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Intangible capital and sectoral energy intensity: Evidence from 40 economies between 1995-2007*

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Abstract: Intangible capital has been found to be an increasingly important source of productivity and economic growth. However, its effects on energy intensity have received little attention. Given the importance of reducing energy intensity, this study advances the understanding of the relationship between intangible capital and sectoral energy intensity by taking advantage of a rich dataset of 40 economies derived from the World Input Output Database (WIOD), spanning across 13 years (1995 - 2007). A relatively robust causal relationship between intangible capital and sectoral energy intensity has been identified. The qualitative and quantitative interactions of this relationship with income level and sectoral heterogeneity have also been revealed. It is found that the effect of intangible capital in reducing sectoral energy intensity generally diminishes along with increasing income level but moderate quadratic relationship is identified in some types of intangible capital. Finally, sectors where intangible capital have the largest and smallest effect are also pinpointed.

Key words: Intangible capital; Energy intensity; Sectoral level; World Input Output Database
JEL classification: Q40; Q57; O33; O50

1. Introduction

Intangible capital has been identified to have significant impacts on economic activities. Intangible capital is often defined as the immaterial resources that enter the production process and are of importance for the creation of new products as well as

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the improvement of existing products and the production process. Examples of intangible capital include research and development (R&D) investment, advertising (brand equity), organization capital, staff training, technology licenses, patents, and copyrights (Corrado et al. 2013). Numerous economists have devoted much effort to measuring it as well as evaluating its role from various perspectives, which includes studies on intangible capital as a source of growth in different economies at both national and sectoral level (e.g. van Ark et al. 2009; Corrado and Hulten 2010; Chun and Nadiri 2016), the discussion on the role of intangible capital in firms' valuation and productivity (e.g. Atkeson and Kehoe 2005; Arato and Yamada 2012; Eisfeldt and Papanikolaou 2013; Gourio and Rudanko 2014) and adding intangible capital to solve macroeconomic puzzles (e.g. McGrattan and Prescott 2010; Borgo et al. 2013; Gourio and Rudanko 2014a).

While the economic effect of intangible capital has been well documented, its environmental counterpart has received little attention. One important environmental dimension is the change in energy intensity, or energy efficiency, associated with the increasing use of intangible capital. Energy intensity remains a concern of climate change and environmental scientists due to the fact that economic activities still primarily rely on fossil fuels (Wang et al. 2011; Zhang and Da 2015). Although renewable energy is growing over time, it is unlikely to take a leading role in the near future when facing the increasing energy demand. World energy consumption is forecast to increase 48% by 2040 and fossil fuels are likely to still account for more than 3/4 of the world energy consumption by then (U.S. Energy Information Administration, 2016). Air pollution from the consumption of fossil fuels has been an increasing health concern: it is now the fourth greatest risk factor for human health worldwide (IEA, 2016).

Energy efficiency (EE), often measured by energy intensity, is a cost-effective way to decouple economic growth from energy demand and its associated carbon emissions and other pollutions. Energy efficiency is regarded as a key policy to reconcile the increasing tension between economic growth and climate change mitigation around the world (Han et al., 2018). Decreasing energy intensity is a direct method to decouple economic growth from energy consumption and associated carbon emissions (Proskuryakova and Kovalev, 2015). Reducing energy intensity is also considered to be an effective approach to mitigating climate change, addressing peak oil and improving energy security (Sadorsky, 2013). The European Union (EU) has made energy intensity a key pillar of its climate change strategy (Löschel et al., 2015). Furthermore, decline in sectoral energy intensity is found to be a major driver of decline in aggregate energy intensity (Greening et al., 1997; Ma and Stern, 2008; Sue Wing, 2008; Voigt et al., 2014; Wang and Wei, 2016; Wang et al., 2018, 2017), which indicates that it is important to study the factors that drive the dynamic of sectoral energy intensity.

Although the role of intangible capital in economic and productivity growth has been widely discussed in the existing literature, a causal relationship between intangible capital and sectoral energy intensity has not yet to be established. Intangible capital impacts the productivity through increasing value added per unit of product and the number of unit produced given constant inputs. When value added per unit is increased or more units are produced given constant energy input, the energy intensity is likely to decline. The literature often focuses on the role of R&D (Fisher-Vanden et al., 2004; Herrerias et al., 2016; Newell et al., 1999) or information and communication technology (ICT) (Zhou et al., 2018) but neglects the roles of other types of intangible capital in energy efficiency improvement. Furthermore, the heterogenous effects of intangible capital on sectoral energy intensity in various sectors and economies of different development stages remain unknown.

This study aims to advance the knowledge of the role of intangible capital in affecting energy intensity by taking advantage of a rich worldwide dataset from the World Input Output Database (WIOD) developed within the 7th Framework Program of the European Commission and providing a much more comprehensive analysis on the role of intangible capital in sectoral energy intensity. The WIOD provides a comprehensive set of harmonised indicators including energy use, value added and intermediates for 34 sectors across 40 economies, which is essential for the calculation of energy intensity and intangible expenditure at the sector level. The harmonisation and data matching process used by the WIOD also ensures the comparability of variables for different economies.

This study is important for both academic and policy areas. This study will advance the knowledge on the relationship between intangible capital and energy intensity and the heterogenous effects of intangible capital on sectoral energy intensity across economies of different development stages as well as various sectors. This study is also useful to policy makers for better understanding the heterogeneous role of intangible capital in various economies and sectors. For example, this study will inform the industry and policy makers a few new channels of reducing energy intensity in addition to R&D investment. The role of intangible capital in improving energy efficiency among countries in different development levels also can inform the global efforts on narrowing development gap (Sheng and Shi, 2013) and achieving UN goals of Sustainable Energy for All. The pinpoint of sectors can also suggest priority of investing intangible capital across sectors for the purpose of reducing energy intensity.

The contributions of this paper are fourfold. First, it constructs a large sectoral dataset of intangible capital across 40 economies that is suitable for econometric analysis for future studies. Second, it innovatively establishes a theoretical causal relationship between intangible capital and sectoral energy intensity. Third, it provides new knowledge on the heterogenous effects of intangible capital on sectoral energy intensity, which might generate important information for policy analysis[1]. Analysis

[1] The heterogeneity in production structure and the rule of decreasing marginal effect indicate the energy intensity reduction effect of intangible capital may vary across sectors and economies. Specifically, since physical capital like machines and buildings are the main contributors of energy use, sectors that are more physical capital intensive might benefit less from intangible capital in terms of energy intensity reduction; the intangible capital stock of high income economies is often higher than

by sector and by economy is conducted to reveal how the effects of intangible capital vary in different sectors as well as at different development stages. Fourth, the effects of income on the reduction effect of intangible capital on sectoral energy intensity are identified.

