, only the sum of all primary energy inputs is used in this

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[5] The World Input-Output Database (WIOD): http://www.wiod.org/new_site/home.htm

[6] See Appendix 3 for the full list of economies included in WIOD.

[7] See Appendix 4 for the classification of industry and technological level.

[8] For each year in both versions of the WIOT, there are 41 economies in the intermediate inputs matrix (including the rest of the world), and each of them has 35 sectors, which means each intermediate inputs matrix contains 41*35*41*35 = 2059225 data points; in the final demand matrix, each economy has 5 kinds of final demands, which yields 41*35*41*5 = 294175 data points. Accordingly, a single year in the WIOT has 2059225 + 294175 = 2353400 data points.

[9] Primary energy: HCOAL, BCOAL, CRUDE, NATGAS, HEATPROD, NUCLEAR, HYDRO, GEOTHERM, SOLAR, WIND, OTHRENEW, and OTHSOURC. Secondary energy: COKE, DIESEL, GASOLINE, JETFUEL, LFO, HFO, NAPHTA, OTHPETRO, OTHGAS, WASTE, BIOGASOL, BIODIESEL, BIOGAS, ELECTR, and LOSS.

[10] Eight categories of emissions: CH4, CO, CO2, N2O, NH3, NMVOC, NOX and SOX.

study. Total emissions are defined as the sum of all 8 emission sources. Since energy consumption and emissions are measured by physical units (TJ and tonnes, respectively), energy consumption or emissions from different sources can simply be added up without applying any deflating technique.

3.2 Structural decompositions of energy consumption and total emissions

Following the basic input-output equations and linear algebra notations (Miller & Blair, 1985) and Dietzenbacher, Hoen, and Los' (2000) approach of decomposing the technical coefficient matrix, E, the scalar of energy consumption or total emissions, can be specified as follows:

$$E = e'(I - A^{*}\circ A^{T})^{-1}sC \qquad (1)$$

Where:

$\mathrm{e}' = [\mathrm{e}_1, \cdots, \mathrm{e}_{1435}]$, which is a vector of sectors' energy inputs (TJ) per US dollar of gross output or total emissions (tonnes) per US dollar of gross output. It measures energy intensity or total emission intensity. Note that WIOT contains 41 economies and each of them has 35 sectors.

I is a1435*1435 identity matrix.

A^* indicates a 1435*1435 matrix of aggregate intermediate inputs per unit of gross output by sector by economy. For any buyer, say, Sector j in Economy s, the value in the matrix $[A^*]_{i\,j}^{\;\,s}$ measures the total amount of products from Sector i purchased by Sector j in Economy s as intermediate inputs for producing one unit of output, ($i = 1, 2, \cdots, 35; r, s = 1, 2, \cdots, 41$). It is an indicator related to productivity, which measures the inter-industry structure in intermediate inputs: how efficient the intermediate inputs are consumed by the buyers to produce one unit of gross output. Note that ° refers to the Hadamard product.

A^T is a 1435*1435 matrix of trade coefficients in intermediate inputs. It is the shares of the products of Sector i in Economy r in the total amount of the same products bought by Sector j in Economy s for producing one unit of output ($i,\ j = 1, 2, \cdots, 35; r, s = 1, 2, \cdots, 41$). It is an indicator measuring the trade structure in intermediate inputs.

s is the structural coefficient matrix in final demand (1435*41 matrix), where $s_{n,m}$ denotes the share of Sector n in the total final demand of Economy m ($n = 1, 2, \cdots, 1435;\ m = 1, 2, \cdots, 41$). It is designed to measure the consumption structure in final demand.

C is a vector of economies' total final demand (41*1 vector). It is designed to measure the level of economic development.

Between two consecutive years, say, year 0 and 1, the ratio of energy consumption or total emissions, $\frac{E_1}{E_0}$, can be accurately decomposed into five influencing factors, or in other words, can be viewed as a mathematical product of five factors, as shown in the table below (see Appendix 1 for details on how to derive these five decomposition factors).

Decomposition factors	First method for energy consumption / total emissions decomposition between year 0 and 1	Second method for energy consumption / total emissions decomposition between year 0 and 1
Factor 1: change in e, intensity effect	$Factor\ 1^1_{0\to1} = \frac{e_1^{'} \left(I - A_1^* \circ A_1^T\right)^{-1} s_1 C_1}{e_0^{'} \left(I - A_1^* \circ A_1^T\right)^{-1} s_1 C_1}$	$Factor\ 1^2_{0\to1} = \frac{e_1^{'} \left(I - A_0^* \circ A_0^T\right)^{-1} s_0 C_0}{e_0^{'} \left(I - A_0^* \circ A_0^T\right)^{-1} s_0 C_0}$
Factor 2: change in A^*, inter-industry structural effect	$Factor\ 2^1_{0\to1} = \frac{e_0^{'} \left(I - A_1^* \circ A_1^T\right)^{-1} s_1 C_1}{e_0^{'} \left(I - A_0^* \circ A_1^T\right)^{-1} s_1 C_1}$	$Factor\ 2^2_{0\to1} = \frac{e_1^{'} \left(I - A_1^* \circ A_0^T\right)^{-1} s_0 C_0}{e_1^{'} \left(I - A_0^* \circ A_0^T\right)^{-1} s_0 C_0}$
Factor 3: change in A^T, trade effect in intermediate inputs	$Factor\ 3^1_{0\to1} = \frac{e_0^{'} \left(I - A_0^* \circ A_1^T\right)^{-1} s_1 C_1}{e_0^{'} \left(I - A_0^* \circ A_0^T\right)^{-1} s_1 C_1}$	$Factor\ 3^2_{0\to1} = \frac{e_1^{'} \left(I - A_1^* \circ A_1^T\right)^{-1} s_0 C_0}{e_1^{'} \left(I - A_1^* \circ A_0^T\right)^{-1} s_0 C_0}$
Factor 4: change in s, structural change effect in final demand	$Factor\ 4^1_{0\to1} = \frac{e_0^{'} \left(I - A_0^* \circ A_0^T\right)^{-1} s_1 C_1}{e_0^{'} \left(I - A_0^* \circ A_0^T\right)^{-1} s_0 C_1}$	$Factor\ 4^2_{0\to1} = \frac{e_1^{'} \left(I - A_1^* \circ A_1^T\right)^{-1} s_1 C_0}{e_1^{'} \left(I - A_1^* \circ A_1^T\right)^{-1} s_0 C_0}$
Factor 5: change in C, total final demand effect	$Factor\ 5^1_{0\to1} = \frac{e_0^{'} \left(I - A_0^* \circ A_0^T\right)^{-1} s_0 C_1}{e_0^{'} \left(I - A_0^* \circ A_0^T\right)^{-1} s_0 C_0}$	$Factor\ 5^2_{0\to1} = \frac{e_1^{'} \left(I - A_1^* \circ A_1^T\right)^{-1} s_1 C_1}{e_1^{'} \left(I - A_1^* \circ A_1^T\right)^{-1} s_1 C_0}$

Where $Factor\ i^1_{0\to1}$ and $Factor\ i^2_{0\to1}$ indicate factor i between year 0 and 1 obtained by using the first and the second decomposition method, respectively ($i = 1, 2, 3, 4\ and\ 5$).

Since the structural decomposition equations are not unique (Dietzenbacher & Los, 1998), there are two versions of the decomposition factors. In order to estimate the impact of each factor in Equation (1) on $\frac{E_1}{E_0}$, the share of energy consumption (or total emissions) between year 0 and 1, the control variable technique is used. The idea is that only one variable is changed every time and all other variables remain constant. For instance, in Factor 1 in the first decomposition method, $Factor\ 1_{0\to 1}^{1} = \frac{e_1'(I-A_1^{*}\circ A_1^{T})^{-1}s_1C_1}{e_0'(I-A_1^{*}\circ A_1^{T})^{-1}s_1C_1}$, only e', energy intensity (or total emission intensity), is changed and all other factors remain constant. In fact, if the subscripts are reversed simultaneously for those components that are constant, the other version of the decomposition factor can be obtained (e.g. $Factor\ 1_{0\to 1}^{2}$). Likewise, the inter-industry structure in intermediate inputs A^{*}, the trade effect in intermediate inputs A^{T}, the structural coefficient in final demand s and total final demand C are changed in all other decomposition factors.

The two versions of decomposition factors are expressed as follows:

$$\frac{E_1}{E_0} = \prod_{i=1}^{5}(Factor\ i_{0\to 1}^{1})$$

and

$$\frac{E_1}{E_0} = \prod_{i=1}^{5}(Factor\ i_{0\to 1}^{2})$$

Since the multiplicative form of the decompositions is used here, $\frac{E_1}{E_0}$ is compared to 1:

$$\frac{E_1}{E_0}\colon \begin{cases} if > 1\colon \mathit{more\ energy\ consumption\ (or\ emissions) in\ the\ sector\ in\ year} 1\ \mathit{than\ in\ year}\ 0; \\ if = 1\colon \mathit{no\ changes\ in\ energy\ consumption\ (or\ emissions) between\ year} 0\ \mathit{and\ year}\ 1; \\ if < 1\colon \mathit{less\ energy\ consumption\ (or\ emissions) in\ the\ sector\ in\ year} 1\ \mathit{than\ in\ year}\ 0. \end{cases}$$

Applying these criteria, performance in terms of total primary energy consumption and total emissions by sector, industry and manufacturing technological group can be accurately assessed and compared.

Two versions of structural decomposition equations between a pair of consecutive years have been illustrated above. To estimate the impacts of decomposition factors on relative changes of energy consumption (or total emissions) between 1995 and 2009, however, some special computing procedures are inevitably needed for two crucial reasons: (1) Trade flows in WIOT are measured in monetary units and their value per unit constantly changes over time. Additionally, domestic inflation exists universally in every sector. This implies a lack of consistent monetary measurement in WIOT. (2) Obviously, decomposition results calculated from the two decomposition equations must differ.

To eliminate the impacts of inconsistent monetary measurement, all time series monetary data need to ideally be comparable. The availability of the previous years' version of WIOT at current prices makes this possible. The basic idea is that for any pair of consecutive years (e.g. year t and $t+1$), monetary data at current prices for year t and the previous years' monetary data at current prices, year $t+1$, are used in the decompositions. This is the "chain mechanism" applied to the structural decompositions of energy consumption and total emissions. A detailed description on "chain mechanism" is provided in Appendix 2.

