Productivity and Energy Intensity in Latin America

Energy Division/ Infrastructure
and Energy Department

Ariel Yepez
Luis San Vicente Portes
Santiago Guerrero

TECHNICAL
NOTE Nº
IDB-TN-02158

April 2021

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Ariel Yepez
Luis San Vicente Portes
Santiago Guerrero

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Cataloging-in-Publication data provided by the
Inter-American Development Bank
Felipe Herrera Library
Yépez-Garcia, Rigoberto Ariel.
Productivity and energy intensity in Latin America / Ariel Yepez, Luis San Vicente Portes, Santiago Guerrero.
p. cm. — (IDB Technical Note ; 2158)
Includes bibliographic references.
1. Energy consumption-Latin America. 2. Labor productivity-Latin America. 3. Industrial productivity-Latin America. I. San Vicente Portes, Luis. II. Guerrero, Santiago. III. Inter-American Development Bank. Energy Division. IV. Title. V. Series.
IDB-TN-2158
JEL Codes: J24, O24, Q40, Q41
Keywords: Energy intensity, Productivity, Industrial Productivity, Energy Consumption

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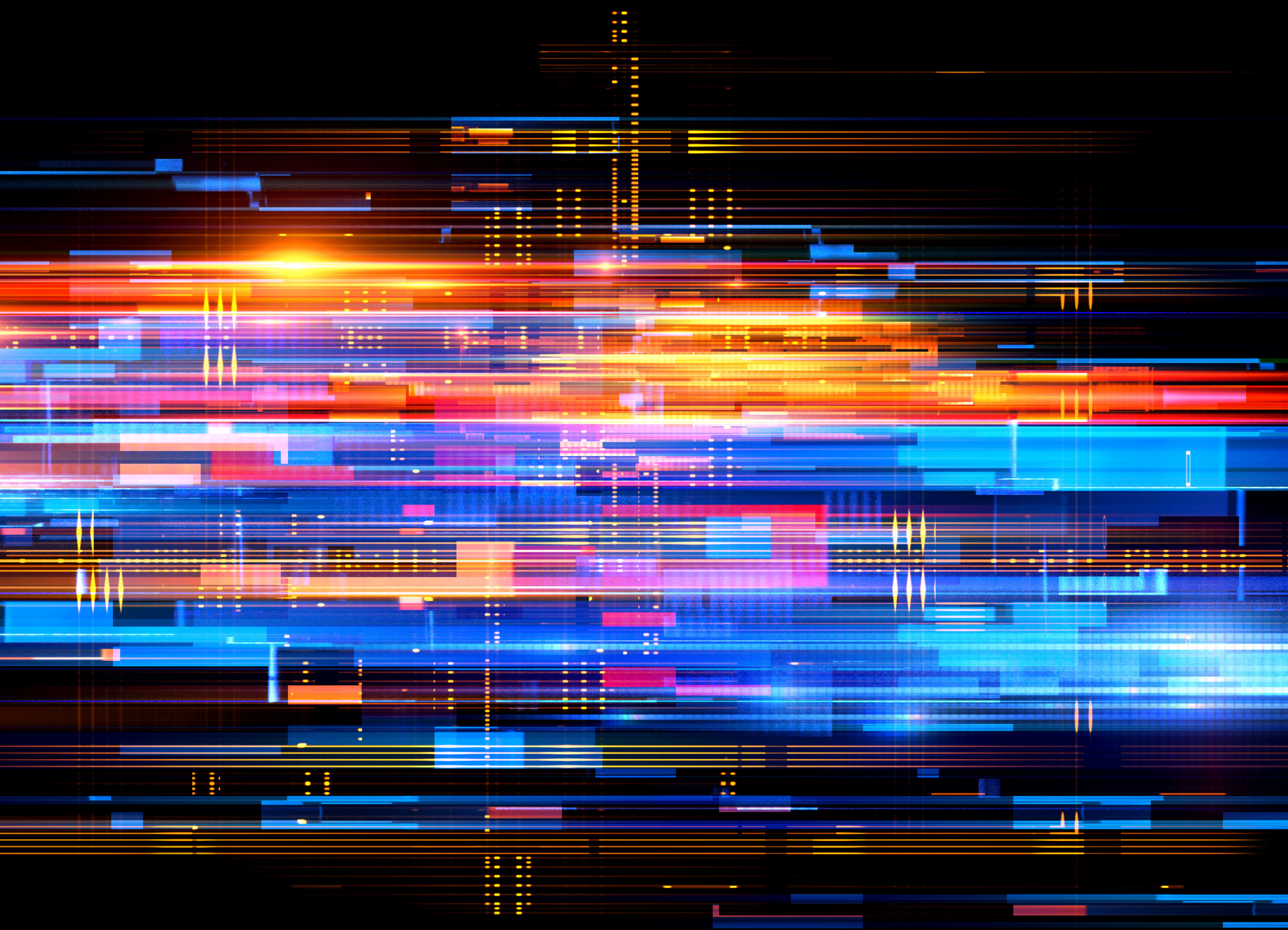
PRODUCTIVITY AND ENERGY INTENSITY IN LATIN AMERICA



Ariel Yepez • Luis San Vicente Portes • Santiago Guerrero

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PRODUCTIVITY AND ENERGY INTENSITY IN LATIN AMERICA

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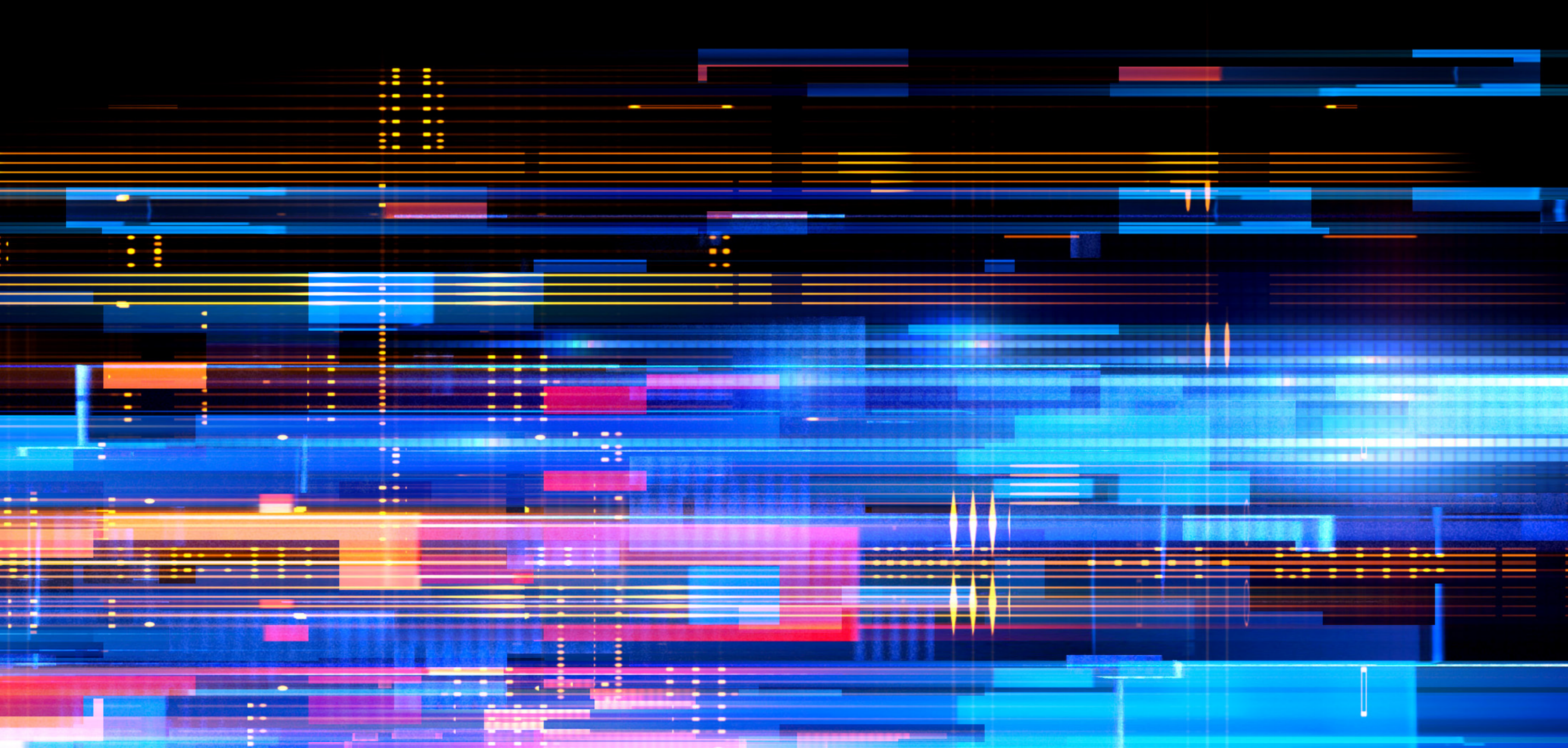
INTRODUCTION



INTRODUCTION

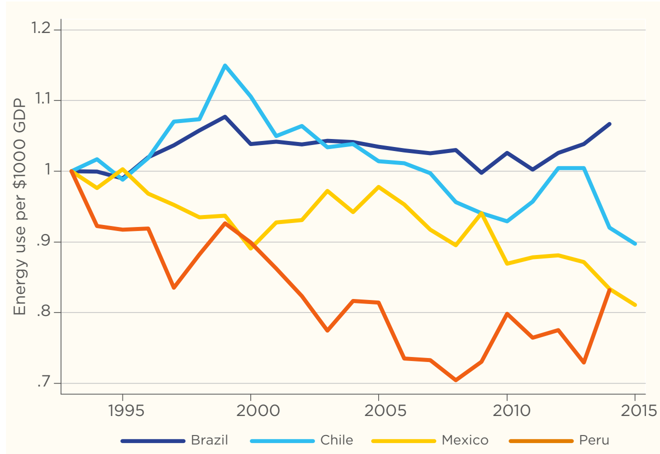
Within an industrial setting, what would one's conjecture be about the relation between Energy Intensity (EI) and productivity? Could higher energy use be associated to more capital intensive processes, and thus higher output (per worker)? Or Ceteris paribus, are productivity indicators inversely associated with energy intensity? So that more productive firms or industries tend also to be more energy efficient. The nature of this question is multifold as there are historical, geographical, institutional, developmental, and policy variables that jointly affect industrial development as well as a nation's energy supply.

