WPS6387

Policy Research Working Paper 6387

The Energy Transition of the Transition Economies

An Empirical Analysis

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The World Bank
Europe and Central Asia Region
Office of the Chief Economist
March 2013

Policy Research Working Paper 6387

Abstract

The aggregate manufacturing energy intensity of 28 countries in Eastern Europe and Central Asia had declined by 35 percent during 1998–2008. This study reveals strong evidence of convergence: less efficient countries improved more rapidly and the cross-country variance in energy productivity narrowed over time. An index decomposition analysis indicates that energy intensities declined largely because of more efficient energy use rather than shifts from energy intensive to less intensive manufacturing activities. Income growth and energy price increases were the main drivers of the convergence. They dominated the impact of trade, which led to specialization in energy intensive industries.

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The Energy Transition of the Transition Economies:
An empirical analysis[1]

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Key Words: Manufacturing Energy Intensity, Energy Productivity Convergence, Index Decomposition, Trade, Eastern Europe and Central Asia

JEL Classification: O13, O47, P28, Q40

Sector Board: Energy and Mining

[1] I thank Uwe Deichmann and Indermit Gill for useful comments and suggestions. I thank Sofia Chiarucci and Po Ying Wong for excellent research assistance. The usual disclaimer applies.
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I. Introduction

The Eastern Europe and Central Asia region had one of the least efficient manufacturing sectors in the world because of the region's historical emphasis on heavy industries and artificially low energy prices during the Soviet era.[3] Since the transition period started two decades ago, the sector's energy productivity (value added per unit of energy input) has consistently improved – by almost 35 percent between 1998 and 2008. As a result, although manufacturing value added increased by more than 50 percent over the period, energy consumption had been stabilized at around 250 million tons of oil equivalent (mtoe). How did the region achieve this impressive decoupling of economic growth from energy use? This paper seeks to answer the question by empirically examining the trend and determinants of manufacturing energy use for 28 countries in ECA. [4]

Using detailed sector and country-level data, we conduct three types of analysis. First, we compare energy productivity performance over time and across countries. We ask the following questions: Is the trend of declining energy intensity consistent across the region? Do lagging countries catch up with technological leaders? Second, we decompose the manufacturing sector into 11 subsectors and investigate whether the reduction in energy intensity is more attributable to changes in the mix of production activities (the structural effect), or to the fundamental improvement in the use of energy (the efficiency effect). Finally, we identify the economic factors that have driven changes in energy intensity, energy efficiency and the structural composition of industrial activities.

The analysis reveals strong evidence of cross-country convergence: not only the inter-country variation in energy intensity has reduced; but there is also a tendency of more rapid improvement in countries that had high energy intensity initially. Beyond this general trend, we find some Central Asian countries are notable exceptions where energy intensity had remained largely unchanged. Interestingly, intrinsic efficiency improvement turns out to have contributed to most of the reduction in manufacturing energy intensity, whereas structural change had had a less influence, and had led to higher energy intensity in some countries.

Country-level analysis indicates that rising per capita income and higher energy prices are strong predictors of more efficient energy use, both through the channel of efficiency rather than structural mix. A one percent increase in per capita GDP is on average associated with a 1.3

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[3] Manufacturing consists of all industrial activity outside of mining and construction. The detailed composition of manufacturing industry is described in section III.

[4] Following the definition of World Bank regions, Eastern European and Central Asia includes Albania, Armenia, Azerbaijan, Belarus, Bosnia & Herzegovina, Bulgaria, Croatia, the Czech Republic, Estonia, Georgia, FYR Macedonia, Hungary, Kazakhstan, Kosovo, the Kyrgyz Republic, Latvia, Lithuania, Moldova, Montenegro, Poland, Romania, the Russian Federation, the Slovak Republic, Slovenia, Tajikistan, Turkey, Turkmenistan, Ukraine and Uzbekistan. Kosovo and Montenegro are not included in the analysis because energy consumption data are not available for these two countries.

percentage point reduction in manufacturing energy intensity. A 10 percent increase in the price of electricity is associated with a 2.6 percentage point reduction in manufacturing energy intensity. Furthermore, energy intensity slightly increases with the increase in the share of manufacturing exports in output, suggesting that trade induces specialization on more energy-intensive industries.

In spite of many existing cross-country studies on energy intensity comparison and determinants (for example, Howarth et al. 1991; Uanander e al, 1991; Mulder and de Groot 2007), relatively few have looked at the trends in developing countries. Frankhauser and Cornillie (2004) and Markandya et al. (2005) are some exceptions who examine economy-wide energy intensity change in the ECA region. Our analysis differs from their analysis in that we focus on the manufacturing sector, the largest energy user in the region and a sector that perhaps also offers the largest opportunities for energy savings. We also cover more countries and years and look at changes during the second decade of transition.

The rest of the paper proceeds as follows. Section II provides background information about the manufacturing sector in ECA. Section III describes the data. Section IV presents empirical methods and results. Section V discusses the conclusions and policy implications.

II. Background – Manufacturing in Eastern Europe and Central Asia

During the Soviet era, manufacturing was the cornerstone of centrally planned economies of ECA. Leaders emphasized rapid industrialization, particularly of heavy industry, to foster economic growth. This heavy industry was also vastly inefficient. To facilitate industrial production and social welfare, central planners kept energy prices well below cost recovery levels. Of all non-OECD subsidies to fossil fuels (including electricity) in 1991, totaling $270-$330 billion, roughly two-thirds were in the former Soviet Union and Eastern Europe (Myers and Kent, 2001). Subsidies distorted price signals and led to extraordinary profligacy in the use of energy. In 1990, the former Soviet Union's energy intensity, defined as the ratio of primary energy consumption to GDP, was 70 percent higher than the United States and 2.5 times that of Western Europe. The gap is especially evident in the manufacturing sector where energy use per unit of output was 3 times higher than in the U.S. and 3.5 times higher than in the Western Europe (U.S. Congress, 1993).

The early years of transition brought a sharp contraction in manufacturing output following the disruption of traditional trade and financial links and an end to centrally planned production (Havrylyshyn et al, 1998). Between 1991 and 1993, manufacturing value added fell on average by 30 percent. In parallel, manufacturing energy consumption dropped on average by 27 percent across all countries. Most transition countries continued the comprehensive reform programs, including the liberalization of energy prices. Price supports for fossil fuels in Russia and Eastern Europe were greatly reduced. Bringing laws into agreement with the EU's further accelerated the process of eliminating remaining subsidies. Even in Russia, gasoline and diesel prices for industry (which received two-thirds of energy subsidies in 1994) have increased to world market levels, although gas prices still remain below border price levels (IFC, 2008).

