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Intangible capital and sectoral energy intensity: Evidence from 40 economies between 1995 and 2007[☆]

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A B S T R A C T

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 on reducing sectoral energy intensity generally diminishes along with increasing income level but a 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.

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 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, 2014b) 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 by 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

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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 dynamics 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 units 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 heterogeneous 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 harmonized 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 harmonization 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 heterogeneous 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 the 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 heterogeneous effects of intangible capital on sectoral energy intensity, which might generate important information for policy analysis.[1] Analysis by sector and by the 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: Section 2 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 a 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 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 Leontief 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

[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 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.

[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.

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