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Innovation Investments and Energy Efficiency: A Cluster Analysis of Iranian Industries

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A B S T R A C T

The present paper investigates the effects of innovation investments such as research and development (R&D) expenditures (divided into domestic and foreign) and information and communications technologies (ICT) investments on energy intensity in three clusters of Iranian industries including small, medium, and large industries during 2000-2012. The findings obtained from panel GMM method indicated that in all clusters, domestic R&D expenditures did not have a significant impact on energy intensity, while foreign R&D expenditures led to a considerable decrease in energy intensity. Moreover, ICT investments resulted in a rise in energy intensity. As it was expected, spillovers from these innovations, especially R&D spillover led to a decline in energy intensity.

1. Introduction

In recent decades, it has been widely recognized that technological changes have the potential to improve energy efficiency. Similarly, the role of innovation investments including information and communications technologies (ICT) and research and development (R&D) in shaping energy demands and energy consumer behavior has been remarkably expanded. The broader impact of the rise of these innovations expenditures has been underappreciated, especially in advanced economies. In particular, technological change at firm level has led to a shift in emphasis from using tangible capital such as machinery, equipment, and buildings to using intangible capital such as ICT and R&D (Hao & Ark, 2013).

However, it is maintained that ICT and R&D leave two conflicting impacts on energy intensity, so the net effect is not clear and depends on the relative magnitude of these countervailing forces. First, ICT and R&D can reduce the demand for energy through the process innovation, that is, the substitution of a new technology for an old technological product that brings about a lower level of energy consumption by increasing efficiency. This effect is called "the substitution effect". Second, ICT and R&D products increase GDP and result in an economic boost that increases energy consumption. Likewise, ICT and R&D require the installation of new plants and machineries which require much energy. Therefore, it increases the demand for energy. This effect is called "the income effect" or "the compensation effect" (Edquist et al., 2001; Lei et al, 2012; Romm, 2002). Whether positive or negative effects of ICT and R&D dominate energy intensity is an unresolved question. In this regard, empirical studies are required to clarify this issue. On the other hand, there is a belief that an industry's technological progress not only depends on internal knowledge input, but also benefits from external technological spillovers. A number of researchers Kamien *et al.* 1992; Mowery & Rosenberg 1989; Suzumura, 1992) noted that smaller firms that do not invest in R&D as much as they do in large companies are also deemed as being innovative. This observation indicates that enterprise knowledge spillovers (across firms) happen because of a firm's own investment in R&D, and if it was up to the firms, they would like to appropriate all knowledge generated as the result of their innovation efforts. Griliches (1992) distinguishes two types of technological spillovers, namely, vertical spillovers and horizontal spillovers. Through transaction-based linkages, buyer-seller relationships among firms often incur vertical spillovers that occur at inter-industry level. Horizontal spillovers that happen at intra-industry level basically refer to knowledge transmission. In this respect, research conducted in one firm can stimulate the creation of new knowledge or the fruition of previous ideas in a different firm. In this case, new knowledge is gained from new goods and becomes part of a general pool of knowledge (Koo, 2005). This type of knowledge spillover can be obtained without direct input–output connections among firms or industries through technology-based linkages. Jaffe (1986) describes these linkages using the idea of "technological closeness." When two firms or industries utilize much similar technology in production, innovations made by each firm or industry may turn out to be more useful to the other firm or industry. Furthermore, when spillover effects are present, firms face free-riding incentives that stymie internal innovation efforts. Free-riding incentives may induce some industry to reducing their own expenditures on innovation (Lei et al, 2012).