The market-friendly reforms had a far-reaching impact on the transformation of the energy economies. When the sharp initial decline gave way to gradual economic recovery, energy consumption continued to decline and then stabilized at around 250 million tons of oil equivalent (mtoe) per year. Meanwhile, manufacturing output has increased by more than 50 percent during 2002- 2008, as shown in Figure 1. This has occurred because the average manufacturing energy intensity declined by 35 percent from 0.4 kilogram of oil equivalent (koe) per dollar (ppp) in 1998 to 0.26 koe per dollar (ppp) in 2008.[5] If energy intensity had remained at its 2002 level, energy demand would have been 776 mtoe higher, the equivalent of 10 years' total energy consumption in Ukraine today.

While manufacturing energy intensity at the regional level had sharply declined, sub-regions show disparate behavior. Figure 2-a presents energy intensity trend for six sub-regions/countries. Central Asia is notably lagging behind in terms of the reduction in energy intensity. In fact, Kazakhstan, the Kyrgyz Republic, and Tajikistan had all experienced an increase in energy intensity since 2000 as shown in Figure 2-b. In the rest of the paper, we explore why countries were not doing equally well and identify the driving factors behind the trend of energy productivity.

III. Data

Data used in this paper come from three sources. The energy consumption data are obtained from the International Energy Agency (IEA) World Energy Statistics and Balances database (2012). The database reports final energy consumption of manufacturing in 28 ECA countries. The manufacturing sector is further broken out by 11 subsectors at the two-digit level of the international standard industrial classification Revision 4 (ISIC Rev. 4).

The aggregate value added of manufacturing is reported in constant 2000 US dollars in the World Development Indicators (WDI) (2012). To compare energy intensity levels across countries, we apply purchasing power parity (PPP) exchange rates to convert all values into constant 2005 international dollars. The theoretically ideal PPP exchange rate to use at the sector level would be based on the output prices of the sector, rather than on aggregate expenditure prices. However, due to the limited availability of producer price-based PPPs, we follow the standard practice of using expenditure PPPs for cross-country convergence analysis (such as in Dollar and Wolff, 1993 and Mulder and Groot, 2007).

[5] Energy intensity is measured by energy use per unit of manufacturing value added. Energy use is defined as final energy consumption excluding energy losses in the generation, transmission and distribution of purchased electric power. Value added presents the net economic output, or gross economic output less the value of purchased inputs. It is derived by subtracting the cost of materials, supplies, fuel and purchased electricity from the value of final outputs.

For decomposition analysis, we obtain value added of manufacturing at the subsector level from United Nations Industrial Development Organization (UNIDO) Yearbook of Industrial Statistics (INDSTAT4) (2011). INDSTAT4 reports manufacturing value added at the three-digit level of ISIC Rev.3 for selected ECA countries. We match IEA (2012) with INDSTAT4 (2011) to calculate subsector energy intensity at the ISIC Rev.4 two-digit level. INDSTAT4 reports value added in current prices, denominated in US dollars. We use the GDP deflator of each country to convert values of different years into 2000 prices and then to constant international dollars using 2005 PPP rates.

Per capital GDP (PPP based), the capital-labor ratio of manufacturing and the share of exports in total manufacturing value added are all obtained from WDI (2012). Energy prices are obtained from Energy Regulators Regional Association's tariff database and Eurostat.

IV. Empirical Strategy and Results

In this section, we present three types of empirical analysis to identify the sources and mechanisms of energy intensity change in the manufacturing sector of ECA. First, we conduct a cross-country convergence analysis to test whether backward countries are catching up with efficient ones. Second, using an index decomposition method, we investigate the extent to which the change in energy intensity is induced by structural shifts vs. efficiency improvements. Finally we explore the determinants of energy intensity, the structural mix and the efficiency levels based on regression analyses.

A. Energy Intensity Convergence

Convergence analysis is typically used in the context of economic growth and goes back to Barro and Sala-i-Martin (1992). There are different definitions of convergence in the literature. The reduction in cross-sectional variance in productivity is called σ-convergence. The tendency of less productive countries to grow faster is called β-convergence.

To measure σ-convergence in the context of the energy intensity analysis, we look at the trend of cross-country variance over time. The mean and standard deviation of energy intensity for an unbalanced panel of 28 countries in ECA during 1998-2008 are shown in Figure 3-a. To avoid selection bias, we also present the same statistics for a balanced panel of 23 countries.[6] For both samples of countries, the average energy intensity had declined steadily on average at a rate of 3.2 percent per year. The group of countries as a whole was converging towards more efficient economies (EU-15) with the gap in manufacturing energy intensity between ECA and EU15 average more than halved over the sample period.

The standard deviation of energy intensity had also reduced, indicating that the gap between the less efficient and the technology leaders were narrowed over time. The reduction in cross-section

[6] Value added data are not available for Albania during 2004-2006, Romania in 2002, Russia during 1998-2001, Serbia during 1998-1999 and Turkmenistan during 2005- 2008.

dispersion can be seen again in Figure 3-b, which plots fitted normal densities for the logs of manufacturing energy intensity in 1998 and 2008.

To test the existence of β-convergence, we conduct regressions of the rate of energy intensity change, $\Delta\left(\frac{E}{Y}\right)$, on initial levels of energy intensity, $ln(\frac{E}{Y})_i^{1998}$ for the 25 countries where data on energy intensities are available for both the initial (1998) and end (2008) years. The regression equation and results are presented below.

$$\Delta ln(\frac{E}{Y})_i = \alpha + \beta ln(\frac{E}{Y})_i^{1998} + \varepsilon_i \quad (1)$$

($\alpha = -0.654$ [$SE = 0.178$]; $\beta = -0.212$ [$SE = 0.123$]; R^2=0.157)

($\alpha = -0.991$ [$SE = 0.232$]; $\beta = -0.393$ [$SE = 0.154$]; R^2=0.321) (excluding Central Asia)

The coefficient on the initial levels is negative and statistically significant at 10-percent level when all countries are considered. Excluding Central Asian countries, the coefficient of the initial level almost doubles in absolute term and is statistically significant at the 5 percent level. The R^2 also increases. The results indicate that countries with higher energy intensity at outset are catching up to more productive countries, especially for those outside Central Asia. However, the simple regression only has limited ability to explain cross-country difference in energy intensity. Even without accounting for Central Asia, the regression accounts for only 30 percent of the cross-country variance in the rate of energy intensity change. In the following, we further explore the underlying process of energy-intensity change across countries.