This study seeks to assess the relationship between these variables in the industrial sector of four Latin American countries. Under alternative measures of productivity, namely, average labor productivity and total factor productivity (TFP), we find a statistically negative relationship between productivity and Energy intensity.

We first provide a look at national energy intensity and economy-wide total factor productivity. The purpose of analyzing aggregate data is to probe deeper two well accepted facts; the first is the Kuznets-like relationship in regard to energy intensity (as countries transition from lower income levels to higher income EI rises, peaks, and then tends to decrease), and the second is that total factor productivity trends upward over time. A closer look at the embedded relationship between EI and productivity in the aggregate sets the stage for a refined look at the industrial sector level.

As motivation for the subject of the relationship between EI and productivity, we begin with the economy-wide perspective. Energy intensity at the national level is measured by the Energy Use per $1000 of GDP. Agrarian economies, for instance, exhibit lower energy use than industrial ones. As countries develop further and economic activity shifts towards services, then, EI begins to decline. Such inverted-U pattern is common to the development process. Normalized to the year 1994, Figure 1, shows the trajectory of EI in the four countries under study: Brazil, Chile, Mexico and Peru. Except for Brazil, EI has decreased in all the countries.

FIG 1. **Energy Intensity**

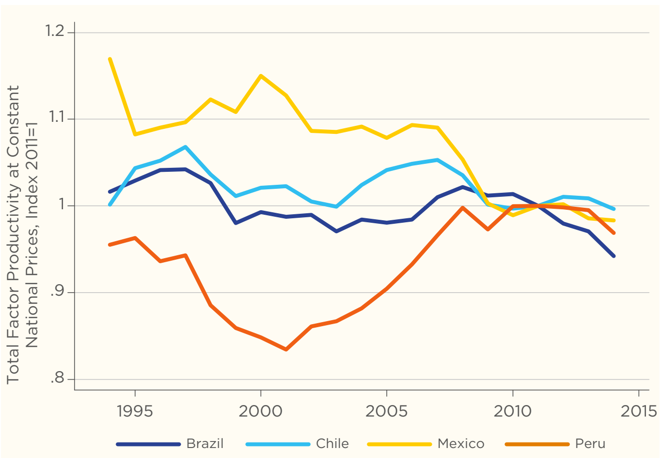


Source: WDI.

Note: This figure shows the trend in Energy Intensity (Energy Use: kilogram of oil equivalent per $1000 GDP at constant 2011 PPP normalized to 1 for the year 1994) for Brazil, Chile, Mexico, and Peru from 1994 to 2015. Source: World Development Indicators, World Bank.

In terms of productivity, the Inter-American Development Bank has found an increasing productivity gap in Latin American countries (IDB, 2016). Figure 2, with data from the Federal Reserve Bank of St. Louis (FRED database) displays total factor productivity in constant prices for the countries under study. Except for Peru until 2011, these countries have experienced a decrease in TFP; thereafter it has fallen in all countries.

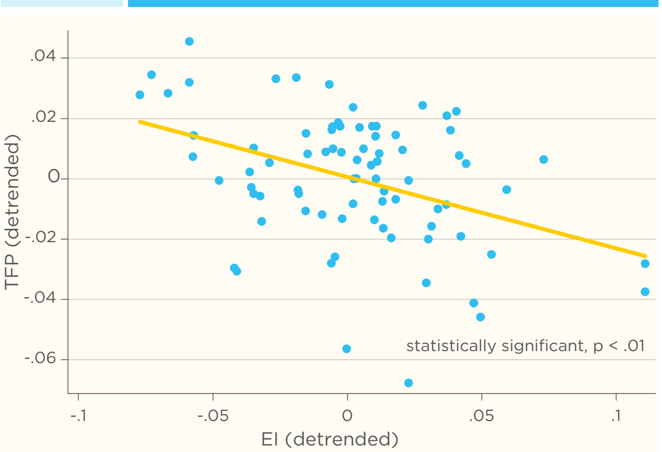
FIG 2. **Total Factor Productivity**



Source: Federal Reserve Bank of St. Louis (FRED).

Note: This figure shows the trend in Total Factor Productivity in constant national prices, indexed relative to the year 2011, for Brazil, Chile Mexico, and Peru. The sample spans the period 1994 to 2015. Source: FRED, Federal Reserve Bank of St. Louis.

FIG 3. **Total Factor Productivity and Energy Intensity**



Source: Authors' calculations.

Note: This figure shows a statistically significant negative relationship between Energy Intensity and Total Factor Productivity at the national level. Both variables have been de-trended based on a linear time trend. The sample covers the period 1994 to 2015 for Brazil, Chile, Mexico, and Peru. Source: Authors' calculations.

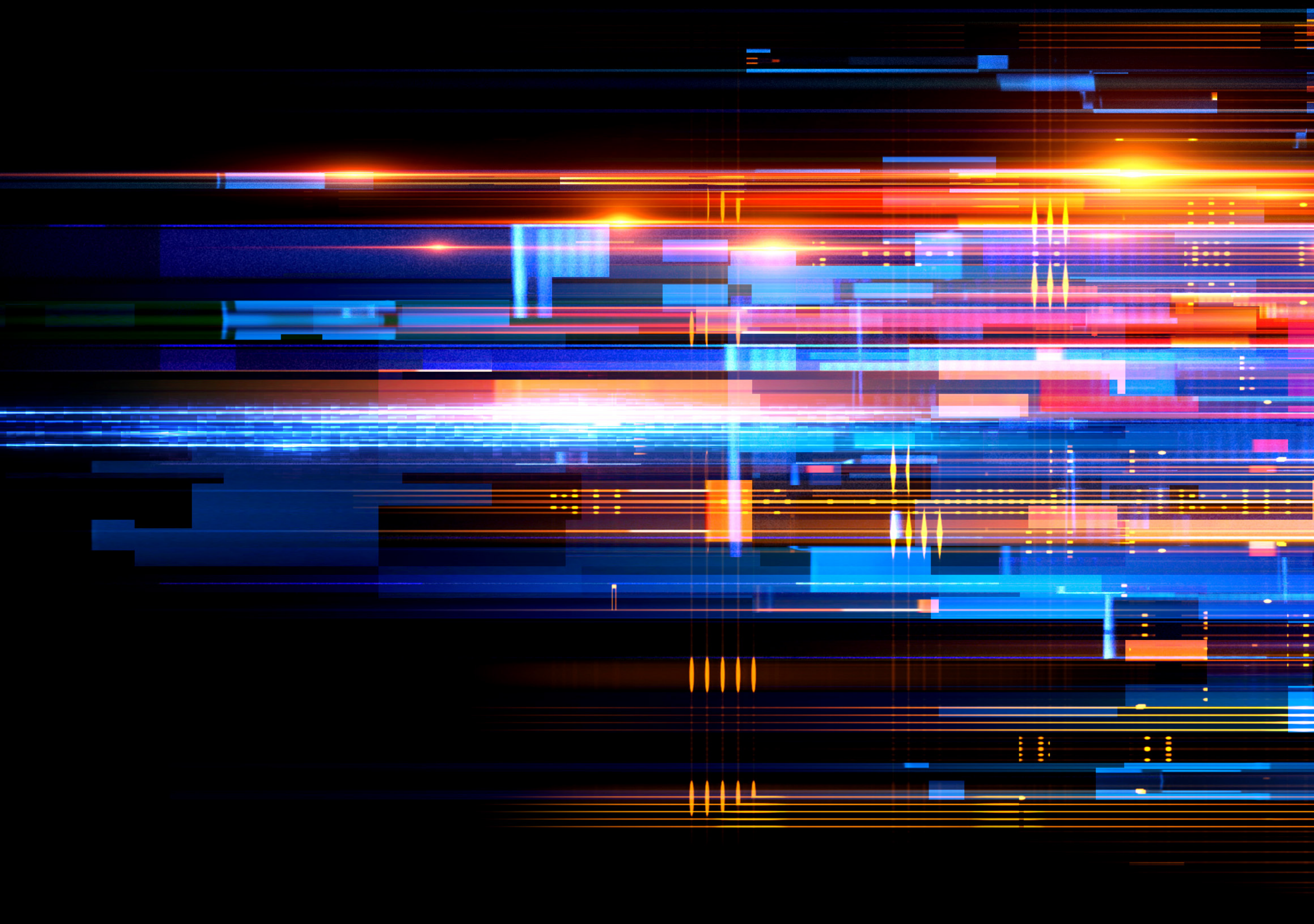
At the aggregate level, accounting for the trends in EI and productivity, we observe a negative and statistically significant as shown in Figure 3. Based on the industrial sector surveys, the same pattern is found after controlling for country, sector, year, and other drivers of EI, as presented in the sections below.