This paper is organized as follows: the next section describes the definition and measurement of sectoral energy intensity and intangible investment; section 3 discusses the theoretical linkage between intangible capital and sectoral energy intensity; section 4 depicts the data and methodology; section 5 explains the empirical results; section 6 draws the conclusion.

2. Measuring sectoral energy intensity and intangible capital

2.1 Sectoral energy intensity

Two definitions of sectoral energy intensity co-exist in the literature: one is the energy use divided by sectoral value added and the other is the energy use denominated by sectoral gross output. Both methods have theoretical basis, and their uses depend on the method of decomposition applied. If the aggregate energy intensity is decomposed using index decomposition analysis (IDA), then we have the following:

$$I = \frac{E}{Y} = \sum_i \frac{Y_i}{Y}\frac{E_i}{Y_i} = \sum_i S_i I_i$$

I is the aggregate energy intensity in an economy of which the definition is the

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that of middle and low-income economies, and according to the rule of decreasing marginal effect the reduction effect may decrease as the income increases.

aggregate energy use *E* divided by the gross domestic product (GDP) *Y* of this economy. Y_i is the value added of sector *i*, E_i is the energy use of sector *I*, and S_i is the share of sector *i* in the aggregate economy. Obviously, the energy intensity of sector *i*, I_i, in this context should be defined as sectoral energy use divided by sectoral value added to avoid the double counting problem the other definition has.

If the aggregate energy intensity is decomposed using the structural decomposition analysis (SDA), then we have the following:

$$E = \hat{\varepsilon}(\mathrm{I} - \mathrm{A})^{-1}\hat{y}$$

E is the aggregate energy use; $\hat{\varepsilon}$ is a diagonal matrix of energy intensity in different sectors; $(\mathrm{I} - \mathrm{A})^{-1}$ is the Leontif inverse; $\hat{y}$ is a diagonal matrix of the final demand. In this case, the sectoral energy intensity is defined as sectoral energy use divided by sectoral gross output.

In this study, the definition of energy intensity comes from the IDA method, that is, sectoral energy use divided by sectoral value added. Using value added as the denominator for energy intensity allows better comparison of energy intensity of the same sector with different outsourcing structures[2], and the use of this definition is common in existing literature (Zhang 2003; Ma and Stern 2008; Mulder and de Groot

[2] For example, sector A in China specializes in manufacturing the final goods while sector A in the US specializes in producing the core parts of the final goods. Sector A in China is likely to have a much lower ratio of value added to gross output than that of the US. Assuming they use the same amount of energy, sector A in China is likely to have a lower gross output denominated energy intensity even though sector A in the US is apparently more productive and has higher intangible capital stock and better technology. If we use the value added as the denominator, the energy intensity of sector A in the US is likely to be lower than that of China, which is consistent with the fact that sector A in the US has better technology.

2012; Wu 2012). The measurement of sectoral energy use is derived from the World Environmental Account in the WIOD. The sectoral energy use data in the WIOD is aggregated across 26 energy carriers and is measured in physical units (TJ). The sectoral value added is acquired from the World Supply and Use Tables in WIOD, which will be deflated to 1995 constant USD[3].

2.2 Intangible capital

In the recent two decades, an increasing effort has been devoted to finding suitable measures for intangible capital. Two common measures are currently being used. One is based on aggregate estimates derived from firm expenditures on “intangibles” such as R&D, advertising and innovation (Corrado et al., 2009) while the other is mainly based on the reported intangible assets in firms’ balance sheets (Marrocu et al., 2012). The empirical evidence in both cases is unanimous in pointing at intangible capital as a key element in the modern knowledge economy. When it comes to intangible capital at sectoral level, it is more appropriate to adopt the expenditure-based approach and therefore this study follows the approach of Corrado et al. (2009).

To estimate the intangible capital stock, the first step is to measure the flow of intangible investment. Three types of intangible expenditure defined by Corrado et al. (2009) are derived from the intermediate statistics from the supply and use tables within the WIOD, which is summarized as Table 1. The accumulation of intangible capital follows the standard perpetual inventory method:

[3] The deflation method used will be introduced in section 4.1.

$$\mathrm{IC}_{s,t} = \mathrm{IC}_{s,t-1}(1-\delta_s) + IN_{s,t}$$

where IC refers to intangible capital; the subscript *s* and *t* respectively denote the category *s* of intangible capital and time; δ refers to depreciation rate; IN is intangible investment. To implement the law of motion of intangible capital, an initial value must be chosen, which is according to

$$\mathrm{IC}_{s,0} = \frac{IN_{s,0}}{g_s + \delta_s}$$

where g_s is chosen to match the average real growth rate of the intangible investment s in a sector.

Table 1 Measurement and depreciation rate of intangible investment

Intangible investment	Method	Depreciation rate[4]
Computerized information	Distribute the aggregate gross fixed investment in computerized information according to the use of 'computer and related services' intermediate	0.33
Innovative property (R&D)	Use 'research and development services' intermediate adjusted by the outsourcing ratio	0.2
Economic competency		
Brand equity (advertising)	Use 60%[5] of 'other business activities'[6] adjusted by the outsourcing ratio	0.6
Organization capital and staff training[7]	Use 'education services' intermediate adjusted by the outsourcing ratio	0.4

Source: Authors' own construction

Notes: Outsourcing ratio is defined as the ratio of the value added to total intermediates. The reason why the intermediates statistics should be adjusted by the outsourcing ratio is that in the supply and use tables only outsourced intangible expenditure is counted and directly using the intermediate statistics neglects the internally produced intangible expenditure.

Following Eisfeldt and Papanikolaou (2013), the intangible capital IC is scaled by the real capital stock of a sector to alleviate the possible estimation bias caused by

[4] The depreciation rate follows Corrado et al. (2009).
[5] Corrado et al. (2009) estimate 60% of the advertising expenditure should be capitalized
[6] 'Other business activities' includes advertising as well as market research expenditure.
[7] Organization capital and staff training refers to the firm-specific human and structural resources (Corrado et al. 2009), which can be indicated by the education expenditure of firms.

productivity shocks and the observations with zero intangible capital is dropped. Using the amount of tangible capital as the denominator for intangible capital also has the advantage of controlling the size of a sector. Compared with the national level measurement of Corrado et al. (2009) and the literature following it, this measurement might be of lower accuracy. The source of inaccuracy might be caused by the deviation of the measured outsourcing ratio to the actual outsourcing ratio, 'other business activities' intermediates including expenditure that is not intangible investment, the distribution of computerized information investment across sectors inconsistent with that of 'computer and related services' intermediate etc. However, since the econometrics approach used in this study have some tolerance of measurement error, the constructed dataset should satisfy the analysis requirement[8].