To take into account the results from the two methods, the average is commonly used. Since this study uses the multiplicative form of decomposition equations, the mean value of the log points of factors is employed. The final equation of the energy consumption / total emissions decomposition is shown below[11].

$$log\left(\frac{E_{2009}}{E_{1995}}\right) = \frac{1}{2}\sum_{i=1}^{5}\left[\, log\left(\prod_{t=1995}^{2008} Factor\ i_{t\to t+1}^{1}\right) + log\left(\prod_{t=1995}^{2008} Factor\ i_{t\to t+1}^{2}\right)\right] \qquad (2)$$

Where the value of $\frac{1}{2}\left[log\left(\prod_{t=1995}^{2008} Factor\ i_{t\to t+1}^{1}\right) + log\left(\prod_{t=1995}^{2008} Factor\ i_{t\to t+1}^{2}\right)\right]$ is the log point of factor i in the decomposition of energy consumption (or total emissions) between year 1995 and 2009, $i = 1, 2, 3, 4\ and\ 5$.

3.3 Structural decompositions of aggregate energy intensity and total emission intensity

Section 3.2 presented the decompositions of total energy consumption and total emissions. Since there is a large discrepancy in total energy consumption or total emissions between sectors, the intensity concept (energy consumption per unit of gross output or emissions per unit of gross output) is introduced to make different sectors comparable. Using the same notations described in Section 3.2 (see Appendix 1), the scalar of gross output becomes $t(I - A^{*}\circ A^{T})^{-1}sC$. Here, t is a 1*1435 aggregation vector where every element is 1, so that the term is transferred into a scalar. Note that

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[11] Taking the log yields (see Appendix 2):

$$log\left(\frac{E_{2009}}{E_{1995}}\right) = log\left(\prod_{t=1995}^{2008} Factor\ 1_{t\to t+1}^{1}\right) + log\left(\prod_{t=1995}^{2008} Factor\ 2_{t\to t+1}^{1}\right) + \cdots + log\left(\prod_{t=1995}^{2008} Factor\ 5_{t\to t+1}^{1}\right),$$

and

$$log\left(\frac{E_{2009}}{E_{1995}}\right) = log\left(\prod_{t=1995}^{2008} Factor\ 1_{t\to t+1}^{2}\right) + log\left(\prod_{t=1995}^{2008} Factor\ 2_{t\to t+1}^{2}\right) + \cdots + log\left(\prod_{t=1995}^{2008} Factor\ 5_{t\to t+1}^{2}\right).$$

Equation (2) is obtained by adding the two log versions of the equations above.

aggregate energy intensity or total emission intensity is defined as energy inputs (TJ) per US dollar of gross output or total emissions (tonnes) per US dollar of gross output, that is, $\frac{E}{t(I-A^{*\circ}A^{T})^{-1}sC}$. Accordingly, the share of aggregate energy intensity or total emission intensity between two consecutive years, say, year 0 and 1, can be expressed as follows:

$$\frac{Intensity\ in\ the\ year\ 1}{Intensity\ in\ the\ year\ 0}=\frac{\frac{E_1}{t(I-A_1^{*}\circ A_1^{T})^{-1}s_1C_1}}{\frac{E_0}{t(I-A_0^{*}\circ A_0^{T})^{-1}s_0C_0}}=\frac{E_1}{E_0}*\frac{t(I-A_0^{*}\circ A_0^{T})^{-1}s_0C_0}{t(I-A_1^{*}\circ A_1^{T})^{-1}s_1C_1} \qquad (3)$$

Employing the same control variable technique explained in Section 3.2, Equation (3) can be decomposed into the following two versions through identical transformations in algebra (see Appendix 1 for details on how to derive these decomposition factors):

Decomposition factors	The first method for intensity decomposition between year 0 and 1	The second method for intensity decomposition between year 0 and 1
Factor 1: change in e, intensity effect	$factor\ 1_{0\rightarrow 1}^{1}=\frac{e_1^{\prime}\ (I-A_1^{*}\circ A_1^{T})^{-1}s_1C_1}{e_0^{\prime}\ (I-A_1^{*}\circ A_1^{T})^{-1}s_1C_1}$	$factor\ 1_{0\rightarrow 1}^{2}=\frac{e_1^{\prime}\ (I-A_0^{*}\circ A_0^{T})^{-1}s_0C_0}{e_0^{\prime}\ (I-A_0^{*}\circ A_0^{T})^{-1}s_0C_0}$
Factor 2: change in A^{*}, inter-industry structural effect	$factor\ 2_{0\rightarrow 1}^{1}=$ $\frac{e_0^{\prime}\ (I-A_1^{*}\circ A_1^{T})^{-1}s_1C_1}{e_0^{\prime}\ (I-A_0^{*}\circ A_1^{T})^{-1}s_1C_1}*\frac{t(I-A_0^{*}\circ A_1^{T})^{-1}s_1C_1}{t(I-A_1^{*}\circ A_1^{T})^{-1}s_1C_1}$	$factor\ 2_{0\rightarrow 1}^{2}=\frac{e_1^{\prime}\ (I-A_1^{*}\circ A_0^{T})^{-1}s_0C_0}{e_1^{\prime}\ (I-A_0^{*}\circ A_0^{T})^{-1}s_0C_0}*$ $\frac{t(I-A_0^{*}\circ A_0^{T})^{-1}s_0C_0}{t(I-A_1^{*}\circ A_0^{T})^{-1}s_0C_0}$
Factor 3: change in A^{T}, trade effect in intermediate inputs	$factor\ 3_{0\rightarrow 1}^{1}=$ $\frac{e_0^{\prime}\ (I-A_0^{*}\circ A_1^{T})^{-1}s_1C_1}{e_0^{\prime}\ (I-A_0^{*}\circ A_0^{T})^{-1}s_1C_1}*\frac{t(I-A_0^{*}\circ A_0^{T})^{-1}s_1C_1}{t(I-A_0^{*}\circ A_1^{T})^{-1}s_1C_1}$	$factor\ 3_{0\rightarrow 1}^{2}=\frac{e_1^{\prime}\ (I-A_1^{*}\circ A_1^{T})^{-1}s_0C_0}{e_1^{\prime}\ (I-A_1^{*}\circ A_0^{T})^{-1}s_0C_0}*$ $\frac{t(I-A_1^{*}\circ A_0^{T})^{-1}s_0C_0}{t(I-A_1^{*}\circ A_1^{T})^{-1}s_0C_0}$
Factor 4: change in s, structural change effect in final demand	$factor\ 4_{0\rightarrow 1}^{1}=$ $\frac{e_0^{\prime}\ (I-A_0^{*}\circ A_0^{T})^{-1}s_1C_1}{e_0^{\prime}\ (I-A_0^{*}\circ A_0^{T})^{-1}s_0C_1}*\frac{t(I-A_0^{*}\circ A_0^{T})^{-1}s_0C_1}{t(I-A_0^{*}\circ A_0^{T})^{-1}s_1C_1}$	$factor\ 4_{0\rightarrow 1}^{2}=\frac{e_1^{\prime}\ (I-A_1^{*}\circ A_1^{T})^{-1}s_1C_0}{e_1^{\prime}\ (I-A_1^{*}\circ A_1^{T})^{-1}s_0C_0}*$ $\frac{t(I-A_1^{*}\circ A_1^{T})^{-1}s_0C_0}{t(I-A_1^{*}\circ A_1^{T})^{-1}s_1C_0}$
Factor 5: change in C, total final demand effect	$factor\ 5_{0\rightarrow 1}^{1}=$ $\frac{e_0^{\prime}\ (I-A_0^{*}\circ A_0^{T})^{-1}s_0C_1}{e_0^{\prime}\ (I-A_0^{*}\circ A_0^{T})^{-1}s_0C_0}*\frac{t(I-A_0^{*}\circ A_0^{T})^{-1}s_0C_0}{t(I-A_0^{*}\circ A_0^{T})^{-1}s_0C_1}$	$factor\ 5_{0\rightarrow 1}^{2}=\frac{e_1^{\prime}\ (I-A_1^{*}\circ A_1^{T})^{-1}s_1C_1}{e_1^{\prime}\ (I-A_1^{*}\circ A_1^{T})^{-1}s_1C_0}*$ $\frac{t(I-A_1^{*}\circ A_1^{T})^{-1}s_1C_0}{t(I-A_1^{*}\circ A_1^{T})^{-1}s_1C_1}$

Where $factor\ i_{0\rightarrow 1}^{1}$ and $factor\ i_{0\rightarrow 1}^{2}$ denote factor i between year 0 and 1 based on the first and second decomposition method ($i=1,2,3,4\ and\ 5$). Similarly, the share of intensity between two years can be viewed as a product of these five decomposition factors:

$$\frac{Intensity\ in\ the\ year\ 1}{Intensity\ in\ the\ year\ 0} = \frac{\dfrac{E_1}{t(I - A_1^* \circ A_1^T)^{-1} s_1 C_1}}{\dfrac{E_0}{t(I - A_0^* \circ A_0^T)^{-1} s_0 C_0}} = \prod_{i=1}^{5} (factor\ i_{0\to1}^{1}) = \prod_{i=1}^{5} (factor\ i_{0\to1}^{2})$$

Similarly, $\frac{Intensity\ in\ the\ year\ 1}{Intensity\ in\ the\ year\ 0}$ is compared to 1:

$$\frac{Intensity\ in\ the\ year\ 1}{Intensity\ in\ the\ year\ 0}: \begin{cases} if > 1: more\ energy\ (or\ emission) intensive\ in\ the\ sector\ in\ year\ 1\ than\ in\ year\ 0; \\ if = 1: no\ changes\ in\ energy\ (or\ emission) intensity\ between\ year\ 1\ and\ year\ 0; \\ if < 1: less\ energy\ (or\ emission) intensive\ in\ the\ sector\ in\ year\ 1\ than\ in\ year\ 0. \end{cases}$$

Following the same logic, the final version of intensity decomposition equation is illustrated below.

$$log\left(\frac{2009\ intensity\ in\ 1995\ US\$}{1995\ intensity\ in\ 1995\ US\$}\right) = \frac{1}{2}\sum_{i=1}^{5}\left[\ log\left(\prod_{t=1995}^{2008} factor\ i_{t\to t+1}^{1}\right) + log\left(\prod_{t=1995}^{2008} factor\ i_{t\to t+1}^{2}\right)\ \right] \quad (4)$$

Where the value of $\frac{1}{2}\left[log\left(\prod_{t=1995}^{2008} factor\ i_{t\to t+1}^{1}\right) + log\left(\prod_{t=1995}^{2008} factor\ i_{t\to t+1}^{2}\right)\right]$ is the log point of factor i in the decomposition of aggregate energy intensity (or emission intensity) between year 1995 and 2009, $i = 1, 2, 3, 4\ and\ 5$.

