Breaks and Trends in OECD Countries' Energy-GDP Ratios

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ABSTRACT

This paper uses the econometrics of endogenous structural breaks to examine changes in energy intensity for OECD countries over 1960-2009. Nearly all OECD countries currently have significant negatively trending energy-GDP ratios; but for several countries those negative trends are recent, and two countries have recent significant *positive* trends. For several countries, energy intensity had a significant positive trend followed by a break and then a significant negative trend. Those break-dates, however, appear to have little to do with level of development (GDP per capita). Instead, among the likely causes of break timing are the volatile energy prices of the 1970s and early 1980s and the increased concern for the environment in the late 1960s and early 1970s. These findings have implications for future modeling of energy consumption as well as for the role of energy price policy in developed and developing countries.

JEL codes: Q43, O13

Key words: energy intensity; endogenous structural breaks; modeling environment and development

1. Introduction

The energy consumption to GDP (energy-GDP) ratio, or energy intensity, is an important topic of research in energy/environment; assumptions about that ratio and how it changes often form the backbone of projections of energy use and carbon dioxide emissions. A number of factors influence a country's aggregate level of energy intensity: (1) economic structure (the share of energy-intensive industries in total economic output); (2) sectoral composition of energy use (i.e., the relative shares of different end-uses like industry, buildings, and transport); (3) fuel mix; and (4) efficiency in the conversion and end-use of energy. Because of the direction that many of those factors are trending, there is a strong belief that energy intensities of OECD countries are declining. Yet, very few studies have focused on determining explicitly what recent individual country energy-GDP trends are.

A popular idea, which perhaps began with Goldenberg and Reddy (1990), is that the energy/GDP ratio follows an inverted U-path: energy intensity first increases as part of economic development/industrialization, but at higher levels of development energy intensity falls as economic structure typically shifts from industry to services and end-use efficiency improves. Galli (1998) and Medlock and Soligo (2001) confirmed the inverted-U hypothesis using panel econometric methods to explore the effect of income on total energy use. Galli (1998) used data from ten developing Asian countries spanning 1973-1990, whereas Medlock and Soligo (2001) used a 28 country sample that included many OECD countries and some developing countries (mostly Asian), covering 1979-1995.

Grubler (2004), who studied the long-run historical path of energy intensity for several countries, agrees with the inverted-U hypothesis regarding *commercial* energy (i.e., fuels that are traded in a formal market, typically, fossil-derived fuels), arguing that the initial increase is caused by "… the substitution of commercial energy carriers for traditional energy forms and technologies." However, he observed that *total* energy intensities (i.e., those that include traditional fuels such as fuelwood and dried cow dung) generally decline over time. Grubler (2004) showed a peak in commercial energy intensity in the early 1900s for the US and around 1950 for Japan.

Gales et al. (2007) made a similar distinction as did Grubler, considering total energy (which includes traditional sources such as food for men and working animals, firewood, wind and water, and peat) as well as modern energy (same concept as commercial energy) in their examination of energy intensity trends for Sweden, Holland, Italy, and Spain over 200 years. Their plots of modern energy intensity over 1865-1995 indicated clear peaks around 1975 for Sweden, Netherlands, and Italy, but energy intensity appeared to be still increasing during their study period for Spain. Also, they argued that technological change accounted for much more of the decline in energy intensity than the rising importance of services did.

Reduced form, income driven inverted-U models have been heavily criticized and at least partially discredited when applied to pollution—the so-called Environmental Kuznets Curve hypothesis—for several reasons (e.g., Stern 2004). One such reason is the objection to the "…assumption of a causal role of income growth and the inadequacy of reduced-form specifications that presume that a common income-related process … adequately describes the generation of the pollutant of interest," (Carson 2010). In addition, the statistical grouping of countries at different stages of development does not necessarily approximate the actual development process that real countries go through. Indeed, Deacon and Norman (2006) used nonparametric methods to examine the income-pollution relationships of individual countries and observed that those within-country relationship patterns did not differ significantly from what would be expected to occur by chance.

Moomaw and Unruh (1997) also took an individual country approach and tested the stability of a simple linear relationship between CO_2 per capita emissions and GDP per capita for a number of developed countries using data spanning 1950-1992, choosing 1973 as the *a priori* break-date, and employing a standard Chow test for structural change. They rejected the null hypothesis of no structural change, typically finding that individual countries switched from a positive to a negative linear relationship between emissions and income at the time of the first oil crisis.

This paper employs a now well-used method that determines the existence and timing of structural breaks endogenously to examine the energy-GDP paths for OECD countries over 1960-2009. All OECD countries experienced a break in their energy intensity trends, and most countries had two or more breaks. The current energy intensity trend for nearly all OECD countries is negative—however, for several of those countries their negative trend is recent, and two countries currently have positive trends. Considering endogenous breaks is important because energy intensity over this period has an inverted-V shape (a significant positive trend followed by a break and a significant negative trend) for 13 countries. Contrary to some earlier studies, however, that break-date appears to have little to do with *level* of development (either GDP per capita or energy consumption per capita). Instead, the timing of the energy-GDP ratio inverted-V breaks appears to be a reaction to the volatile energy prices of the 1970s and early 1980s or a result of increased environmental awareness and environmentally-focused institutions in the late 1960s and early 1970s. These findings have implications for future modeling of the energy-GDP ratio as well as for the role of energy price polices in developed and developing countries.