B. Energy Intensity Decomposition

Manufacturing energy intensity can drop for two main reasons: manufacturing shifts towards different products that require less energy to make (the structural effect) or manufacturing firms make production processes more efficient so they require less energy to produce the same products (the efficiency effect). Specifically, assuming there are *N* subsectors within manufacturing, the manufacturing energy intensity can be written as:

$$I_t = \frac{E_t}{Y_t} = \sum_{i=1}^{N} \frac{e_{it}}{y_{it}} \frac{y_{it}}{Y_t} = \sum_{i=1}^{N} E_{it} S_{it} \quad (2)$$

where E_t and Y_t are the overall energy consumption and value added of manufacturing in year t. e_{it} and y_{it} are energy consumption and value added of subsector i in year t. The aggregate energy intensity (I_t) is thus expressed in terms of sectoral energy efficiency(E_{it}) and production structure (S_{it}) which is measured by the sector share of the manufacturing value added ($S_{it}=y_{it}/Y_{it}$).

To attribute changes in energy intensity between changes in efficiency and structural composition, various index decomposition methods have been used to isolate the impact of one variable from the other, so that the overall change in energy intensity between the end year ($t=T$)

and the base year (t=0) can be described as the multiplication of the structural (D_{str}) and efficiency (D_{Eff}) indexes:

$$\frac{I_T}{I_0} \equiv D_{int} = D_{Str} D_{Eff} \quad (3)$$

where D_{int} is the intensity index, I_t and I_0 are defined the same as previously. For example, using Laspeyres index, one estimate the impact of structural or efficiency change by holding the efficiency or structural level constant at the base year value and use base year energy intensity as the fixed weight. The Laspeyres structural and efficiencies indexes are given by:

$$L_{Str} = \sum_i S_{i,T} E_{i,0} / \sum_i S_{i,0} E_{i,0} \qquad L_{Int} = \sum_i S_{i,0} E_{i,T} / \sum_i S_{i,0} E_{i,0} \quad (4)$$

By reversing the role of base year and end year, one obtains the Passches index:

$$P_{Str} = \sum_i S_{i,T} I_{i,T} / \sum_i S_{i,0} I_{i,T} \qquad P_{Int} = \sum_i S_{i,T} I_{i,T} / \sum_i S_{i,T} I_{i,0} \quad (5)$$

More details about the calculation of index numbers can be found in Ang (2004). Ang and Zhang (2000) provide a thorough literature review of energy index decomposition. In this paper, we adopt the Fischer (1921) Ideal Index approach. The Fisher Idea index is the geometric mean of the Laspeyres and Paasche numbers:

$$F_{Str} = (L_{Str} P_{Str})^{1/2} \qquad F_{Int} = (L_{Int} P_{Int})^{1/2} \quad (6)$$

Fisher Ideal index provides a perfect decomposition of an aggregate energy intensity into structural and efficiency components, which is a very attractive property for interpreting the relative importance of industry composition and efficiency effects.[7] Boyd and Roop (2004) first apply the Fisher Idea index to examine the trends of energy intensity for U.S. Manufacturing sector. Metcalf (2008) uses the same decomposition method to analyze energy intensity change at the state level in the U.S.

To construct the structural and efficiency indexes, we divide the manufacturing sector into 11 subsectors based on the ISIC system. These subsectors are iron and steel, chemical and petrochemical, non-ferrous metals, non-metallic minerals, transport equipment, machinery, food and tobacco, paper and pulp, wood and wood products, and textile and leather. Continuous time series value added data are only available at the subsector level for 14 countries mostly during 2001-2007. This data availability dictates the countries selected and the period of investigation for the decomposition analysis. Figure 4 presents the decomposition results for the group of 14 countries as a whole between 2001 and 2007. Table 1 presents the decomposition results at the country level.

As shown in Figure 4 and Table 1, efficiency improvements contributed to most of the reduction in energy intensity, while structural shifts had actually offset some of the efficiency gains in a

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[7] See Boyd and Roop (2004) for a discussion on the superlative theoretical properties of a Fisher Ideal index.

handful of countries. For example, in Bulgaria, aggregate energy intensity of the manufacturing sector in 2007 was of 61 percent of its intensity level in 1998. The structural index was 105 percent of its level in 1998 while the efficiency index was 57 percent of its 1998 level. In other words, had the energy efficiency stayed the same, total energy intensity would have increased by 5 percent between 1998 and 2007. In Russia, the 32 percent reduction in energy intensity can be attributed almost entirely to improvements in energy efficiency during 2001-2007.

Several facts need to be underlined when interpreting the above results. First, the decomposition analysis (at the two-digit ISIC level) may mask some important structural shifts within an industrial subsector. For example, within the paper and pulp sector, pulp is much more energy intensive than paper; within the steel sector, shifts from oxygen steel to electric steel will reduce the intensity of energy use. Intra sector shifts from basic to specialized manufacturing are not analyzed here, but are certainly relevant.

Second, although value added data allow the measurement of energy efficiency for heterogeneous industries, value added is also influenced by a range of pricing effects unrelated to changes in the level of physical production. For example, prices of steel and chemicals have surged during the worldwide commodity boom during the 2000s. The steel and chemical sectors' considerable decline in energy intensity may in part reflect the price development.[8]

Finally, it should be noted that structural change in the manufacturing industry is different from structural change at the aggregate, economy-wide level. Under market forces, all transition economies faced a drastic structural adjustment, which led to the downsizing of the heavy industry. Several studies confirm the general patterns of structural transformation from industry to service in the region (Fankhauser and Cornillie, 2004 and EBRD, 2010). In contrast, analysis in this paper focuses on the structural change inside the manufacturing industry during the second decade of the transition.

C Determinants of Manufacturing Energy Intensity

What have driven changes in manufacturing energy intensity, as well as efficiency and industrial structural mix? A number of factors may have played a role. These include: *Income* - As income grows, consumer demand and investment for manufactured goods expand. As countries turns over its capital stock – equipment and factories- to meet increasing demand, efficiency will be enhanced. *Energy prices* – When energy is relatively cheap, there is little incentive for industry to reduce its energy use, or shift to less energy intensive sectors. *Capital intensity of manufacturing* - Depends on whether capital and energy are substitutes or complements, there is a negative or positive relationship between capital and energy intensities. *Trade* – On one hand, trade could facilitate information and technology spillover that help improve energy efficiency; Trade could also expose enterprises to higher level of competition in the international markets

[8] We measure energy intensity in terms of energy consumption per volume of product physical outputs for the steel and cement industry. The observed trend of increasing energy efficiency is robust to the alternative indicator.

and creates pressure to cut costs and save energy (EBRD, 2010). On the other hand, trade could contribute to cross-country divergence in energy intensity by stimulating international specialization (Grossman and Helpman, 1991). Finally, government energy policies and public awareness can be important in promoting rational use of energy.