3.4 Understanding the decomposition factors

After completing all identical algebraic transformations illustrated above, we obtain five factors for the structural decompositions of energy consumption, total emissions, aggregate energy intensity and emission intensity. We now turn to gaining in-depth understanding of the economic implications of these five factors.

3.4.1 Decompositions of energy consumption and total emissions

In the decompositions of energy consumption and total emissions, Factor 1, the impact related to changes in the intensity matrix *e* (energy consumption or emissions per unit of gross output by sector) when all other factors remain constant, is closely related to energy efficient (or emission reducing) technology. The second factor denotes the impact related to changes in matrix A^*, which measures the inter-industry structure, that is, the change in quantity of intermediate inputs within sectors required to produce one unit of gross output. It can reflect technological change related to productivity or factor substitution. Factor 3, the impact related to changes in matrix A^T, measures the trade structure in intermediate inputs within sectors (sectors' trade compositions). The fourth factor, the impact related to changes in matrix s, indicates the change in the consumption structure in economies' final demand. It can determine changes in the sectors' shares in the final demand of the economy. It might be related to product substitution or changing preference. The fifth factor, the impact related to changes in economies' total final demand matrix C, determines the impact of economic development (how many products are consumed in final demand).

The five factors summarize five aspects of economic activity based on data at a relatively "micro" level (sectoral data across various economies) and have the same expressions in either the decomposition of energy consumption or the decomposition of total emissions. Yet the outcome variables of this type of decomposition differ: one is the aggregate amount of energy consumption of a given sector, a given industry or a given manufacturing technological group for the global economy; the other is total emissions. Note that change in energy consumption does not necessarily display the same patterns as change in total emissions. Factor 1 in energy consumption decompositions is interpreted as the impact caused by changes in energy intensity on energy consumption, while the same factor in decompositions of total emissions is the impact related to changes in emission intensity on total emissions. The other four factors measure the same aspects in both types of decompositions, but should be interpreted as impacts of these four factors on the dynamics of energy consumption and total emissions, respectively. The logic behind such an interpretation is that these four factors describe economic activities in a general sense (productivity, trade structure, final demand consumption structure and total final demand) and can simultaneously lead to changes in energy consumption as well as in total emissions[12]. Performing two types of decomposition with the same four factors can reflect different aspects of the development process.

3.4.2 Decompositions of aggregate energy intensity and emission intensity

The interpretation of the five factors in the decomposition of aggregate energy intensity and emission intensity is similar to those in the decomposition of energy consumption (or total emissions). Factor 1, the impact related to changes in intensity, has the same expression as that in the decomposition of energy consumption (or total emissions), which reflects the impact of energy efficient (or emission reducing) technology on aggregate energy intensity (or emission intensity). But the change in aggregate energy or emission intensity can be caused by some other factors that are not related to energy efficient (or emission reducing) technology, that is, inter-industry

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[12] For example, if consumers' preference shifted to a less energy intensive product and production shifted to this new product as well, total energy consumption might decrease and there might be a change in total emissions (note that an energy intensive product is not necessarily an emission intensive product).

structural effect, trade effect in intermediate inputs, structural change effect in final demand and total final demand effect. It implies that changes in aggregate energy intensity (or emission intensity) might be caused without technological change (for example, changes in consumer preference or trade structure).

Similarly, five factors in this type of decomposition describe the aggregate intensity change in the variables from a sectoral perspective. Note that change in aggregate energy intensity might have different patterns than change in aggregate emission intensity. Factor 1 in aggregate energy intensity decomposition shows the impact related to change in sectoral energy intensity on aggregate energy intensity, while Factor 1 in emission intensity decomposition measures the impact related to sectoral energy intensity on aggregate emission intensity. The other four factors (productivity, trade structure, final demand consumption structure and total final demand) can result in various consequences, and in both kinds of intensity decomposition, they reflect impacts on aggregate energy intensity and aggregate emission intensity, respectively, in order to describe both aspects of development.

For each of the five decomposition factors listed in all the decompositions above, similarly a value larger than 1 signifies a positive effect of the factor on the right-hand outcome side. The factor with a value less than 1 would lower the increases of the outcomes. The closer the value is to 1, the weaker the impact of the factor. By applying such criteria, the influencing factor or factors can be clearly identified.

Using Equation (2) and Equation (4), the decomposition results are aggregated by sector instead of by the economy[13]. The results for the global economy are aggregated into three industrial groups:

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[13] To do this, the premultiplication of the sectoral aggregation matrix S^{sum} needs to be applied to every term on both the left- and right-hand side of Equation (2) and Equation (4). The matrix S^{sum} is constructed as follows:
For the value in Row n and Column m ($n = 1,2,\cdots 35; m = 1,2,\cdots,1435$),

$$S_{n,m}^{sum} = \begin{cases} 1, \mathit{if\ the\ trade\ flow's\ sector\ of\ origin\ and\ destination\ sector\ are\ identical}; \\ \qquad 0, \mathit{otherwise}. \end{cases}$$

Note that n here represents the sector of the world. Following a similar logic, the aggregation matrices for calculating the results for industrial groups and manufacturing subgroups can be constructed.
Intuitively, the formation of S^{sum} is:

	Sector 1 of Economy 1	Sector 2 of Economy 1	……	Sector 1 of Economy 2	……
Sector 1	1	0	……	1	……
Sector 2	0	1	……	0	……
……	……	……	……	……	……

primary industry, manufacturing and services. Global manufacturing is aggregated into three technological groups: low-tech manufacturing, medium-/low-tech manufacturing and medium-/high-tech manufacturing.

4. Results

Equation (2) is derived to decompose the relative changes of energy consumption and total emissions over 1995 to 2009. Equation (4) is used for the decompositions of aggregate energy intensity and total emission intensity over 1995 to 2009. Table 1 below is a collective illustration of the decomposition results of energy consumption, aggregate energy intensity, total emissions and total emission intensity by aggregated industry and by manufacturing technological group. In Table 1, the first column represents relative change of energy consumption, aggregate energy intensity, total emissions and total emission intensity, followed by other five decomposition factors. The product of five decomposition factors should in principle be equal to the relative change between 1995 and 2009, but there is a very small error in computing. Appendix 5 provides a more detailed version of decomposition results by sector listed in the WIOD.

According to Table 1, all industrial groups and manufacturing technological groups show an increase in energy consumption and an improvement in energy efficiency. Except for the low-tech manufacturing group that generated fewer emissions in 2009, total emissions increased in all other manufacturing technological groups and industrial groups. Total emission intensity was lower in all categories. Factor 1, the intensity effect, was lower than 1 in all cases, which implies that energy efficient (or emission reducing) technology contributes to reducing all four indicators. The other four factors are quite dynamic across industrial groups and manufacturing technological groups. The details of Table 1 will be discussed later.

Table 1 Decomposition results of energy consumption, aggregate energy intensity, total emissions and total emission intensity over 1995 to 2009

		Ratio between 2009 and 1995	Factor 1: change in e: intensity effect	Factor 2: change in A^*: inter-industry structural effect	Factor 3: change in A^T: trade effect in intermediate inputs	Factor 4: change in s: structural change effect in final demand	Factor 5: change in C: total final demand effect
Energy consumption decomposition	Total manufacturing	1.2209	0.7733	0.9953	1.0093	0.9744	1.6129
	Low-tech manufacturing	1.1431	0.7691	0.9424	1.0145	0.9215	1.6870
	Medium/low-tech manufacturing	1.2242	0.7809	0.9954	1.0083	0.9748	1.6024
	Medium/high-tech manufacturing	1.2471	0.7027	1.0353	1.0173	1.0109	1.6668
	Primary industry	1.3682	0.8385	1.1705	0.8751	0.9372	1.6996
	Services	1.4619	0.7472	1.1375	1.0150	1.0052	1.6859
Aggregate energy intensity decomposition	Total manufacturing	0.7641	0.7733	0.9688	0.9969	0.9990	1.0242
	Low-tech manufacturing	0.8572	0.7691	0.9790	1.0072	1.0440	1.0827
	Medium/low-tech manufacturing	0.8103	0.7809	1.0149	0.9967	1.0200	1.0056
	Medium/high-tech manufacturing	0.6596	0.7027	0.9341	1.0007	0.9495	1.0575
	Primary industry	0.8051	0.8385	1.0532	0.8601	1.0627	0.9974
	Services	0.9296	0.7472	1.0691	1.0186	0.9872	1.1573
Total emissions decomposition	Total manufacturing	1.1633	0.6481	0.9923	1.0282	0.9906	1.7761
	Low-tech manufacturing	0.9730	0.6216	0.9728	1.0277	0.9216	1.6986
	Medium/low-tech manufacturing	1.2371	0.6923	0.9721	1.0288	0.9915	1.8021
	Medium/high-tech	1.0793	0.5372	1.0808	1.0263	1.0421	1.7381