To perform the classical econometric test for structural change, the Chow (1960) test, the break-date must be known *a priori*. Beginning in the early 1990s (and continuing today) a number of authors developed and subsequently improved tests to endogenously determine the timing of a structural break when the break-date is unknown. Glynn et al. (2007) provided a recent survey of the state of the art of these break tests. These econometric methods for endogenously determining an unknown break-date on time series have been widely used in the economic growth literature (e.g., Ben-David and Papell 1998; and Ben-David et al. 2003) as well as in the energy/environment literature.

For example, Lanne and Liski (2004) examined the CO_2 per capita emissions trends over the period 1870-1998 for 16 early industrialized countries using endogenous methods allowing for multiple structural breaks. In contrast to Mommaw and Unruh, Lanne and Liski rejected the oil price shocks as events causing permanent breaks in the structure and level of emissions; instead, Lanne and Liski found evidence of downturns in increasing per capita emissions trends occurring early in the 20th century, and evidence of stable declining per capita emissions for only two countries. Huntington (2005) used a single break procedure to endogenously determine a break in the carbon emissions-GDP relationship for the US over 1870-1998, and similar to Lanne and Liski, found an early break in 1913. Liddle (2009) found a statistically significant break in the residential electricity consumption per capita trends for about half of OECD countries over 1960-2006.

Two recent studies focused on energy intensity trends. Rao and Rao (2009) used a multiple endogenous break method (from Bai and Perron 2003) to examine the energy intensity trend of Fiji over 1970-2005, and determined a significant role for energy price shocks experienced there. Le Pen and Sevi (2010) analyzed the energy intensity trends of 25 OECD countries over 1960-2004 using a test that allowed for a deterministic or stochastic trend and found that only 10 countries had a significant deterministic trend at the 0.05 level (eight trends were negative and two were positive). However, Le Pen and Sevi did not consider the possibility of breaks within the trends.

2. Data and Methods

I examine the International Energy Agency's (IEA) data series: total primary energy supply (TPES) divided by GDP, which is in units of tons of oil equivalent (toe) per thousand year-2000 purchasing price parity (PPP) US dollars (USD), converted to natural logs for the

OECD countries from 1960 to 2009.[1] A visual inspection of energy/GDP paths suggests that many OECD countries' experience can be described by linear trends around break-points. (The paths of a few sample countries are shown in Figures 1a-d below.)

To consider trends in energy-GDP ratios, I employ an approach similar to Rao and Rao (2009), and consider growth rates from a simple trend line regression:

$$y_t = a + bt + e_t \tag{1}$$

Also like Rao and Rao (2009), I use the Bai and Perron (1998, 2003) method that allows for multiple endogenous structural breaks and trending regressors. Rao and Rao were cognizant of the complicated issue of uncertainty with respect to deterministic and stochastic trends, and argued that if a linear deterministic trend is wrongly assumed where a significant stochastic trend is actually present, then an endogenous breaks method would uncover a large number of structural breaks. Although, as Rao and Rao acknowledge, their approach does not resolve completely the deterministic versus stochastic trends issue, it seems a reasonable means to proceed and leverage the advantages of the multiple endogenous structural breaks method.

The Bai and Perron method produces several test statistics; following their recommendations (Bai and Perron 2003), I focus on two: (i) the sup$F_T(k)$ test for the null hypothesis of no structural break against the alternative of a fixed number of k breaks; and (ii) sup$F(l+1|l)$ test, which is a sequential test of the null hypothesis of l break(s) against the alternative of $l + 1$ breaks. The sup$F_T(k)$ test determines whether at least one break is present; if that test indicates the presence of at least one break, then the number of breaks, m, is revealed by the sequential examinations of the second set of tests such that sup$F(l+1|l)$ are insignificant for $l >= m$.

[1] The energy data begins in 1971 for Czech Republic, Korea, Mexico, and Slovak Republic, in 1970 for the new federal states of Germany, and in 1965 for Hungary.

3. Breaks and trends in Energy/GDP

Table 1 displays the sup$F(l+1|l)$ statistics for $l <= 3$ and the break years for each country. In performing the tests, a maximum of six endogenous breaks were allowed. The sup$F_T(k)$ tests were significant for k between 1 and 6 for all countries at the 5% level or higher. The sup$F$(5|4) and sup$F$(6|5) were not significant at even the 10% level for all countries (and thus are not shown). All countries' energy-GDP ratios had at least one break; in fact, the majority of countries (19 of 29 countries) had two or more breaks (the US was the only country with four breaks).