To understand which factors are more important in determining the patterns of ECA's manufacturing energy intensity change, we estimate the following equation:

$$ln(\frac{E}{Y})_{it} = \beta_0 + \beta_1 lnI_{it} + \beta_2 lnP_{it} + \beta_3 lnC_{it} + \beta_4 E_{it} + \beta_t T_t + c_i + \varepsilon_{it} \quad (7)$$

where $(\frac{E}{Y})_{it}$ is manufacturing energy intensity in country *i* at year *t*. I_{it} is the per capita GDP measured in 2005 PPP based international dollars. P_{it} is the industrial electricity prices measured in 2000 US dollars.[9] C_{it} is the capital-labor ratio indicating the capital intensity of the manufacturing activity.[10] E_{it} is the percentage of export in manufacturing valued added and is included as a measure of trade intensity. c_i is an unobserved country fixed effect, which include country specific characteristics that are fixed over time, such as culture, climate zone[11] and government regulation and so on. We also include year fixed effects, T_t (t = 1998-2008), to control for common cyclical components such as a common technology shock. ε_{it} is an idiosyncratic error term. β_0, β_1, β_2, β_3 and β_4 are parameters to be estimated. Summary statistics of variables are presented in Table 2. If the country-specific effects c_i are correlated with other explanatory variable which in turn are orthogonal to the error term ε_{it}, then OLS and Random effects estimation would be biased but a within transformation will yield consistent estimators.

As discussed in the previous section, energy intensity changes can be disaggregated into structural and efficiency components. Based on the same model specification, we estimate the determinants of structural and efficiency changes using index numbers of the 14 countries presented in Table 1.

Columns (1) , (2) and (3) of Table 3 report results from estimating determinants of manufacturing energy intensity identified in equation (7) via OLS, fixed effects and random effects models. The parameter estimates are very sensitive to the choice of model. The Hausman test decisively rejects the null hypothesis that the unobserved variable c_i is uncorrelated with the

[9] We also include industrial gas prices in the regression, which does not quantitatively affect the estimation results but reduces the sample size.

[10] We also control for the capital investment growth ratio of the manufacturing sector. High turn-over rate of capital stocks could mean more efficient facilities. It turns out there is no statistically significant relationship between the growth of capital stock and energy intensity. Including this variable does not qualitatively change the estimation results of other parameters but reduces the number of observations.

[11] In some manufacturing sectors, portion of the energy consumption is influenced by weather conditions. The influence on energy consumption is different form industry to industry. Given the lack of time-series data on country-level weather conditions, and that heating and cooling degree days tend to be stable within country. The analysis does not specifically control for weather conditions in analyzing the energy consumption performance within the manufacturing sector.

other independent variables at the 1% level. In this case, only fixed effects specification reported in column (2) yields consistent estimators, and is the preferred estimate.

Controlling for country and year fixed effects, the parameter estimates suggest that all independent variables reported in Table 3 are strong predictors of a country's manufacturing energy intensity. A one percent increase in per capita GDP is associated with a 1.3 percentage point decrease in energy intensity. A one percent increase in industrial electricity price is associated with a 0.26 percentage point decrease in energy intensity. Both results are statistically significant at the 1 percent level.

The estimates of capital-labor ratio show that manufacturing energy intensity first increases then decreases with the increase of capital intensity with the turning point slightly below the sample mean. This inverted-U relationship suggests that diminishing returns to capital may partially explain energy-productivity convergences across countries. [12]

Another interesting finding that emerged from the results is that energy intensity slightly increases with the increase of the share of exports in total manufacturing, lending support for the hypothesis that trade induces specialization on more energy intensive industries. This result is not entirely surprising. As demonstrated in the model in Krugman (1987), comparative advantage leads to specialization in the tradable-goods sectors. Because the region has abundant energy resources and relatively low energy prices, many of the region's countries are net carbon exporters. In fact, Ukraine, Russia, and Kazakhstan are the first, third, and fourth most carbon- (and energy-) intensive exporters in the world (Davis and Caldera 2010). EU enlargement also offers access to a larger market and opportunities for specialization. Some new EU member states including Hungary, Bulgaria, Estonia, Romania and Latvia have the most specialized industrial structures. For example, Hungary is highly specialized in refined petroleum products, while Bulgaria shows high specialization in mining and quarrying (European Commission, 2011). This specialization effect dominates other, potentially positive effects of trade on energy productivity, such as technological spillover and increased competition.

One concern with the above analysis is that the causal effect between economic growth and energy intensity is likely to be two-way. Energy efficient technologies can improve productivity (Cleveland et al, 2000); Reductions in energy demand could also free up capital required for energy requirement and cut expenses. Both effects can spur economic growth. It is also likely that non-residential energy prices are affected by the amount of energy consumed in the industry - that is energy price may be endogenously determined by energy intensity. Furthermore, the above analysis assumes an instant response of energy intensity to income and energy price

[12] This is consistent with findings of Metcalf (2008) based on US data. However, to be noted, there has been no consensus about the sign of the elasticities of substitution between energy and capital. Some authors suggest the need to disaggregate capital inputs into working capital and physical capital, and find that energy is generally complement to physical capital and a substitute for working capital (Field and Grebenstein, 1980). Solow (1987) demonstrates either relationship is possible when using aggregated capital data.

change within a year. More realistically, energy using behavior responds to price changes with some lags.

To address these concerns, we estimate a dynamic panel model where the current level of energy intensity depends on the level of energy intensity in the last period as described in equation (8). We then use the difference generalized methods of moments (GMM) technique outlined in Arellano and Bond (1991) to obtain consistent estimators. To account for the potential endogeneity of income and energy prices, we use the log of per capital income and the log of electricity prices lagged 2 to 4 periods as instruments in the GMM model. The estimation results are presented in column (4) of Table 4. Although some estimated coefficients changed in magnitude[13], none changed in sign and these results are similar to those obtained by treating income and price as exogenous. The specification also easily passes the overidentification test.

$$ln(\frac{E}{Y})_{it} = \beta_0 + \gamma ln(\frac{E}{Y})_{it-1} + \beta_1 lnI_{it} + \beta_2 lnP_{it} + \beta_3 lnC_{it} + \beta_4 E_{it} + T_t + c_i + \varepsilon_{it} \quad (8)$$

Table 4 reports estimates from three separate regressions of equation (7) using energy intensity, structure and efficiency indexes as the dependent variables. The income and price elasticities of the intensity and efficiency indexes are both negative and statistically significant at the 1 percent level. The income and price elasticity of the efficiency index are higher than those for the overall intensity index in absolute term. In contrast, the structural index is less responsive to income and price changes. The income and price elasticities of structural index are in the opposite sign and are statistically insignificant. The results are consistent with those from the previous section. They show that income growth and price reform help reduce energy intensity. This is achieved mostly through intrinsic efficiency improvements, whereas structural change in the mix of industrial activities had a less influence on the level of aggregate energy intensity and may have partially offset efficiency gains.