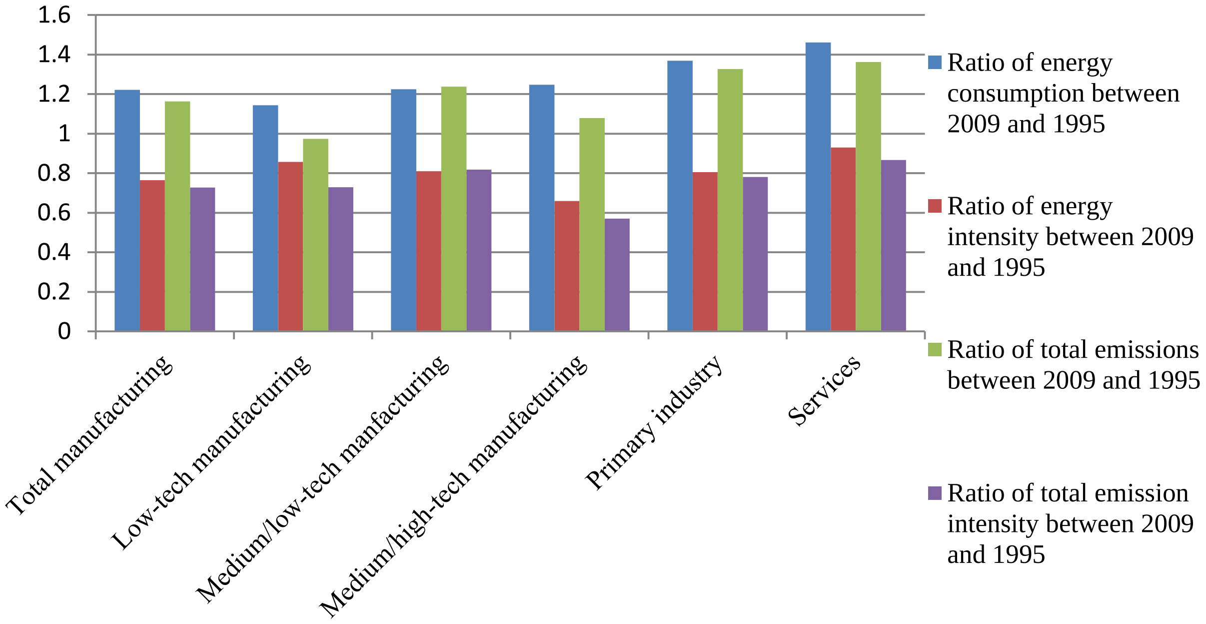
	manufacturing						
	Primary industry	1.3261	0.8300	1.0789	0.9248	0.8922	1.7948
	Services	1.3627	0.6422	1.1514	1.0301	1.0351	1.7286
Total emission intensity decomposition	Total manufacturing	0.7281	0.6481	0.9658	1.0156	1.0156	1.1278
	Low-tech manufacturing	0.7297	0.6216	1.0106	1.0204	1.0441	1.0902
	Medium/low-tech manufacturing	0.8189	0.6923	0.9911	1.0171	1.0375	1.1310
	Medium/high-tech manufacturing	0.5709	0.5372	0.9752	1.0096	0.9787	1.1028
	Primary industry	0.7804	0.8300	0.9708	0.9089	1.0117	1.0532
	Services	0.8666	0.6422	1.0821	1.0338	1.0166	1.1866

Instead of looking in depth into specific sectors, this paper focuses on results at aggregated industry level, because they can provide important information about common patterns shared by sectors with similar characteristics. More importantly, this study focuses specifically on the technological level of manufacturing sectors due to the key role technology plays in development.

4.1 Performance: energy consumption, aggregate energy intensity, total emissions and total emission intensity

This section summarizes performance in terms of energy consumption, aggregate energy intensity, total emissions and total emission intensity by aggregated industry and by manufacturing technological level between 1995 and 2009 on the basis of the decomposition results presented in Table 1. Figure 1 below compares the performance results in a more intuitional way.

Figure 1Performance in energy consumption, aggregate energy intensity, total emissions and total emission intensity over 1995 to 2009



As shown in Figure 1 and Table 1, the largest increases in both energy consumption and total emissions are found in services, that is, by 46.19 per cent and 36.27 per cent, respectively, compared to 1995. The smallest increase in energy consumption as well as in total emissions was recorded in manufacturing, namely by 22.09 per cent and 16.33 per cent, respectively, in 2009 compared to 1995. In primary industry, energy consumption grew by 36.83 per cent in 2009, and the growth of total emissions was 32.61 per cent. Both values are between the levels of manufacturing and services. For the performance of energy intensity and total emission intensity, the changes in all industries were below 1 in 2009, which means that energy efficiency and total emission efficiency improved. Interestingly, the same pattern still holds: the best improvement in energy efficiency as well as in total emission efficiency was achieved in manufacturing, i.e. a 23.59 per cent decrease in energy intensity and a 27.19 per cent decrease in total emission intensity, respectively. In relative terms, the sector in which the least improvements were recorded was services, which saw a 7.04 per cent decrease in energy intensity and a 13.3 per cent decrease in total emission intensity. The explanation for such phenomena is the following. On the one hand, due to structural change generated by economic development, economic resources have been continuously shifted to services from industries, leading to an increasingly large economic scale in services which requires a growing amount of energy and produces more emissions. On the other hand, in relative terms, manufacturing is more technologically intensive, and technological change and innovation play a more crucial role in manufacturing. For example, energy efficient or emission reducing technologies are much easier to apply in manufacturing.

Figure 1 presents the performance of three subgroups of manufacturing classified by technological level, namely low-tech manufacturing, medium-/low-tech manufacturing and medium-/high-tech manufacturing. Interestingly, the changes in energy consumption and total emissions in low-tech manufacturing were lowest: a 14.13 per cent increase in energy consumption but a 2.7 per cent decrease in total emissions. Low-tech manufacturing is the only subgroup in which a decrease in total emissions was observed. The largest increase in energy consumption was found in medium-/high-tech manufacturing (24.71 per cent); the largest increase in total emissions was in medium-/low-tech manufacturing (23.71 per cent), which showed a very high level of energy consumption growth (22.42 per cent). In medium-/high-tech manufacturing, total emissions increased at a much smaller level in 2009 by 7.93 per cent. Unsurprisingly, medium-/high-tech manufacturing indicated the largest improvement in reducing energy intensity and emission intensity. One possible explanation is industrial upgrading, which leads to a shift in resources from low-tech manufacturing to technologically superior subgroups.

4.2 Decompositions of energy consumption and total emissions

Based on the decomposition results in Table 1, this section provides a more clear-cut illustration of all the factors' effects by transferring them into log points, as shown in Figure 2 and Figure 3. In this section, the outcome variable is energy consumption or total emissions.

4.2.1 Common pattern

According to both bar charts, there are several crucial findings. First, for every aggregated industry and for every manufacturing subgroup classified by technological level, the most influencing decomposition factor contributing positively to increasing energy consumption and total emissions is Factor 5, the impact related to changes in economies' total final demand. One convincing explanation is that with the improvement in living standard as well as the increasing global population, demand for agricultural, manufacturing products and services has been greatly stimulated, resulting in growing economic scales in the sectors. More energy inputs need to be consumed and more emissions are produced in the production process. For energy decompositions, the strongest Factor 5 is found in primary industry (1.6996) and low-tech manufacturing among the manufacturing subgroups (1.6870). For total emissions decompositions, still, primary industry has the most influencing Factor 5 (1.7948), while surprisingly among the manufacturing subgroups, Factor 5 of the medium-/low-tech manufacturing is the strongest (1.8021).

Second, for aggregated industry and manufacturing subgroups, the overwhelming factor that contributes to the reduction in both energy consumption and total emissions is Factor 1, the impact caused by changes in energy intensity or total emission intensity. This factor is closely related to energy efficient or emission reducing technologies. Due to innovation, diffusion and application of such types of technologies, the energy inputs consumed and the emissions generated to obtain one unit of gross output have been significantly lowered, thus slowing down the growth of energy consumption and total emissions. The strongest Factor 1 in energy consumption decomposition for aggregated industry is services (0.7472); in total emissions decomposition it is medium-/high-tech manufacturing for the manufacturing subgroups (0.7027). Clearly, technology plays a significant role in decreasing the growth of energy consumption and total emissions, especially in technologically intensive sectors.

Third, other decomposition factors seem to have a less influential or even neutral effect in shaping the dynamics of energy consumption and total emissions. For aggregated industries, Factor 2, the impact related to changes in inter-industry structure, is relatively stronger in primary industry and services, leading to an increase in both energy consumption and total emissions. This most likely means that, driven by increasing market demand, market agents in both industries significantly improved their productivity, resulting in expansions in energy and emissions-related production or businesses. Specifically, for primary industry, both Factor 3 (the impact due to changes in trade structure in intermediate inputs) and Factor 4 (the impact related to structural changes in economies' total final demand) are detrimental to the growth of energy consumption and total emissions, which most likely implies that less energy or emissions-intensive inputs have been consumed through trade in the production process of primary industry, and in final demand, the market shares of this industry shifted to other industries. For manufacturing subgroups, perhaps due to industrial upgrading, market shares of low-tech manufacturing shrunk, as shown by the negative effect of Factor 4 in the decompositions of energy consumption and total emissions.

More interestingly, in every aggregated industry and manufacturing subgroup, Factor 1 and Factor 5 affect the dynamics of energy consumption and total emissions in the opposite direction; Factor 1 is the factor that always leads to declines of outcome variables and Factor 5 leads to increases. Accordingly, the increases in energy consumption or the total emissions caused by Factor 5 can partially or largely be offset by Factor 1. Consequently, though energy consumption and total emissions increased, they could have increased by a much higher percentage. We refer here to the detection of such a common pattern in decompositions of energy consumption and total emissions as compensation effect. Empirically, the compensation effect convincingly demonstrates how it is possible to achieve sustainable development-reducing energy intensity and total emission intensity through technological change. Similar findings are found in Weber's (2009) study on the U.S. economy from 1997 to 2002 and Zhong's (2014) study on energy consumption decompositions at the level of the economy using the same database. Our study covers an additional aspect of emissions and demonstrates that the compensation effect still holds at sectoral level in the decompositions of both energy consumption and total emissions.

