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New Evidence from a Multi-Country Multi-Sector Data Set

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Abstract

This paper revisits the relationship between energy intensity and economic growth, using a flexible piecewise linear regression model. Based on a panel data set of 137 economies during 1990–2014, the analysis identifies a threshold effect of income growth on energy intensity change: although energy intensity is negatively correlated with income growth throughout the entire sample and study period, the declining rate significantly slows by more than 30 percent after the level of per capita income reaches $5,000. Based on index decomposition, the analysis also finds that although structural change is important for intensity levels in all countries, the efficiency effect is more important in higher-income countries. The results suggest that when countries move beyond lower-middle-income levels, energy efficiency policies become far more critical for sustaining the rate of improvement in energy efficiency.

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Relationship between Energy Intensity and Economic Growth:
New Evidence from a Multi-Country Multi-Sector Data Set[1]

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I. Introduction

The energy sector plays an important role in economic development. But energy consumption is also associated with human-induced climate change because of the dominant role of fossil fuels in power production. Energy use tends to increase with development as countries shift from labor-intensive agriculture to capital and energy intensive industries. As the structural transformation proceeds, they subsequently move into information-intensive services. Energy intensity therefore initially increases with rising incomes and then decreases—a pattern comparable to the Environmental Kuznets Curve (EKC) that describes the relation between per capita GDP and environmental degradation.

The EKC pattern in the income and pollution relationship has been extensively documented (Dasgupta et al., 2002; Carson, 2010). Recently, there is also a growing literature on the validity of EKC in the context of energy use. For example, Luzzati and Orsini (2009) analyze the relationship between per capita GDP and aggregate energy consumption for a sample of 113 countries over 1971 to 2004. Their findings based on different econometric techniques (parametric and semi-parametric) and across different sample groups (world, cross-countries, and individual countries) do not support the energy-EKC hypothesis. On the other hand, Medlock and Soligo (2001), van Benthem and Romani (2009) and van Benthem (2015) document an S-shaped relationship between energy intensity and economic growth. Specifically, they find that the income elasticity of energy demand peaks at a GDP per capita level between $5,000 and $10,000, and trends towards zero for high-income levels. Burke and Csereklyei (2016) present disaggregated analysis of the elasticity of energy demand. Their findings suggest substantial heterogeneity in income elasticity of energy use across sectors: industry and services sectors are most responsive to income growth, followed by residential and agricultural sectors.

Another strand of related literature tests the hypothesis of cross-country convergence of energy intensity. Specifically, these studies examine whether cross-country variation in energy intensity is getting smaller (so-called sigma-convergence) and whether less efficient countries reduce their energy intensity faster than more efficient ones (beta-convergence). While the majority of studies find convergence across developing and developed countries (such as Mielnik and Goldemberg, 2000; Markandya et al., 2006; Ezcurra, 2007; Csereklyei et al., 2016; Burke and Csereklyei, 2016), others argue for a more nuanced picture of convergence in energy intensity. For example, Le Pen and Sevi (2010) do not find evidence for global convergence for a group of 97 countries during 1971 – 2003. When looking at subgroups, they find non-convergence is "less strongly rejected" for the Middle East, OECD and Europe sub-groups. Ezcurra (2007) show that developing counties tend to converge at a higher level of energy intensity, while for developed countries at least two different levels of convergence are observed. Stern (2012) shows that divergence in energy efficiency is mostly associated with economies that are lacking in economic progress.

A third strand of literature explores the determinants of the growth rate of energy intensity. For example, using data for 51 sectors in 19 OECD countries from 1980 to 2005, Mulder and de Groot (2011) find that reductions in energy intensity have been driven more by within-sector energy efficiency improvements than by changes in the composition of activities at the economy level or within the manufacturing and service sectors. In another paper, Mulder and de Groot (2012) show that aggregate convergence in energy intensity of 18 OECD countries from 1970 to 2005 is almost entirely driven by convergence of within-sector energy intensity levels, and not by convergence of the sector composition of economies. By using output distance functions, Wang (2013) decomposes energy intensity change across 100 countries from 1980 to 2010 into five components: technological catch-up, technological progress and changes in the capital-energy ratio, labor-energy ratio and output structure. Technological progress, capital accumulation and changes in output structure contributed positively to lowering energy intensity while a decrease in the labor-energy ratio increased intensities.

As this brief survey shows, the existing EKC and convergence literature does not present conclusive evidence on the relationship between energy intensity and economic growth. In this paper we therefore revisit this question using a large data set of 137 economies over the period of 1990-2014. In our main estimation model, we adopt a novel piece-wise regression method which imposes less structure on the relationship between the level of economic growth and energy intensity. We find a negative correlation between GDP per capita and energy intensity across the entire sample and study period. However, the downward slope flattens out at higher values of GDP. The inflection point is at a per capita income level of around $5,000. We also find evidence of cross-country convergence in energy intensity. Finally, based on index decomposition, we investigate the extent to which shifts in economy-wide energy intensity are affected by structural vs. efficiency changes at the country level. The analysis shows that while structural change is important for intensity levels in all countries, the efficiency effect is more important for higher-income countries. This finding supports the income threshold effect identified earlier: the relatively automatic efficiency gains (as a result of income gains) are at lower levels of GDP (and thus the steeper slope), while the harder problem (improving efficiency) is more important in higher income countries. The results suggest that when countries move beyond lower-middle income levels, energy efficiency policies become far more important if they want to continue the rate of improvement in energy efficiency.

II. Data

Energy consumption data are obtained from the International Energy Agency (IEA) World Energy Statistics and Balances data set. We calculate aggregate energy intensity as total final energy consumption divided by total GDP (GDP per capita times population). Sector-level energy intensity is defined as energy consumption of agriculture, industry and services divided by sector value added.

Data on GDP and value added in agriculture, services, and industry and manufacturing sectors are from the World Bank World Development Indicators (WDI). [2] For comparison across countries and over time, all values are converted into PPP-based constant 2005 prices.

We also control for other country characteristics, including exports and imports, age structure of the population, and population density. All these factors may lead countries to converge to different steady-state levels of energy intensity. Data on these variables are also obtained from WDI.

Overall, we have an unbalanced panel of 137 economies from 1970 to 2014, and a balanced panel of 64 countries during the same period. Since the attrition rate is relatively high, it may be difficult to tell whether a change over time is picking up a real development or just a change in the composition of the sample. However, eliminating countries with missing data could cause sample selection bias, if countries with missing data are systematically different from those that have complete observations over the study period. In the following we report results from the unbalanced panel. For robustness

[2] Last Updated: 05/26/2017.

check, we also estimate the models using the balanced panel and with data from the Penn World Tables (1980-2014). Conclusions of the paper are robust to these alternative data sources.