3. Intangible capital and energy intensity: a theoretical analysis

Intangible capital, including innovations, could have significant effect on energy intensity reduction, or energy efficiency improvement. The role of innovations on energy intensity reduction has been well documented in the literature (Fisher-Vanden et al., 2004; Herrerias et al., 2016; Newell et al., 1999). Hao and van Ark (2013) in their preliminary study on the correlation between intangible investment and sectoral energy intensity using data from nine developed European economies, argued that intangible investment can promote technical change, innovations in energy

[8] If the measurement error is randomly distributed, it will not cause bias in the estimation results; if the measure error is sector-specific, then it will be eliminated by the sector specific intercept.

conservation as well as less use in tangible capital that accounts for the largest proportion of energy consumption in production and then reduce energy intensity. However, the theoretical relationship between other components of the intangible capital and energy intensity has not been discussed. The pricing power, improved operational efficiency resulting from organization capital and staff training and computerized information can also exert significant impacts on lowering sectoral energy intensity and then the air pollutant and carbon emissions. Motivated by the fact that intangible capital is a key production factor used by firms, this study proposes a simple theoretical analysis of the relationship between intangible capital and energy intensity. Before proceeding, the energy intensity is defined as follows:

$$\mathrm{I}_{i,j,t} = \frac{E_{i,j,t}}{\mathrm{Y}_{i,j,t}} \tag{1}$$

where $\mathrm{I}_{i,j,t}$ refers to the energy intensity of sector *i* in country (economy) *j* at time *t*; E_{ij} is the energy use of sector *i* in country *j*; Y_{ij} is the value added of sector *i* in country *j*. That is, the energy intensity is defined as the ratio of energy use to value added, which has been discussed in detail in section 2.

Next, a production function based on value added method is assumed as follows:

$$\mathrm{Y}_{i,j,t} = A_{i,j,t} F_i(L_{i,j,t}, K_{i,j,t}, IC_{i,j,t}) \tag{2}$$

where $A_{i,j,t}$ is the productivity of sector *i* in country *j* at time *t*; L, K, IC are respectively the labour input, tangible capital input and intangible capital input of sector i in country *j*; $F_i(L_{i,j,t}, K_{i,j,t}, IC_{i,j,t})$ is the production function of sector i. Using value added as output and labour and capital as inputs at sectoral level is common in existing literature and therefore well founded (Wei et al., 2007).

Moreover, assume that using intangible capital does not consume extra energy, which is consistent with the nature of intangible capital[9]. Therefore, we have the relationship between intangible capital and sectoral level energy intensity based on equations (1) and (2) as follows:

$$\frac{\partial(\frac{E_{i,j,t}}{Y_{i,j,t}})}{\partial IC_{i,j,t}} = -\frac{E_{i,j,t}}{{Y_{i,j,t}}^2} A_{i,j,t} \frac{\partial F_i(L_{i,j,t}, K_{i,j,t}, IC_{i,j,t})}{\partial IC_{i,j,t}} < 0 \quad (3)$$

Equation (3) is the derivative of energy intensity with respect to intangible capital, which is negative. This indicates that the increase in intangible capital can lower sectoral energy intensity. The mechanism is intuitive: the increasing use of intangible capital increases the value added given other inputs remain constant but does not increase energy use, and then lower the energy intensity.

Theoretically, intangible capital might have two channels to increase value added assuming constant other inputs. One is through increasing pricing power and then value added per unit of product. Not only product creation/ improvement R&D but also brand equity is often found to be associated with the pricing power of firms and then value added per unit of products (Corrado et al., 2005; Jones and Williams, 2000). Since R&D as a source of pricing power has been well regarded, the following illustration mainly focuses on the brand equity. Brand equity is often found to create a

[9] For example, using new design, R&D knowledge or new management practices does not consume energy. It is the tangible capital such as equipment and buildings that consume energy.

price premium for a product. Advertising itself can alter the preference of consumers: they may perceive a well-advertised product with distinctive packaging as being of high quality. Specifically, Klein and Leffler (1981) argue that consumers often use advertising intensity as an indicator of quality. Kirmani and Wright (1989) then provide empirical evidence for this proposition, showing that consumers do perceive products with high advertising expenditure as of high quality and are therefore willing to pay a price premium.

The other channel is through improving production efficiency and then increasing the units produced given constant resource input. R&D, organization capital as well as software are found to enhance the production process and then the production efficiency (Corrado et al., 2005). Examples include new production protocol, advanced management practice as well as well trained workers.

In the section 4 and 5, we will test the empirical relationship between intangible capital and energy intensity. It is worth noting that this study works beyond establishing a causal relationship between intangible capital and sectoral energy intensity – heterogeneity in this relationship as well as the heterogenous impacts of income level on sectoral energy intensity across economies and sectors are also tested.

4. Data source and empirical strategy

A dataset of intangible capital for 40 economies across 34 sectors from 1995 to 2007[10] is constructed based on the data retrieved from the WIOD and the capitalization criteria for intangible capital of Corrado et al. (2009), which provides a solid basis for an insightful analysis of the heterogenous impacts of intangible capital and economic development on sectoral energy intensity. Basic fixed effects regressions are then used to provide an overall picture of the roles of various intangible capital across service and non-service sectors and economies of high income and low income. System GMM method is further utilized to establish a relatively robust causal relationship. Finally, multilevel regressions are conducted to identify the quantitative heterogeneity in the impacts of various intangible capital on sectoral energy intensity.

4.1 The WIOD and the Penn World Table 8.1

The WIOD is built on national accounts data that was developed within the 7th Framework Programme of the European Commission. The WIOD database has two main advantages compared with previously available data sources. First, throughout the data collection efforts, harmonization procedures were applied to ensure international comparability of the data. This ensures data quality and minimizes the risk of measurement errors. Second, the WIOD includes sectoral price deflators, the use of which allows one to retain important information and the heterogeneity of the sectors with respect to price dynamics. This represents an improvement over the use

[10] The sector-specific deflator, which is derived from the supply and use tables in previous year price, is only available from 1995 to 2007.

of aggregate national price deflators. A complete list of 34 sectors included in the database is showed in appendix A.

The intangible capital data is derived from the supply and use tables within the WIOD; the energy use data is obtained from the World Environmental Account. The real tangible capital stock at 1995 constant price is obtained from the Social Economic Account and is converted to 1995 constant USD. The Penn World Table 8.1 provides the variable of GDP per capita (see Feenstra et al. 2015) for more detailed discussion). All data from the Penn World Table 8.1 is converted to 1995 constant USD based on the national price level and 1995 USD exchange rate.