Figure 2Decomposition of energy consumption over 1995 to 2009

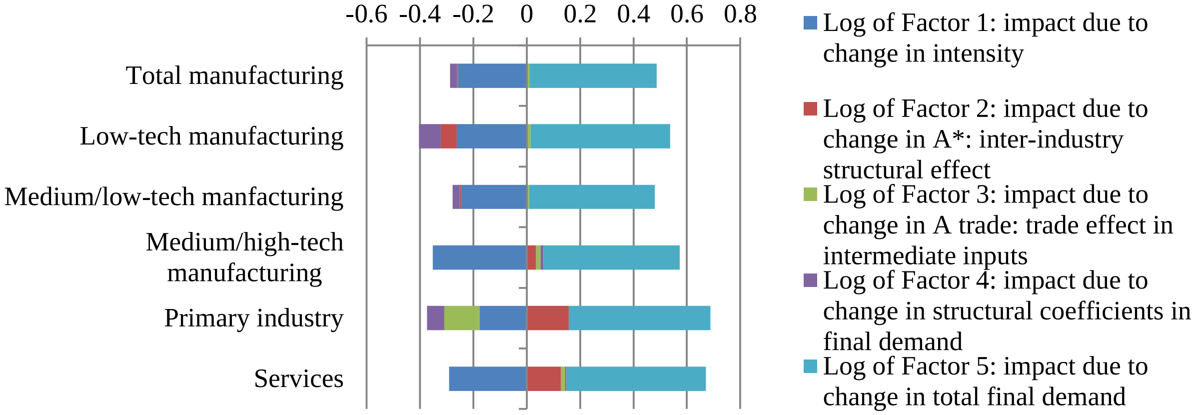
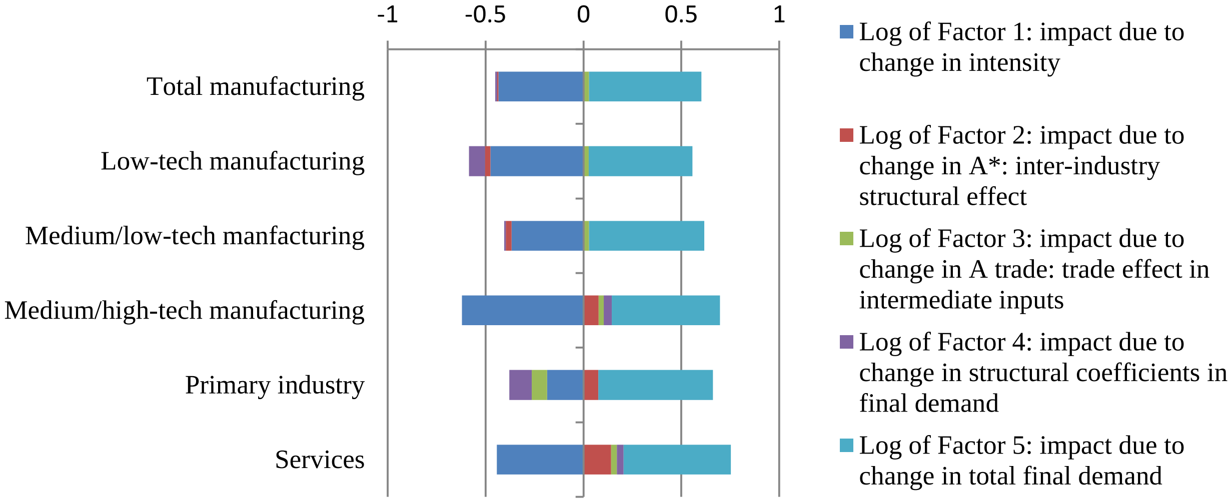


Figure 3Decomposition of total emissions over 1995 to 2009



4.3 Decompositions of energy intensity and total emission intensity

We can zoom in on the dynamics of aggregate energy intensity and total emission intensity by decomposing their relative changes during the period under research. Table 1 provides decomposition results of aggregate energy intensity and total emission intensity from 1995 to 2009. In this section, the outcome variable is aggregate energy intensity or total emission intensity. Similarly, the log point version of both bar charts is illustrated in Figure 4 and Figure 5.

The most important finding is that in both decompositions of aggregate energy intensity and total emission intensity the overwhelming factor is Factor 1, that is, the impact due to changes in intensity within economic sectors, which implies that energy or emission efficiency-improving technological change which occurs within sectors is the driving factor for reducing aggregate energy intensity and total emission intensity. In terms of magnitude, Factor 1 of medium-/high-tech manufacturing in both types of decompositions is the strongest one compared to the other manufacturing subgroups and aggregated industries. The other factors that are not related to energy efficient (or emission reducing) technology generally have a weaker impact on changes in aggregate energy intensity or total emission intensity.

Factor 3, the trade effect in intermediate inputs, plays a role in reducing the aggregate energy intensity and total emission intensity of primary industry. This finding is consistent with Section 4.2, namely that less energy and emission intensive inputs are consumed through trade for production purpose due to changes in consumer preferences and product substitution. This particular case demonstrates that aggregate energy intensity and total emission intensity could be reduced without technological change.

Factor 5, the economies' total final demand effect, causes an increase in aggregate energy intensity and total emission intensity for nearly all categories except for primary industry in the energy consumption decomposition. But the impact of the only negative Factor 5 is very weak (about 0.9974), which only causes a small fluctuation on the outcomes. A weak final demand effect in intensity decompositions is reasonable. Compared to the same factor in the decompositions of energy consumption or total emissions, this factor in the intensity decompositions has an additional weight of gross output ratio, which is designed to eliminate the impact of discrepancy in total energy consumption and total emissions allowing for a comparison of different sectors. The final demand effect is closely related to the scale of economy: logically, sectors with larger gross outputs consume more energy and generate more emissions.

Figure 4Decomposition of aggregate energy intensity over 1995 to 2009

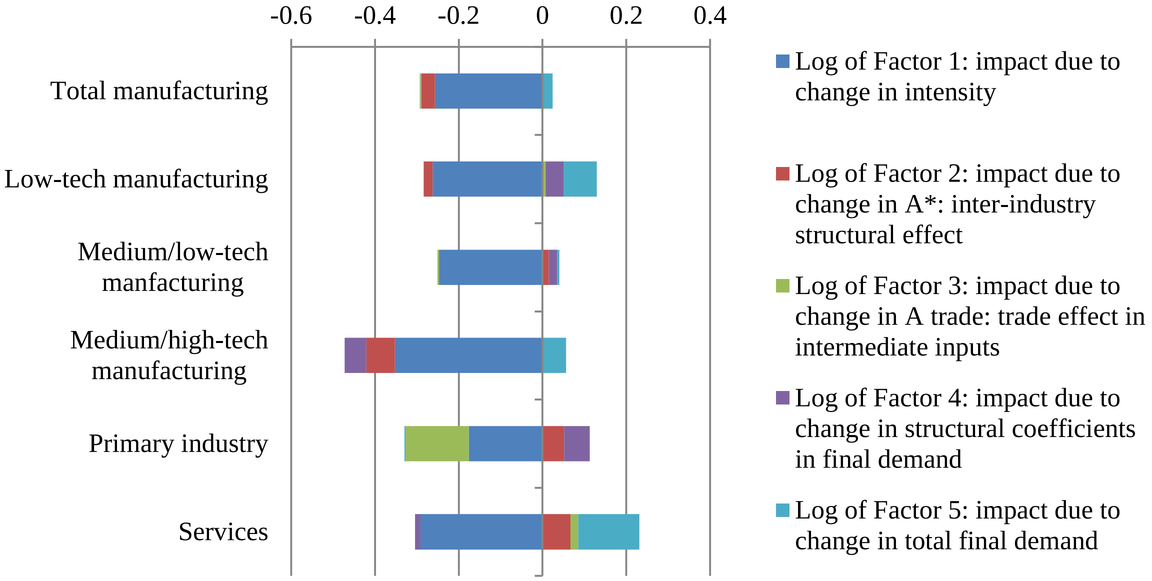
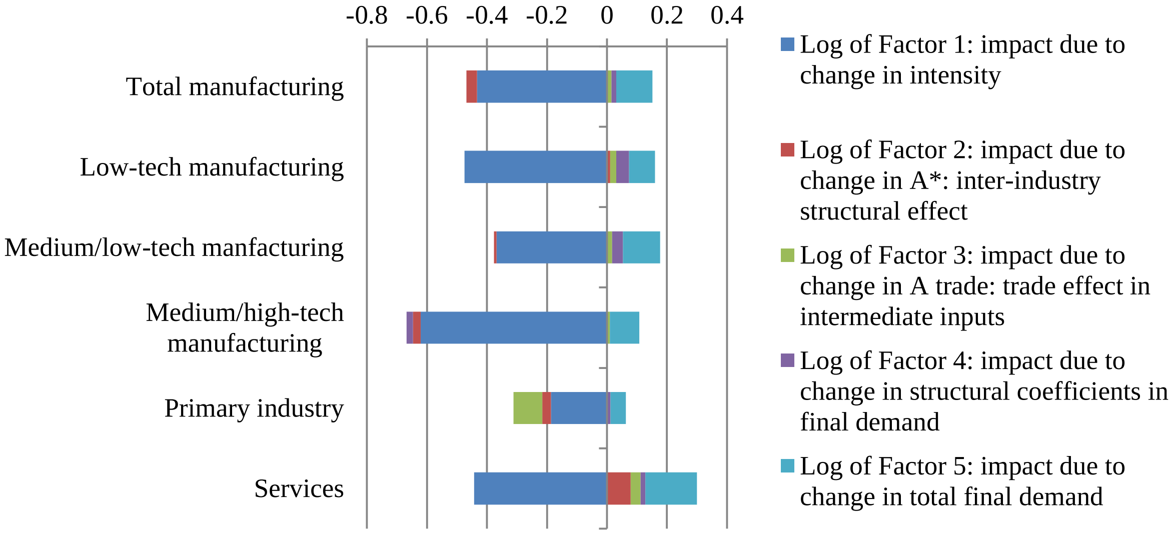


Figure 5Decomposition of total emission intensity over 1995 to 2009



5. Conclusions

This study empirically investigates the historical dynamics of energy consumption, aggregate energy intensity, total emissions and total emission intensity at sectoral level from 1995 to 2009 based on the new World Input-Output Database (WIOD). Applying the structural decomposition approach, the relative changes in the relevant economic variables over time during the period under research are broken down into five crucial contributing factors: intensity effect, inter-industry structural effect, trade effect in intermediate inputs, structural change effect in final demand and total final demand effect. Additionally, a chain mechanism is designed for deflating purposes. We find empirical evidence that supports the implementation of UNIDO's ISID concept.

The crucial findings at sectoral level include (1) the compensation effect found in both energy consumption and total emissions decompositions, namely that the increases in energy consumption and total emissions stimulated by total final demand can be partially or even largely offset by the negative effect of intensity changes caused by efficiency-related technological change; and (2) the overwhelming role of intensity effect within sectors in reducing aggregate energy intensity or total emission intensity, which is found in intensity decompositions. Our findings are very reasonable. If increasing outputs constantly requires an increase in inputs, the scarcity of resources (e.g. fossil fuels) along with rising environmental burdens logically implies the end of economic growth, unless we consume the resources in a more efficient way. These findings suggest that efficiency-based technological change should be the focal point for achieving ISID.