It is our understanding that no other study has set out to explore the relationship between energy intensity and productivity narrowly defined as we do, and at the industrial-sector level. There is, however, a body of work whose focus is on economic development and energy use. Such studies have identified a Kuznets-like relationship between energy use and economic advancement. For instance, one of the most recent is by Rajbhandari and Zhang (2017) who find a bi-directional causality link between lower EI and economic growth in middle-income countries at the national level. Deichmann et al. (2018) based on a panel of 137 economies for the period 1990-2014, find a threshold income level of 5,000 U.S. dollars after which energy intensity and economic growth significantly move apart. For his part, Stern (2011) studies the role of energy constraints on economic growth. Closer to our analysis is the study by Cantore et al. (2016) who use data from 29 developing countries, and as outlined above at the national level, find a negative relationship between energy intensity and total factor productivity.

Given our industry-level analysis we believe that a deeper understanding will come from studying the nexus between productivity-enhancing managerial interventions and their effect on energy and non-energy inputs alike. Such interventions ought to lower EI and raise productivity. Boyd and Pang (2000) find plant-level differences in productivity based on cumulative output (i.e. learning curve), energy prices, and energy efficiency projects that spill over to entire production processes in the glass industry. More recently Ryan (2018) conducted a field experiment in Indian manufacturing firms in which treatment plants which had been subject to energy consulting, reported higher energy productivity, longer hours, and an increased use of skilled labor. Earlier work by Levy (1985) finds that technological change linked to variations in energy use result in lower labor demand i.e. higher operational efficiency.

The study is organized as follows: Section 2 describes the industrial surveys used in the analysis; Section 3 presents the methodology; the results are collected in Section 4; and Section 5 provides conclusions and policy recommendations.

DATA



DATA

The data used for this study is based on publicly available sources from annual industrial/manufacturing surveys of Brazil, Chile, Mexico, Peru, and the United States as well as country-level sources from the World Bank. Industrial surveys are representative surveys of the countries' industrial sector and are usually the basis of the calculation of the contribution of industries to economic activity.

Country-level variables were obtained from the World Development Indicators of the World Bank.

The period covered in the analysis for the longest samples is for the years 2003 to 2014. Although data from manufacturing surveys spans up to 2015 in some cases, country variables only covered up to 2014.

TABLE 1. Years Covered by Country and Industrial Subsector

Subsector	Brazil	Chile	Mexico	Peru	USA
Food Manufacturing (311)	12	13	12	7	12
Beverage and Tobacco Product Manufacturing (312)	12	1	12	7	12
Textile Mills (313)	12	13	12	8	12
Textile Product Mills (314)	12	0	12	8	12
Apparel Manufacturing (315)	12	0	12	7	12
Leather and Allied Product Manufacturing (316)	12	13	12	6	12
Wood Product Manufacturing (321)	12	13	12	7	12
Paper Manufacturing (322)	12	0	12	8	12
Printing and Related Support Activities (323)	12	12	12	7	12
Petroleum and Coal Products Manufacturing (324)	12	0	11	0	12
Chemical Manufacturing (325)	12	12	12	7	12
Plastics and Rubber Products Manufacturing (326)	12	13	12	6	12
Nonmetallic Mineral Product Manufacturing (327)	12	13	12	8	12
Primary Metal Manufacturing (331)	12	13	12	7	12
Fabricated Metal Product Manufacturing (332)	12	11	12	8	12
Machinery Manufacturing (333)	12	12	12	7	12
Computer and Electronic Product Manufacturing (334)	12	3	10	4	12
Electrical Equipment, Appliance, and Component Manufacturing (335)	12	11	12	5	12
Transportation Equipment Manufacturing (336)	12	13	12	7	12
Furniture and Related Product Manufacturing (337)	12	11	12	0	12
Miscellaneous Manufacturing (339)	12	12	12	2	12
Total	**252**	**189**	**249**	**126**	**252**
Source	Pesquisa Industrial Anual: Empresa - PIA Empresa	Encuesta Nacional Industrial Anual	Encuesta Industrial Anual	Encuesta Económica Anual	Annual Survey of Manufactures
Period covered	2004-2013	2003-2014 with gaps	2003-2014 with gaps	2007-2014 with gaps	2003-2014

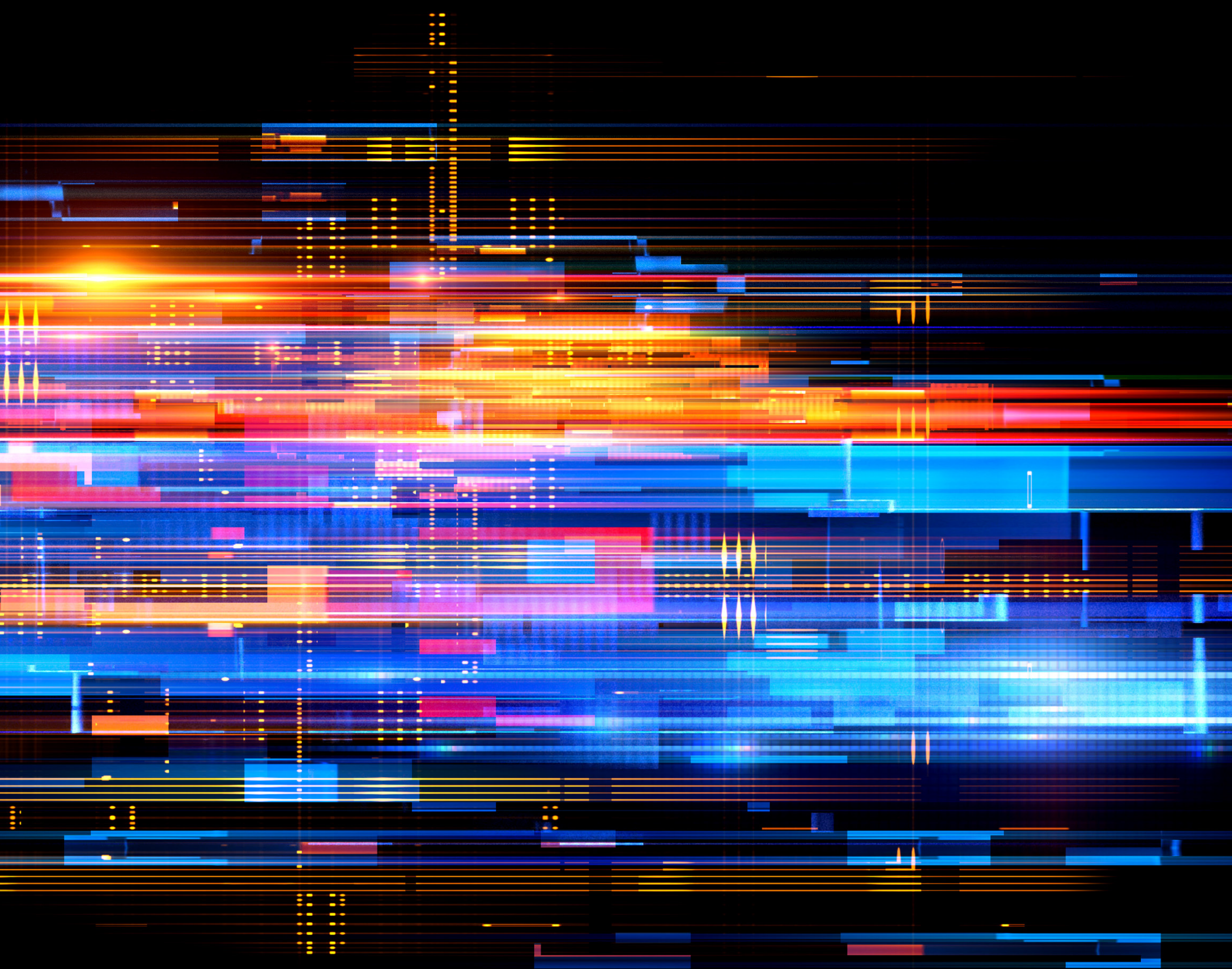
In total there are 21 manufacturing subsectors, based on the NAICS classification. A conversion from the CIIU classification data from Brazil, Chile, and Peru was performed to homologize the data with Mexico and the United States. Also for Chile and Peru there are several industrial subsectors with limited data for the period under study; these were omitted from the analysis. Table 1 presents the years covered by subsector for each country, as well as the data sources.

Based on these surveys and on the country-level data, the main controls used in the estimation of the relationship between energy intensity and productivity are investment in machinery and equipment, government education expenditure (as a proxy for human capital investment), electricity production from hydropower (proxy for energy availability), energy imports (proxy for energy sufficiency), trade volumes, electric power transmission and distribution losses (proxy for the quality of the power supply). Nominal variables were converted into real (U.S. dollar) terms. Table 2 presents summary statistics of variables used in the estimation.