4.2 Empirical strategy

The key variables of interest in this study are the intangible tangible ratio and the income level of an economy. To provide an overall picture of the heterogenous impacts of intangible capital on sectoral energy intensity, several interaction terms and control variables are introduced. That is, an empirical model is assumed as follows

$$I_{i,j,t} = \beta_1 \frac{IC_{s,i,j,t}}{TC_{i,j,t}} + \beta_2 \frac{IC_{s,i,j,t}}{TC_{i,j,t}} \times low\_income + \beta_3 \frac{IC_{s,i,j,t}}{TC_{i,j,t}} \times service + \beta_4 gdp_{pc_{j,t}} \times low\_income + \beta_5 gdp_{pc_{j,t}} \times service + \beta_6 gdp_{j,t} + \beta_7 time_t + \alpha + \varepsilon_{i,j,t}, \quad (4)$$

where I is the sectoral energy intensity, *IC* is intangible capital and *TC* is tangible capital. The subscript *s* represents intangible capital *s*; *i, j, t* respectively stand for sector *i*, country *j* and time *t*; gdp denotes the aggregate GDP of an economy, which is used to control for the economy size; *time* refers to the time fixed effects. α is the intercept and $\varepsilon_{i,j,t}$ is the error term. low_income indicates whether an economy is low income or not, the classification of which follows that of the World Bank[11]. $service$ denotes whether a sector is a service sector or not, the classification of which is demonstrated in Appendix A. $time_t$ is the year dummy, which controls for the fluctuation of energy price as well as worldwide shocks. All variables are in the form of logarithm except for the dummy variables.

To eliminate the possible estimation bias, we introduce the system GMM method. Although endogeneity is unlikely to be present in this case given relevant variables, time fixed effects and individual sectoral fixed effects are controlled, it is still possible that there are some unobservable factors that simultaneously affect the sectoral energy intensity and the intangible capital to tangible capital ratio and thus undermines the causal effects proposed in this study. For instance, some economy or sector specific environmental policies might influence both the energy intensity and the intangible capital ratio; the increase in sectoral productivity might simultaneously decrease the sectoral energy intensity and change the intangible tangible ratio subject to the production structure of a sector. System GMM uses both lagged differenced variables and lagged variables as instruments, which can partially solve the endogeneity problems. Compared with differenced GMM, system GMM method has better estimation efficiency because it additionally assumes that the first differences of instrumental variables are uncorrelated with the fixed effects, which allows the introduction of more instruments and therefore improves estimation efficiency

[11] Please see https://datahelpdesk.worldbank.org/knowledgebase/articles/906519.

dramatically (Roodman, 2009). To test the validity of the instruments as well as the additional assumption on which system GMM is based, the Hansen (1982) J test and the Arellano-Bond test will be conducted.

To further analyse the impacts of intangible capital across economies of different income level and various sectors, multilevel analysis is then conducted. Multilevel analysis provides economy and sector specific coefficients for variables of interest, which forms the basis of a more detailed study on the heterogenous effects of intangible capital on sectoral energy intensity. Specifically, a two-level hierarchy structure is identified: the first is the economy level while the second is the sector level. The coefficient of a specific sector therefore consists of three components: the worldwide average, the deviation due to the economy it belongs to and the deviation caused by sector-specific factors. Additional regressions will also be conducted to study the quantitative interactions between the economy and sector specific coefficients and the income level.

4.3 Descriptive analysis

The features of the dataset used in this study is summarized in Table 2. It consists of 605 sectors from 40 economies across approximate 12 years with more than 7,000 observations in total. The heterogeneity of GDP per capita and aggregate GDP indicates that the sample covers economies of different income level and scale. The variation of production structure can also be seen from the large standard deviation of various intangible tangible ratios.

Table 2 Descriptive statistics

Variable		Mean	Std. Dev.	Min	Max	Observations
log(energy intensity)	overall	1.76	1.76	-7.42	11.99	N = 7662
	between		1.66	-2.70	8.32	n = 637
	within		0.64	-2.95	6.57	T-bar = 12.03
log(Intangible/Tangible)	overall	-2.69	2.08	-13.06	10.79	N = 7662
	between		1.82	-10.14	6.25	n = 637
	within		1.03	-16.21	6.82	T-bar = 12.03
log(RD/Tangible)	overall	-5.48	2.39	-17.90	10.78	N = 7332
	between		2.20	-12.34	5.89	n = 612
	within		0.94	-27.19	-0.58	T-bar = 12.00
log(CI/Tangible)	overall	-3.97	2.36	-17.97	10.23	N = 7104
	between		2.08	-9.82	5.78	n = 588
	within		1.13	-15.86	5.69	T-bar = 12.08
log(BE/Tangible)	overall	-3.92	1.62	-13.70	4.40	N = 7377
	between		1.45	-10.99	1.57	n = 614
	within		0.74	-13.88	2.04	T-bar = 12.01
log(OC&ST/Tangible)	overall	-6.33	1.82	-15.74	3.00	N = 7406
	between		1.67	-12.72	-0.29	n = 620
	within		0.72	-21.78	-2.79	T-bar = 11.95
log(GDP per capita)	overall	2.47	1.14	-0.96	4.36	N = 7662
	between		1.14	-0.73	4.16	n = 637
	within		0.14	1.97	3.04	T-bar = 12.03
log(GDP)	overall	12.09	1.68	8.18	16.19	N = 7662
	between		1.67	8.38	16.04	n = 637
	within		0.15	11.54	12.70	T-bar = 12.03

Note: The unit of GDP per capita is thousand 1995 USD; the unit of GDP is million 1995 USD; the unit of energy intensity is trillion joules (TJ) per million 1995 USD.
Source: Authors' own calculation.

To illustrate the overall relationship between intangible capital and sectoral energy intensity, scatter plots and best fitting lines are drawn for overall intangible tangible ratio as well as its various categories (please see Figure 1, sectoral fixed effect has been controlled). Significant negative relationship can be easily seen from all of its subfigures with varying slopes. However, correlation itself is not causal relationship and the heterogenous impacts of intangible capital on sectoral energy intensity still remain unclear. The next section will further discuss these issues.