Table 1 reports descriptive statistics for the 137 economies in the unbalanced sample. The variables reported are GDP (PPP) per capita, total final energy consumption and population size. The numbers are period averages. The sample covers the entire spectrum from poor to rich countries.

III. Relationship between energy intensity and economic development

A. Descriptive analysis

We are interested in the relationship between energy intensity and economic development. One hypothesis that can be derived from the literature is that the relationship between energy intensity and economic development follows a Kuznet's curve (inverted u-shape). Energy intensity increases in early stages of development (industrialization) and it decreases in later stages of development (transition to a services economy). Structural change of the economy is a long process that is unlikely to be reflected in a panel of only 44 years. However, it is still possible to study this hypothesis. If it were true, we would expect a negative association between energy intensity and GDP per capita for developed countries and a positive association for developing countries (and possibly no association for countries that are in the middle of the transition).

Another hypothesis is that there is a negative association between energy intensity and economic development with no trend shift. The theoretical justification behind this hypothesis is that economic development increases opportunities to make production processes more efficient and therefore reduces energy intensity. If this negative association was preceded by an initial positive one, as the EKC hypothesis suggests, it would have pre-dated the compilation of reliable cross-country data. The remaining possibilities are that there is no association between growth and energy intensity or that energy intensity keeps rising with incomes (a positive association). These patterns are not supported by any theories or evidence.

Exploratory data analysis suggests it is appropriate to take logs of both variables. Taking logs does not change the direction of the relationship and therefore does not affect our conclusions regarding the main hypotheses. But the logarithm makes an exponential shape linear and allows correlation and regression analysis of the data.

As a first step we calculate the correlation coefficient between energy consumption per $PPP and GDP per capita PPP for all 137 economies in the data set (Table A1). For about 40 percent of the countries we find a very strong negative linear association between the two variables with a correlation coefficient of -0.9 or smaller. For another 35 percent of the countries we find a moderate to strong negative association with correlation coefficients between -0.9 and -0.5. Of the remaining countries, 16 show a weak to very weak negative association and 15 countries show a weak positive association. The overall impression from the correlation analysis is that there is a fairly strong negative association between energy consumption per $PPP and GDP per capita PPP for most countries. If the relationship followed a Kuznets curve, we would expect a negative association in developed countries and a positive association in developing countries. Even a cursory look at Table A1 contradicts this hypothesis: We find the same strong negative linear association for countries like India, Nigeria and

China as for countries like the United States, the United Kingdom and Germany. On the other hand, the relatively rich EU members Spain and Portugal show only a weak negative or even a positive association between the two variables.

B. Econometric analysis

In the econometric analysis, we first specify the following fixed effects model to test the relationship between energy intensity and economic development

$$logEI_{it} = \beta_1 \cdot logGDP_{it} + \gamma_1 E_{it} + \gamma_2 V_{it} + \gamma_3 X_{it} + \mu_i + \rho_t + v_{it} \quad (1)$$

Where EI_{it} is log energy intensity of country *i* in year t, GDP_{it} is log GDP per capita. Previous studies suggest the importance of controlling for sector composition of an economy when analyzing the relationship between income and energy intensity (Burke and Csereklyei, 2016; Medlock and Soligo, 2001). We therefore include on the right-hand-side of equation (1) a vector E_{it}, which is a set of control variables for the composition of final energy demand. It includes the percentage of total energy consumption used in industry, transport, residential, services, agriculture and non-energy use. The reference category is non-specified other energy consumption, all variables are coded between 0 and 1. V_{it} is a set of control variables including value added in industry, agriculture, manufacturing and services as well as exports and imports. All variables are measured as a percentage of total GDP and coded between 0 and 100. X_{it} is a set of demographic variables which could affect energy consumption patterns. It includes population density as well as the percentage of the population aged 14 or younger and 65 and older (the working age population is the reference category). Population density is measured as the number of people per 1,000 square kilometers of area, and the other two variables are coded between 0 and 100. Finally, μ_i is a country fixed effect capturing time-invariant country specific characteristics; ρ_t is a time fixed effect controlling for yearly shocks that are common to all countries; and v_{it} is the error term.

The results of these regressions are shown in Table 2. In the first column we report the results of a simple pooled OLS specification, in the second column we add country fixed effects, and in the third column we add time fixed effects. The coefficient of log GDP per capita is negative and highly significant in all three cases, but its magnitude changes when the country and time fixed effects are included. Adding the control variables for the composition of energy consumption changes the explanatory power of the model, but the coefficient of log GDP per capita remains relatively stable. Adding the control variables for the structure of the economy also increases the explanatory power moderately, but also diminishes the size of the coefficient of log GDP per capita. Adding the demographic controls again increases the explanatory power of the model and enlarges the magnitude of the coefficient of log GDP per capita again. Overall, these regressions are strong evidence for a negative association between GDP per capita and energy intensity. An increase of GDP per capita by 1 percent is associated with a decrease of energy intensity by 0.62 percent.

The scatter plot in Figure 1 and also the country by country correlation analysis in the previous section indicate that the relationship between log GDP per capita and log energy intensity is not perfectly linear, because there are a few countries with no or a positive association. We thus include a squared term of log GDP per capita to equation (1) to allow for a more flexible functional form and also to test for an inverted U-shaped relationship.

$$logEI_{it} = \beta_1 \cdot logGDP_{it} + \beta_2 \cdot logGDP_{it}^2 + \gamma_1 E_{it} + \gamma_2 V_{it} + \gamma_3 X_{it} + \mu_i + \rho_t + v_{it} \quad (2)$$

The results are reported in Table 3. They are qualitatively similar to the results from the previous regressions, but thanks to the more flexible functional form the explanatory power is always higher than in Table 2. The coefficients of log GDP per capita are always negative and significant, and the coefficients of log GDP per capita squared are always positive and significant. This is an indicator for a U-shaped relationship. However, when we calculate the minimum of the parabola ($= -\beta_1/(2 \cdot \beta_2)$), we find that the minimum is always near the right border of the observed values of log GDP per capita (except for the pooled OLS regression). It is thus not a real minimum, in fact we are fitting the left-hand side of a parabola to the data, thus the relationship between log GDP per capita and log energy intensity is always negative but flattening out for higher values of log GDP per capita. In other words, these regressions do not show evidence for a u-shaped or inverted u-shaped relationship between the two variables.