Table 1

Table 2 shows the trends over each period (defined by the break dates in Table 1) for each country. Following the logic from Rao and Rao (2009), the number of breaks is not so great that the hypothesis of linear deterministic trends with breaks should be rejected in favor of stochastic trends. Indeed, the country with the most breaks in its energy-GDP ratio, the US, had a negative trend over the entire study period (and a statistically significant negative trend since 1969). Furthermore, the data shown in Grubler (2004), who displayed US energy intensity from 1850-2000, suggests a consistent negative trend for the US since early 1900s. Also, the US was one of the few countries that Le Pen and Sevi (2010), who did not test for breaks, uncovered a significant, deterministic negative trend. Lastly, of the 19 countries with multiple breaks, only five countries experience more than one statistically significant sign change in their trend over the study period. Interestingly, two of those five were determined to have significant deterministic trends by Le Pen and Sevi: Poland (negative) and Portugal (positive).

Table 2

All but three countries currently are experiencing significant negative trends in energy intensity—Luxembourg (since 2002) and Mexico (since 1999) have significant positive trends, while Turkey has an insignificant trend (with a positive mean) since 2003. Six countries have had significant negative trends over the entire period (Australia, Austria, Czech Republic, Germany, Hungary, and UK), and three more had such trends except for an early period with an insignificant trend (Belgium, France, and US). Yet, several countries are on *recent* negative trends, which were preceded by a period of significant positive trends: Greece (since 1996), Japan (since 1999), Korea (since 1998), Portugal (since 2001), and Spain (since 2004).

3.1 Patterns of Energy/GDP

Over nearly all of the 1960-2009 period, the Energy/GDP paths of all but one OECD country (Turkey) can be described by linear trends with breaks. Most of these countries' Energy/GDP paths (22 of 28) either declined throughout or increased then decreased, i.e., an inverted-V path (13 countries,[2] typified by Netherlands).

However, five countries combined inverted-V shaped paths with V-shaped paths, and one country (Luxembourg) had a V-shaped Energy/GPD path. Portugal and Spain had negative trends that were broken early and followed by fairly long positive trends (which only recently returned to negative trends). Mexico, arguably the least developed country in the sample, had an N-shaped path: Energy/GDP increased until 1987, when it began to decline, but resumed increasing in 1999 (although at a much lower rate than it did over 1971-1987). More curious are Luxembourg, which had a significant negative trend until 2002 when it became positive, and Poland, which switched from significant negative to significant positive during the first oil crises (counter-intuitively), but then back to negative during the second oil crises (as expected). Japan, different still, had a saw-tooth type path: after increasing until 1974, energy intensity had its substantial decline interrupted during 1987-1999, where it increased slightly, before it resumed declining at a similar rate as it did

[2] Korea's Energy/GDP path was significant and positive for most of 1971-1998 (after which it was significant and negative). During 1980-1989, however, the path was essentially flat but had a statistically insignificant slight negative trend.

over 1974-1987. The Energy/GDP paths of Netherlands, Korea, Spain, and Japan are displayed in Figures 1 a-d.

Figures 1 a-d

4. Temporal causes of breaks in Energy/GDP

Many of the breaks reported in Table 2 correspond to a change in slope of a still rising or declining trend; however, the most interesting types of breaks are the ones leading to an inverted-V pattern, i.e., a significant positive trend followed by a significant negative one. Inverted-V type breaks also are types of breaks that, when not considered, may have led Le Pen and Sevi (2010) to find so few OECD countries with deterministic energy intensity trends.

4.1 Oil crises and increased environmental concern

Figure 2 indicates the number of countries with and the timing of the 19 inverted-V type breaks (on the left y-axis) and shows the real international crude oil price from 1960-2009 (on the right y-axis). Table 3, further below, names those countries and lists their corresponding GDP per capita in that break year. The two world oil crises of the 1970s and early 1980s and the period of relatively high oil prices in between appear to have influenced the timing of several countries' break-dates (although not all). The first oil crisis[3] is dated 1973-1974, whereas the second oil crisis of 1979-1981, which corresponded to the fall of the Shah in Iran and the beginning of the Iran-Iraq war, led to considerably higher prices than the first oil crisis. Five of the inverted-V breaks occurred around the two oil crises or in the intermittent period of high prices (1975-1978)—and thus, responses to those high energy prices may have caused structural changes that lead to a lower energy intensity path. Yet, seven breaks occurred prior to 1973.

[3] OAPEC announced on October 15, 1973, their embargo, which would precipitate the first oil crisis that led to a price spike later in 1974; but oil prices already had begun to increase earlier in that year.

Figure 2

Policy driven by current moods or *zeitgeist* rather than level of development may have caused many of those earlier breaks. Indeed, the late 1960s and early 1970s (before the first oil crisis) was a period of heightened environmental awareness/concern in many OECD countries. For example, *The Population Bomb* by Paul Ehrlich was published in 1968; *The Limits to Growth* was published by the Club of Rome in 1972; the first Earth Day was held in 1970, and the first United Nations Conference on the Human Environment was held in Stockholm in 1972, which led directly to the creation of several government environmental agencies and the UN Environment Program. In the US, the first Clean Air Act was passed in 1963 and updated in 1967 and 1970; in 1969 oil spilled from an offshore well in California's Santa Barbara Channel, an event that was credited with expediting environmental legislation/institutions, such as National Environmental Policy Act of 1969, the Clean Water Act in 1972, and the establishment of the Environmental Protection Agency in 1970. Clean Air Acts were passed in Canada, New Zealand, and the UK in 1970, 1972, and 1968, respectively.