Performance in energy consumption, aggregate energy intensity, total emissions and total emission intensity can shed additional light. Compared to primary industry and services, the increases in energy consumption and total emissions in manufacturing are the smallest, most likely due to the relatively larger decline in energy intensity and total emission intensity. This finding implies a paradigm for development that can incorporate UNIDO's ISID initiative: in the context of structural change dynamics, the key for achieving economic sustainability is to slow down the growth of manufacturing energy consumption and total emissions through technological change, given the fact that manufacturing is the largest contributor to global energy consumption and total emissions. For manufacturing subgroups, the medium-/low-tech manufacturing warrants more attention when designing industrial policies, because it has the second largest increase in energy consumption and the highest increase in total emissions compared to the other manufacturing subgroups, but shows relatively less improvements in energy intensity and total emission intensity. Accordingly, it is recommendable and benificial for industrial policymakers to design policies in favour of technological change toward higher efficiency in medium-/low-tech manufacturing.

Appendix 1: Deriving the decomposition factors between two consecutive years

Structural decompositions of energy consumption and total emissions

Following the basic input-output equations and linear algebra notations (Miller & Blair, 1985), E, the scalar of energy consumption or total emissions, can be simply defined as:

$$E = e'Lf \qquad (1)$$

Where:

$\mathrm{e}' = [\mathrm{e}_1, \cdots, \mathrm{e}_{1435}]$, which is a vector of sectors' energy inputs (TJ) per US dollar of gross output or total emissions (tonnes) per US dollar of gross output. Note that WIOT comprises 41 economies and each of them includes 35 sectors.

L is the Leontief inverse matrix (1435*1435 square matrix), defined as $L = (I - A)^{-1}$. I is a1435*1435 identity matrix and A denotes the matrix of intermediate inputs per unit of gross output (1435*1435 matrix), that is, the technical coefficient matrix defined as $\mathrm{A} = \mathrm{Z} * (\hat{\mathrm{x}})^{-1}$. Matrix Z is the intermediate inputs matrix in WIOT (1435*1435 matrix). $\hat{\mathrm{x}}$ stands for the diagonal matrix of x, the vector of sectors' gross outputs, $\mathrm{x}' = [\mathrm{x}_1, \cdots, \mathrm{x}_{1435}]$.

$\mathrm{f}' = [\mathrm{f}_1, \cdots, \mathrm{f}_{1435}]$, where f_i indicates the total outputs of the *i-th* sector spent on final demand ($i = 1, 2, \cdots, 1435$).

Then, between two consecutive years 0 and 1, the relative change of energy consumption or total emissions is:

$$\frac{E_1}{E_0} = \frac{e_1' L_1 f_1}{e_0' L_0 f_0} \qquad (2)$$

To estimate the impacts of e', L and f on $\frac{E_1}{E_0}$, the control variable technique is applied to Equation (2):

$$\frac{E_1}{E_0} = \frac{e_1' L_1 f_1}{e_0' L_1 f_1} * \frac{e_0' L_1 f_1}{e_0' L_0 f_1} * \frac{e_0' L_0 f_1}{e_0' L_0 f_0} \qquad (3)$$

On the basis of Dietzenbacher et al.'s (2000) approach to further decompose matrix A, matrix L becomes:

$$L = (I - A^{*} \circ A^{T})^{-1} \qquad (4)$$

Where:

A^{*} indicates a 1435*1435 matrix of aggregate intermediate inputs per unit of gross output by sector by economy, formally defined as $\forall$ r: $[A^{*}]^{r\,s}_{i\,j} = \sum_{1}^{41} A^{r\,s}_{i\,j}$, for trade flows from Sector i in Economy r to Sector j in Economy s ($i, j = 1, 2, \cdots, 35;\ r, s = 1, 2, \cdots, 41$). Mathematically, $A^{*} = A^{sum} * A$. Here, matrix A^{sum} is an aggregation matrix (1435*1435 matrix) constructed as follows[14]:

For the value in Row n Column m ($n, m = 1, 2, \cdots, 1435$),

$$A^{sum}_{n,m} = \begin{cases} 1, if\ the\ trade\ flow's\ sector\ of\ origin\ and\ destination\ sector\ are\ identical; \\ 0, otherwise. \end{cases}$$

Note that here n denotes the sector in Economy r ($r = 1, 2, \cdots, 41$).

A^{T} is a 1435*1435 matrix of trade coefficients in intermediate inputs, which is formally defined as $[A^{T}]^{r\,s}_{i\,j} = A^{r\,s}_{i\,j} / [A^{*}]^{r\,s}_{i\,j}$. Then $A = A^{*} \circ A^{T}$; ° denotes the Hadamard product.

Moreover, taking into account the impacts at economy level, f can be rewritten as follows:

$$f = sC \qquad (5)$$

Where:

s is the structural coefficient matrix in final demand (1435*41 matrix), where $s_{n,m}$ denotes the share of Sector n in the total final demand of Economy m ($n = 1, 2, \cdots, 1435;\ m = 1, 2, \cdots, 41$).

C is a vector of economies' total final demand (41*1 vector).

Substituting Equation (4) and Equation (5) into Equation (3) yields:

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[14] The formation of A^{sum} is:

	Sector 1 of Economy 1	Sector 2 of Economy 1	……	Sector 1 of Economy 2	……
Sector 1 of Economy 1	1	0	……	1	……
Sector 2 of Economy 1	0	1	……	0	……
……	……	……	……	……	……

$$\frac{E_1}{E_0} = \frac{e_1' L_1 f_1}{e_0' L_1 f_1} * \frac{e_0'\left(I - A_1^* \circ A_1^T\right)^{-1} f_1}{e_0'\left(I - A_0^* \circ A_1^T\right)^{-1} f_1} * \frac{e_0'\left(I - A_0^* \circ A_1^T\right)^{-1} f_1}{e_0'\left(I - A_0^* \circ A_0^T\right)^{-1} f_1} * \frac{e_0' L_0 s_1 C_1}{e_0' L_0 s_0 C_1} * \frac{e_0' L_0 s_0 C_1}{e_0' L_0 s_0 C_0} \tag{6}$$

The structural decomposition equations are not unique (Dietzenbacher & Los, 1998). Equation (6) only shows one of the possibilities. In fact, if the subscripts are reversed simultaneously for those components which are identical in both numerator and denominator, Equation (6) still definitely holds, as shown below:

$$\frac{E_1}{E_0} = \frac{e_1' L_0 f_0}{e_0' L_0 f_0} * \frac{e_1'\left(I - A_1^* \circ A_0^T\right)^{-1} f_0}{e_1'\left(I - A_0^* \circ A_0^T\right)^{-1} f_0} * \frac{e_1'\left(I - A_1^* \circ A_1^T\right)^{-1} f_0}{e_1'\left(I - A_1^* \circ A_0^T\right)^{-1} f_0} * \frac{e_1' L_1 s_1 C_0}{e_1' L_1 s_0 C_0} * \frac{e_1' L_1 s_1 C_1}{e_1' L_1 s_1 C_0} \tag{7}$$

For simplicity, Equation (6) and Equation (7) are viewed as products of five factors which are expressed as follows:

$$\frac{E_1}{E_0} = \prod_{i=1}^{5}\left(Factor\ i_{0\rightarrow 1}^{1}\right) \tag{8}$$

and

$$\frac{E_1}{E_0} = \prod_{i=1}^{5}\left(Factor\ i_{0\rightarrow 1}^{2}\right) \tag{9}$$

Where $Factor\ i_{0\rightarrow 1}^{1}$ and $Factor\ i_{0\rightarrow 1}^{2}$ indicate factor i between year 0 and 1 obtained by using the first and second decomposition method, respectively ($i = 1, 2, 3, 4\ and\ 5$).

Structural decompositions of aggregate energy intensity and total emission intensity

To decompose aggregate energy intensity and total emission intensity, by transferring component Lf to the left-hand side, the expression of aggregate energy intensity or total emission intensity can be obtained by rewriting Equation (2):

$$\frac{\frac{E_1}{tL_1 f_1}}{\frac{E_0}{tL_0 f_0}} = \frac{E_1}{E_0} * \frac{tL_0 f_0}{tL_1 f_1} \tag{10}$$

Where t is a 1*1435 aggregation vector where every element is 1, so that tLf becomes a scalar.

By introducing A^*, A^T, s and C and employing the same control variable technique, Equation (10) can be decomposed into the following two different versions through some identical transformations in algebra:

$$\frac{\frac{E_1}{tL_1 f_1}}{\frac{E_0}{tL_0 f_0}} = \prod_{i=1}^{5}(factor\ i_{0\rightarrow 1}^{1}) = \prod_{i=1}^{5}(factor\ i_{0\rightarrow 1}^{2}) \qquad (11)$$

Where $factor\ i_{0\rightarrow 1}^{1}$ and $factor\ i_{0\rightarrow 1}^{2}$ denote factor i between year 0 and 1 based on the first and second decomposition method ($i = 1, 2, 3, 4\ and\ 5$). The detailed decomposition factors are shown in Section 3.3.