To adopt a more flexible functional form without imposing structure on the relationship between GDP and energy intensity, we apply a piecewise linear model similar to the one Myrskylä et al. (2009) implemented. The starting point is a piecewise linear relationship that fits two different linear models to the left and to the right of a critical value of log GDP per capita:

$$logEI_{it} = (\alpha^{pre} + \beta^{pre} \cdot logGDP_{it}) \cdot B_{it}^{pre} + (\alpha^{post} + \beta^{post} \cdot logGDP_{it}) \cdot B_{it}^{post} + \mu_i + \rho_t + v_{it} \qquad (3)$$

where B_{it}^{pre} is an indicator variable that is equal to 1 to the left of the critical value of log GDP per capita and 0 otherwise. B_{it}^{post} is an indicator variable that is equal to 1 to the right of the critical value of log GDP per capita and 0 otherwise. If β^{pre} is negative and β^{post} is positive, then the relationship is V-shaped (or U-shaped). If β^{pre} is positive and β^{post} is negative, then the relationship is inverted V-shaped. If both coefficients have the same sign, it is interesting to compare the magnitudes of the coefficients, because the piecewise linear model can also show that parts of the relationship are steeper/flatter than others.

Before we explain how to obtain the critical value of log GDP per capita, we first note that we do not estimate equation (3) directly but rather in its differences-in-differences version

$$\Delta logEI_{it} = \alpha \cdot \Delta B_{it}^{pre} + \beta^{pre} \cdot B_{it}^{pre} \cdot \Delta logGDP_{it} + \beta^{post} \cdot B_{it}^{post} \cdot \Delta logGDP_{it} + \Delta\gamma_t + \Delta v_{it} \qquad (4)$$

where Δ is the difference operator $\Delta x_t = x_t - x_{t-1}$. The differencing implicitly controls for the country fixed effects and accounts for autocorrelation in the residuals. The coefficients obtained from the differences-in-differences model comes closer to a causal interpretation than the coefficients obtained from a levels equation. As additional robustness check, we estimate the same model with the first lag of the log GDP per capita variable.

$$\Delta logEI_{it} = \alpha \cdot \Delta B_{it}^{pre} + \beta^{pre} \cdot B_{it}^{pre} \cdot \Delta logGDP_{i(t-1)} + \beta^{post} \cdot B_{it}^{post} \cdot \Delta logGDP_{i(t-1)} + \Delta\gamma_t + \Delta v_{it} \qquad (5)$$

To find the optimal value for the threshold between the two linear models, we use the following numerical procedure: We estimate equation (4) for any possible critical value within the range of observations (within 5.8 and 11.7) in steps of 0.1. We calculate the likelihood for each model and then pick the critical value for which the model has the largest likelihood (maximum likelihood estimation). In Figure 2 we show a plot of the likelihoods of all models with critical values between 5.8 and 11.3, the maximum is at 8.5. Thus, we estimate equations (4) and (5) with critical values of 8.5, that is B_{it}^{pre} is equal to 1 if log GDP per capita is smaller than 8.5 and 0 otherwise, and B_{it}^{post} is 1 if log GDP per capita is greater or equal 8.5 and 0 otherwise.

The results for the two differences-in-differences regressions are reported in Table 4. For both equations, the coefficients are negative and highly significant, both to the right and to the left of the critical value of log GDP per capita. However, the slope is much steeper (we find a more negative coefficient) to the left of the critical value than to the right. These results confirm the previous finding from the fixed effects estimations. The relationship between log GDP per capita and log energy intensity is negative for the entire observation period, but the slope flattens out for higher values of GDP per capita. Specifically, when per capita GDP reaches around $5,000, the declining rate of energy intensity with respect to economic growth significantly slows down by more than 30 percent. This finding suggests that energy productivity increases as income grows. However, the income elasticity of energy demand increases with income. As a result, after exceeding a threshold of around $5,000 GDP per capita, the efficiency dividends of economic growth become much smaller. More aggressive energy efficiency policies are needed to sustain rapid and continued improvement in energy productivity as income levels surpass the threshold.

IV. Convergence of energy intensity

In an exploratory data analysis (time series plots of energy intensity) we got the impression that energy intensity is converging to the same level across countries. We will now investigate this hypothesis more systematically. Typically, convergence analysis is used in the context of economic growth and goes back to Barro and Sala-i-Martin (1991). In order to achieve convergence, or in other words for poor countries to catch up to GDP per capita levels of rich countries over time, two things are necessary: beta convergence and sigma convergence. For beta convergence we study the association between the average growth rate of GDP per capita and the initial level of GDP per capita for a given time period. We speak of beta convergence if the regression coefficient (beta) of the initial level of GDP per capita is negative – as an explanatory variable for the growth rate of GDP per capita. The negative beta coefficient implies that initially poorer countries had higher average growth rates than initially richer countries. Sigma convergence means that the standard deviation of GDP per capita decreases over time. If we find both, we speak of convergence.

How do these concepts translate to convergence of energy intensity? For energy intensity, convergence means that countries that use a lot of energy per dollar of GDP over time catch up to levels of countries that use less energy per dollar of GDP. Thus, we speak of beta convergence in this context if higher rates of reduction in energy consumption per dollar of GDP are associated with higher initial levels of energy consumption per dollar of GDP. Different from convergence of GDP per capita, in this context beta convergence is implied by a positive beta coefficient in the regression. The meaning of sigma convergence is exactly the same as in the GDP per capita context.

We calculate the total change in log energy consumption per dollar of GDP between 1990 and 2014 and divide it by the level in 1990. This is a simple measure for the rate of reduction in energy consumption per dollar of GDP. We then run a regression with the rate of reduction as a dependent variable and the initial level of log energy consumption per dollar of GDP as the explanatory variable according to equation (6):

$$\Delta I_{it} = \beta \log(I_{i0}) + \varepsilon_{it} \quad (6)$$

ΔI_{it} is the growth rate of energy intensity of country *i* during the period from 1990 to 2014. I_{i0} is the energy intensity of country *i* in year 1990 and ε_{it} is the error term. The result is shown in the left panel of Figure 3. Indeed, the beta coefficient is positive and highly significant (beta= .029 and $p<0.01$). Quite remarkably, the variation in the initial level of log energy consumption per dollar of GDP explains about 42 percent of the variation in the rate of reduction across countries. We thus find strong evidence for beta convergence.

In the right panel of Figure 3, we show fitted normal densities for log energy consumption per dollar of GDP for 1990 and 2014. One can clearly see that the density became much narrower over time (and also that the mean shifted to the left). Indeed, the standard deviation decreases from 0.649 in 1990 to 0.511 in 2014. We thus find evidence for sigma convergence. As we find both beta and sigma convergence, we can thus conclude that countries with high initial levels of energy intensity are converging to the levels of countries with low energy intensity.