TABLE 2. Summary Statistics

Variable	Mean	Std. Dev.	Min.	Max.
Energy intensity (Energy Expenditures/Value Added)	0.08	0.08	0.00	1.02
Investment in machinery and equipment (1000 USD)	823,270	7,272,397	4	205,000,000
Government education expenditure (% GDP)	4	1	3	6
Electricity Production from Hydro (% Total Electricity Production)	46	28	8	84
Energy imports, net (% of energy use)	8	37	-52	71
Trade (% of GDP)	50	18	22	81
Electric power transmission and distribution losses (% of output)	13	4	5	17
TFP	2	3	0	29
Value added(USD 1000)/Worker	54	83	1	977
Total observations: 816				

METHODOLOGY



METHODOLOGY

Our methodology builds up momentum so to speak. We start out with simple correlations between energy intensity and productivity. These associations control for industry, country, and year for comparison purposes but do not probe the underlying determinants of EI, as we do by the end of the analysis in the more elaborate regression models. At this later stage the focus is on the link between EI (clean of other effects) and productivity. The stripped down version of EI controls for key economic variables such as natural endowments, trade openness, international competitiveness, capital (equipment), and power reliability.

As for productivity, we work with two measures of productivity that are calculated by sector. The first is TFP (Solow residual) and the second average labor productivity or output per worker. Both are useful as they inform about different aspects of the production process. TFP can be tied to general improvements in the use of capital and labor; labor productivity relates to the complementarity between capital and labor and any other efficiency enhancements in the overall production process.

Then, the issue of the relationship between energy intensity and productivity can lend itself to a debate on the question of how is productivity measured? Just as a preview of our results, the findings point that regardless of productivity measure, productivity and energy intensity move in opposite directions. This is not surprising given how TFP and output per worker correlate in the data.

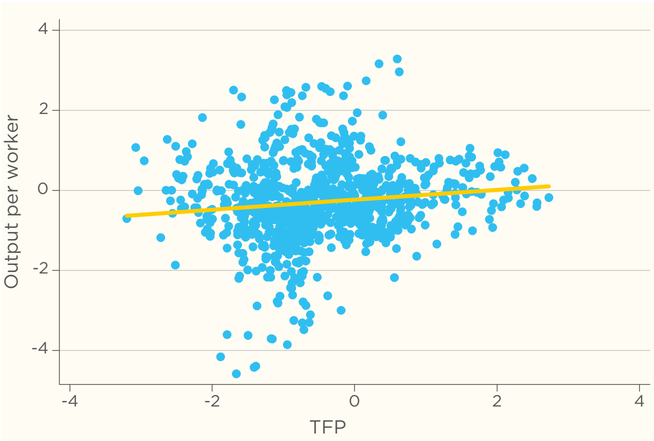
As motivation for the subject of the relationship between EI and productivity, we begin with the economy-wide perspective. Energy intensity at the national level is measured by the Energy Use per $1000 of GDP. Agrarian economies, for instance, exhibit lower energy use than industrial ones. As countries develop further and economic activity shifts towards services, then, EI begins to decline. Such inverted-U pattern is common to the development process. Normalized to the year 1994, Figure 1, shows the trajectory of EI in the four countries under study: Brazil, Chile, Mexico and Peru. Except for Brazil, EI has decreased in all the countries.

This is how it is so. At a theoretical level a Cobb-Douglas production function explicitly accounts for a term for total factor productivity entering multiplicatively as a scale factor on the production inputs: capital and labor. The generic functional form is: $Y=zK^{\alpha} L^{1-\alpha}$, where Y stands for output, z for technology, K for capital, and L for labor; and α represents the capital share of income. In this context anything that enhances the output associated to a fixed amount of capital and labor counts as an increase in total factor productivity, z. The measure in itself is somewhat uninformative, and thus following Solow, it is calculated as the residual output not accounted for changes in the use of capital or labor. In the literature higher TFP has been attributed to policy changes, institutional development, technological progress, managerial innovation, energy prices, and even "good luck".

On the other hand, we have output per worker, or the average product of labor. In this case either an increase in capital or in total factor productivity make labor more productive, due to input complementarity or more efficient use of resources. All else equal, a higher production function mapped from the domain of labor, means higher output per worker.

As pointed out before, in this study we construct the industry-level counterparts of these indicators. Based on the industrial surveys a measure for total factor productivity is calculated, as well as one for output per worker by sector. Figure [4] shows how they are correlated in the sample for Brazil, Chile, Mexico, and Peru; therein lies the common finding in terms of these productivity measures and energy intensity.

FIG 4. **Total Factor Productivity and Labor Productivity**

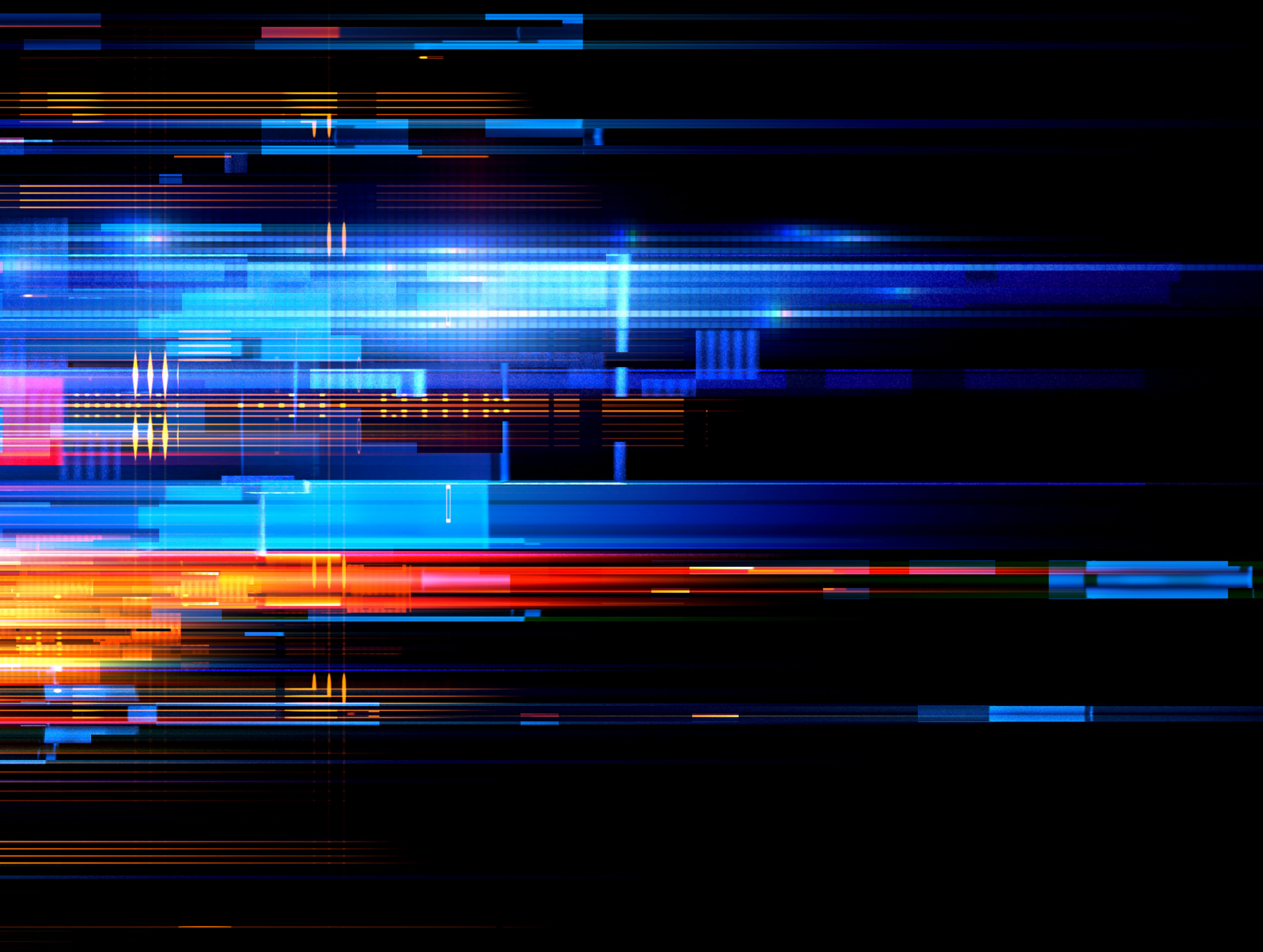


Source: Authors' calculations.

Note: This figure shows a positive relation between output per worker and Total Factor Productivity. The sample covers the period 2003 to 2014 for Brazil, Chile, Mexico, and Peru. Source: Authors' calculations.

As discussed below, our reading of the pairs: high EI <-> low productivity; and low EI <-> high productivity lead us to believe that at the industry level this relationship is likely to be driven by technological innovations and/or managerial interventions, where in the case of the latter, an organizational overhaul ought to result on a more efficient input use, including energy. Industrial surveys do not allow to tease out such effects, rather firm-level analysis would be the appropriate approach, however, as the regression models below show, after controlling for a host of factors that can influence energy intensity, the negative relationship remains. As a guide to future work one can conceive a firm-level or plant-level survey where energy use and new technologies and organizational changes can be connected. Here, however, we present the empirical correlation of total factor productivity and output per worker in the sample under study.

RESULTS

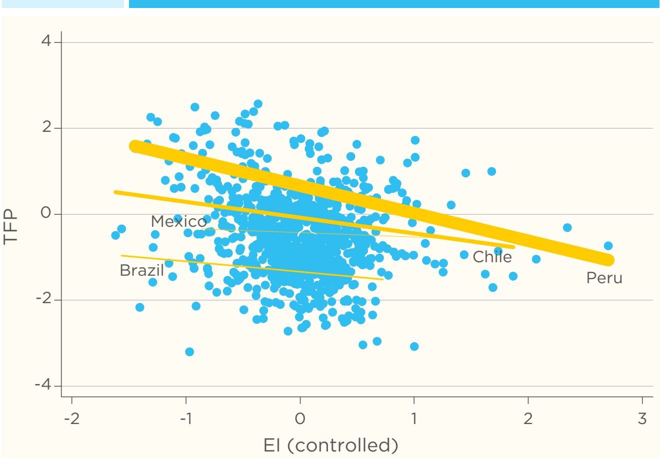


RESULTS

With a clear understanding of the productivity measures, in a constructivist fashion, next we standardize the industry estimates for energy intensity by stripping away time, country, and industry effects to begin the analysis. Country variations, and sector characteristics imply a broad range in the estimates of energy intensity, leading us to create a new variable for energy intensity to control for such variation, and ultimately develop a refined mapping of energy demands to productivity.