Appendix 2: Using chain mechanism as the deflating strategy

For example, the first method for energy consumption / total emissions decomposition can be obtained through the following procedures:

Between 2009 and 2008, using the previous years' prices version of monetary data for 2009 and current prices version of monetary data for 2008:

$$\frac{E_{2009}}{E_{2008}} = Factor\ 1^{1}_{2008\rightarrow 2009} * Factor\ 2^{1}_{2008\rightarrow 2009} * \cdots * Factor\ 5^{1}_{2008\rightarrow 2009} \qquad \text{(Pair 1)}$$

Between 2008 and 2007, using the previous years' prices version of monetary data for 2008 and current prices version of monetary data for 2007:

$$\frac{E_{2008}}{E_{2007}} = Factor\ 1^{1}_{2007\rightarrow 2008} * Factor\ 2^{1}_{2007\rightarrow 2008} * \cdots * Factor\ 5^{1}_{2007\rightarrow 2008} \qquad \text{(Pair 2)}$$

Between 1996 and 1995, using the previous years' prices version of monetary data for 1996 and current prices version of monetary data for 1995:

$$\frac{E_{1996}}{E_{1995}} = Factor\ 1^{1}_{1995\rightarrow 1996} * Factor\ 2^{1}_{1995\rightarrow 1996} * \cdots * Factor\ 5^{1}_{1995\rightarrow 1996} \qquad \text{(Pair 14)}$$

There are 14 pairs of consecutive years between 1995 and 2009. Then, multiplying all equations, that is, (Pair 1), (Pair 2), ⋯, (Pair 14),

$$\frac{E_{2009}}{E_{2008}} * \frac{E_{2008}}{E_{2007}} * \cdots * \frac{E_{1996}}{E_{1995}} = \left(\prod_{t=1995}^{2008} Factor\ 1^{1}_{t\rightarrow t+1}\right) * \left(\prod_{t=1995}^{2008} Factor\ 2^{1}_{t\rightarrow t+1}\right) * \cdots * \left(\prod_{t=1995}^{2008} Factor\ 5^{1}_{t\rightarrow t+1}\right) \qquad (12)$$

Let component $\prod_{t=1995}^{2008} Factor\ i^{1}_{t\rightarrow t+1}$ denote the decomposition factor i obtained from the first method for energy consumption / total emissions decomposition between 1995 and 2009, $i = 1, 2, \cdots, 5$. Note that the equation above applies only for the first method. Following the same procedures, the second method for energy consumption / total emissions decomposition is the following[15]:

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[15] The procedures can be written in a more sophisticated way, as shown here: $\frac{E_{2009}}{E_{1995}} = \prod_{t=1995}^{2008} \frac{E_{t+1}}{E_t} = \prod_{i=1}^{5} \prod_{t=1995}^{2008} Factor\ i^{1}_{t\rightarrow t+1} = \prod_{i=1}^{5} \prod_{t=1995}^{2008} Factor\ i^{2}_{t\rightarrow t+1}$

$$\frac{E_{2009}}{E_{2008}} * \frac{E_{2008}}{E_{2007}} * \cdots * \frac{E_{1996}}{E_{1995}} = \left(\prod_{t=1995}^{2008} Factor\ 1_{t\to t+1}^{2}\right) * \left(\prod_{t=1995}^{2008} Factor\ 2_{t\to t+1}^{2}\right) * \cdots * \left(\prod_{t=1995}^{2008} Factor\ 5_{t\to t+1}^{2}\right) \qquad (13)$$

Here, component $\prod_{t=1995}^{2008} Factor\ i_{t\to t+1}^{2}$ indicates the decomposition factor i between 1995 and 2009 calculated by using the second method for energy consumption / total emissions decomposition, $i = 1, 2, \cdots, 5$.

For the structural decompositions of aggregate energy intensity and total emission intensity, applying the similar computing procedure yields:

$$\frac{\frac{E_{2009}}{tx_{2009}^{*}}}{\frac{E_{1995}}{tx_{1995}^{current}}} = \frac{2009\ intensity\ (2008\ US\$)}{2008\ intensity\ (2008\ US\$)} * \frac{2008\ intensity\ (2007\ US\$)}{2007\ intensity\ (2007\ US\$)} * \cdots * \frac{1996\ intensity\ (1995\ US\$)}{1995\ intensity\ (1995\ US\$)}$$

The first method for intensity decomposition is:

$$\frac{\frac{E_{2009}}{tx_{2009}^{*}}}{\frac{E_{1995}}{tx_{1995}^{current}}} = \frac{\frac{E_{2009}}{tx_{2009}^{pyp}}}{\frac{E_{2008}}{tx_{2008}^{current}}} * \frac{\frac{E_{2008}}{tx_{2008}^{pyp}}}{\frac{E_{2007}}{tx_{2007}^{current}}} * \cdots * \frac{\frac{E_{1996}}{tx_{1996}^{pyp}}}{\frac{E_{1995}}{tx_{1995}^{current}}} =$$

$$\left(\prod_{t=1995}^{2008} factor\ 1_{t\to t+1}^{1}\right) * \left(\prod_{t=1995}^{2008} factor\ 2_{t\to t+1}^{1}\right) * \cdots * \left(\prod_{t=1995}^{2008} factor\ 5_{t\to t+1}^{1}\right) \qquad (14)$$

and the second method for intensity decomposition is:

$$\frac{\frac{E_{2009}}{tx_{2009}^{*}}}{\frac{E_{1995}}{tx_{1995}^{current}}} = \frac{\frac{E_{2009}}{tx_{2009}^{pyp}}}{\frac{E_{2008}}{tx_{2008}^{current}}} * \frac{\frac{E_{2008}}{tx_{2008}^{pyp}}}{\frac{E_{2007}}{tx_{2007}^{current}}} * \cdots * \frac{\frac{E_{1996}}{tx_{1996}^{pyp}}}{\frac{E_{1995}}{tx_{1995}^{current}}} =$$

$$\left(\prod_{t=1995}^{2008} factor\ 1_{t\to t+1}^{2}\right) * \left(\prod_{t=1995}^{2008} factor\ 2_{t\to t+1}^{2}\right) * \cdots * \left(\prod_{t=1995}^{2008} factor\ 5_{t\to t+1}^{2}\right) \qquad (15)$$

Where x_{2009}^{*} denotes the 2009 gross output measured in US\$ 1995 and price level; $x_{t}^{current}$ is the current prices version of gross output in year t; x_{t+1}^{pyp} denotes the previous years' prices version of gross output in year $t+1$; components $\prod_{t=1995}^{2008} factor\ i_{t\to t+1}^{1}$ and $\prod_{t=1995}^{2008} factor\ i_{t\to t+1}^{2}$ stand for decomposition factor i between 1995 and 2009 from the first and second decomposition method, respectively[16].

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[16] The sophisticated version of the procedures are:

$$\frac{\frac{E_{2009}}{tx_{2009}^{*}}}{\frac{E_{1995}}{tx_{1995}^{current}}} = \prod_{t=1995}^{2008} \frac{\frac{E_{t+1}}{tx_{t+1}^{pyp}}}{\frac{E_{t}}{tx_{t}^{current}}} = \prod_{i=1}^{5} \prod_{t=1995}^{2008} factor\ i_{t\to t+1}^{1} = \prod_{i=1}^{5} \prod_{t=1995}^{2008} factor\ i_{t\to t+1}^{2}$$

Appendix 3: Economies listed in WIOD

Australia, Austria, Belgium, Brazil, Bulgaria, Canada, China, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, India, Indonesia, Ireland, Italy, Japan, South Korea, Latvia, Lithuania, Luxembourg, Malta, Mexico, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden, Taiwan, Turkey, United Kingdom, United States, Rest of the World.

Appendix 4: Sectors listed in WIOD; industry and manufacturing technological level classifications

Sector	Industry		Description
1	Primary industry		Agriculture, Hunting, Forestry and Fishing
2			Mining and Quarrying
3	Manufacturing	Low-tech	Food, Beverages and Tobacco
4		Low-tech	Textiles and Textile Products
5		Low-tech	Leather, Leather and Footwear
6		Low-tech	Wood and Products of Wood and Cork
7		Low-tech	Pulp, Paper, Paper Printing and Publishing
8		Medium/low-tech	Coke, Refined Petroleum and Nuclear Fuel
9		Medium/high-tech	Chemicals and Chemical Products
10		Medium/low-tech	Rubber and Plastics
11		Medium/low-tech	Other Non-Metallic Mineral
12		Medium/low-tech	Basic Metals and Fabricated Metal
13		Medium/high-tech	Machinery, Nec
14		Medium/high-tech	Electrical and Optical Equipment
15		Medium/high-tech	Transport Equipment
16		Low-tech	Manufacturing, Nec; Recycling
17	Services		Electricity, Gas and Water Supply
18			Construction
19			Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel
20			Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles
21			Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods
22			Hotels and Restaurants

23		Inland Transport
24		Water Transport
25		Air Transport
26		Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies
27		Post and Telecommunications
28		Financial Intermediation
29		Real Estate Activities
30		Renting of M&Eq and Other Business Activities
31		Public Admin and Defence; Compulsory Social Security
32		Education
33		Health and Social Work
34		Other Community, Social and Personal Services
35		Private Households with Employed Persons

Appendix 5 Full decomposition results

Table 2 Full decomposition results of energy consumption over 1995 to 2009

Sector	Relative change between 2009 and 1995	Factor 1: change in e: intensity effect	Factor 2: change in A^*: inter-industry structural effect	Factor 3: change in A^T: trade effect in intermediate inputs	Factor 4: change in s: structural change effect in final demand	Factor 5: change in C: total final demand effect
1	0.8180	0.5871	0.9267	0.9895	0.8262	1.8388
2	1.5070	0.9011	1.2170	0.8549	0.9584	1.6772
3	1.2887	0.7638	1.0573	1.0028	0.8745	1.8196
4	0.9725	0.5216	0.9610	1.0513	1.0247	1.8010
5	0.8380	0.5390	0.9753	0.9994	0.8789	1.8147
6	0.8495	0.6703	0.9034	0.9869	0.8734	1.6277
7	1.2824	1.0255	0.8386	0.9938	0.9449	1.5880
8	1.1931	0.8018	0.9922	1.0015	0.9655	1.5510
9	1.2686	0.7343	1.0156	1.0216	1.0065	1.6543
10	1.3480	0.7960	1.1411	0.9480	0.9230	1.6961
11	1.5028	0.7473	0.8741	1.0399	1.0238	2.1610
12	1.3853	0.5936	1.0549	1.0787	1.0740	1.9096
13	0.7824	0.3641	1.0975	1.0483	1.0117	1.8463
14	1.1985	0.5202	1.3896	0.8778	1.1449	1.6497
15	1.5450	0.7353	1.1054	1.0405	1.0176	1.7952
16	0.8899	0.5485	0.9555	1.1103	0.9683	1.5791
17	1.5239	0.7632	1.1489	1.0171	1.0108	1.6905
18	0.9800	0.4469	1.0292	0.9953	1.0804	1.9812
19	1.1599	0.8194	1.0268	0.9915	0.9591	1.4497
20	1.2144	0.6551	1.0834	1.0009	1.0456	1.6351
21	1.2308	0.9042	1.0002	0.9916	0.9411	1.4584
22	1.5505	0.7943	1.0619	1.0450	0.9843	1.7872
23	1.1600	0.7921	0.9956	0.9575	0.9080	1.6918
24	1.1012	1.5007	0.9858	0.6861	0.6185	1.7543
25	1.5463	1.0021	0.9598	1.0539	1.0855	1.4054
26	0.7876	0.4472	1.1394	0.9982	0.9559	1.6199
27	0.9476	0.3797	1.2560	0.9870	1.2889	1.5618

28	1.2040	0.6832	1.0803	0.9765	1.0582	1.5788
29	0.8905	0.4663	1.0671	0.9999	1.0405	1.7202
30	1.9396	0.8609	1.3430	1.0088	1.0539	1.5779
31	0.7252	0.5031	0.9930	0.9988	0.9345	1.5551
32	1.1136	0.6551	1.0512	1.0012	0.9237	1.7487
33	1.5742	0.8933	1.0305	1.0025	1.0977	1.5539
34	1.1125	0.7994	1.0096	1.0062	0.8319	1.6469
35						

Note that results for Sector 35 are not available due to missing data.