In Figure 4 we show box plots for log energy intensity for 1990, 2000, 2010 and 2014. A box plot displays the median, the first quartile, the third quartile and the largest and smallest adjacent values.[3] The following observations are noteworthy: First quartile, median, third quartile and largest value all decrease over time. The outside values get closer to the largest adjacent observation over time. The smallest adjacent value also decreases over time, though the largest change occurred between 1990 and 2000. After 2000, the smallest adjacent value stayed fairly constant. The smallest value can be considered as the "technology frontier" or "minimal energy consumption required per unit of output". According to this picture, the frontier did not move very much between 2000 and 2014, rather the rest of the distribution moved closer to the frontier. Given that there is a generally increasing trend for per capita income across the sample, this result appears to be consistent with our earlier conclusion that as income rises above a certain threshold, reducing energy intensity becomes more difficult.

To examine whether there is also a difference in the speed of convergence on different sides of the income threshold, we divide the sample into two subgroups based on whether a country-year observation lies below or above the cutoff point at log per capita GDP of 8.5. We calculate the conditional convergence rate according to $\rho = -[\left(\frac{1}{T}\right)\log(\beta + 1)]$ (Barro and Sala-i-Martin, 1992; Islam, 1995), where T is the length in the time dimension under consideration (25 years in our case) and β is the coefficient obtained from equation (6). The results are reported in Table 5. The rate of unconditional convergence for groups below and above the income threshold is roughly 0.10 percent and 0.14 percent, respectively. The difference between the two groups is small and the lower-income sample even has a lower convergence rate. The result could reflect different economic growth rates of the two groups.

V. Index Decomposition

In this section, we investigate how much of the improvement in energy intensity is due to structural change and how much is due to efficiency improvements, and whether the income threshold effects identified earlier play a role in the relative importance of structural vs. efficiency changes. To this end we use the Fisher Ideal Index Decomposition for structural change in energy intensity as described in Boyd and Roop (2004). We consider three sectors: industry, agriculture and services. As described in Boyd and Roop (2004) we first calculate a Laspeyres and a Paasche index of energy intensity for structure and efficiency using the following formulas from Boyd and Roop (2004):

Laspeyres	Paasche
$L_{Str} = \Sigma_i S_{i,T} I_{i,0} / \Sigma_i S_{i,0} I_{i,0}$	$P_{Str} = \Sigma_i S_{i,T} I_{i,T} / \Sigma_i S_{i,0} I_{i,T}$
$L_{Int} = \Sigma_i S_{i,0} I_{i,T} / \Sigma_i S_{i,0} I_{i,0}$	$P_{Int} = \Sigma_i S_{i,T} I_{i,T} / \Sigma_i S_{i,T} I_{i,0}$

S: agriculture, industry and services share of GDP

I: energy intensity

0: first year

[3] Values that are more than 1.5 times the interquartile range (distance between first and third quartile) away from the median are plotted separately.

T: last year

i: industry, agriculture, service

The Fisher index is the geometric mean of the Laspeyres and the Paasche index. The aggregate Fisher index is the product of the structural part and the intensity part.

Table 6 displays the values of the Fisher index (aggregate, structure and efficiency) for the year 2014 (base year 1990=1) in ascending order of the aggregate index. The structural index ranges between 0.5 and 1.3 while the efficiency intensity ranges from 0.2 to 1.6.[4] To examine whether structural change or efficiency improvement plays a more important role in influencing aggregate energy intensity, we estimate the following country fixed-effects model.

$$F_{agg}=\alpha F_{Str}+\beta F_{eff}+u_i+e_i \qquad (7)$$

F_{agg} is the aggregate intensity index, F_{str} is the structural index and F_{eff} is the efficiency index. u_i are time-invariant country fixed effects. e_i is the error term. Similar to the convergence analysis, we conduct both full sample analysis and sub-sample analysis based on the previously identified income threshold. Table 7 reports the estimation results, where column (1) corresponds to the full sample estimation, and columns (2) and (3) correspond to sub-samples below and above the income threshold, respectively.

The results suggest that structural change has made a higher contribution to variation in energy intensity for the full sample of observations. However, for country-year observations that are above the income threshold, efficiency change plays a more important role in driving the change in aggregate intensity.

VI. Conclusion

Reducing the amount of energy required to produce a unit of output is a priority in efforts to slow climate change. This paper contributes to the literature on the relationship between energy use and economic growth by better describing the energy intensity trajectory as incomes grow. Specifically, our results confirm a negative correlation between GDP per capita and energy intensity as well as cross-country convergence in energy intensity. We also identify a transition from a relatively rapid lowering of energy intensity to slower gains. Using a flexible econometric approach, we show that as countries reach a per capita income of about $5,000 (PPP)—slightly above the level considered by the World Bank as upper-middle income—the downward sloping curve of energy use per unit of GDP flattens out. Index decomposition identifies the relative contribution of structural change versus energy efficiency to lowering energy intensity. It shows that the former is important at all income levels, while energy efficiency is more important at higher income levels.

The results suggest that we can expect to see relatively rapid improvements in energy intensity as the economies in today's poor countries grow. However, as they move beyond lower-middle income, the role for energy efficiency policies then becomes far more critical if a country wants to continue the rate of improvement in energy efficiency (Deichmann and Zhang 2013). There is now a much better

[4] Malta is dropped as an outlier.

understanding of different policy instruments for improving energy efficiency—even if we do not yet sufficiently understand why they are not adopted at a scale that would seem beneficial (Gillingham and Palmer 2014). Energy efficiency gains likely will require numerous sector-specific instruments such as targeted revenue-neutral environmental taxation (eco-taxes) and other price instruments, stricter regulations, and public investments.