Naturally, it is not surprising that oil price increases could have had the effect of altering energy intensity trajectories of developed (particularly developed, market-based) countries beyond what would have occurred merely because of 1960s/early 1970s environmental policy. At the time of the first oil crisis, nearly all OECD countries were heavily reliant on fossil fuels for their energy. And since 1978 (the first year in which IEA price data is available), the prices of various fossil fuels are correlated with each other, and the prices of petrol and electricity are highly correlated in all OECD countries—even ones like France and Norway that have substantial nuclear and hydro-electricity capacities.[4]

[4] For the 27 countries with sufficient data, the lowest correlation coefficient between petrol price and electricity price was 0.58 for Spain. For 17 countries, the correlation coefficient was greater than 0.86.

Furthermore, Liddle (2009) found that six OECD countries[5] had over 1970-1976 significant breaks in their residential electricity consumption per capita trends, and all six countries had substantially lower trends (all positive) post-break. Additionally, for five countries, residential electricity per capita flattened between the mid-1970s and mid-1980s (after increasing previously) (Liddle, 2009).

Also, aggregate energy intensity can fall if countries shift from consuming fuels like coal to consuming electricity, or similarly, if they shift from using coal to create electricity to using non-fossil fuels in electricity generation. Indeed, such a shift seems to have happened in most OECD countries. Inspecting the series share of TPES from non-fossil fuel sources (i.e., nuclear, hydro, geothermal, solar, and wind) for OECD countries reveals the likely impact that policy changes (instituted in response to increased environmental concern and oil prices) had on the consumption of those non-fossil fuels: in 1971 only six OECD countries received more than 10% of TPES from non-fossil fuels, and only three countries received more than 20%; by 1981 those two counts had increased to nine and six countries, respectively, and by 1991 to 16 and nine countries, respectively (the latest IEA data indicates 18 and 10 countries, respectively).

4.2 Energy/GDP as a function of development (inverted-U)

Table 3 displays the timing of the 19 inverted-V breaks along with the corresponding GDP per capita in the break year. The table provides little suggestion that similar levels of GDP per capita led to the change in sign of energy intensity trends (e.g., Galli, 1998 and Medlock and Soligo, 2001). Generally, the countries with the earlier break dates have the associated lower levels of GDP per capita, and the countries with later break dates have the associated higher levels of GDP per capita. The average GDP per capita at the break date is $15,000 with a standard deviation of over $5,100.

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[5] Those countries were: Belgium, Ireland, Netherlands, Spain, United Kingdom, and United States.

As further evidence that the break-dates had little to do with development level, of the seven late inverted-V breaks (and thus unlikely heavily influenced by the oil price spikes or increased environmental concern of the 1960s and 1970s), six occurred in countries that had among the lowest energy consumption and intensities in the 1960s and 1970s (Greece, Korea, Mexico, New Zealand, Portugal, and Spain); and thus, their relatively late breaks might be indicative of a convergence process. (Indeed, Liddle 2009 found evidence of energy intensity convergence among OECD countries.) Furthermore, for two of those countries, Korea and New Zealand, macro-economic events likely played a role, namely, the Asian financial crisis[6] and the 1990-1991 recession, respectively. The seventh late-breaking country, Japan, had already had a major inverted-V break in 1974, and its 1999 break appears merely to have reestablished the previous downward trend in Energy/GDP that (likely) was triggered by high oil prices (see Figure 1-d).

Table 3

By contrast, the panel-based studies of Galli (1998) and Medlock and Soligo (2001) found energy intensity peaks that arose at relatively low levels of GDP per capita[7] and, accordingly, occurred relatively early. Medlock and Soligo (2001) found that, for their sample, peak energy intensity was reached at around $2,600 GDP per capita (in 1985 USD PPP)—a level of development at which every developed country in their sample, except Greece and Portugal, had achieved by 1960. Galli (1998) calculated that at Korea's energy intensity turning-point its GDP per capita was around $4,200 1985 USD PPP—a level Korea reached in 1985; however, Table 2 here shows that Korea's turning-point (inverted-V break-point) happened in 1998, and Korea was on a mostly strong *increasing* energy intensity trend prior to that date (see also Figure 1-b). The breaks associated with higher levels of GDP per

[6] The Asian financial crisis began in July 1997, but its effects lingered through 1998.
[7] Both the Galli and Medlock and Soligo studies used a different source of GDP per capita (from the Penn World Tables), but the timing at which a given relative level of GDP per capita occurs should be roughly consistent with the IEA series used here.

capita found here probably stem from: the longer, updated data series used here; use of an individual country approach rather than the pooled panel approach of the other studies; and the other studies' inclusion of developing countries in their cross-sections.