Table 3 Full decomposition results of aggregate energy intensity over 1995 to 2009

Sector	Relative change between 2009 and 1995	Factor 1: change in e: intensity effect	Factor 2: change in A^*: inter-industry structural effect	Factor 3: change in A^T: trade effect in intermediate inputs	Factor 4: change in s: structural change effect in final demand	Factor 5: change in C: total final demand effect
1	0.5810	0.5871	0.9731	0.9777	1.0124	1.0274
2	0.6879	0.9011	0.8882	0.8355	0.9858	1.0435
3	0.9236	0.7638	1.0291	0.9994	1.0112	1.1627
4	0.6930	0.5216	1.0195	1.0231	1.1546	1.1033
5	0.6243	0.5390	1.0347	0.9797	1.0442	1.0942
6	0.6704	0.6703	0.9575	0.9753	1.0219	1.0482
7	1.0766	1.0255	1.0051	0.9894	1.0077	1.0477
8	0.7666	0.8018	0.9638	0.9910	0.9758	1.0258
9	0.7913	0.7343	1.0218	1.0038	0.9961	1.0546
10	0.8453	0.7960	1.1079	0.9289	0.9576	1.0775
11	1.0458	0.7473	0.9977	1.0302	1.0915	1.2474
12	0.9375	0.5936	1.0889	1.0675	1.1417	1.1900
13	0.5011	0.3641	1.0765	1.0366	1.0752	1.1470
14	0.4167	0.5202	1.0407	0.8492	0.8755	1.0353
15	0.9982	0.7353	1.0555	1.0393	1.0643	1.1627
16	0.6927	0.5485	0.9551	1.1165	1.1041	1.0725
17	0.9331	0.7632	1.0644	1.0087	1.0359	1.0993
18	0.7076	0.4469	1.0161	0.9975	1.2176	1.2827
19	0.8773	0.8194	1.0120	1.0041	0.9963	1.0576

20	0.7614	0.6551	1.0456	1.0054	1.0082	1.0967
21	0.8848	0.9042	1.0127	0.9941	0.9665	1.0058
22	1.1216	0.7943	1.0593	1.0447	1.0312	1.2374
23	0.7829	0.7921	1.0003	0.9590	0.9486	1.0861
24	0.4615	1.5007	0.7642	0.6921	0.5736	1.0136
25	1.0986	1.0021	0.9972	1.0572	1.0994	0.9459
26	0.4888	0.4472	1.0186	1.0060	0.9782	1.0904
27	0.3590	0.3797	0.9511	0.9909	0.9514	1.0544
28	0.6572	0.6832	0.9439	0.9816	0.9495	1.0936
29	0.6245	0.4663	1.0679	1.0030	1.0123	1.2352
30	0.9967	0.8609	1.0397	1.0218	0.9858	1.1056
31	0.5067	0.5031	1.0036	0.9997	0.9261	1.0839
32	0.8032	0.6551	1.0243	1.0012	1.0136	1.1794
33	0.9770	0.8933	1.0131	1.0021	0.9606	1.1215
34	0.7757	0.7994	0.9740	1.0094	0.8466	1.1659
35						

Note that results for Sector 35 are not available due to missing data.

Table 4 Full decomposition results of total emissions over 1995 to 2009

Sector	Relative change between 2009 and 1995	Factor 1: change in e: intensity effect	Factor 2: change in A^*: inter-industry structural effect	Factor 3: change in A^T: trade effect in intermediate inputs	Factor 4: change in s: structural change effect in final demand	Factor 5: change in C: total final demand effect
1	1.1406	0.7848	0.9458	1.0106	0.8053	1.8882
2	1.5247	0.8782	1.2142	0.8499	0.9801	1.7168
3	1.1814	0.7054	1.0605	1.0045	0.8691	1.8089
4	0.7863	0.4895	0.9572	1.0170	0.9602	1.7187
5	0.6912	0.4999	0.9490	1.0126	0.8383	1.7164
6	1.2023	0.7927	0.9829	1.0140	0.8951	1.7000
7	0.9285	0.6675	0.8749	1.0193	0.9513	1.6397
8	1.2481	0.7917	1.0066	1.0099	0.9681	1.6018
9	1.1110	0.5771	1.0490	1.0404	1.0164	1.7357
10	1.2042	0.7007	1.1294	0.9601	0.9313	1.7017
11	1.3251	0.7398	0.8763	1.0377	0.9953	1.9790

12	1.1638	0.6033	1.0150	1.0469	1.0119	1.7941
13	0.8497	0.3617	1.0677	1.0382	1.1130	1.9042
14	1.0359	0.4244	1.3594	0.9063	1.2021	1.6482
15	1.0969	0.5376	1.0875	1.0436	1.0359	1.7353
16	0.8100	0.5100	0.9597	1.0945	0.9644	1.5679
17	1.5185	0.6551	1.1999	1.0296	1.0477	1.7909
18	1.1753	0.7468	1.0111	0.9984	0.9321	1.6725
19	0.9922	0.7238	0.9903	0.9948	0.9497	1.4852
20	0.8156	0.4991	1.0199	0.9968	1.0421	1.5424
21	0.8760	0.6108	0.9700	1.0000	0.9785	1.5111
22	1.0101	0.6531	1.0279	1.0114	0.9360	1.5893
23	1.3132	0.8323	0.9996	0.9995	0.9644	1.6374
24	1.0043	0.3240	1.3082	1.2069	1.1295	1.7379
25	1.4492	0.8647	0.9928	0.9872	1.0529	1.6243
26	1.9834	1.0317	1.1531	1.0257	0.9850	1.6501
27	1.4251	0.4853	1.3402	1.0002	1.3856	1.5810
28	0.9037	0.4826	1.1409	0.9812	1.0829	1.5446
29	0.8496	0.5118	1.0094	1.0019	1.0144	1.6181
30	1.1966	0.5700	1.2928	0.9941	1.0699	1.5268
31	0.8444	0.5712	0.9943	0.9999	0.9581	1.5518
32	1.1167	0.6876	1.0213	1.0014	0.9287	1.7102
33	1.1227	0.6631	1.0134	1.0013	1.0827	1.5412
34	1.0726	0.6636	1.0459	1.0074	0.9489	1.6167
35						

Note that results for Sector 35 are not available due to missing data.

Table 5 Full decomposition results of total emission intensity over 1995 to 2009

Sector	Relative change between 2009 and 1995	Factor 1: change in e: intensity effect	Factor 2: change in A^*: inter-industry structural effect	Factor 3: change in A^T: trade effect in intermediate inputs	Factor 4: change in s: structural change effect in final demand	Factor 5: change in C: total final demand effect
1	0.8102	0.7848	0.9931	0.9985	0.9868	1.0550
2	0.6960	0.8782	0.8862	0.8305	1.0082	1.0681
3	0.8467	0.7054	1.0321	1.0011	1.0049	1.1559

4	0.5603	0.4895	1.0154	0.9897	1.0818	1.0529
5	0.5149	0.4999	1.0068	0.9927	0.9959	1.0349
6	0.9488	0.7927	1.0418	1.0021	1.0473	1.0947
7	0.7795	0.6675	1.0486	1.0147	1.0146	1.0818
8	0.8020	0.7917	0.9778	0.9994	0.9785	1.0595
9	0.6930	0.5771	1.0554	1.0222	1.0060	1.1065
10	0.7551	0.7007	1.0965	0.9408	0.9662	1.0811
11	0.9221	0.7398	1.0003	1.0280	1.0611	1.1423
12	0.7875	0.6033	1.0478	1.0360	1.0758	1.1180
13	0.5442	0.3617	1.0473	1.0266	1.1829	1.1830
14	0.3602	0.4244	1.0181	0.8768	0.9192	1.0343
15	0.7087	0.5376	1.0384	1.0424	1.0835	1.1239
16	0.6305	0.5100	0.9592	1.1006	1.0996	1.0649
17	0.9298	0.6551	1.1116	1.0211	1.0738	1.1646
18	0.8486	0.7468	0.9983	1.0007	1.0505	1.0829
19	0.7505	0.7122	0.9761	1.0074	0.9865	1.0834
20	0.5114	0.4991	0.9843	1.0012	1.0049	1.0345
21	0.6298	0.6108	0.9821	1.0025	1.0049	1.0421
22	0.7307	0.6531	1.0254	1.0111	0.9806	1.1005
23	0.8863	0.8323	1.0044	1.0010	1.0075	1.0512
24	0.4208	0.3240	1.0141	1.2175	1.0476	1.0041
25	1.0296	0.8647	1.0315	0.9903	1.0663	1.0932
26	1.2309	1.0317	1.0309	1.0338	1.0080	1.1107
27	0.5399	0.4853	1.0149	1.0042	1.0228	1.0673
28	0.4933	0.4826	0.9969	0.9864	0.9716	1.0699
29	0.5958	0.5118	1.0102	1.0050	0.9869	1.1619
30	0.6149	0.5700	1.0008	1.0069	1.0007	1.0697
31	0.5900	0.5712	1.0049	1.0009	0.9495	1.0816
32	0.8054	0.6876	0.9952	1.0014	1.0191	1.1535
33	0.6968	0.6631	0.9964	1.0008	0.9474	1.1123
34	0.7478	0.6636	1.0090	1.0106	0.9656	1.1445
35						

Note that results for Sector 35 are not available due to missing data problem.

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