Figure [5] presents the scatter plot of Energy Intensity and Total Factor Productivity for the pooled observations for Brazil, Chile, Mexico, and Peru, while tracing the corresponding regression lines for each of the countries. This is not a statement on causality or statistical inference, but rather an illustration of the nature of the relationship.

FIG 5. **Total Factor Productivity and Energy Intensity**



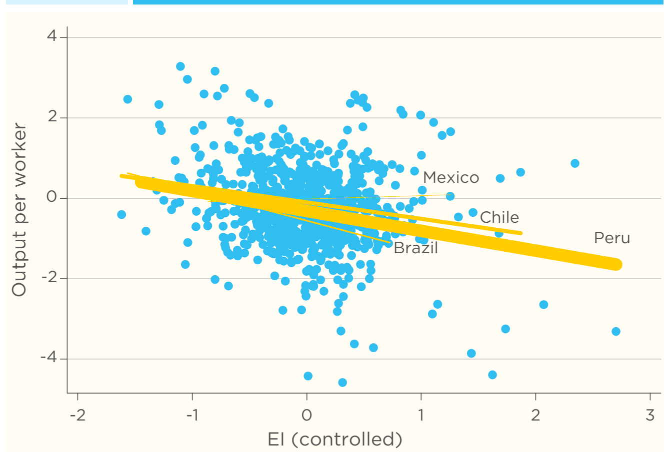
Source: Authors' calculations.

Note: This figure shows a negative relation between EI and TFP with country regressions only controlling for industry, year, and country. The sample covers the period 2003 to 2014 for Brazil, Chile, Mexico, and Peru. Source: Authors' calculations.

Some important aspects to highlight from the analysis are the range of the observations that span each of the countries' samples, and also the strength of the relationship given by the slope. In this case, Peru comes at the top on both counts: longest range and steepest slope. For instance, the range for Brazil is the smallest, and Mexico exhibits the flattest slope. Recall that this is not the final stance on the relationship between these variables; below we control for other factors that can, indeed, influence both variables.

The same way that total factor productivity seems to decrease with higher energy intensity, output per worker, or the average product of labor is decreasing in energy intensity, as well. Figure [6] shows a negative pattern when all the sector-level observations are pooled and each country has a regression of its own. In this case, Peru still exhibits the longer range, but it is Brazil that has the strongest relation i.e. the steepest slope. Mexico does reveal a connection between these variables.

FIG 6. **Output per Worker and Energy Intensity**



Source: Authors' calculations.

Note: This figure shows a negative relation between EI and labor productivity with country regressions only controlling for industry, year, and country. The sample covers the period 2003 to 2014 for Brazil, Chile, Mexico, and Peru. Source: Authors' calculations.

A corollary from these figures is another angle on that overarching pattern of a negative relationship between productivity measures and energy intensity. In other words, why are workers less productive when there is more energy use per unit of output? At first glance this sounds counter-intuitive, when one thinks that energy use is tied to capital, and capital complements labor. In terms of total factor productivity, why is it the case that once one accounts for capital (which uses energy to run) and labor, the higher the energy intensity the lower the Solow residual? Again, this study cannot provide a definite answer, but it does suggest that energy efficiency spans beyond the running of machinery and equipment, but rather depends on the performance of the company as a whole.

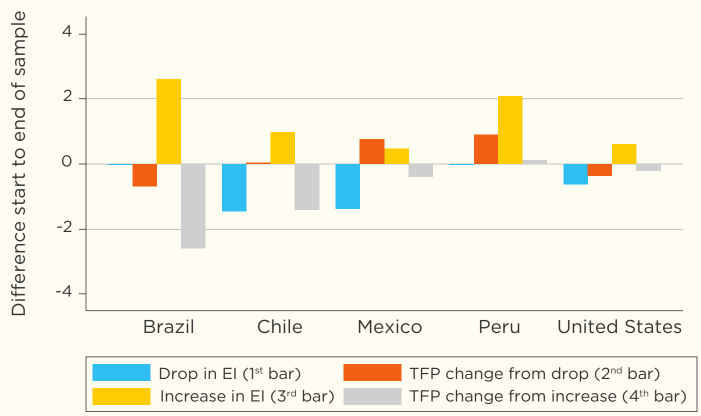
BOX 1. Going to Extremes - Energy Intensity and Productivity

The analysis of the relationship between Energy Intensity and productivity in this study spans a range of perspectives, from the aggregate, to detailed regression analysis. In between these bookends, there was the sector-level characterization of the relation by only controlling for sector, year, and country without further controls. There one can see that when using Total Factor Productivity as the measure for productivity, the strength of the relation varies by country, with Peru exhibiting the strongest relationship (steepest slope) and Mexico, somewhat, the weakest (flattest slope). Consistent across perspectives, though, it was found that there is a negative relationship between productivity and energy intensity across countries and across sectors.

The regression analysis, by construction, yields average effects across industries, in this Box, the relationship between EI and TFP is explored by singling out the largest increase in EI and the largest decrease in EI with their corresponding change in TFP in the span of the sample. Following the storyline of the study, increases (decreases) in EI should be associated with decreases (increases) in TFP.

This way, this Box takes aim at the largest changes (up and down) in Energy Intensity and the associated change in TFP. This allows to look at only extreme observations at both ends of the spectrum. Thus, in this Box the analysis centers on the countries' experience in those sectors that reported the highest increases and the biggest drops in EI and the corresponding change in TFP. In addition to Brazil, Chile, Mexico, and Peru, the exercise includes the United States as well.

Change in EI and TFP
(Maximum increase or decrease in EI)



Authors' calculations

As seen above, at the extremes the story remains the same. Across countries the sectors that experienced the largest increases in Energy Intensity in the span of sample, all reported a decrease in Total Factor productivity. In the other direction the evidence is weaker, but in the cases of Chile and Mexico, lower Energy Intensity led to higher Total Factor Productivity.

BOX 1. Going to Extremes - Energy Intensity and Productivity (continued)

As the focus of the analysis goes from average relations to the largest sector changes in the span of the sample, there is something particular about those industries for which Energy Intensity increased and their productivity declined. From the Table, one can see that the largest changes in EI occurred in capital intensive sectors; in a way, this deepens the puzzle. Curiously, the case of Chile showcases the upstream and downstream ends of the supply chain.

Country	EI Increase	TFP
Brazil	Petroleum and Coal Products Manufacturing (324)	down
Chile	Fabricated Metal Product Manufacturing (332)	down
Mexico	Nonmetallic Mineral Product Manufacturing (327)	down
Peru	Paper Manufacturing (322)	down
U.S.	Computer and Electronic Product Manufacturing (334)	down
Country	**EI Decrease**	**TFP**
Brazil	Miscellaneous Manufacturing (339)	down
Chile	Primary Metal Manufacturing (331)	up
Mexico	Petroleum and Coal Products Manufacturing (324)	up
Peru	Transportation Equipment Manufacturing (336)	up
U.S.	Petroleum and Coal Products Manufacturing (324)	down

The final turn in the discussion of the relationship between EI and productivity takes us to a systematic characterization of other variables that can affect EI apart from productivity. The first observation is the level of development of a given country. Over time, EI projects a Kuznets-like shape as it appears as a feature of economic development. As a way to understand it, consider that in the early stages of development, EI tends to rise as economies shift from agriculture to industry, then EI begins to fall as the service sector overtakes industry to become the largest share of GDP. As noted before Deichmann et al. (2018) point to $5000 U.S. dollar per capita threshold after which energy intensity begins to dissociate from economic growth.

With a stronger focus on energy intensity as such, Jimenez and Mercado (2013), investigate EI trends and determinants at the aggregate level using a sample that spans from 1971 to 2010 with 20 Latin American countries from a total of 75. They find a decrease in EI associated to efficiency gains with no signs of sector reallocation, which could shift EI, as well. In their work they find GDP growth, per capita GDP, the fuel energy mix, and oil prices as key determinants of energy use. In contrast to their work in this investigation the key working variables are both EI and productivity at the sector level.

In particular, we use the following set of regressors to explain EI:

» Investment in machinery and equipment: this variable is used to control for energy use, under the assumption that equipment and machinery run on energy, and thus changes in the sectors' capital stock are relevant for energy consumption.

» Government education expenditure (% of GDP): shifts towards a knowledge-based economy are associated to higher stages of development; during earlier phases energy intensity may rise, though at later ones, energy intensity may fall. This variable provides an alternative link to the Kuznets-like relationship in energy intensity beyond per capita GDP.

- Electricity production from hydro (% of total power generation): this is a proxy for natural resources, for which a greater endowment of energy-friendly resources could be reflected in the country's pattern of production and thus in its EI.

- Net energy imports (% of total energy use): this variable also reflects the energy endowment of the country. Energy-scarce countries are less likely to specialize in energy demanding sectors.