Although studies on the relationship among ICT, R&D, and energy intensity have flourished recently, there is a paucity of research in this area. Vanden et al (2002) analyzed the factors causing the fall in industrial energy intensity in China during 1997-1999. They found that energy prices and R&D expenditures were significant reasons behind declining energy intensity, and industry composition was deemed as a less important factor. In addition, the impact of R&D spending on energy intensity suggested that firms had been using resources for energy saving innovations. Kumar (2003) attempted to identify and measure the factors behind the Indian Manufacturing energy efficiency. He found that R&D activities were important contributors to the decline in firm-level energy intensity. Takase and Murota (2004) examined the effect of IT investment on energy consumption in Japan and the United States of America. They distinguished between income and substitution effects. They found that the substitution effect was dominant in Japan, whereas the income effect was dominant in the U.S. Cho et al. (2007) investigated the effects of ICT investment on industries' electricity consumption in South Korea during 1991- 2003. Their results suggest that ICT investment reduces electricity consumption only in the primary metal products sector, whereas in the service sector and most of the manufacturing sectors, ICT investment increases electricity consumption. Liu Chang et al. (2008) found that the increase of expenditure on science and technology contributes to the improvement of energy efficiency in high-energy consumption industries by using panel data collected from China's 29 industrial sectors. Teng (2012) analyzed the effect of R&D (disaggregated as the indigenous R&D, foreign R&D, and domestic R&D) on the energy consumption intensity in China during 1998–2006.The results showed that indigenous R&D contributes to a significant decline of energy intensity in high energy-consuming intensity group and 31 industrial sectors, but it had no significant effect on energy consumption intensity in low energy-consuming intensity group. Purchased foreign technology had a significant negative influence on energy consumption intensity only in 31 industrial sectors. Domestic technology transfer had no significant impact on energy consumption intensity in all samples. Sadorsky (2012) examined the relationship between ICT and electricity consumption in emerging countries. His results demonstrated a positive relationship between ICT and electricity consumption. Rexhaeuse et al (2014) analyzed the relationship between ICT and energy demand using a panel of 10 OECD countries and 27 industries. The results indicated that ICT capital is associated with a significant reduction in energy demand. This relationship differs with regard to different types of energy. ICT use is not significantly correlated with electricity demand, but it was significantly correlated with a reduction in non-electric energy demand. Huang et al (2017) explored the effects of technological factors on energy intensity, including indigenous research and development (R&D) activity and technology spillovers through openness in the form of foreign direct investment, export, and import in one united framework. They employed panel data of China's 30 provinces during 2000 to 2013. The results showed that indigenous R&D plays a crucial and dominant role in declining energy intensity among four technological factors. In addition, technology spillovers coming from the openness of foreign direct investment and import decrease energy intensity except for the export. Zhou et al (2018) analyzed the major drivers behind changes in China's energy intensity with emphasis on ICT and production structure using a three-tier structural decomposition analysis (SDA) approach. The main results indicated that ICT contributed to a 4.54% increment in energy intensity, yet ICT input substitution was conducive to reducing energy use in production. Additionally, ICT influences were more significant in the service and technology-intensive sectors.

Overall, empirical findings suggest that the effect of innovation investments including ICT and/or R&D on energy intensity is ambiguous and depends on the relative magnitude of these countervailing forces (i.e., the substitution effect or the income effect). Nevertheless, these empirical studies are scarce, especially in developing countries. In addition, studies investigating the role of ICT or R&D in energy intensity mainly focused on entire industry sector. However, as the production process, technical standards and the extent of starting new business are different in industries with different sizes. Given that energy intensity of each group is quite different .The analysis is likely to be most useful at cluster level. Therefore, this study was an attempt to address this gap in the literature. To this end, the effects of innovation investments (ICT and R&D) and the spillovers' impacts on industrial energy intensity at cluster level in industries with different sizes were examined. Furthermore, R&D expenditures were divided into the domestic and foreign to present an exact analysis.

The following sections present an overview of the trends in energy intensity, ICT, and R&D intensities in three clusters of Iranian industries. Section three presents research methodology and data description. In section four, the empirical results are presented. The last section includes conclusion and recommendations.

2. Overview of trends in Iranian industries at the cluster level

This section presents an overview of trends in energy intensity, ICT, and R&D intensities in Iranian industries. In order to carry out a better analysis, all industries were classified into three clusters including small, medium, and large industries according to their size. Then, the trends among them were compared

Figure 1 illustrates the average energy intensity performance for every cluster before 2000 (1990-1999) and after 2000 (2000-2012). We calculated energy intensity for every cluster by calculating the ratio of energy consumption (barrel oil) to total outputs (million LCU). The comparison of energy intensity levels for the clusters indicates that they experienced a considerable decrease after 2000. It may be due to the government policies that encourage the industries to improve their technology by investing in efficient machineries and equipment, especially to use further innovation activities.

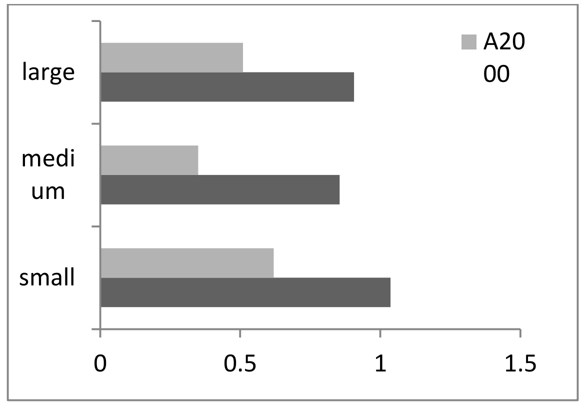

Figure 1. Energy intensity in Iranian industries at cluster level

*A2000 and B2000 refer to after 2000 and before 2000, respectively.