Of course, it is possible that the countries that had significant negative trends throughout the study period and the countries that had mostly negative trends that were preceded by insignificant trends would have been shown to have energy intensity peaks at similar levels of early development had a much longer data set been available. However, the limited number of countries for which such long-run data is available suggests that would not be the case. Grubler's (2004) data suggests a peak in the early 1900s for the US and a peak around 1950 for Japan (when Japan's GDP per capita was less than half that of the US's in the early 1900s). The case for development-based peaks is even less convincing for European countries. Data from Gales et al. (2007) shows an ultimate energy intensity peak in the mid-1970s for Italy, Netherlands, and Sweden after increasing energy intensity since the mid-1800s (most steeply prior to 1915 for Netherlands and Sweden); whereas, Spain's energy intensity appears to be increasing still though 1995 (where the data used by Gales et al. ends).

5. Conclusions

Nearly all OECD countries currently have significant negatively trending energy-GDP ratios, but for several countries those negative trends are recent, and two countries (Luxembourg and Mexico) have recent significant positive trends. For six countries, energy-GDP ratio was declining throughout the study period; but for 12 countries (and arguably 13, since Korea had a period of an insignificant trend sandwiched between two periods of increasing energy intensity) energy intensity had a significant positive trend followed by a break and a significant negative trend, and three more countries had early insignificant trends followed by significant negative trends. But the break-dates associated with those inverted-V patterns had little to do with common levels of GDP per capita. Rather than economic development, the high energy prices of the 1970s and early 1980s and the increased concern for the environment in the late 1960s and early 1970s likely caused the energy intensity turn-around in many countries.

Thus, the timing of energy intensity declines (or inverted-V path slope changes) is related to significant events rather than being associated with a certain level of development (or per capita GDP) in an inverted-U fashion. That conclusion echoes Moomaw and Unruh (1997), who argued a similar experience was true for developed countries' per capita carbon emissions paths. Yet, the idea that energy intensity is non-monotonic, i.e., increasing in the early stages of development and then falling in later stages, is theoretically appealing and generally characterizes a cross-section of the world's countries at any one time. It is not surprising that Galli (1998) and Medlock and Soligo (2001) found statistical evidence of this type of relationship in their panel regressions that included both developed and developing countries.

The fact that significant events—specifically events that involve (rather large) price increases (e.g., oil crises)—helped to spur lower energy intensity paths suggests that polices like "putting a price on carbon" could have a role in further lowering energy intensities. Furthermore, the results for OECD countries presented here suggest that lower energy intensity is not necessarily a natural part of the development process; thus, today's less developed countries may not experience such a decline in energy intensity unless policies like energy price subsidies are ended.

Allowing for breaks, a considerably larger number of OECD countries were found to have deterministic energy intensity trends than uncovered by Le Pen and Sevi (2010)—in no small part because at least 12 countries were found here to have significant positive trends followed by a break and significant negative trends. However, the deterministic trend with breaks model may not be preferable to a stochastic trend model for all the countries displayed in Table 2. For example, Mexico and Turkey may not fit the deterministic trend model because they are still very much developing countries; also, data from 1960 may not be a long enough series to develop an accurate picture for Japan and Spain—again, longer time series data indicates a mostly declining energy intensity since 1950 for Japan (from Grubler 2004) and a mostly increasing energy intensity since 1865 for Spain (from Gales et al. 2007).

Finally, analysts using energy-GDP ratios as a basis to produce medium-to-long-run energy consumption projections should consider whether energy/GDP should be a function of GDP per capita; such caution is advised because OECD countries vary considerably in both the timing of, and the level of GDP per capita corresponding to, their energy intensity downturns. Further caution is advised in selecting the historical data used to calculate the energy-GDP ratio since many countries appear to be on relatively recent trends.

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Table 1. Bai and Perron endogenous structural break tests on OECD countries' energy-GDP ratios

	sup*F*(*l*+1|*l*) statistics to determine the number of breaks				**Timing of breaks**			
	sup*F*(1|0)	sup*F*(2|1)	sup*F*(3|2)	sup*F*(4|3)				
Australia	49.4***	8.3	9.7	4.6	1973			
Austria	14.3**	8.3	5.9	3.8	1980			
Belgium	20.6***	14.9**	18.6**	3.3	1967	1980	1995	
Canada	105.3***	21.8***	9.2	8.2	1971	1991		
Czech Rep.	18.5***	8.0	12.7	3.8	1984			
Denmark	99.2***	5.7	7.6	4.6	1970			
Finland	28.4***	23.2***	3.7	4.3	1967	1992		
France	29.9***	14.6**	8.5	2.8	1969	1984		
Germany	53.4***	7.9	6.3	4.5	1989			
Greece	122.0***	58.5***	13.2	9.2	1971	1996		
Hungary	157.8***	6.9	3.8	6.9	1997			
Ireland	102.6***	38.2***	7.7	6.1	1974	1989		
Italy	73.1***	86.7***	10.3	12.2	1969	1985		
Japan	41.6***	35.1***	23.2***	6.2	1974	1987	1999	
Korea	41.3***	16.2**	15.6**	7.2	1980	1989	1998	
Luxembourg	26.3***	29.4***	7.4	11.4	1974	2002		
Mexico	120.9***	23.0***	5.4	3.1	1987	1999		
Netherlands	326.7***	7.1	7.8	4.4	1971			
New Zealand	108.2***	7.6	8.6	7.0	1990			
Norway	165.1***	9.3	3.4	2.4	1970			
Poland	285.6***	13.7*	23.5***	7.1	1973	1981	1997	
Portugal	15.8**	24.8***	4.9	4.0	1968	2001		
Slovakia	139.5***	21.1***	13.9*	5.8	1977	1990	2000	
Spain	106.5***	15.7**	27.7***	5.1	1965	1976	2004	
Sweden	73.4***	32.0***	4.0	5.7	1967	1996		
Switzerland	160.4***	9.4	4.1	3.9	1978			
Turkey	45.6***	23.3***	4.1	5.9	1971	2003		
United Kingdom	40.0***	65.3***	7.0	2.0	1969	1990		
United States	150.4***	22.8***	16.5**	17.1**	1969	1976	1986	1996