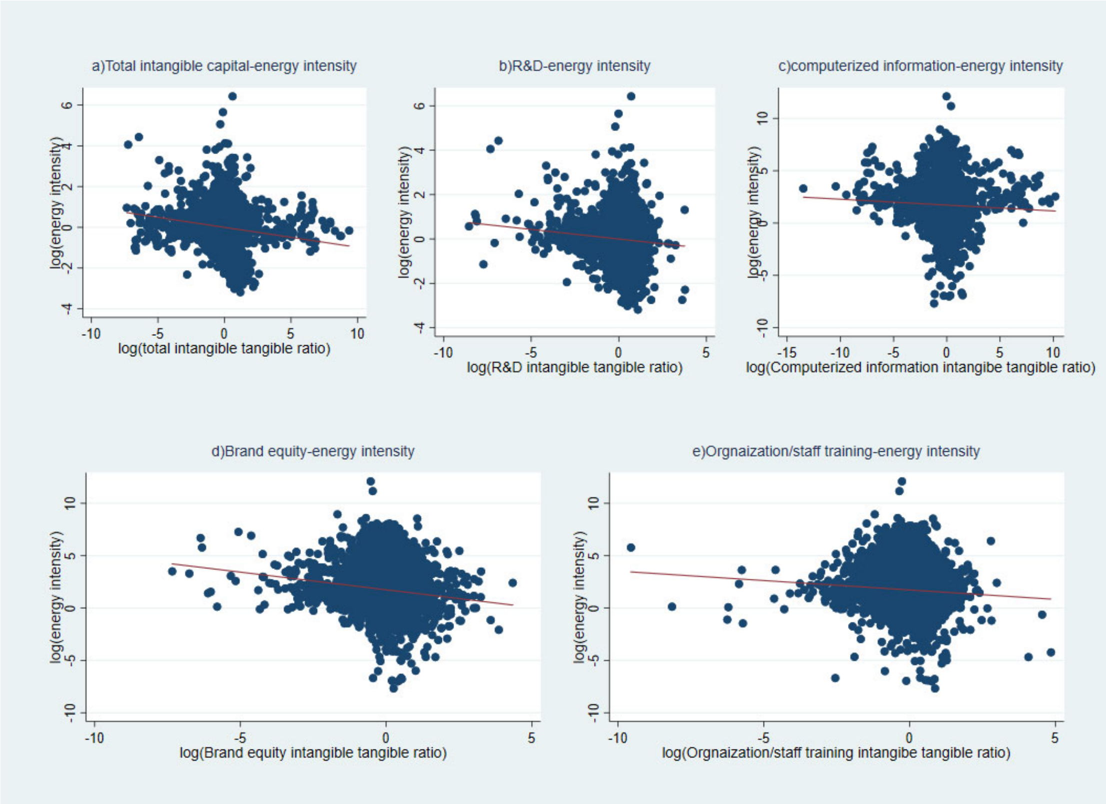


Figure 1 Scatter plots of the relationship between intangible capital and sectoral energy intensity (sectoral fixed effects controlled)

Source: Authors' own calculation.

5. Empirical results

5.1 An overall picture

Table 3 demonstrates the heterogenous impacts of intangible capital and income level on sectoral energy intensity. The negative relationship between intangible capital, income level and sectoral energy intensity can be clearly seen. When controlling for income level and intangible tangible ratio, the larger the economy a sector belongs to, the less energy efficient the sector is, which might be caused by the diseconomy of scale.

The overall intangible capital and its four major components have consistent impacts on energy intensity. On average, a 1% increase in overall intangible tangible ratio leads to a 0.09% decline in sectoral energy intensity; a 1% increase in R&D tangible ratio leads to a 0.10% decrease in sectoral energy intensity; a 1% increase in computerized information (CI) tangible ratio leads to a 0.05% drop in sectoral energy intensity; a 1% increase in brand equity (BE) causes 0.29% reduction in sectoral energy intensity; a 1% rise in organization capital and staff training (OC&ST) leads to a 0.176% decrease in sectoral energy intensity.

In respect of the role of income level, a 1% increase in GDP per capita generally leads to an approximately 5% decrease in sectoral energy intensity. When it comes to the heterogenous effects across service and non-service sectors as well as high and low and middle income economies, it is found that the impacts of intangible capital and income level in reducing sectoral energy intensity are larger in service sectors and low and middle income economies. For the impacts of intangible capital, the differences can be as large as 10 times and as small as 10%. As for the impacts of income level, the difference is much smaller.

Table 3 Heterogenous impacts of intangible capital and income level on sectoral energy intensity (Fixed effects)

	Fixed effects									
Sectoral energy intensity	All Intangible		R&D		CI		BE		OC&ST	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Intangible	-0.0923***	-0.0275**	-0.104***	-0.0459***	-0.0517***	-0.00559	-0.294***	-0.219***	-0.176***	-0.148***
	(0.0169)	(0.0128)	(0.0152)	(0.0147)	(0.0127)	(0.00879)	(0.0267)	(0.0305)	(0.0181)	(0.0164)
Intangible×service		-0.0669***		-0.128***		-0.0287*		-0.0361		-0.0728***
		(0.0249)		(0.0346)		(0.0147)		(0.0460)		(0.0110)
Intangible×low income		-0.200***		-0.0528		-0.171***		-0.114**		-2.807
		(0.0418)		(0.0693)		(0.0351)		(0.0495)		(2.537)
GDP pc	-5.460***	-4.801***	-6.748***	-5.875***	-5.943***	-4.555***	-5.846***	-5.137***	-5.553***	-4.985***
	(0.731)	(0.603)	(0.762)	(0.642)	(0.776)	(0.599)	(0.696)	(0.582)	(0.736)	(0.628)
GDP pc×service		-0.0777		-0.0757		-0.0238		-0.0634		-0.0708
		(0.163)		(0.166)		(0.144)		(0.153)		(0.167)
GDP pc×low income		-2.274***		-2.190***		-3.495***		-2.045***		-2.202***
		(0.316)		(0.323)		(0.421)		(0.284)		(0.335)
GDP	4.914***	4.969***	6.143***	5.964***	5.441***	4.287***	5.196***	5.139***	4.938***	5.090***
	(0.773)	(0.681)	(0.805)	(0.726)	(0.838)	(0.661)	(0.734)	(0.655)	(0.776)	(0.707)
Constant	-44.64***	-46.77***	-56.02***	-55.78***	-48.70***	-38.19***	-47.25***	-48.14***	-45.18***	-48.15***
	(7.603)	(6.828)	(7.855)	(7.224)	(8.138)	(6.461)	(7.167)	(6.521)	(7.593)	(7.063)
Observations	7,288	7,288	6,899	6,899	6,796	6,796	7,035	7,035	7,090	7,090
R-squared	0.233	0.296	0.235	0.287	0.211	0.282	0.327	0.367	0.244	0.288
Number of id	603	603	576	576	562	562	586	586	594	594
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. CI denotes computerized information; BE stands for brand equity; OC&ST indicates organization capital and staff training.