A comparison of the coefficient estimates on export intensity helps distinguish the impact of trade on efficiency and structural change. While a higher share of exports is negatively correlated with the efficiency index (showing improvement in energy efficiency), it is strongly positively correlated with the structural index with a *p*-value less than 0.001. The results provide further evidence that the specialization effect of trade dominates other positive effects of trade on energy efficiency, and may have acted to raise overall energy intensity in the region.

V. Conclusions and Policy Implications

Manufacturing was the cornerstone of the centrally planned economies in ECA. Today, it still plays an important role both measured by its economic contribution and its environmental impact. Manufacturing is the largest energy user, accounting for 28 percent of total energy use, and the

[13] Price elasticity is no longer statistically significant probably due to the reduced sample size resulting from the use of lagged variables as instruments.

second-largest carbon emitter, responsible for 34 percent of total carbon dioxide (CO_2) emissions in the region in 2009 (Deichmann and Zhang, 2013).

This paper investigates the source and mechanism of energy intensity change in the manufacturing sector of ECA during 1998- 2008. There had been a remarkable reduction in manufacturing energy intensity over the period. The average energy intensity was reduced by 35 percent by 2008. Meanwhile, there is evidence of both σ- and β- convergence: the gap in energy intensity between leaders and backward countries was narrowed over time. Meanwhile, the reduction in energy intensity had been more rapid in countries that had higher energy intensity initially. Notable exceptions are Kazakhstan, the Kyrgyz Republic and Tajikistan, where energy intensity was increased over the period.

To shed light on the sources of industrial energy use change, we decompose aggregate energy intensity into efficiency and structural components using Fisher Ideal Index. The decomposition analysis suggests that the bulk of the reduction in energy intensity has occurred because of improvements in energy efficiency as opposed to shifts from energy intensive to less intensive manufacturing activities.

We then conduct regression analysis to identify factors driving the change in aggregate energy intensity, energy efficiency and structural composition. The results show that both income growth and rising energy prices helped lower overall manufacturing energy intensity in ECA countries. A one percent increase in per capita GDP is on average associated with a 1.3 percentage point reduction in energy intensity; a 10 percent increase in an electricity price is associated with a 2.6 percentage point reduction in energy intensity, *ceteris paribus*. In addition, the efficiency index is much more sensitive to income and price changes than the structural index, suggesting that both income and price drive intensity change largely through the efficiency rather than the structural channel. Finally, energy intensity increases slightly with increase in manufacturing exports, implying that trade induces specialization in more energy intensive industries.

Overall, the analysis suggests that economic developments have played an especially important role in improving energy efficiency. Prior to the global financial crisis, GDP grew on average at 7 percent annually in ECA. Since consumption of manufacturing commodities tends to closely related to GDP, demand for manufacturing outputs have also increased. In order to satisfy increased demand for commodities, countries either increased capacity utilization, or added new, more efficient capacity, thereby reducing the share of smaller, less efficient production units.[14] In contrast, in Central Asia, where production levels have stalled, manufacturers have failed to upgrade to more efficient technologies.

[14] One widely reported example is in Romania, benefitting from strong growth in demand, industrialists introduced modern technologies into outmoded or newly built facilities at a rapid pace, increased the production of commodities—especially those for sale in foreign markets—and plowed the proceeds back into further upgrade and expansion of industrial production.

Rising energy prices also explains the convergence in energy intensity. Industrial electricity prices on average increased by 12 percent during 1998-2008 in ECA. Higher energy prices cause energy intensity to fall by encouraging the adoption of energy saving technologies—especially in sectors where energy constitutes a significant portion of their total costs. This includes the introduction of more energy efficient machines, production processes or materials. For example, producing clinker from raw material is the main energy-consuming process in a cement factory. Using other synthetic material to substitute for clinker can significantly reduce energy use in cement production.

Industry sector normally consists of a small number of large players with similar manufacturing processes. It is therefore the part of the economy best organized to become more energy efficient. Although industry in ECA has become much more efficient over the past decade, the potential for reducing energy use and associated CO_2 emissions is high. The region produces 5 percent of manufacturing value added in the world, but consumes 9 percent of energy. Many ECA countries still use several times more energy per unit of output than their Western partners, as shown in Figure 3-a. The energy savings potential estimated for three energy-intensive industrial sectors (iron and steel, cement, and pulp and paper) in ECA amounts to 50 percent of current energy use (Deichmann and Zhang, 2013). Given the old vintage of capital stock in ECA, upgrading to energy efficient technologies are likely to be cost-effective if undertaken as part of the natural cycle of plant replacement. This offers an excellent opportunity for new technology deployment to have an impact on energy savings in the near to medium term.

Empirical results in this paper provide several policy implications for improving manufacturing energy efficiency in the region:

First, one obvious strategy to improve energy productivity is to target energy efficiency efforts on industries with high energy intensity, high total energy use, and high economic growth. Industries undergoing growth in production are less capital restricted and may also be more receptive to efforts to improve their competitive edge through increased management of energy costs.

Second, despite recent progress in energy price reforms, subsidies still persist in many countries in ECA. The effectiveness of continued energy price reforms in the region will largely determine the potential to save energy.

Finally, the lack of energy-use data is one of the stumbling blocks to developing rational energy efficiency strategies and policies. Important data gaps remain, especially in Central Asian countries. For example, more than 80 percent of the industrial energy use is reported as “non-specified” in Kazakhstan, Kyrgyz, Turkmenistan and Uzbekistan. Collection of good quality, timely and detailed data should be a priority in these countries in order to provide the basis for rational policy making.