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Figure 1: Scatterplot of log energy intensity and log GDP per capita

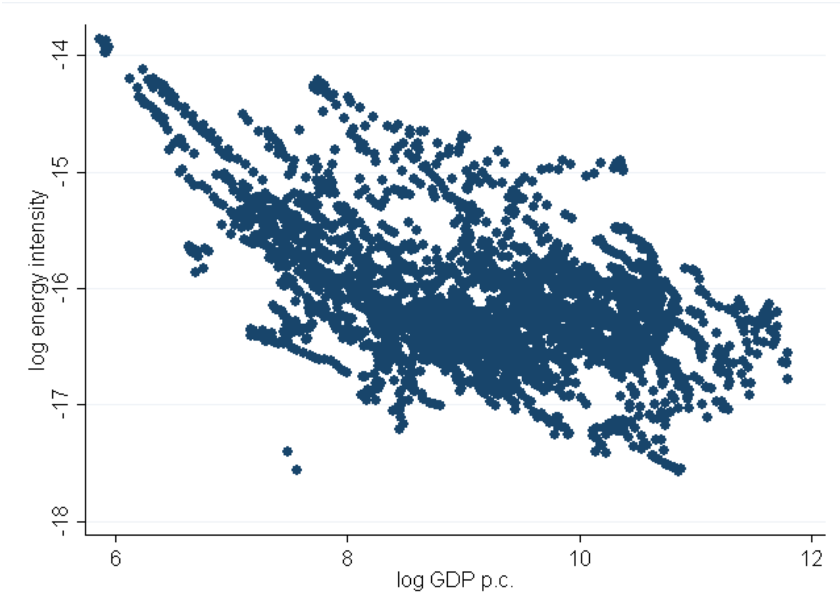


Figure 2: Likelihood for cut-off in piecewise linear regression

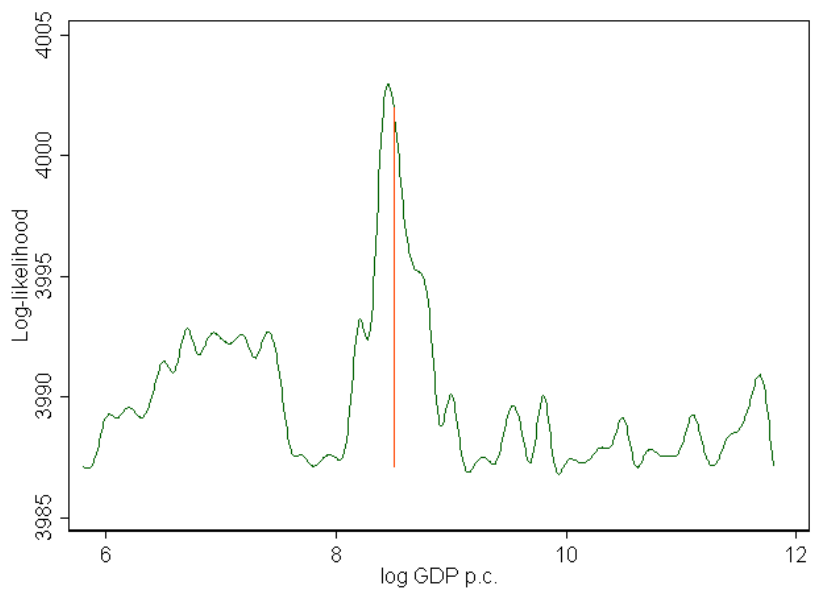


Figure 3: Energy Intensity Convergence: Beta and Sigma Convergence

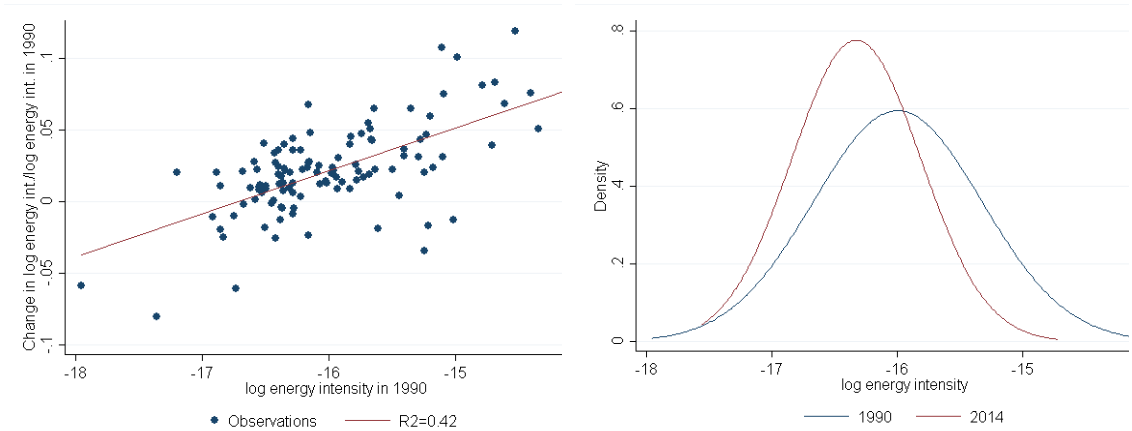
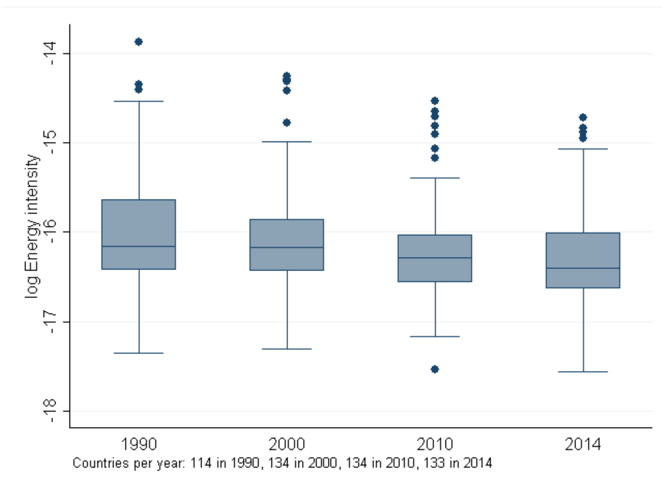


Figure 4: Box plots of log energy consumption per dollar for selected years [5]



[5] This graph does not include Brunei, which had a log energy intensity of -18 in 1980 and thus constitutes an extreme outlier (because of oil price effects).