The question is whether R&D and ICT strongly contribute to a decrease in energy intensity levels in Iranian industries after 2000? Both ICT and R&D intensities for every cluster were examined in 2000 and 2012 (with availability of data) successively. It is noteworthy that total R&D expenditures were divided into two parts, that is, domestic and foreign. Figure 2. shows ICT intensity for each cluster measured as the ratio of ICT investment to total investment. Obviously, the share of ICT compared to that of total investments is low. In addition, the comparison of ICT intensity indicates that all clusters underwent a decline in ICT intensity between 2000 and 2012. This is because ICT infrastructures are not successfully adopted by Iranian companies.

Figures 3 and 4 display both domestic and foreign R&D intensities for every cluster during investigated periods. We calculated domestic R&D intensity for each cluster through the ratio of its internal expenditures for technology development and technological innovation expenditures to total expenditures. Additionally, we calculated foreign R&D intensity for each cluster by the ratio of its funding for purchasing foreign technology to total expenditures. The figures show that in all clusters, domestic R&D intensity is low, and it decreased between 2000 and 2012. However, in all clusters, foreign R&D intensity was high, and it increased between 2000 and 2012 except for small cluster. These findings confirm that Iranian firms have little incentive to spend domestic expenditures on technology development, presumably due to high costs and time-consuming process. Hence, Iranian companies prefer to purchase foreign technology.

Overall, the figures indicate that in Iranian firms, energy intensity has decreased after 2000. At the same period, ICT intensity as well as domestic R&D intensity have declined, but foreign R&D intensity has increased. Therefore, it can be concluded that the foreign R&D plays a major role in rising energy efficiency in Iranian firms.

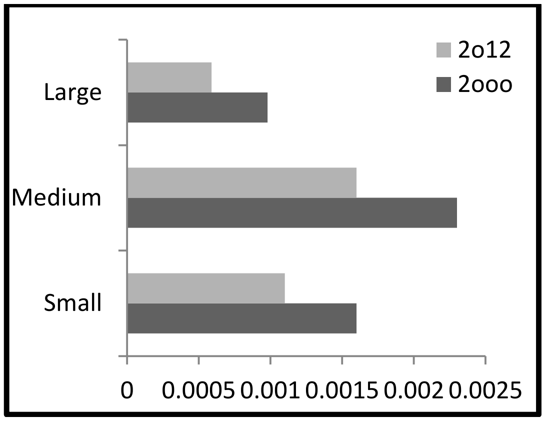

Figure 2. ICT intensity in Iranian industries at cluster level

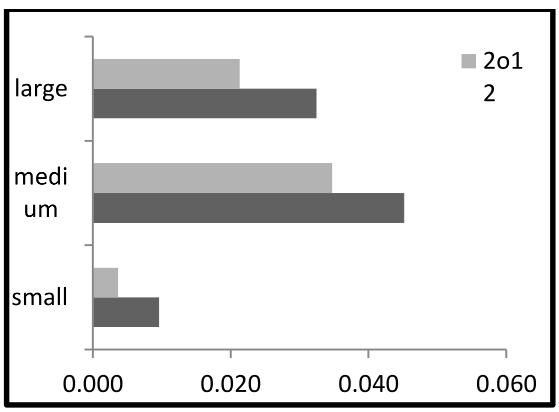

Figure 3. Domestic R&D intensity in Iranian industries at cluster level

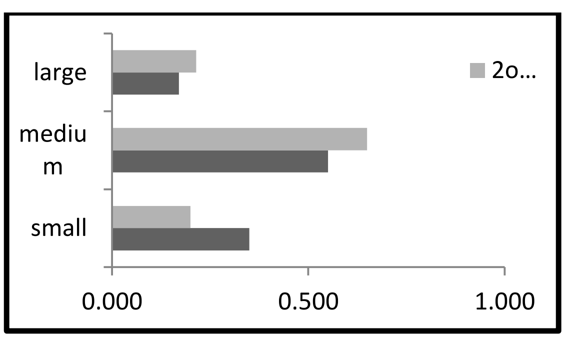

Figure 4. Foreign R&D intensity in Iranian industries at cluster level

3. Methodology and Data description

3. 1. Model specification

We use a Cobb-Douglas production function as follows:

$$Q = A\,K^{\alpha}\,L^{\beta}\,E^{\gamma} \qquad (١)$$

Q refers to the output; A denotes the total factor productivity (TFP); K denotes the capital stock; L refers to the employment; and E is the energy consumption. Assuming constant returns to scale, Production Cost can be calculated as follows:

$$C(P_K, P_L, P_E, P_M, A) = A^{-1} P_K^{\beta_K} P_L^{\beta_L} P_E^{\beta_E} P_M^{\beta_M} Q \qquad (2)$$