Notes: The sup$F_T(k)$ tests were significant for k between 1 and 6 for all countries at the 5% level or higher. The sup$F(5|4)$ and sup$F(6|5)$ were not significant at even the 10% level for all countries. Statistical significance indicated by: *** 0.01, ** 0.05, or * 0.1 level.

Table 2. OECD energy-GDP trends over 1960-2009 with endogenously determined structural breaks

Trends for countries with one break					
Australia	1960-1973	1973-2009			
	-0.00505**	-0.0062***			
Austria	1960-1980	1980-2009			
	-0.0028*	-0.0056***			
Czech Republic	1971-1984	1984-2009			
	-0.013***	-0.022***			
Denmark	1960-1970	1970-2009			
	0.033***	-0.019***			
Germany	1970-1989	1989-2009			
	-0.014***	-0.016***			
Hungary	1965-1997	1997-2009			
	-0.0028***	-0.030***			
Netherlands	1960-1971	1971-2009			
	0.031***	-0.017***			
New Zealand	1960-1990	1990-2009			
	0.011***	-0.018***			
Norway	1960-1970	1970-2009			
	0.028***	-0.012***			
Switzerland	1960-1978	1978-2005			
	0.022***	-0.0059***			
Trends for countries with two breaks					
Canada	1960-1971	1971-1991	1991-2009		
	0.0088***	-0.014***	-0.018***		
Finland	1960-1967	1967-1992	1992-2009		
	0.021***	-0.0085***	-0.021***		
France	1960-1969	1969-1984	1984-2009		
	0.000022	-0.016***	-0.0092***		
Greece	1960-1971	1971-1996	1996-2009		
	0.043***	0.018***	-0.021***		
Ireland	1960-1974	1974-1989	1989-2009		
	0.0076***	-0.0099***	-0.038***		
Italy	1960-1969	1969-1985	1985-2009		
	0.046***	-0.020***	-0.0017*		
Luxembourg	1960-1974	1974-2002	2002-2009		
	-0.015***	-0.048***	0.037***		
Mexico	1971-1987	1987-1999	1999-2009		
	0.018***	-0.010***	0.0054*		
Portugal	1960-1968	1968-2001	2001-2009		
	-0.014**	0.015***	-0.019***		
Sweden	1960-1967	1967-1996	1996-2009		
	0.011*	-0.0047***	-0.031***		
Turkey	1960-1971	1971-2003	2003-2009		
	0.0049	0.0014**	0.00072		
United Kingdom	1960-1969	1969-1990	1990-2009		
	-0.0061**	-0.023***	-0.029***		
Trends for countries with three breaks					
Belgium	1960-1967	1967-1980	1980-1995	1995-2009	
	-0.0030	-0.012***	-0.0037*	-0.0202***	
Japan	1960-1974	1974-1987	1987-1999	1999-2009	
	0.016***	-0.022***	0.0064***	-0.017***	
Korea	1971-1980	1980-1989	1989-1998	1998-2009	
	0.025***	-0.0019	0.015***	-0.018***	
Poland	1960-1973	1973-1981	1981-1997	1997-2009	
	-0.0042*	0.032***	-0.034***	-0.036***	
Slovakia	1971-1977	1977-1990	1990-2000	2000-2009	
	0.0098*	-0.0081***	-0.041***	-0.068***	
Spain	1960-1965	1965-1976	1976-2004	2004-2009	
	-0.012*	0.032***	0.0022***	-0.038***	
Trends for country with four breaks					
United States	1960-1969	1969-1976	1976-1986	1986-1996	1996-2009
	-0.00084	-0.012***	-0.035***	-0.013***	-0.021***

Note: Statistical significance indicated by: *** 0.001, **0.01, or * 0.05 level.