Source: Authors' own calculation.

To establish a relatively robust causality between intangible capital and sectoral energy intensity, system GMM method is adopted to eliminate the possible endogeneity. Relevant results are revealed in Table 4. Compared with the fixed effects regressions, the negative relationship between intangible capital, its major components and energy intensity remains robust with small decline in scale. Specifically, a 1% rise in overall intangible tangible ratio is predicted to improve sectoral energy intensity by 0.02%; a 1% increase in R&D tangible ratio on average reduces sectoral energy intensity by 0.09%; a 1% growth in computerized information tangible ratio generally leads to a 0.005% drop in sectoral energy intensity; a 1% rise in brand equity tangible ratio is predicted to decrease energy intensity by 0.25%; a 1% increase in organization capital and staff training tangible ratio on average causes a 0.17% decline in sectoral energy intensity. As for the impacts of income level, due to the collinearity caused by using lagged and differenced income level as instruments, in many cases it becomes insignificant or positive. The coefficients of aggregate GDP also become insignificant. The results from system GMM regressions are a progress from earlier studies (Hao and van Ark, 2013): it evidences a causal relationship between intangible capital and sectoral energy intensity. However, the outcomes demonstrated above only compare the impacts of intangible capital and income level across different groups. The next section will have a deeper look at this rich dataset by carrying out additional analysis.

Table 4 Heterogenous impacts of intangible capital and income level on sectoral energy intensity (system GMM)

	system GMM									
Sectoral energy intensity	All Intangible		R&D		CI		BE		OC&ST	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Intangible	-0.0248*	-0.0153	-0.0809**	-0.0838***	-0.00451	-0.00722	-0.252***	-0.154***	-0.168***	-0.349***
	(0.0133)	(0.0108)	(0.0330)	(0.0279)	(0.0144)	(0.0102)	(0.0420)	(0.0432)	(0.0505)	(0.00509)
Intangible×service		-0.0889***		-0.141***		0.00518		-0.0464		-0.0825***
		(0.0219)		(0.0233)		(0.0140)		(0.0348)		(0.000707)
Intangible×low income		-0.0888***		-0.0200		0.0244		0.00295		0.0799
		(0.0343)		(0.0261)		(0.0162)		(0.0456)		(0.135)
GDP pc	0.0191	0.124	-0.238***	-0.217***	-0.153*	-0.00224	0.0376	0.156**	0.00809	0.0983*
	(0.0797)	(0.0830)	(0.0851)	(0.0635)	(0.0928)	(0.0729)	(0.0999)	(0.0717)	(0.104)	(0.0572)
GDP pc×service		-0.350***		-0.271***		-0.275***		-0.249***		-0.276***
		(0.0531)		(0.0564)		(0.0465)		(0.0842)		(0.0348)
GDP pc×low income		0.306**		-0.740***		-0.107		-0.215**		-0.536***
		(0.145)		(0.0757)		(0.144)		(0.109)		(0.0537)
GDP	-0.0552	-0.0408	0.104	0.145***	0.0799	0.0278	-0.00348	0.00421	-0.0228	-0.0868**
	(0.0637)	(0.0508)	(0.0684)	(0.0294)	(0.0718)	(0.0506)	(0.0904)	(0.0446)	(0.0846)	(0.0407)
Constant	1.076	1.091**	-0.411	-0.512*	-0.176	0.643	0.0701	-0.00311	-0.152	0.697*
	(0.654)	(0.451)	(0.701)	(0.291)	(0.645)	(0.449)	(0.870)	(0.406)	(0.842)	(0.406)
Observations	4,347	5,231	4,138	4,138	4,097	4,912	4,212	4,212	4,243	4,243
R-squared	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Number of id	600	601	574	574	560	560	584	584	591	591
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; CI denotes computerized information; BE stands for brand equity; OC&ST indicates organization capital and staff training; for the results of Hansen (1982) J test and Arellano-Bond test, please see appendix B

Source: Authors' own calculation.

5.2 Fully analysing the heterogenous impacts: a multilevel regression approach

To better take advantage of this large dataset, multilevel regressions are conducted to assign economy and sector specific coefficients to all individual sectors. Table 5 illustrates the baseline results from multilevel regressions. The coefficients of intangible tangible ratio remain close to those in Table 3 and 4 except for "All Intangible" the scale of which is significantly larger. As for income level, all coefficients become insignificant, which indicates that the heterogeneity of its impacts in reducing sectoral energy intensity might be high. The diseconomy of scale as revealed by the positive coefficients of aggregate GDP remains similar as the results in Table 3. Table 6 aims to test the linear and quadratic relationship between the impacts of intangible capital on sectoral energy intensity and income level. Under the linear framework, it is found that intangible capital in an economy of higher income is likely to have lower impacts on sectoral energy intensity. Specifically, a 10% increase in income level is associated with a 0.0009 increase in the coefficient of overall intangible tangible ratio, which is roughly 0.5% of the baseline result. For various categories of intangible capital, the increase ranges from 0.002 to 0.003, which is approximately 1% to 3% of the baseline coefficients.

When it comes to the quadratic relationship, an inverted U-shape relationship is observed. Specifically, the impact of overall intangible in reducing sectoral energy intensity first increases along with rising income, and when income reaches 6,759 USD per capita the impact begins to decline when income increases; the counterparts of brand equity and organization capital and staff training both also demonstrate an inverted U-shape pattern, with a turning point respectively of 5772 USD per capita and 6653 USD per capita. As for R&D and computerized information, the turning point is too large for the data range and as a result they do not have a 'real' quadratic relationship.

Another interesting question to investigate is the heterogenous impacts across sectors. Figure 2 depicts an overall picture of this heterogeneity. The pattern of the heterogenous impacts is consistent with the results in Table 3 and 4: service group is likely to have a higher impact than non-service group. Within the service group, financial intermediation (J), real estate activities (70), education (M) and health and social work (N) are the largest beneficiaries from intangible capital in terms of energy intensity. The transport sectors (60, 61, 62) are the smallest beneficiaries from intangible capital within the service group. When it comes to the non-service group, the coefficients of machine nec (29)[12], electrical and optical equipment (30t33), transport equipment (34t35) and manufacturing nec, recycling (36t37) have the largest scale; the counterparts of coke, refined petroleum, and nuclear fuel (23), rubber and plastics (25), other non-metallic mineral products (26), basic metals fabricated metal products (27t28), and electricity, gas and water supply (E) have the smallest scale, which can be as low as 60% less than the benchmark coefficients. The heterogeneity of the effects of intangible capital in reducing energy intensity might be due to the heterogeneity in production structure.