P_L, P_K, P_E, and P_M refer to the prices of labor, capital, energy and raw materials. β_L, β_K, β_E and β_M represent the related price elasticity, respectively. According to Shepard's lemma, after making P_E-derivation, eq. (2) can be changed to the following as:

$$E = \frac{\beta_E A^{-1} P_K^{\beta_K} P_L^{\beta_L} P_E^{\beta_E} P_M^{\beta_M} Q}{P_E} \qquad (3)$$

By setting $P_Q = P_K^{\beta_K} P_L^{\beta_L} P_E^{\beta_E} P_M^{\beta_M}$ and dividing both sides by Q, the energy intensity equation is calculated as follows:

$$EI = \frac{E}{Q} = \frac{\beta_E A^{-1} P_Q}{P_E} \qquad (4)$$

According to Hu and Wang (2006), TFP depends on knowledge capital. Thus, to capture the influence of knowledge capitals including both ICT and R&D on energy intensity, we assumed that TFP is a function of them. Additionally, we divided total R&D into two part, that is, domestic R&D ($R\&D^d$) including internal expenditures on technology development and technological innovation expenditures and foreign R&D ($R\&D^f$) including funding for purchasing foreign technology. Therefore, we set TFP function as follows:

$$TFP = e^{\,g(ICT, R\&D^d, R\&D^f) + \varepsilon} \qquad (5)$$

By replacing eq. (5) with eq. (4) and taking logarithm on both sides, energy intensity equation for industry i can be calculated as follows:

$$\ln(EI)_{it} = \alpha + \beta \ln(ICT)_{it} + \gamma \ln(R\&D^d)_{it} + \delta \ln(R\&D^f)_{it} + \theta \ln\left(\frac{P_E}{P_Q}\right)_{it} + \varepsilon_{it} \qquad (6)$$

In fact, there are various channels through which an industry may benefit from R&D and ICT spillovers from other industries (inter- industry spillovers).

However, knowledge spillovers are not necessarily associated with an economic transaction and could be facilitated by technological linkages between sectors. Therefore, we consider their spillovers effects on energy efficiency by setting

$R\&D^S$ and ICT^S variables in eq. (6) as follows:

$$\ln(EI)_{it} = \alpha_i + \alpha_1 \ln(ICT)_{it} + \alpha_2 \ln(R\&D^d)_{it} + \alpha_3 \ln(R\&D^f)_{it} + \alpha_4 \ln(\frac{P_E}{P_Q})_{it} + \alpha_5 \ln(R\&D^S)_{it} + \alpha_6 \ln(ICT^S)_{it} + \varepsilon_{it} \quad (7)$$

$R\&D^S$ and ICT^S are the related spillovers that show the volume of external R&D and ICT expenditures causing spillover effects, respectively.

Finally, in line with our speculation, since the production process, technical standards, and the extent of opening up are varied in different industries, energy intensity of each sector is totally different. Thus, such an analysis is likely to be most useful at the cluster level. Therefore, we classified total industries into three clusters including large, medium and small according to their size. Then, we estimated eq. (7) for each cluster.

3.2. Data description

As mentioned before, we attempted to examine the effects of innovation investments including ICT investments, R&D expenditures (divided into domestic and foreign), and the relevant spillovers on energy intensity in three clusters of Iranian industries including small, medium and large industries as far as size was concerned. The final regression model for each cluster was gained from eq. (7). Data were annual and obtained from the statistical center of Iran. The years from 2000 to 2012were selected as the study period, considering the availability of data. The data description is as follows:

EI_{it} denotes energy intensity of industry i at time t. Energy intensity was calculated as the ratio of energy consumption (barrel oil) to output (million LCU); α_i is industry-fixed effect; ICT denotes ICT intensity calculated as the ratio of ICT investment to total investments; $R\&D^d$ refers to domestic R&D intensity calculated as the ratio of internal expenditures on technology development and technological innovation to total expenditures; $R\&D^f$ is foreign R&D intensity calculated as the ratio of funding for purchasing foreign technology to total expenditures; $\frac{P_E}{P_Q}$ refers to the energy relative price calculated as the ratio of the fuel and power price index to producer price index. Moreover, $R\&D^S$ and ICT^S are their related spillovers, respectively. $R\&D^S$ for the industry i is defined as the ratio of the difference between R&D expenditures for total industries and the industry i to the difference between their total expenditures. ICT^S for an industry i was defined as the ratio of the difference between ICT investments for total industries and the industry i to the difference between their total investments. Finally, ε_{it} is a disturbance term assumed to be uncorrelated.

Dynamic Panel Data Technique method was used A reliable solution for the efficient estimation of dynamic panels was set by Arellano and Bond (1991) using the Generalized Method of Moments (GMM). This estimator has been extremely popular, especially in the context of empirical dynamic research as it allows discluding some of the OLS assumptions. Arellano and Bond estimator accounts for the endogenous lagged dependent variable and provides consistent parameter estimates even in the presence of endogenous right-hand-side variable. It also allows for individual fixed effects, heteroskedasticity, and autocorrelation within individuals (Roodman, 2006). Consistency of the GMM estimator depends on the validity of the instruments. As suggested by Arellano and Bond (1991), Arellano and Bover (1995), and Blundell and Bond (1998), two specification tests were used. Firstly, Sargan/Hansen test of over-identifying restrictions testing for overall validity of the instruments and the null hypothesis indicated that all instruments as a group are exogenous. The second test examining the null hypothesis demonstrated that error term ε_{it} of the differenced equation is not serially correlated, particularly at the second order (AR 2). One should not reject the null hypothesis of both tests.

4. Empirical results

Before estimating the above model for each cluster, an important step was to test for unit roots with stationary covariates. Hence, we used the Im, Pesaran, and Shin (2003) unit root test assuming that the series are non-stationary. Table 1 presents the results of Im, Pesaran and Shin (IPS) unit root test. The findings demonstrate that all variables in all clusters are stationary at the level. In other words, all variables are integrated with order (0).

Table 2 reports the results of estimations for three clusters of industries, that is, small, medium and large industries regarding their size. The findings indicate that in small size industries, ICT intensity had a positive effect on energy intensity, but this effect was not found to be statistically significant. Additionally, despite the fact that domestic R&D intensity did not have a significant impact on energy intensity, foreign R&D intensity was found to be significant and had a considerable negative impact on energy intensity. Thus, a percent increase of foreign R&D intensity led to a fall in energy intensity to 0.23 percent at 5% significant level. Likewise, as it was expected, the spillovers from ICT and R&D have negative and significant effects on energy intensity, so a percent increase of them tends to diminish energy intensity to 0.032 and 0.29 percent, respectively.

Moreover, in medium-sized industries, ICT intensity has a negligible positive and significant effect on energy intensity, so a percent increase of it results in an increase in energy intensity to 0.006 percent. In addition, despite the fact that the impact of domestic R&D intensity on energy intensity was not found to be significant, foreign R&D intensity a strong negative and significant effect on energy intensity, so a percent increase of it dropped energy intensity to 1.31 percent. Likewise, the spillovers from ICT and R&D had negative and significant effects on energy intensity, so a percent increase of them led to a decline in energy intensity to 0.08 and 2.46 percent, respectively.

Furthermore, in large-sized industries, ICT intensity had a low positive and significant effect on energy intensity; so a percent increase of it caused energy intensity to rise to 0.003 percent. Furthermore, in spite of the fact that the effect of domestic R&D intensity on energy intensity was not found to be significant, foreign R&D intensity had a relatively strong negative and significant impact on energy intensity, and a percent increase in foreign R&D intensity decreased energy intensity to 0.87 percent. Similarly, the spillovers from both ICT and R&D had negative and significant effects on energy intensity, and a percent increase in them made energy intensity drop to 0.045 and 2.36 percent, respectively. As a truism, spillovers from innovation technology (i.e., ICT and R&D) in a firm would promote technology transfer in other companies and finally induce improving factors productivity, especially energy.

Overall, it can be concluded that in Iranian firms, ICT investments lead to a rise in energy intensity. In other words, income effect is dominant. Domestic R&D expenditures do not have a significant effect on energy intensity, while Foreign R&D expenditures result in a sharp drop in energy intensity. In addition, as it was expected, the spillovers from these innovations, especially R&D spillover decrease energy intensity.