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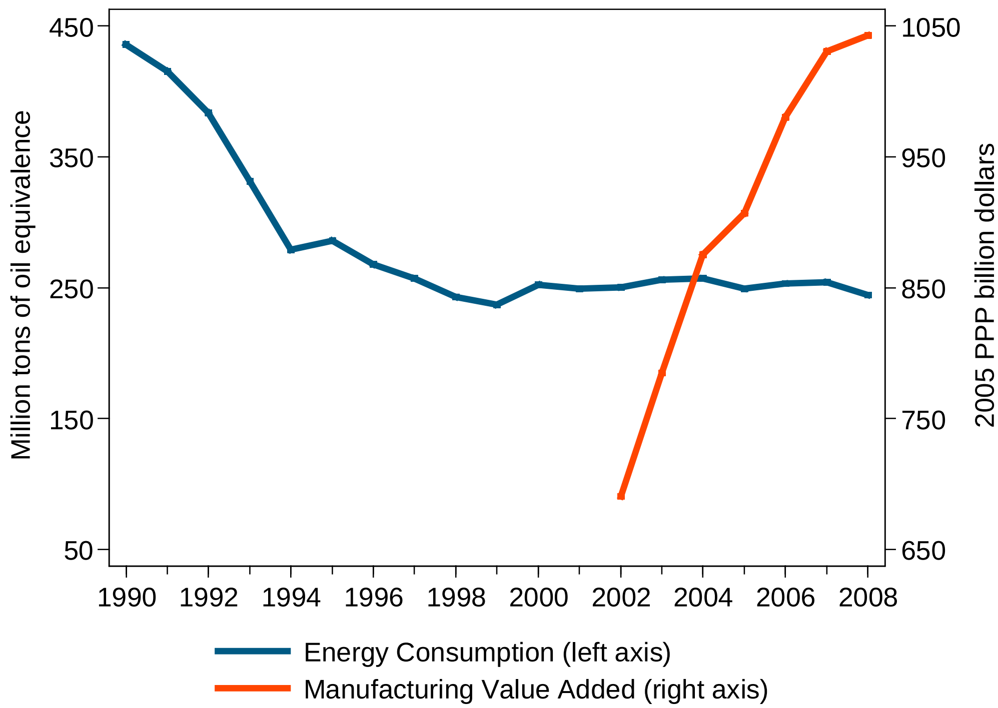
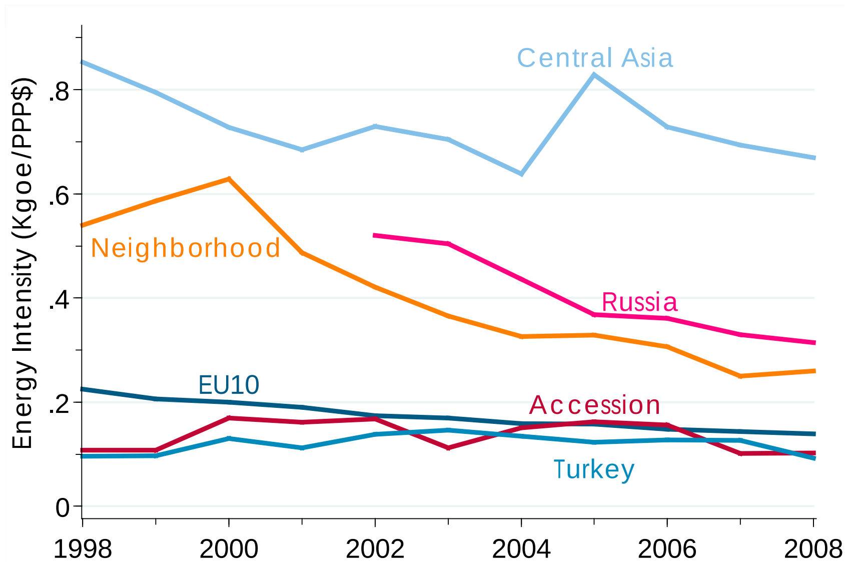
Figure 1 Decoupling of Energy Consumption from Manufacturing Output in Eastern Europe and Central Asia



Note: Manufacturing value added are not available for Russia and Serbia before 2002. PPP = purchasing power parity

Figure 2 Manufacturing Energy Intensity in Eastern Europe and Central Asia, by Subregion/Country , 1998–2008

a. By Sub-region



Note: kgoe = kilograms of oil equivalent. PPP = purchasing power parity. EU-10 countries include Bulgaria, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, the Slovak Republic, and Slovenia. EU accession countries in this analysis include Albania, Bosnia and Herzegovina, Croatia, the former Yugoslav Republic of Macedonia, and Serbia. Neighborhood states include Armenia, Azerbaijan, Belarus, Georgia, Moldova, and Ukraine. Central Asian nations include Kazakhstan, the Kyrgyz Republic, Tajikistan, Turkmenistan, and Uzbekistan.

b. By country in Central Asia

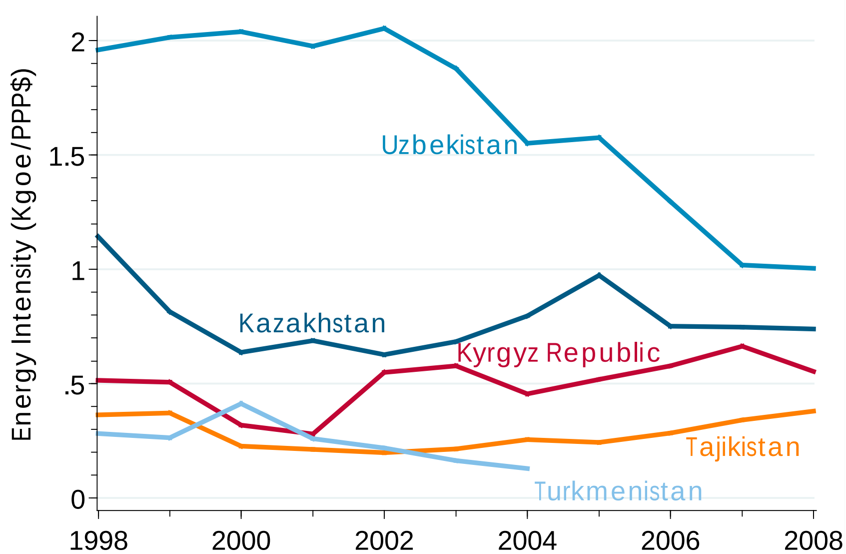
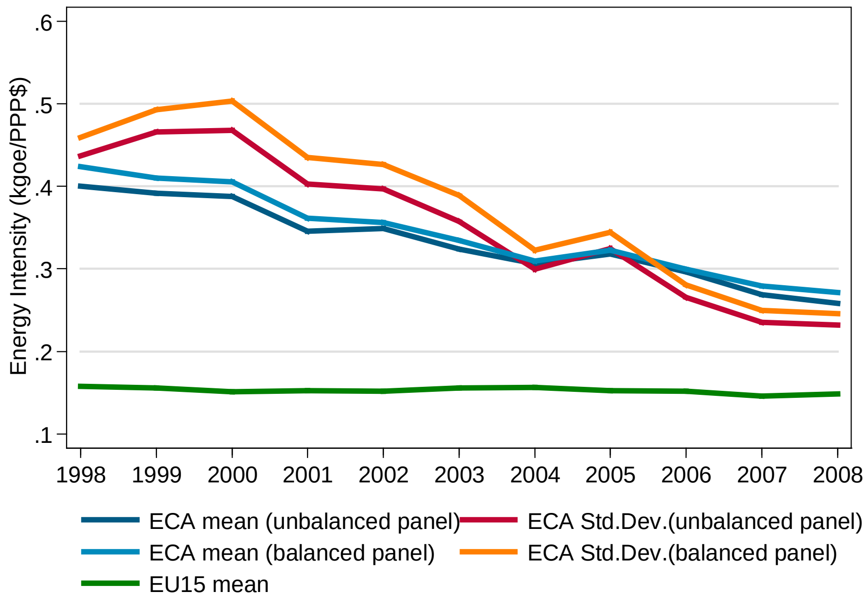