Table 1 Summary statistics (period averages) for the 137 economies

Country	GDP p.c.	C(Energy)	Population	Country	GDP p.c.	C(Energy)	Population
Qatar	120,371	8,363	971	Hungary	19,404	17,949	10,159
United Arab Emirates	91,285	29,787	4,593	Slovak Republic	19,142	11,544	5,372
Brunei	83,208	860	341	Russian Federation	18,346	454,862	145,585
Kuwait	80,735	9,845	2,396	Gabon	18,176	2,406	1,299
Luxembourg	78,399	3,446	454	Croatia	18,112	6,937	4,467
Norway	57,065	19,581	4,594	Lithuania	17,508	5,784	3,389
Singapore	55,826	10,518	4,207	Malaysia	16,782	32,673	24,128
Switzerland	50,961	19,507	7,363	Poland	16,114	63,573	38,279
United States	45,368	1,465,972	286,382	Chile	15,868	19,762	15,510
Bahrain	42,200	3,673	841	Latvia	15,738	4,146	2,317
Oman	41,481	6,673	2,542	Argentina	15,601	47,624	37,888
Denmark	41,260	14,363	5,378	Venezuela, RB	15,567	36,434	25,364
Netherlands	40,688	59,770	16,015	Mexico	14,536	100,630	105,562
Saudi Arabia	39,294	79,833	23,095	Kazakhstan	14,408	37,531	15,785
Austria	38,803	24,594	8,122	Turkey	14,384	61,553	65,149
Ireland	38,762	10,093	4,025	Cuba	13,768	8,324	11,106
Hong Kong SAR, China	38,451	7,862	6,610	Uruguay	13,666	2,728	3,298
Sweden	37,422	34,295	9,025	Romania	13,640	26,475	21,652
Germany	37,219	230,486	81,591	Iran, Islamic Rep.	13,605	113,367	67,204
Canada	37,139	186,403	31,501	Lebanon	12,816	3,337	3,699
Belgium	37,075	39,658	10,457	Montenegro	12,240	805	613
Australia	35,960	69,457	19,867	Panama	12,197	2,190	3,151
Italy	35,147	127,407	57,841	Brazil	12,192	164,671	179,867
Finland	34,788	24,407	5,217	Mauritius	12,065	665	1,186
France	34,390	158,732	62,060	Suriname	11,818	515	480
Japan	34,190	312,992	126,642	Bulgaria	11,510	10,647	7,926
United Kingdom	33,148	142,358	60,066	Algeria	11,191	19,515	32,155
Cyprus	29,805	1,408	973	Botswana	11,075	1,431	1,791
Spain	29,434	82,561	42,517	Thailand	10,721	60,940	63,170
New Zealand	29,240	12,180	3,975	Costa Rica	10,718	2,608	4,004
Israel	25,725	11,519	6,516	South Africa	10,575	60,770	45,775
Slovenia	25,406	4,646	2,010	Serbia	10,451	8,941	7,464
Greece	25,367	17,934	10,801	Iraq	10,425	18,483	25,292
Portugal	24,804	17,508	10,306	Belarus	10,262	20,989	9,847
Malta	24,177	352	394	Macedonia	9,491	1,665	2,019
Libya	23,898	9,076	5,492	Colombia	9,338	22,091	41,398
Czech Republic	23,395	27,003	10,332	Azerbaijan	8,777	8,456	8,264
Korea, Rep.	22,810	127,167	47,167	Jordan	8,600	3,799	5,198
Trinidad & Tobago	21,923	8,803	1,285	Ecuador	8,458	7,890	13,066

Estonia	20,317	3,175	1,395	Dominican Rep.	8,446	4,358	8,824
Jamaica	8,320	2,178	2,612	Myanmar	2,034	11,930	48,184
Tunisia	8,128	5,772	9,804	Senegal	1,974	1,755	10,653
Egypt, Arab Rep.	7,956	37,571	71,593	Bangladesh	1,892	17,234	134,500
Peru	7,620	11,515	26,521	Cambodia	1,861	3,539	12,447
Turkmenistan	7,471	11,636	4,569	Tajikistan	1,855	2,292	6,581
Bosnia & Herzeg.	7,148	2,626	3,912	Tanzania	1,729	13,673	36,987
Kosovo	7,138	1,076	1,830	Benin	1,653	2,302	7,587
Namibia	7,015	1,119	1,921	Nepal	1,638	8,315	24,044
Ukraine	6,982	87,717	48,604	Haiti	1,637	2,118	8,836
Indonesia	6,807	122,971	217,661	Eritrea	1,516	566	3,755
Albania	6,622	1,613	3,064	Togo	1,251	1,391	5,257
Paraguay	6,588	3,793	5,452	Niger	813	1,820	12,570
El Salvador	6,533	2,700	5,802	Ethiopia	785	27,916	71,227
Sri Lanka	6,332	7,331	18,973	Congo, Dem. Rep.	667	15,007	52,737
Guatemala	6,125	6,256	12,390	Mozambique	659	7,055	19,728
Mongolia	6,094	2,227	2,485				
China	5,526	1,120,968	1,268,418				
Morocco	5,180	9,892	29,466				
Congo, Rep.	5,065	904	3,332				
Georgia	4,940	3,369	4,334				
Angola	4,720	6,949	16,746				
Philippines	4,713	23,033	80,880				
Bolivia	4,688	3,566	8,668				
Armenia	4,460	1,967	3,120				
Yemen, Rep.	3,849	3,846	19,007				
Honduras	3,809	3,264	6,480				
Pakistan	3,767	56,478	144,810				
Nigeria	3,747	86,100	131,933				
Nicaragua	3,593	1,873	5,137				
Moldova	3,250	2,673	3,624				
Uzbekistan	3,199	34,771	25,394				
Vietnam	3,147	31,652	79,062				
India	3,059	359,441	1,087,461				
South Sudan	2,915	537	7,703				
Côte d'Ivoire	2,884	4,652	17,104				
Sudan	2,606	8,388	29,785				
Ghana	2,565	5,282	20,189				
Zambia	2,533	5,605	11,412				
Cameroon	2,486	5,722	17,013				
Kyrgyz Republic	2,468	2,718	5,014				
Kenya	2,336	10,274	33,288				

Zimbabwe	2,053	8,415	12,729

Table 2: Panel regressions. Dependent variable: log energy intensity, Eq. (1)

	(1)	(2)	(3)	(4)	(5)	(6)
log GDP p.c.	-0.26***	-0.64***	-0.62***	-0.68***	-0.58***	-0.62***
	(0.007)	(0.012)	(0.017)	(0.016)	(0.020)	(0.021)
E(Industry, %)				0.78***	0.40***	0.39***
				(0.079)	(0.095)	(0.096)
E(Transport, %)				-0.35***	-0.34***	-0.29***
				(0.088)	(0.097)	(0.098)
E(Residential, %)				-0.79***	-0.70***	-0.72***
				(0.070)	(0.081)	(0.081)
E(Services, %)				-0.27**	-0.15	-0.11
				(0.135)	(0.148)	(0.148)
E(Agriculture, %)				-0.05	-0.25	-0.24
				(0.189)	(0.191)	(0.190)
E(Non-energy, %)				1.53***	1.11***	1.21***
				(0.144)	(0.164)	(0.164)
VA(Agriculture, %)					0.00***	0.00***
					(0.001)	(0.001)
VA(Industry, %)					0.00**	0.00***
					(0.001)	(0.001)
VA(Manufacturing, %)					0.01***	0.01***
					(0.001)	(0.001)
VA(Services, %)					-0.00***	-0.00***
					(0.001)	(0.001)
Exports, %					-0.00**	-0.00***
					(0.000)	(0.000)
Imports, %					0.00*	0.00**
					(0.000)	(0.000)
Pop. 0-14, %						-0.01***
						(0.002)
Pop. 65+, %						-0.00
						(0.004)
Pop. Density						0.00***
						(0.000)
Observations	3,238	3,238	3,238	3,238	2,717	2,698
R-squared	0.284	0.487	0.490	0.595	0.582	0.591
Country Effects	No	Yes	Yes	Yes	Yes	Yes
Year Effects	No	No	Yes	Yes	Yes	Yes