Table 3. Break year GDP per capita for OECD countries with inverted-V type energy-GDP paths

	Break year	**Break year GDP per capita (yr-2000 US$ PPP)**
Finland	1967	10,332
Sweden	1967	14,467
Italy	1969	12,149
Denmark	1970	15,530
Norway	1970	14,477
Canada	1971	15,810
Netherlands	1971	15,907
Ireland	1974	9,346
Japan	1974	13,804
Slovakia	1977	9,105
Switzerland	1978	23,362
Poland	1981	7,130
Mexico	1987	7,512
New Zealand	1990	18,034
Greece	1996	18,443
Korea	1998	13,974
Japan	1999	24,811
Portugal	2001	18,627
Spain	2004	22,522
Average		15,018
Standard deviation		5,145

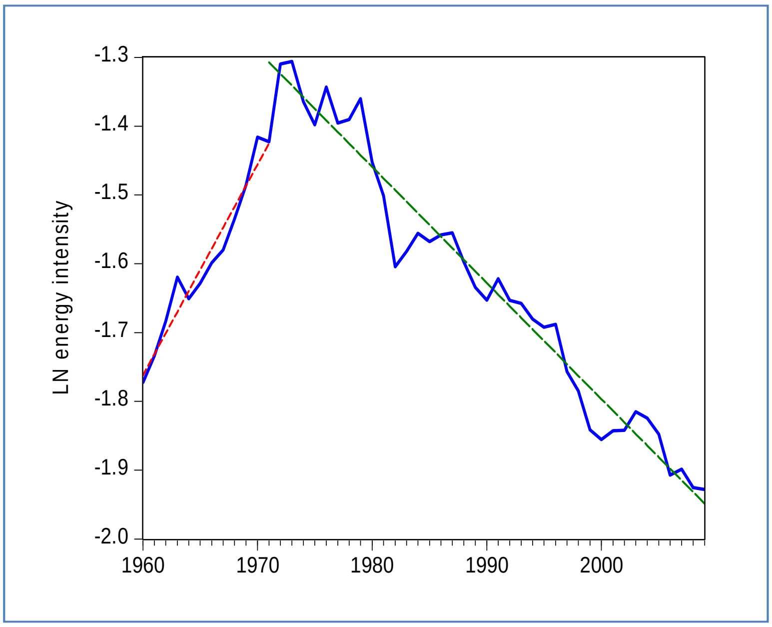

Figure 1-a. Natural log of energy intensity for Netherlands, 1960-2009, and two linear trend lines with a break in 1971.

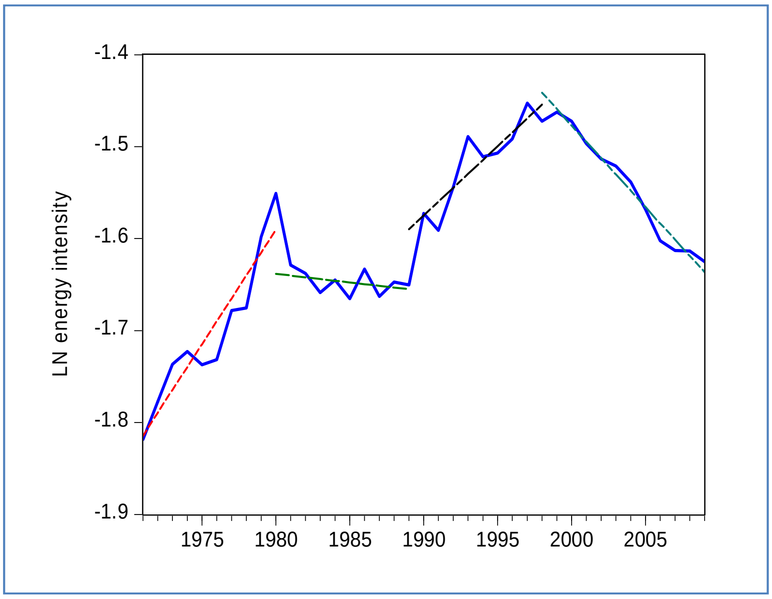

Figure 1-b. Natural log of energy intensity for Korea, 1971-2009, and four linear trend lines with breaks in 1980, 1989, and 1998.

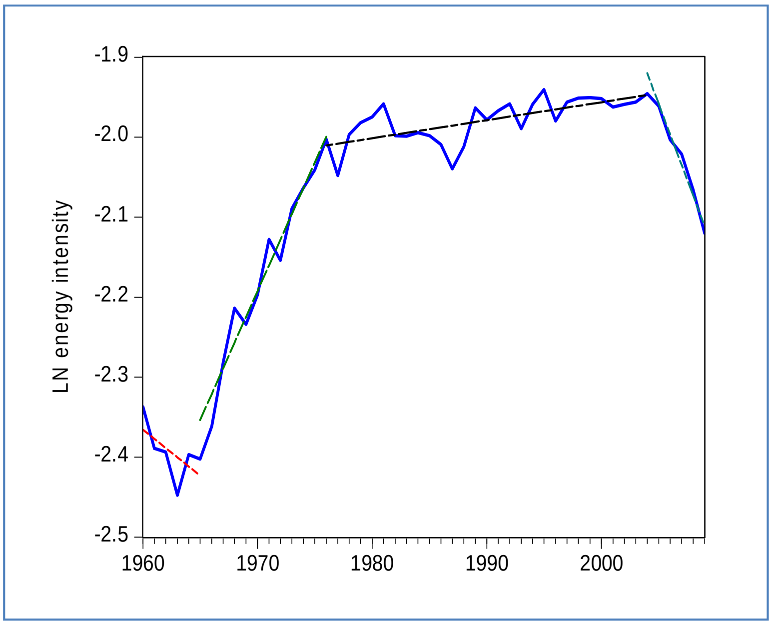

Figure 1-c. Natural log of energy intensity for Spain, 1960-2009, and four linear trend lines with breaks in 1965, 1976, and 2004.