[12] "nec" means "not else classified".

Table 5 Baseline results derived from multilevel regressions

	Multilevel				
	(1)	(2)	(3)	(4)	(5)
VARIABLES	All Intangible	R&D	CI	BE	OC&ST
Intangible	-0.207***	-0.0930***	-0.0940***	-0.318***	-0.155***
	(0.0278)	(0.0189)	(0.0233)	(0.0500)	(0.0251)
GDP pc	0.616	-0.227	0.878	-0.103	1.010
	(0.690)	(0.796)	(0.846)	(0.664)	(0.721)
GDP	1.470***	2.378***	1.415**	1.740***	1.136**
	(0.520)	(0.603)	(0.637)	(0.502)	(0.548)
Constant	-21.09***	-30.03***	-20.89***	-22.67***	-18.36***
	(5.408)	(6.126)	(6.233)	(5.062)	(5.594)
Observations	7,288	6,899	6,796	7,035	7,090
Number of economies	39	36	34	37	38
Number of sectors	603	576	562	586	594
Year FE	YES	YES	YES	YES	YES

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; CI denotes computerized information; BE stands for brand equity; OC&ST indicates organization capital and staff training. The dependent variable is sectoral energy intensity.

Source: authors' own calculation.

Table 6 Income level and the impacts of intangible capital on sectoral energy intensity

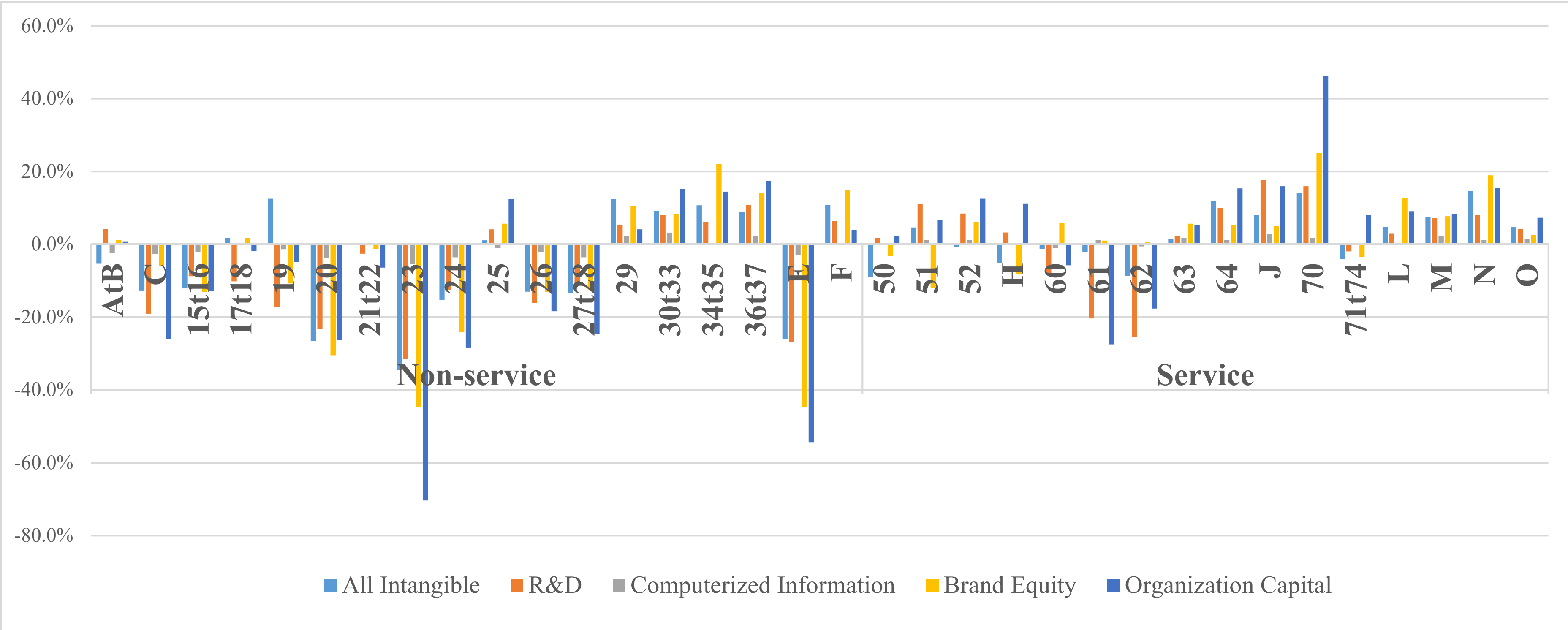
	Random coefficients of intangible tangible ratio (economy level)									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
VARIABLES	All Intangible	All Intangible	R&D	R&D	CI	CI	BE	BE	OC	OC
GDP pc	0.00869***	-0.0707***	0.0250***	0.0474***	0.0292***	0.0932***	0.0279***	-0.171***	0.0197***	-0.0775***
	(0.00140)	(0.00574)	(0.000687)	(0.00292)	(0.000899)	(0.00400)	(0.00329)	(0.0139)	(0.00112)	(0.00497)
GDP pc^2		0.0185***		-0.00507***		-0.0140***		0.0451***		0.0221***
		(0.00129)		(0.000644)		(0.000856)		(0.00307)		(0.00110)
Constant	-0.0360***	0.0245***	-0.0533***	-0.0715***	-0.0686***	-0.125***	-0.113***	0.0487***	-0.0509***	0.0274***
	(0.00389)	(0.00572)	(0.00193)	(0.00301)	(0.00257)	(0.00429)	(0.00927)	(0.0143)	(0.00313)	(0.00495)
Observations	7,288	7,288	6,976	6,976	6,822	6,822	7,096	7,096	7,180	7,180
R-squared	0.005	0.032	0.159	0.167	0.134	0.167	0.010	0.039	0.041	0.092

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; CI denotes computerized information; BE stands for brand equity; OC&ST indicates organization capital and staff training. The dependent variable is the individual deviations from the baseline coefficients of the various types of intangible in Table 5.

Note: The effect of intangible capital on sectoral energy intensity is negative, which means the smaller (more negative) the coefficient the larger the effect. When there is a U-shape relationship observed in the above table, it actually indicates an inverted U-shape relationship between the income level and the effect of intangible capital in reducing sectoral energy intensity. The dependent variable is the economy-specific coefficients generated by the multi-level regressions, which is a measurement of the energy intensity reduction effect in different economies.

Source: authors' own calculation.

Figure 2 Heterogenous impacts of intangible capital on sectoral energy intensity across various sectors (compared with baseline results)



Note: the percentage here is the average impact difference of a sector from the baseline results.