As mentioned before, the GMM estimator checks for the validity of the moment conditions by performing the Sargan test for over-identification and tests for serial correlation of the differenced error term. As the corresponding *p*-values of these tests indicate, (See Table 3) the null hypothesis of the validity of instruments cannot be rejected. The first- and second-order serial correlation tests show that there are first-order serial correlations, and there is no evidence of second-order serial correlation in the differenced error terms.

Table 1

IPS unit root test for the industries at cluster level

Variables	Large industries	Medium industries	Small industries
$ln(\text{EI})$	-4.60(0.000)*	-3.94 (0.000)	-3.23 (0.000)
$ln(\text{ICT})$	-4.28 (0.000)	-3.84 (0.000)	-2.02 (0.021)
$ln(R\&D^d)$	-2.40 (0.008)	-2.17 (0.014)	-1.73 (0.041)
$ln(R\&D^f)$	-3.51 (0.000)	-1.63 (0.051)	-1.97 (0.024)
$ln(\frac{P_E}{P_Q})$	-6.22 (0.000)	-3.27 (0.000)	-2.64 (0.007)
$ln(R\&D^s)$	-5.87 (0.000)	-3.26 (0.000)	-3.65 (0.000)
$ln(ICT^s)$	-3.46 (0.000)	-1.77 (0.038)	-1.78 (0.036)

* Numbers in parentheses refer to prob.

Table 2

The results of GMM estimation for the industrial clusters

Variables	Large industries	Medium industries	Small industries
Lagged $\ln(EI)$	-0.39 (-2.27)*	-0. (-2.76)	-0.31 (-2.44)
$ln(\text{ICT})$	0.0036 (1.77)	0.0065 (1.98)	0.004 (1.48)
$ln(R\&D^d)$	-0.016 (-1.18)	-0.0079 (-1.29)	0.0011 (1.13)
$ln(R\&D^f)$	-0.87 (-3.50)	-1.31 (-2.23)	-0.23 (-1.58)
$ln(\frac{P_E}{P_Q})$	-0.025 (-1.91)	-0.045 (-2.54)	-0.038 (-2.46)
$ln(R\&D^s)$	-2.36 (-2.95)	-2.46 (-3.81)	-0.29 (-2.87)
$ln(ICT^s)$	-0.045 (-1.73)	-0.088 (-2.11)	-0.032 (-1.94)

* Figures in parentheses refer to t- statistics.

Table 3

The tests of result validity

Test	Large industries	Medium industries	Small industries
First order (p-value)[1]	0.004	0.00	0.00
Second order (p-value)[2]	0.27	0.25	0.24
Sargan test (p-value)	0.47	0.36	0.43

[1] The null hypothesis is that the instruments are not correlated with the errors.

[2] The null hypothesis is that the errors in the first difference are not serially correlated with the second order.

5. Conclusion

The present study investigates the effects of innovation investments including ICT investments and R&D expenditures (divided into foreign and domestic) on energy intensity in Iranian industries. Since in the production process, technical standards and the extent to which new businesses run are different in the industries, energy intensity of each sector is quite different. Given that such an analysis is likely to be most useful at the clusters level, all industries were classified into three clusters, namely, small, medium and large with respect to their size.

The findings reveal that in three clusters, ICT investment led to a negligible increase in energy intensity. This effect was not found significant in the small sized cluster.

Obviously, the estimated coefficients, to some extent, depend on diffusion of ICT technologies in firms. However, this result confirms that the income effect is dominant in Iranian firms. Additionally, despite the fact that the effect of domestic R&D expenditure on energy intensity was not found significant in any clusters, foreign R&D expenditure considerably decreased energy intensity in three clusters. This finding can be attributed to greater share of foreign R&D expenditures. Put it differently, Iranian companies lack incentives to spend the domestic expenditures on technology development and technological innovation because presumably, it costs a lot and is time-consuming. Thus, Iranian companies opt to purchase international technology. Furthermore, as it was expected, the spillovers effects of these innovation investments led to a reduction in energy intensity in three clusters. Nevertheless, the R&D spillover effect was found to be highly greater than that of ICTs.

In conclusion, in Iranian firms, innovation investments, in particular foreign R&D expenditures play a substantial role in improving energy efficiency. Therefore, the findings of this study suggest that Iranian industries take actions to develop innovation capacity and to promote energy saving technology through cooperation. Technology transfer should also be strengthened simultaneously. The finding also justifies the necessity of governments' intervention to implement policies requiring industries to expand such investments.

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