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 3: Panel regressions. Dependent variable: log energy intensity, Eq. (2)

	(1)	(2)	(3)	(4)	(5)	(6)
log GDP p.c.	-2.06***	-1.08***	-1.14***	-1.54***	-1.54***	-1.57***
	(0.094)	(0.104)	(0.105)	(0.096)	(0.120)	(0.124)
log GDP p.c. sq.	0.10***	0.02***	0.03***	0.05***	0.06***	0.06***
	(0.005)	(0.006)	(0.006)	(0.006)	(0.007)	(0.007)
E(Industry, %)				0.86***	0.46***	0.44***
				(0.078)	(0.094)	(0.095)
E(Transport, %)				-0.27***	-0.29***	-0.27***
				(0.088)	(0.096)	(0.097)
E(Residential, %)				-0.83***	-0.77***	-0.80***
				(0.069)	(0.081)	(0.081)
E(Services, %)				-0.32**	-0.21	-0.15
				(0.134)	(0.146)	(0.147)
E(Agriculture, %)				-0.07	-0.26	-0.29
				(0.187)	(0.188)	(0.188)
E(Non-energy, %)				1.48***	0.99***	1.08***
				(0.142)	(0.162)	(0.163)
VA(Agriculture, %)					0.00	0.00**
					(0.001)	(0.001)
VA(Industry, %)					0.00**	0.00***
					(0.001)	(0.001)
VA(Manufacturing, %)					0.01***	0.01***
					(0.001)	(0.001)
VA(Services, %)					-0.00***	-0.00**
					(0.001)	(0.001)
Exports, %					-0.00***	-0.00***
					(0.000)	(0.000)
Imports, %					0.00**	0.00**
					(0.000)	(0.000)
Pop. 0-14, %						-0.01***
						(0.002)
Pop. 65+, %						-0.01**
						(0.004)
Pop. Density						0.00**
						(0.000)
Observations	3,238	3,238	3,238	3,238	2,717	2,698
R-squared	0.357	0.490	0.494	0.605	0.593	0.601
Country Effects	No	Yes	Yes	Yes	Yes	Yes
Year Effects	No	No	Yes	Yes	Yes	Yes

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4: Differences-in-Differences Regressions, Eqs. (4) and (5)

	Eq. (4)	Eq. (5)
β^{pre}	-0.64***	-0.14***
	(0.029)	(0.033)
β^{post}	-0.43***	-0.09***
	(0.029)	(0.031)
Observations	3,099	2,968
R-squared	0.224	0.073

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 5: Beta-convergence Analysis

	(1)	(2)	(3)
VARIABLES	Full sample	Below	Above
l_base	-0.0190***	-0.0166***	-0.0200***
	(0.002)	(0.004)	(0.003)
Observations	2,748	552	1,692
R-squared	0.028	0.029	0.024

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 6: Aggregate, Structural and Efficiency Index in 2014 based on Fisher Ideal Index Decomposition (1990=1)

Country	Total	Struct.	Intens.	Country	Total	Struct.	Intens.
Azerbaijan	0.185	0.976	0.190	Korea, Rep.	0.813	0.986	0.825
Armenia	0.238	0.902	0.264	Cyprus	0.826	0.679	1.216
Romania	0.355	0.801	0.444	Nigeria	0.827	1.006	0.822
Belarus	0.392	0.944	0.415	Morocco	0.830	0.963	0.862
Bulgaria	0.407	0.706	0.576	Costa Rica	0.832	0.867	0.959
Georgia	0.412	0.934	0.441	Japan	0.841	0.865	0.973
Kyrgyz Republic	0.423	0.859	0.493	Indonesia	0.841	1.028	0.819
Cuba	0.479	1.063	0.451	Italy	0.866	0.885	0.978
Mongolia	0.485	0.919	0.528	Ethiopia	0.870	1.182	0.736
Mauritius	0.520	0.824	0.631	Pakistan	0.874	0.907	0.964
China	0.540	0.996	0.542	Finland	0.903	0.868	1.040
Albania	0.590	0.708	0.832	Kenya	0.923	1.009	0.915
Ukraine	0.601	0.730	0.823	Argentina	0.931	0.919	1.014
Honduras	0.603	1.019	0.592	Tanzania	0.945	1.110	0.851
Tajikistan	0.656	0.845	0.776	Austria	0.946	0.905	1.045
Russian Federation	0.661	0.819	0.807	Venezuela, RB	0.968	0.830	1.166
United Kingdom	0.663	0.868	0.763	Chile	0.975	0.917	1.063
Zimbabwe	0.678	0.929	0.730	Benin	0.980	1.065	0.920
Norway	0.680	1.031	0.660	Panama	1.000	1.191	0.839
Sweden	0.692	0.907	0.763	Brazil	1.013	0.766	1.323
Cameroon	0.696	1.021	0.681	Congo, Rep.	1.037	1.267	0.819
El Salvador	0.698	1.006	0.694	Dominican Rep.	1.038	0.885	1.174
Colombia	0.703	0.867	0.812	Trinidad & Tobago	1.051	1.022	1.029
Mozambique	0.707	1.071	0.660	Algeria	1.101	0.964	1.143
Denmark	0.713	0.891	0.800	Thailand	1.129	0.982	1.150
India	0.728	1.045	0.697	Ecuador	1.130	1.130	1.000
Sudan	0.731	0.597	1.225	Turkey	1.133	0.878	1.291
Ghana	0.745	1.317	0.565	Iran, Islamic Rep.	1.137	1.026	1.108
Macedonia	0.746	0.774	0.965	Senegal	1.145	1.021	1.122
France	0.753	0.884	0.852	Uruguay	1.153	0.902	1.278
Zambia	0.772	0.817	0.944	Congo, Dem. Rep.	1.157	1.094	1.057
Australia	0.773	0.914	0.845	Singapore	1.167	0.935	1.248
Botswana	0.775	0.809	0.958	Uzbekistan	1.210	0.937	1.292
Netherlands	0.787	0.827	0.951	Togo	1.228	0.918	1.337
Tunisia	0.796	0.908	0.877	Bahrain	1.317	1.007	1.307
Switzerland	0.801	0.949	0.844	Bolivia	1.408	1.001	1.407
South Africa	0.806	0.836	0.964	Bangladesh	1.416	1.070	1.324
Philippines	0.806	0.985	0.819	Saudi Arabia	1.429	1.082	1.322
Egypt, Arab Rep.	0.809	1.137	0.711	Nepal	1.586	1.005	1.578
Jordan	0.811	1.004	0.807	Malta	14.383	1.143	12.579
Mexico	0.812	1.053	0.770				