Source: authors' own calculation.

6. Conclusion and policy implications

Lowering sectoral energy intensity is a critical way to reduce energy use and then improve air quality and the environment. Although some efforts have been devoted to studying the relationship between innovation activities and energy intensity (Fisher-Vanden et al., 2004; Herrerias et al., 2016; Newell et al., 1999) as well as the correlation between intangible investment and energy intensity (Hao and van Ark, 2013), a theoretical and comprehensive analysis of the relationship between intangible capital and energy intensity is absent from the literature.

This study advances the knowledge on the relationship between intangible capital and sectoral energy intensity by taking advantage of a large dataset. Examined research questions include: Does intangible capital has a 'real' causal effect on sectoral energy intensity? How does the role of various types of intangible capital vary across economies and sectors? How does income level affect sectoral energy intensity in the context of different economies and sectors?

This study finds that a relatively robust causal relationship between intangible capital (measured as intangible-tangible capital ratio) and sectoral energy intensity exists. The increasing use of intangible capital relative to tangible capital does reduce sectoral energy intensity. However, when income level of an economy becomes higher, intangible capital's reduction effect generally diminishes. Moderate quadratic relationship between the reduction effect of intangible capital on energy intensity and income level in some types of intangible capital is also identified. A moderate inverted U-shape relationship exists in the overall intangible capital as well as economic competency (brand equity, organization capital and staff training), but no “real” quadratic relationship is discovered for R&D and computerized information because the turning point is far beyond the data range.

Across sectors, the sectors that have the largest and smallest effect of intangible capital in reducing energy intensity within service and non-service groups are also pinpointed. Within the service group, sectors requiring high intangible capital ratio tend to have the largest effect, and sectors relying more on physical capital are likely to have the smallest. As for the non-service group, in equipment manufacturing sector, intangible capital tends to have the largest effect, and in raw materials manufacturing as well as utility sectors often have the smallest. These findings demonstrate that intangible capital can enhanced the reduction effect: between sectors within each of the service and non-service sector, the higher the ratio of intangible capital to tangible capital, the stronger the reduction effect.

Through various disaggregated analyses and a multilevel regression analyses, we found a few heterogenous results: 1) brand equity and organization capital improve sectoral energy intensity more than R&D; 2) intangible capital in low and middle income economies have a larger reduction effect on sectoral energy intensity than high income economy; 3) sectors with high intangible capital ratio in the service group and equipment manufacturing sectors in the non-service group tend to enjoy a larger effect from intangible capital on sectoral energy intensity reduction; 4) Income level generally decreases the effect of intangible capital in reducing sectoral energy intensity but a moderate inverted-U shape relationship between income level and the effect of intangible capital in reducing sectoral energy intensity is identified in aggregate intangible capital as well as some disaggregated intangible capital including brand equity and organization capital.

The study offers the following policy implications:

First, in addition to usual R&D, branding equity, such as advertisement and staff training are found to be new instruments to reduce sectoral energy intensity. Our study shows that these two channels have large reduction effect on energy intensity than R&D. While the role of R&D can be expected due to the well-documented role of R&D in the literature, these new policy instruments that support the role of intangible capital in reducing energy intensity is a complementary to the literature.

Second, in terms of global energy intensity reduction, the role of intangible capital should be strengthened in developing economies, where the marginal reduction effect of intangible capital is higher. Despite of the relative large reduction potential to developed countries, developing countries often face limit in capacity. This would also suggest cooperation and transfer of intangible investment could reduce energy intensity even though the total global intangible capital stock is fixed.

Third, reducing energy intensity through restructuring economic needs to prepare for diminishing impact. The service sector has low intangible capital and is often consider to be less energy intensity. While development of service sector could reduce energy intensity, such economic restructuring instrument will have a diminishing role with increasing income level according to our study.

Lastly, within a country, development of sectors with high intangible and tangible capital ratio can reduce the overall intensity. To reduce energy intensity in the short run, efforts should be made in sectors within service group that have high intangible capital ratio and in equipment manufacturing sector within the non-service group. According to our study, these sectors have the largest effect of intangible capital in reducing energy intensity. Therefore, the reduction effect of energy intensity would be boosted if a unit of intangible capital is allocated to the sector with higher intangible capital-capital ratio. For example, in the non-service sector, energy intensity could be reduced by relocated intangible capital to the manufacturing industry from other industries.

Future research directions might include investigating firm-level evidence on the relationship between energy intensity and intangible capital when relevant data is fully available.

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Appendix A

WIOD sectors, definition by NACE and the classification of sectors

NACE	WIOD sectors	Classification
AtB	Agriculture, hunting, forestry and fishing	Non-service
C	Mining and quarrying	Non-service
15t16	Food, beverages and tobacco	Non-service
17t18	Textiles and textile products	Non-service
19	Leather, leather products and footwear	Non-service
20	Wood and products of wood and cork	Non-service
21t22	Pulp, paper, paper products, printing and publishing	Non-service
23	Coke, refined petroleum and nuclear fuel	Non-service
24	Chemicals and chemical products	Non-service
25	Rubber and plastics	Non-service
26	Other non-metallic mineral products	Non-service
27t28	Basic metals and fabricated metal products	Non-service
29	Machinery nec	Non-service
30t33	Electrical and optical equipment	Non-service
34t35	Transport equipment	Non-service
36t37	Manufacturing nec, recycling	Non-service
E	Electricity, gas and water supply	Non-service
F	Construction	Non-service
50	Sale, maintenance and repair of motor vehicles	Service
51	Wholesale trade and commission trade	Service
52	Retail trade, except of motor vehicles and motorcycles	Service
H	Hotels and restaurants	Service
60	Inland transport	Service
61	Water transport	Service
62	Air transport	Service
63	Supporting and auxiliary transport activities	Service
64	Post and telecommunications	Service
J	Financial intermediation	Service
70	Real estate activities	Service
71t74	Renting of machinery and equipment and other business activities	Service
L	Public administration and defence, social security	Service
M	Education	Service
N	Health and social work	Service
O	Other community, social and personal services	Service

Appendix B

Results of Hansen (1982) J test and Arellano-Bond test for Table 4.

Hansen J test: test of overidentifying restrictions

H_0: overidentifying restrictions are valid

Arellano-Bond test for zero autocorrelation in first-differenced errors

Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Hansen J test										
Prob > chi2	0.20	0.44	0.19	0.32	0.62	0.54	0.15	0.08	0.15	0.09
Arellano-Bond test										
Prob > z										
Order 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Order 2	0.79	0.23	0.69	0.44	0.87	0.41	0.98	0.55	0.82	0.59