- Trade (% of GDP): a country's openness to trade can gear it into energy related areas on which it enjoys a comparative advantage.

- Electric power transmission and distribution losses: the quality of the power supply can gear investment decisions towards less capital investment [see Di Bella and Grigoli (2016) and IDB (2016)].

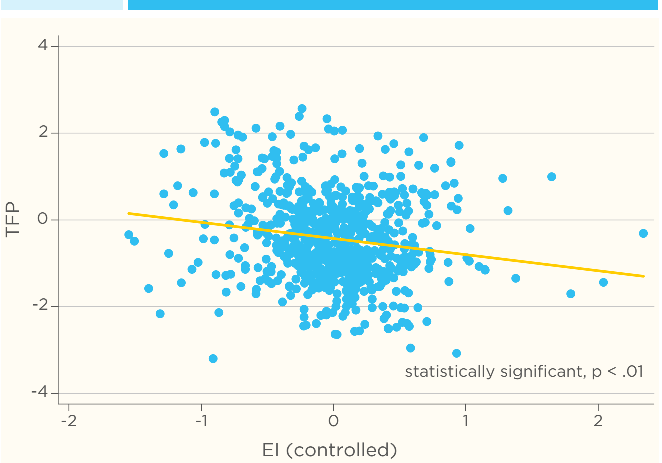
The model estimates confirm, for the most part, the expectation on the determinants of EI. Table 3 shows that controlling for time, country, and industry EI is positively associated to investment in machinery and equipment because of the associated energy use. The purpose of using Government investment in education was two-fold: first as a way to identify the point of development in an energy-use Kuznets-like transition between industrial (more energy intensive) and service (less energy intensive) sectors; and second, to quantify its importance in explaining EI. The positive estimate of the coefficient is suggestive of industrialization, but is not statistically significant. In terms of the countries' energy endowment, higher hydro generation presents a positive coefficient in connection to EI, but it is statistical significant in only one of the models, suggesting a form of comparative advantage stemming from such resources, though the signal is weak. The discussion is not pushed further because it may well be the case the while the country/countries may have high hydro potential, such potential may not have been fully exploited. Linked to endowments, too, more energy imports lower EI, pointing towards less specialization on energy intensive processes. Openness to trade is linked to higher EI which can reflect a sharper industrial export profile. Power transmission losses are important to control as a potential deterrent to investment in energy intensive sectors; however, the point estimates suggest higher EI, this finding warrants further exploration. A possible explanation involves firms' investment in their own power generation capacity, as documented in IDB (2016).

The core of the question under study concerns the connection between EI and productivity. The findings on productivity reveal again that both, TFP and value added per worker are negatively related to EI. In short, higher EI means lower productivity. Figure 7, displays the residual of the EI regression on all controls against TFP. This is what remains after EI has been stripped of the effect of its key determinants and measured against TFP. It is a negative and statistically significant relationship. While we adhere to the findings of Ryan (2018), Boyd and Pang (2000), and Levy (1985), at the micro level (where general efficiency-enhancing interventions reduce the use of both energy and non-energy inputs) and of Rajbhandari and Zhang (2017) at the country level, further research ought to explore what is the root cause of this pattern across industries.

TABLE 3. Determinants of Energy Intensity

Dependent variable: ln (Energy Intensity)	(1)	(2)
ln(Investment in machinery and equipment)	0.00634 [0.0143]	0.0474*** [0.0171]
Government education expenditure (% GDP)	0.0657 [0.0779]	0.0981 [0.0750]
Electricity Production from Hydro (% Total Electricity Production)	0.00102 [0.00556]	0.00914* [0.00545]
Energy imports, net (% of energy use)	-0.0165*** [0.00306]	-0.0205*** [0.00331]
Trade (% of GDP)	0.0297*** [0.00906]	0.0223*** [0.00826]
Electric power transmission and distribution losses (% of output)	0.0779*** [0.0206]	0.0688*** [0.0217]
ln(TFP)	-0.277*** [0.0405]	
ln(Value added/Worker)		-0.322*** [0.0528]
Trend	0.0440*** [0.0137]	0.0538*** [0.0140]
Constant	-89.27*** [27.49]	-109.1*** [28.00]
Observations	816	816
R-squared	0.852	0.853
Country dummies	YES	YES
Time dummies	YES	YES
Subsector dummies	YES	YES
Robust standard errors in brackets *** p<0.01, ** p<0.05, * p<0.1		

FIG 7. Total Factor Productivity and Energy Intensity

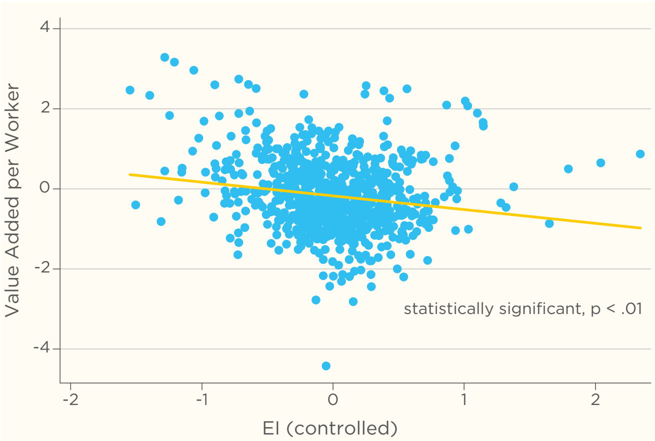


Source: Authors' calculations.

Note: This figure shows a statistically significant negative relationship between Energy Intensity and Total Factor Productivity (measured by the Solow Residual) at the industry level. The plot presents the partial effect of Energy Intensity on Total Factor Productivity after controlling for investment in equipment and machinery, government expenditure on education, hydro power generation, energy imports, openness to trade, and power transmission and distribution losses. The sample covers the period 2000 to 2015 for Brazil, Chile, Mexico and Peru. Source: Authors' calculations.

The point estimates for both productivity measures are in Table 3, and reveal a statistically unambiguous link between these variables. Each of the productivity measures convey different insights. So next, in regard to average labor productivity (value-added per worker), higher EI is linked to lower labor productivity; Figure 8 plots this relationship in terms of the residual of the regression of EI on its key determinants against mean labor productivity. All else equal higher EI is associated to lower labor productivity.

FIG 8. Labor Productivity and Energy Intensity



Source: Authors' calculations.

Note: This figure shows a statistically significant negative relationship between Energy Intensity and average labor productivity (measured as value added per worker) at the industry level. The plot presents the partial effect of Energy Intensity on average labor productivity after controlling for investment in equipment and machinery, government expenditure on education, hydro power generation, energy imports, openness to trade, and power transmission and distribution losses. The sample covers the period 2000 to 2015 for Brazil, Chile, Mexico and Peru. Source: Authors' calculations.

Given the robustness of the findings, future research should be at the firm level, and account for the recent findings in productivity trends. Ayyagari et al. (2015) look at country and firm life-cycle factors in explaining size, growth and productivity. Diao et al. (2017) focus on growth acceleration that enhances within-sector labor productivity growth in some Latin American countries. Exposure to foreign markets can boost productivity through competition and innovation, Faundez et al. (2011) find that export intensity is tied to higher productivity. On the topic of international integration Igan et al. (2016) show that foreign capital availability is linked to faster industry growth. Equally important are the findings of the OECD (2015) that document that global labor productivity growth is mostly happening in companies in the global frontier with stagnant productivity growth in non-frontier. Even though it was controlled for in the analysis in this study, electricity shortages affect productivity as discussed by Grainger and Zhang (2017) and IDB (2016). Hyland and Steinbuks (2016) look at capital adjustment costs as another variable that delays the response to price shocks or delays the adoption of newer technologies. All of these research avenues can be explored with the appropriate data and thus find out if the negative relation between productivity and EI boils down to frictions in the adoption of technology and/or environmental factors that limit newer vintages of capital that result in lower EI.

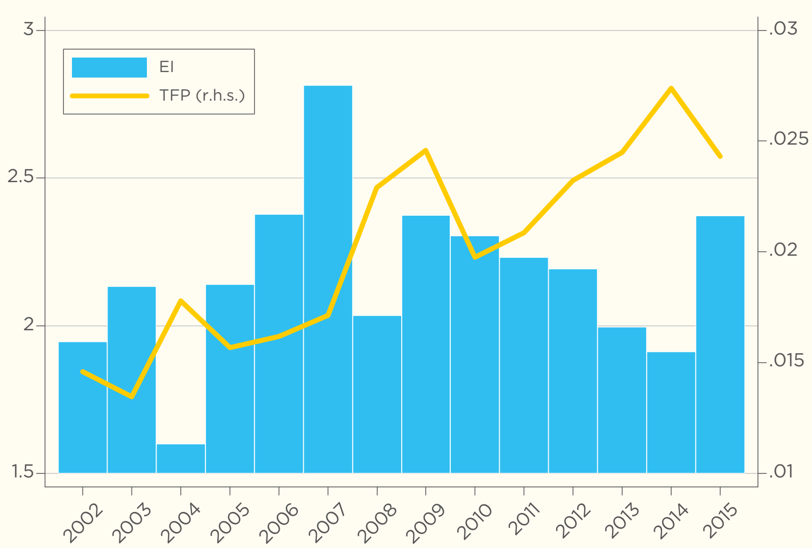
BOX 2. Trends in Relative Energy Intensity and Productivity

The key motivation of the study as a whole is the seeming negative relationship between Energy Intensity and Productivity across our sample of manufacturing industries for the countries under study: Brazil, Chile, Mexico, and Peru. While the regression analysis revealed that no matter the factors that one controls for, such as a country's energy endowment, openness to trade, international energy balance, or simply the use of physical capital and equipment by industry, the relationship remains.