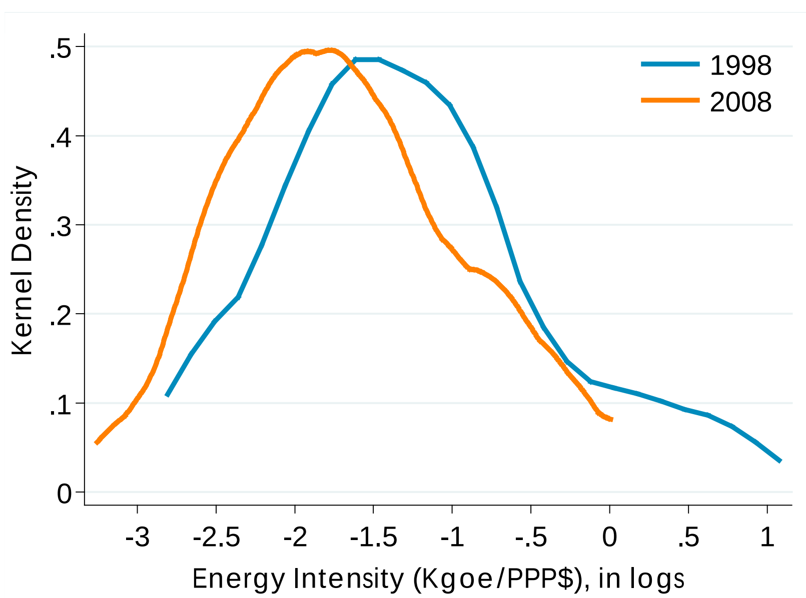
Figure 3 σ- convergence in Manufacturing Energy Intensity in ECA, 1998-2008

a. Mean and Standard Deviation of Manufacturing Energy Intensity



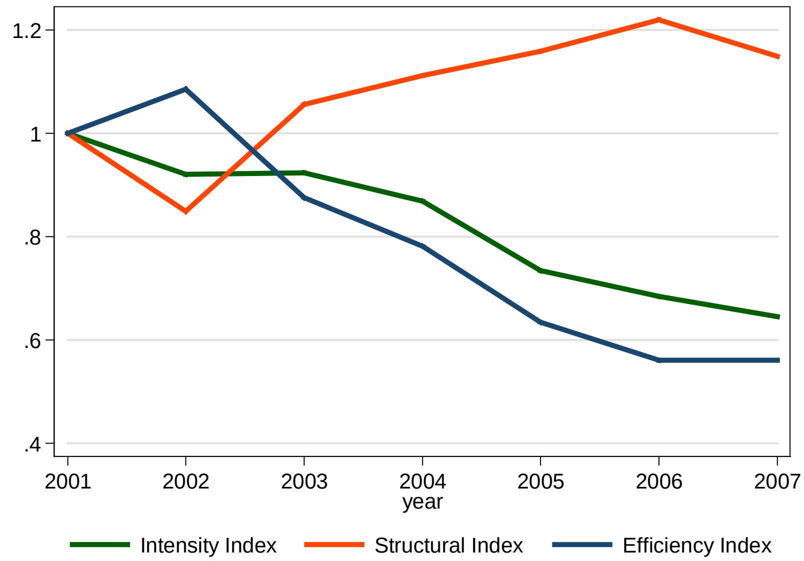
Note: Value added data are not available for Albania during 2004-2006, Romania in 2002, Russia during 1998-2001, Serbia during 1998-1999 and Turkmenistan during 2005- 2008. The balanced panel excludes observations of the five countries. The unbalanced panel includes all 28 countries.

b. Distribution of Manufacturing Energy Intensity



Note: This chart is based on an unbalanced panel of 28 countries.

Figure 4 Fisher Ideal Indexes for Manufacturing Energy Intensity, Structure and Energy Efficiency



Note: The chart is based on index decomposition analysis of manufacturing energy intensity of the following countries during 2001-2007: Albania, Azerbaijan, Bulgaria, Czech Republic, Estonia, Georgia, Hungary, Latvia, Lithuania, Macedonia, Moldova, Poland, Russia and Turkey.