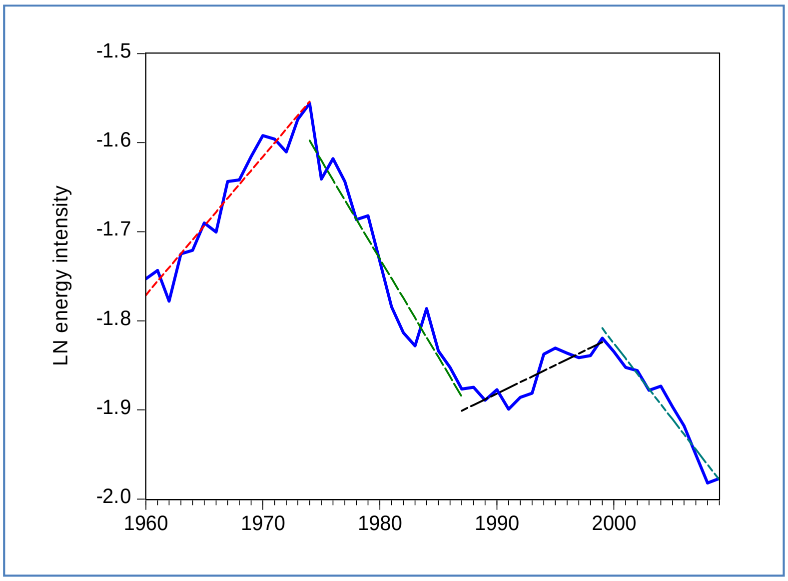

Figure 1-d. Natural log of energy intensity for Japan, 1960-2009, and four linear trend lines with breaks in 1974, 1987, and 1999.

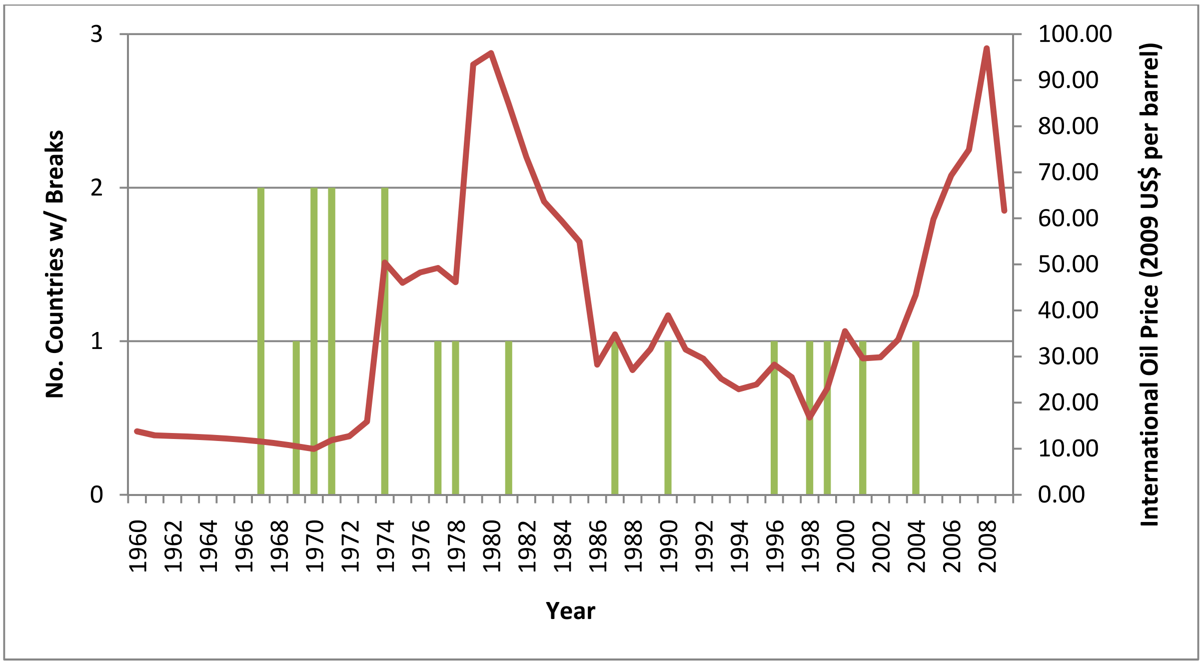

Figure 2. The timing of and the number of OECD countries with inverted-V type breaks in energy intensity trends (bars and left y-axis) and the real international crude oil price (trace and right y-axis), 1960-2009. Price data is from 2009 BP Statistical Review of World Energy, http://www.bp.com/statisticalreview.