This Box takes another approach. It takes the time path of the most Energy Intensive industries (measured as energy expenditure relative to value added) and their Total Factor Productivity (TFP) in Brazil and Mexico and compares them to the corresponding ones in the United States. As before, the analysis is done based on the countries' industrial surveys. With the data at hand, the methodology takes the corresponding Energy Intensity and TFP in, say, the textile industry of Brazil, and compares it to that of the United States in the form of a ratio.

Such display of information is useful in two fronts. For one, it provides a comparison of the countries' energy and productivity profiles and sets them against the same benchmark, the United States. Through this analysis one can observe the relative efficiency in energy use and the lag in productivity on an industry-by-industry basis. The second perspective of this analysis is whether the countries are catching up to the United States in either measure. This approach indirectly illuminates the question of the relationship between Energy Intensity and productivity, because as both cases illustrate, a decrease in relative energy intensity is linked to an increase in relative TFP. This is in fact, one of the thesis and avenue for further research that the study suggests: holistic interventions in productivity enhancements lead to lower input use (including energy) per unit of output.

Brazil (Textiles): Relative EI and TFP



Source: Country Industry Surveys.

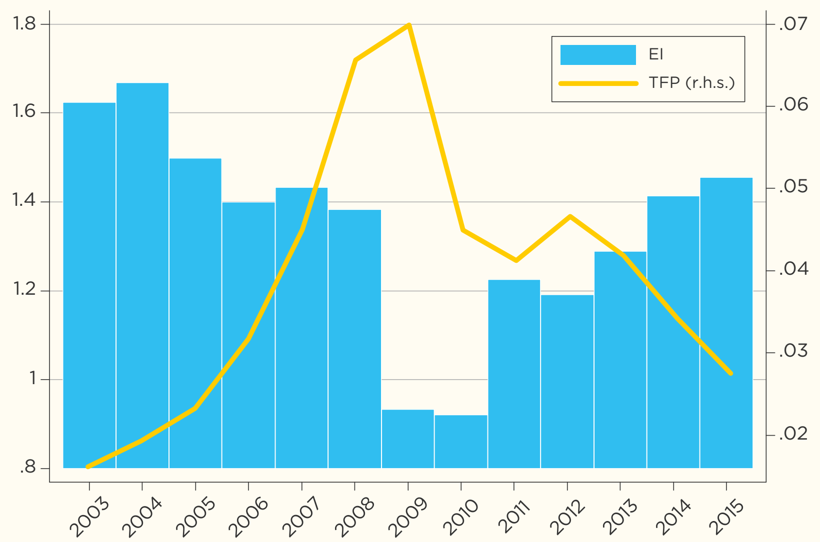
The figure above is a case in point. The Textile industry in Brazil is more energy intensive than that of the United States (left-hand side scale) and much less productive (right-hand side scale) than that of the Unites States; however, there is a hint that as the gap in energy intensity was closing, particularly after 2009, so was that in productivity.

BOX 2. Trends in Relative Energy Intensity and Productivity (continued)

In the case of Mexico, displayed in the figure below, Primary Metals was the most energy intensive industry in the first year of the survey. Using the same approach as with Brazil, the plot shows the relative energy intensity of the sector relative to the United States, as well as for TFP. There are two phases: one of a decrease in relative EI where Mexico was converging to the EI of United States from the beginning of the sample until 2010; and a second phase where the relative EI of Mexico increased. These phases seem to match a mirror behavior in terms of relative TFP in the industry: first rising and then falling. The falling of TFP refers to a drifting away from the United States' technological frontier.

The second insight of this analysis points again into the negative relationship between EI and TFP. Specifically, relative increases in TFP coincide with a decrease in EI, suggesting, as before, that productivity interventions, are likely to reduce energy use.

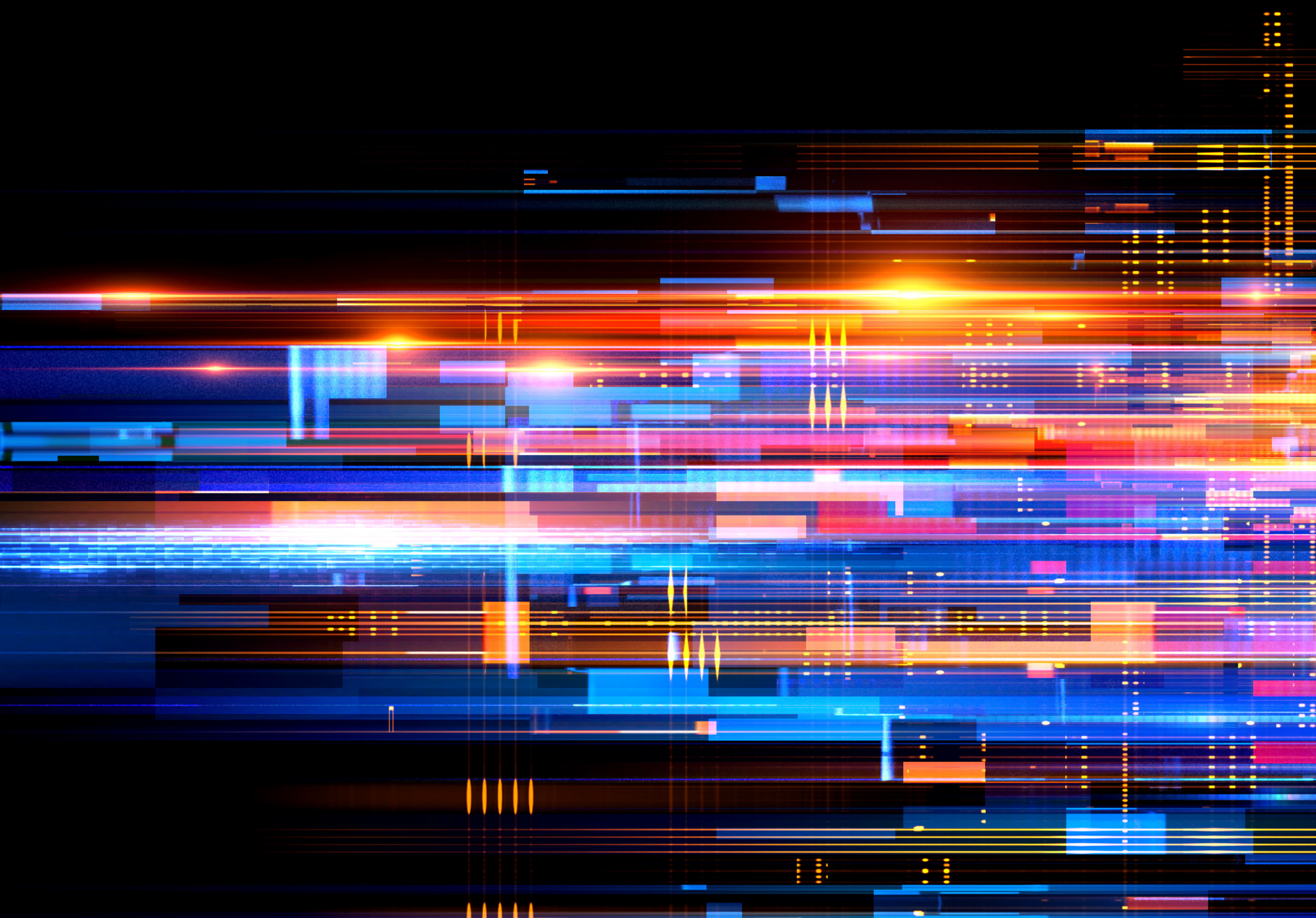
Mexico (Primary Metals): Relative EI and TFP



Source: Country Industry Surveys.

The two examples of the most energy intensive industries in Brazil and Mexico echo the findings across industries: EI and TFP are negatively related. The simple time perspective shows that focusing on a particular industry the pattern remains, a form of self-image of the bigger picture. This brings us to reflect on the lessons drawn from this analysis. From a policy standpoint, support for productivity enhancing interventions ought to result in lower energy intensity per unit of output. The value of this statement lies in the broader notion of general productivity

IS THERE CONVERGENCE IN ENERGY INTENSITY?



IS THERE CONVERGENCE IN ENERGY INTENSITY?

Extending the theme of convergence from Box 2 to all sectors and all countries, this section examines in more detail whether there is convergence in energy intensity between the manufacturing sector in Latin America and that of the United States. An examination of growth rates of energy intensity, productivity and energy intensity gaps between Latin American manufacturing sectors and those of the United States reveals a high degree of heterogeneity (Table 4): Chile, Mexico and the US exhibit decreasing energy intensity annual growth rates (-1%, -0.5% and -0.2%), while Brazil and Peru show fast rates of energy intensity growth (5% and 18%)[1]. Productivity gaps are highest in Brazil: they are 60 times lower than in the US for TFP and 9 times lower for value added per worker, while they are 22 and 23 lower in Chile and Mexico for TFP and 5 and 4 times lower for value added per worker relative to US levels[2]. Energy intensity gaps are rather similar across Latin American countries, around 2 times larger than US levels.

[1] In the case of Peru, due to the lack of data on value added in the industrial survey, energy intensity reflects the ratio of energy costs to the value of production.

[2] Those from Peru are not directly comparable as productivity measures in that country use the value of production rather than value added as reference for their construction.