Table 7: Determinants of Aggregate Energy Intensity Index, fixed effects estimation, Eq.(7)

VARIABLES	(1) Full sample	(2) Below	(3) Above
Fs	1.15***	1.06***	1.11***
	(0.017)	(0.019)	(0.025)
Fi	1.11***	0.95***	1.14***
	(0.003)	(0.012)	(0.003)
Observations	2,007	471	1,136
R-squared	0.988	0.950	0.995

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Appendix

Table A1: Correlation of energy consumption per $PPP and GDP per capita PPP for 137 economies

Country	Corr.	n	Country	Corr.	n	Country	Corr.	n
Ethiopia	*-1,000*	*25*	*New Zealand*	*-0,923*	*25*	*Montenegro*	*-0,733*	*10*
South Sudan	*-0,998*	*3*	*Romania*	*-0,920*	*25*	*Ukraine*	*-0,708*	*25*
Myanmar	*-0,997*	*25*	*Croatia*	*-0,919*	*20*	*Namibia*	*-0,687*	*24*
Nigeria	-0,996	25	South Africa	-0,919	25	Mongolia	-0,684	25
Mozambique	-0,993	25	Denmark	-0,917	25	*Côte d'Ivoire*	*-0,679*	*25*
Mauritius	-0,993	25	Belarus	-0,913	25	Cyprus	-0,633	25
Slovak Republic	*-0,989*	*23*	*Luxembourg*	*-0,907*	*25*	*Albania*	*-0,630*	*25*
Germany	*-0,987*	*25*	Indonesia	-0,907	25	*Georgia*	*-0,628*	*25*
Tanzania	-0,985	25	Azerbaijan	-0,906	25	*Greece*	*-0,626*	*25*
Poland	*-0,984*	*25*	Cuba	-0,902	25	*Kuwait*	*-0,619*	*20*
India	-0,983	25	*Vietnam*	*-0,902*	*25*	Brunei Dar.	-0,606	25
Zimbabwe	*-0,982*	*25*	Botswana	-0,895	25	Argentina	-0,598	25
Australia	-0,982	25	Pakistan	-0,894	25	Armenia	-0,528	25
Congo, Dem. Rep.	*-0,982*	*25*	*Turkmenistan*	*-0,893*	*25*	*Tajikistan*	*-0,503*	*25*
Latvia	*-0,981*	*20*	Tunisia	-0,892	25	Costa Rica	-0,485	25
Nepal	-0,981	25	France	-0,891	25	*Niger*	*-0,355*	*15*
Zambia	*-0,981*	*25*	Mexico	-0,886	25	*United Arab Emir.*	*-0,337*	*25*
Nicaragua	*-0,980*	*25*	Jordan	-0,882	25	Benin	-0,273	25
Bangladesh	-0,979	25	Netherlands	-0,881	25	Italy	-0,262	25
Uzbekistan	*-0,979*	*25*	*Qatar*	*-0,880*	*15*	*Spain*	*-0,250*	*25*
Sri Lanka	*-0,977*	*25*	*Russian Federation*	*-0,877*	*25*	Togo	-0,234	25
Angola	*-0,974*	*25*	Korea, Rep.	-0,873	25	*Bahrain*	*-0,191*	*25*
Sudan	*-0,974*	*25*	*Cambodia*	*-0,865*	*20*	*Eritrea*	*-0,170*	*20*
Finland	-0,973	25	*Haiti*	*-0,858*	*19*	*Guatemala*	*-0,141*	*25*
Estonia	*-0,972*	*20*	Macedonia	-0,854	25	Egypt, Arab Rep.	-0,135	25
Sweden	-0,970	25	Chile	-0,848	25	*Lebanon*	*-0,106*	*25*
Czech Republic	*-0,969*	*25*	Malta	-0,847	25	*Brazil*	*-0,094*	*25*
Kenya	-0,968	25	Turkey	-0,846	25	Morocco	-0,081	25
Philippines	-0,966	25	*Suriname*	*-0,841*	*15*	Ecuador	-0,068	25
Hungary	*-0,955*	*24*	*Hong Kong SAR, China*	*-0,832*	*25*	Uruguay	-0,054	25
China	*-0,954*	*25*	*Kosovo*	*-0,830*	*15*	Singapore	0,060	25
United States	*-0,954*	*25*	*Israel*	*-0,824*	*25*	*Portugal*	*0,077*	*25*
Canada	*-0,953*	*25*	Honduras	-0,822	25	Kyrgyz Republic	0,107	25
Slovenia	*-0,950*	*20*	Cameroon	-0,819	25	*Malaysia*	*0,148*	*25*
Lithuania	*-0,949*	*20*	*Gabon*	*-0,811*	*25*	*Jamaica*	*0,210*	*25*
Norway	-0,948	25	Japan	-0,809	25	*Oman*	*0,305*	*25*
Colombia	-0,947	25	*Moldova*	*-0,800*	*20*	Senegal	0,404	25
Switzerland	-0,942	25	*Belgium*	*-0,792*	*25*	Saudi Arabia	0,496	25
Iraq	*-0,942*	*25*	Austria	-0,788	25	*Yemen, Rep.*	*0,634*	*25*
Ghana	-0,941	25	El Salvador	-0,778	25	Bolivia	0,659	25
Peru	*-0,935*	*25*	*Serbia*	*-0,764*	*20*	Iran, Islamic Rep.	0,688	25
Panama	-0,934	25	*Kazakhstan*	*-0,758*	*25*	*Algeria*	*0,703*	*25*
Bulgaria	*-0,934*	*25*	*Bosnia & Herzegovina*	*-0,752*	*21*	Thailand	0,819	25
Libya	*-0,933*	*13*	*Paraguay*	*-0,749*	*25*	Trinidad & Tobago	0,820	25
Ireland	*-0,931*	*25*	Venezuela, RB	-0,747	25	Congo, Rep.	0,897	25
United Kingdom	-0,923	25	Dominican Republic	-0,745	25			