Table 1 Country-level energy intensity, structure and efficiency indexes

Country	Index	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Albania	Structure	--	--	1	1.051	1.505	0.969	1.038	0.416	0.463	0.442	0.866
	Efficiency	--	--	1	0.927	0.595	0.707	0.485	1.198	0.830	0.734	0.375
	Intensity	--	--	1	0.973	0.896	0.685	0.503	0.498	0.384	0.324	0.325
Azerbaijan	Structure	--	--	--	1.000	1.055	0.930	0.977	1.124	1.090	1.271	1.135
	Efficiency	--	--	--	1.000	0.711	0.605	0.468	0.412	0.384	0.180	0.200
	Intensity	--	--	--	1.000	0.749	0.563	0.458	0.463	0.418	0.228	0.227
Bulgaria	Structure	1	0.931	1.141	1.013	0.882	0.961	1.047	0.968	0.993	1.056	--
	Efficiency	1	0.912	0.766	0.970	1.063	0.901	0.756	0.757	0.693	0.574	--
	Intensity	1	0.849	0.874	0.982	0.937	0.866	0.792	0.733	0.689	0.606	--
Czech Republic	Structure	1	0.931	0.958	0.957	0.917	0.917	0.945	0.930	0.893	0.666	--
	Efficiency	1	0.909	0.887	0.873	0.813	0.706	0.647	0.683	0.602	0.978	--
	Intensity	1	0.847	0.850	0.835	0.746	0.647	0.612	0.635	0.537	0.651	--
Estonia	Structure	--	--	1	1.041	1.044	1.017	1.043	1.058	1.029	1.038	--
	Efficiency	--	--	1	1.080	0.878	0.889	0.855	0.870	0.763	0.816	--
	Intensity	--	--	1	1.124	0.917	0.905	0.891	0.921	0.785	0.848	--
Georgia	Structure	--	--	1	1.182	1.243	0.955	1.254	1.142	1.569	1.736	1.487
	Efficiency	--	--	1	0.491	0.556	0.713	0.439	0.390	0.297	0.242	0.292
	Intensity	--	--	1	0.580	0.691	0.681	0.550	0.446	0.467	0.420	0.435
Hungary	Structure	1	0.917	0.979	0.929	0.874	0.902	0.901	0.874	0.923	0.941	--
	Efficiency	1	1.076	0.964	0.996	1.074	0.921	0.896	0.884	0.804	0.830	--
	Intensity	1	0.987	0.944	0.925	0.939	0.831	0.807	0.772	0.741	0.781	--
Latvia	Structure	--	--	1	1.000	0.975	1.045	1.128	1.013	1.088	1.065	--
	Efficiency	--	--	1	1.001	0.923	0.804	0.759	0.856	0.735	0.691	--
	Intensity	--	--	1	1.001	0.900	0.840	0.856	0.867	0.800	0.736	--
Lithuania	Structure	--	--	1	1.159	1.116	1.083	1.052	1.159	1.314	1.501	1.525
	Efficiency	--	--	1	0.790	0.826	0.730	0.642	0.579	0.538	0.420	0.429
	Intensity	--	--	1	0.916	0.922	0.790	0.675	0.671	0.707	0.631	0.654
Macedonia	Structure	1	1.009	1.124	1.049	0.746	0.710	1.135	0.720	0.704	--	--
	Efficiency	1	0.745	0.743	0.758	1.454	1.351	0.868	1.261	1.212	--	--
	Intensity	1	0.752	0.836	0.795	1.085	0.959	0.985	0.908	0.853	--	--
Moldova	Structure	--	--	--	1	1.008	1.026	0.994	0.996	0.937	0.982	0.993
	Efficiency	--	--	--	1	0.879	0.838	1.079	1.120	1.089	0.915	0.896
	Intensity	--	--	--	1	0.886	0.859	1.073	1.115	1.020	0.898	0.890
Poland	Structure	--	--	1	1.112	0.895	0.878	0.988	0.925	1.101	1.109	--
	Efficiency	--	--	1	0.723	0.940	0.854	0.663	0.659	0.609	0.542	--
	Intensity	--	--	1	0.803	0.841	0.749	0.655	0.610	0.671	0.601	--
Russia	Structure	--	--	--	1	0.991	1.027	1.055	0.978	0.994	1.004	0.985
	Efficiency	--	--	--	1	1.140	0.918	0.830	0.791	0.720	0.712	0.691
	Intensity	--	--	--	1	1.129	0.943	0.875	0.774	0.716	0.715	0.680
Turkey	Structure	--	--	1	1.064	0.687	0.699	0.717	0.726	0.709	--	--
	Efficiency	--	--	1	0.654	1.530	1.955	1.651	1.815	1.555	--	--
	Intensity	--	--	1	0.696	1.051	1.367	1.184	1.317	1.103	--	--

Table 2 Summary Statistics of Variables

Variable	Obs.	Mean	Std. Dev.	Min	Max
Energy Intensity (kgoe/ppp $)	116	0.26	0.28	0.05	1.74
Electricity price (US cents/kWh)	106	6.01	2.64	2.11	19.02
P.C. GDP (2005 PPP)	120	9490	4416	2123	18330
Capital-labor ratio (%)	120	4.79	4.26	0.22	36.41
Share of export in manufacturing (%)	120	62.26	22.43	1.47	88.29

Table 3 Determinants of Manufacturing Energy Intensity

	(1) OLS	(2) Fixed Effects	(3) Random Effects	(4) GMM
Ln (*PCGDP*)	0.0581	-1.289***	0.058	-0.747*
	(0.128)	(0.406)	(0.132)	(0.393)
Ln (*Electricity Price*)	-0.651***	-0.255***	-0.651*	-0.058
	(0.140)	(0.088)	(0.091)	(0.086)
Ln(*Capital Labor Ratio*)	-0.482**	0.428***	-0.482***	0.178
	(0.188)	(0.108)	(0.129)	(0.136)
Ln (*Capita Labor Ratio*)^2	0.064	-0.058**	0.064	-0.046
	(0.058)	(0.027)	(0.032)	(0.037)
Ln(*Ratio of Manufacturing Export*)	-0.142*	0.289**	-0.142	0.066
	(0.081)	(0.129)	(0.099)	(0.098)
Ln(*Energy Intensity*)$_{t-1}$				0.497***
				(0.110)
R^2	0.549	0.089	0.549	
Sargen test (p-value)				0.540
Obs.	102	102	102	70

Note: Columns (1), (2), and (3) report results from estimating determinants of manufacturing energy intensity identified in equation (7) via OLS, fixed effects and random effects models. Column (4) reports the difference-GMM results, using the log of per capita GDP (lnI_{it}) and the log of electricity prices (lnP_{it}) lagged 2 to 4 periods in levels as instruments. Year fixed effects are not reported. Standard errors adjusted for clustering on country are reported in parentheses. *** indicates significant at the 1 percent level. ** indicates significant at the 5 percent level. * indicates significant at the 10 percent level.

Table 4 Determinants of Energy Intensity, Efficiency and Structure Indexes

	(1) Intensity	(2) Efficiency	(3) Structure
Ln (*PCGDP*)	-0.620***	-0.841***	0.221
	(0.172)	(0.235)	(0.213)
Ln (*Electricity Price*)	-0.406***	-0.519***	0.112
	(0.085)	(0.115)	(0.105)
Ln(*Capital Labor Ratio*)	-0.129	0.262	-0.391*
	(0.175)	(0.239)	(0.216)
Ln (*Capita Labor Ratio*)^2	0.075	-0.030	0.105
	(0.057)	(0.077)	(0.070)
Ln(*Ratio of Manufacturing Export*)	0.196**	-0.194	0.390***
	(0.077)	(0.105)	(0.096)
R^2	0.646	0.560	0.281
Obs.	75	75	75

Note: Columns (1), (2), and (3) report results from estimating determinants of manufacturing energy intensity index, energy efficiency index and structural index identified in equation (7) based on a fixed effects model. Year fixed effects are not reported. Standard errors are reported in parentheses. *** indicates significant at the 1 percent level. ** indicates significant at the 5 percent level. * indicates significant at the 10 percent level.