TABLE 4. **High degree of heterogeneity in growth rates of energy intensity and productivity gaps across Latin America**

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
Brazil					
Energy intensity growth	294	0.05	0.22	-0.98	1.57
TFP gap	294	60.41	29.01	7.38	241.38
Value added per worker gap	294	9.21	9.96	1.60	106.86
Energy intensity gap	294	2.28	1.13	0.07	8.47
Chile					
Energy intensity growth	187	-0.01	0.49	-2.30	1.27
TFP gap	190	22.19	26.86	0.84	211.00
Value added per worker gap	190	5.17	3.61	0.22	38.09
Energy intensity gap	190	2.16	1.49	0.27	12.51
Mexico					
Energy intensity growth	252	-0.005	0.12	-0.85	0.43
TFP gap	273	23.12	9.74	4.72	62.79
Value added per worker gap	273	4.66	2.17	1.07	12.94
Energy intensity gap	273	2.69	0.94	0.57	6.49
Peru					
Energy intensity growth	121	0.18	0.78	-3.55	3.04
TFP gap	140	10.52	17.08	0.44	170.42
Value added per worker gap	140	21.16	85.99	0.82	836.86
Energy intensity gap	140	0.53	1.01	0.02	8.56
USA					
Energy intensity growth	273	-0.002	0.12	-0.43	0.55

Again, there is a negative relationship between productivity and energy intensity. To assess whether energy intensity in the manufacturing sector of Latin America will converge to the levels in the US we first test for convergence in both energy intensity and productivity estimating the following equation:

$$ln\left(\frac{Y_{ci,t}}{Y_{ci,t-1}}\right)=A+Bln(Y_{ci,t-1})+CI+T+\theta_{cit} \quad (1)$$

Where $Y_{ci,t}$ refers to either energy intensity or TFP in country c subsector *i*, *A* denotes a constant, $Y_{ci,t-1}$ denotes the lagged value of the dependent variable, *CI* and *T* are country-subsector and time dummies, respectively and θ_{cit} is the error term.

TABLE 5. **Evidence of convergence of energy intensity and TFP to US levels**

(1) Energy Intensity Growth		(2) TFP Growth	
Lag Energy Intensity	-0.418***	Lag TFP	-0.911***
	[0.0551]		[0.0648]
Constant		Constant	-0.406***
			[0.0948]
Observations	803	Observations	803
Number of id	75	Number of id	75
R-squared	0.225	R-squared	0.493

Robust standard errors in brackets. *** p<0.01. The regression controls for country-subsector fixed effects, year dummies and a dummy that takes a value of one for Mexico from 2009 onwards due to a change in the survey methodology.

The results show that there is a negative correlation between the initial level of energy intensity and TFP and the rate of growth of each variable, indicating convergence towards US levels in both variables.

To further investigate the impact of variables that may influence the energy gap, the following equation is estimated:

$$ln\left(\frac{E_{ci,t}}{E_{USi,t}}\right)=a+b ln\left(\frac{TFP_{USi,t}}{TFP_{ci,t}}\right)+X+CI+T+\epsilon_{cit} \quad (2)$$

Where $E_{ci,t}$ denotes energy intensity in country c, subsector i at time t, $E_{USi,t}$ is the energy intensity of subsector i in the US, thus the ratio reflects the gap in energy intensity. The ratio $\frac{TFP_{USi,t}}{TFP_{ci,t}}$ denotes the gap in terms of TFP, X are other covariates which, following the estimation in previous sections, include investment in machinery and equipment, government education expenditure, electricity production from hydro, the extent of trade and electric power transmission and distribution losses.

Table 6 reports the results of the estimation of equation (2), which reinforce the findings from previous sections. TFP gaps tend to increase energy intensity gaps. A 1% increase in the TFP gap is correlated with a 0.2% increase in the energy intensity gap. Higher exposure to trade and power losses are positively correlated with energy intensity gaps, while higher energy imports are negatively correlated with energy intensity gaps.

TABLE 6. **Determinants of energy intensity gaps**

Gap TFP	0.242***
	[0.0667]
ln(Investment in machinery and equipment)	0.0261
	[0.0328]
Government education expenditure (% GDP)	-0.0299
	[0.0904]
Electricity Production from Hydro (% Total Electricity Production)	-0.00314
	[0.00718]
Energy imports, net (% of energy use)	-0.0165***
	[0.00278]
Trade (% of GDP)	0.0315***
	[0.00868]
Electric power transmission and distribution losses (% of output)	0.0778***
	[0.0191]
Constant	-2.655**
	[1.115]
Observations	744
Number of id	75
R-squared	0.371

Robust standard errors in brackets. *** p<0.01. The regression controls for country-subsector fixed effects, year dummies and a dummy that takes a value of one for Mexico from 2009 onwards due to a change in the survey methodology.

POLICY RECOMMENDATIONS

POLICY RECOMMENDATIONS

As an essential driver of economic development, and necessary to most forms of economic activity, energy ranks high in any country's policy agenda. From access, to reliability, to affordability, policymakers must plan for the provision of energy to not constrain economic growth.

On the flip side, a country's energy needs depend on its demographics, stage of development, and industrial structure among other fundamental variables, that are, in turn, shaped by the nation's energy endowment, international integration to other economies, and by industrial policy.

The focus of this study is on energy intensity: the amount of energy used per unit of output. As countries develop, economies shift from agriculture, to industrialization, to services, which each, in turn, is characterized by different energy needs with the intermediate stages of development being the most energy intensive.

In the case of Brazil, Chile, Mexico and Peru, based on industrial surveys and controlling for year, country, and industry, energy intensity is positively related to physical capital, and for these countries' level of development, it is (weakly) increasing in investment in human capital (knowledge-based economy). Energy intensity was also found to be decreasing in energy imports (less specialization in energy intensive processes), and increasing in openness which could be linked to the export profile of the countries. Abundance of hydro resources in this sample of countries was not statistically related to energy intensity, however, it ought to foster emission-free sustainable electrification for countries with such endowments.

The key policy finding is that after controlling for the factors outlined above, EI and productivity are negatively related. One possibility underlying this relationship is that productivity-enhancing interventions reduce energy and non-energy inputs alike. With this in mind, policies aimed at facilitating new vintage investment in physical capital, and incentives for more efficient factors use, shall increase productivity, either measured by TFP (residual of capital and labor) or average labor productivity.

REFERENCES

Ayyagari, M., A. Demirguc-Kunt, and V. Maksimovic (2015). Are Large Firms Born or Made? Evidence from Developing Countries, Policy Research Working Paper 7406. World Bank.

Boyd, G. and J. Pang (2000). Estimating the Linkage between Energy Efficiency and Productivity, Energy Policy, Vol. 28(5), pp. 289-296.

Cantore, N., M. Calì, and D. W. te Velde (2016). Does Energy Efficiency Improve Technological Change and Economic Growth in Developing Countries? Energy Policy, 92, pp. 279-285.

Deichmann, U., A. Reuter, S. Vollmer, and F. Zhang (2018). Relationship between Energy Intensity and Economic Growth: New Evidence from a Multi-Country Multi-Sector Data Set, World Bank Research Working Paper No. 8322.

Diao, X., M. McMillan, D. Rodrik (2017). The Recent Growth Boom in Developing Economies: A Structural Change Perspective, NBER Working Paper 23132.

Di Bella, G. and F. Grigoli (2016). Power It Up: Strengthening the Electricity Sector to Improve Efficiency and Support Economic Activity, WP/16/85, IMF Working Paper.

Faundez, S., N. Mulder, and N. Carpentier (2011). Productivity Growth in Latin American Manufacturing: What Role for International Trade Intensities? CEPAL, Serie Comercio Internacional No. 110. United Nations.

Grainger, C. and F. Zhang (2017). The Impact of Electricity Shortages on Firm Productivity: Evidence from Pakistan, Policy Research Working Paper 8130, World Bank.

Hyland, M. and J. Steinbuks (2016). Capital Adjustment and the Optimal Fuel Choice, Policy Research Working Paper 7857, World Bank.

IDB (2016). Energy, Productivity, and Competitiveness in Latin America. Energy Division, Inter-American Development Bank.

Igan, D., A. Kutan, and A. Mirzaei (2016). Real Effects of Capital Inflows in Emerging Markets, WP/16/235, IMF Working Paper.

Jimenez, R. and J. Mercado (2013). Energy Intensity: A Decomposition and Counterfactual Exercise for Latin American Countries, IDB Working Paper Series No. IDB-WP-441, Inter-American Development Bank.

Levy, S. (1985). Cambio Tecnológico y Uso de la Energía en México, El Trimestre Economico, Vol. 52.

Markandya, A., S. Pedroso-Galinato and D. Streimikiene (2006). Energy intensity in transition economies: Is there convergence towards the EU average?, Energy Economics, 28, pp: 121-145.

OECD (2015). The Future of Productivity, Organization for Economic Co-operation and Development.

Rajbhandari, A. and F. Zhang (2017). Does Energy Efficiency Promote Economic Growth? Evidence from a Multi-Country and Multi-Sector Panel Data Set, Policy Research Working Paper 8077, World Bank.

Ryan, N. (2018). Energy Productivity and Energy Demand: Experimental Evidence from Indian Manufacturing Plants, NBER Working Paper No. w24619.

Sinha, R. (2016). Sectoral Productivity Gaps and Aggregate Productivity, World Bank Working Paper 7737.

Stern, D. (2011). The Role of Energy in Economic Growth, Ecological Economics Reviews 1219, Issue 1, pp. 26-51.