ANALYZING THE ENVIRONMENTAL KUZNETS CURVE BY USING THE ECOLOGICAL FOOTPRINT

By

Nathan Richey

A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
May 4, 2014

Approved by

Henry Thompson, Chair, Professor of Economics
Yaoqi Zhang, Professor of Forestry
Aditi Sengupta, Assistant Professor of Economics

Abstract

This paper presents recent data that suggest a possible existence of an Environmental Kuznets Curve (EKC) using the aggregate environmental health indicator known as the Ecological Footprint (EF). Currently, there is no example of such EKC using EF. However, this paper suggests that previously, no country had obtained a high enough per capita income to reach the EKC turning point. Using the most current data on EF and Income, this paper concludes that only recently have a handful of countries reached the per capita income sufficient to reverse environmental degradation, and subsequently show an inverse relation between EF and Income.

Table of Contents

List of Figures

Introduction

The focus to this paper is to observe the Environmental Kuznets Curve (EKC) by using a general environmental indicator called Ecological Footprint. This analysis uses data from 23 countries across several decades. The object is to show that as a country develops over time, it begins by creating increased environmental harm, eventually reaching a maximum, and then slowly begin to reverse such environmental harm.

The argument for the existence of the EKC is that in the early stages of development, a nation's increase in per capita income is followed by increased environmental degradation. However, as nations become wealthier, demand for green products and services, along with advanced and efficient technology, creates a separation between advancing income and negative environmental pressure. When the two are graphed against each other, an inverted-U shape is seen. This relationship is similar to that of Kuznets 1955 on income inequality (Bagliani, Bravo, Dalmazzone 2008).

Introduced by Rees (1992) and developed by Rees and Wackernagel (1994) and Wackernagel and Rees (1996), Ecological Footprint (EF) is a measure of environmental sustainability which 'represents the critical natural capital requirements of a defined economy or population in terms of the corresponding biologically productive areas' (Wackernagel, Monfreda, Erb, Haberl, Schulz 1999). The calculated EF of a nation is equal to the total land area needed to produce the resources consumed plus, absorb the waste created by such consumption. The Ecological Footprint is considered consumption based indicator because it calculates the total natural capital of goods and services consumed by that nations population, regardless of where the goods and services originated. The calculation then subtracts the natural capital used for those goods and services that are exported (Bagliani, Bravo, Dalmazzone 2008).

Grossman and Krueger (1993) began research of a possible EKC when they analyzed panel data of air quality using several different measurements from a total of 42 countries. Selden and Song (1994) revealed an EKC using data on $SO_{2.}$ Grossman and Krueger (1995) and Shafik and Banyopadhyay (1992) both found carbon emissions to rise with income per capita and water pollution to fall with per capita income. Many studies since have found similar EKC relationships using several different measures of environmental health, including but not limited to:

> Air pollution i.e. (List and Gallet, 1999; Heerink, Kuyvenhoven, van Wijk 2001; Cole, 2003; Khanna, 2002; Bruvoll, Fæhn, Strøm 2003; Deacon and Norman, 2006; Merlevede, Verbeke, Clercq 2006); water pollution i.e. (Torras and Boyce, 1998; Paudel, Bhandari, Johnson 2005); deforestation i.e. (Culas, 2007; Rodriguez-Meza, Southgate, Gonzalez-Vega 2003; Heerink, Kuyvenhoven, van Wijk 2001; Barbier, 2001); hazardous waste and toxins i.e. (Gawande, Berrens, Bohara 2001; Rupasingha, Goetz, Debertin, Pagoulatos 2004); carbon dioxide i.e. (Azomahou, Laisney, Nguyen 2006); among others (see

Cavlovic, Baker, Berrens, Gawande 2000; Dasgupta, Laplante, Wang, Wheeler 2002; Copeland and Taylor, 2004 for reviews).

Interestingly, of all the current literature on EKC no studies have been able to show an EKC relationship using a single aggregate measure of environmental sustainability and changes in national per capita income (Stern, 1998; Plassmann and Khanna, 2006). (Caviglia-Harris, Chamber, Kahn 2009).

The biggest criticism of most EKC findings is the lack of an aggregate measure of environmental pressure, specifically from consumption. The Ecological Footprint (EF), however, has found its way to be a widely used such measure. So far analyses that have used EF as the dependent variable haven't produced results that suggest the existence of an EKC (Bagliani et al 2008; Caviglia-Harris, Chamber, Kahn 2009). Nevertheless, the results from this paper, while using the most recent data available, seem to suggest that an EKC can be observed. Although many differences exist between those results and the ones presented here, one major difference is the use of data from the past decade, '00-'10. The results presented here show that the turning point required for the inverted-U shape of the EKC is present at income levels that have only been reached in the last decade. Therefore, it could be the case that previous results do not explain the existence of an EKC because they fail to use the most recent observations between 2001 and 2008.

The data used for the national income indicator comes from The Conference Board *Total Economy Database*. This uses GDP per capita in 2010 USD, converted to 2010 price levels with updated 2005 EKS PPPs. The EKS procedure is a multilateral method that computes the *n*th root of the product of all possible Fisher indexes between n countries. It has the properties of base-country invariance and transitivity. EKS results are considered to be better suited to comparisons across countries of the price and volume levels of individual aggregates (UNSD 1992).

The Ecological Footprint calculations were gathered from the Global Footprint Network's (GFN) National Footprint Accounts. These accounts are determined from large international databases sourced from the United Nations and the International Energy Agency. The 2011 National Footprint Accounts use over 6,000 data points for each country and year to determine the area required to produce the biological resources a country consumes and to absorb its wastes. This area is reported in global hectares (global acres), hectares (acres) with world-average productivity, for each year from 1961 through 2008. The Ecological Footprint uses yields of primary products (from cropland, forest, grazing land, and fisheries) to calculate the area necessary to support a given activity. Countries differ in the productivity of their ecosystems, and this is reflected in the accounts (GFN).

Maslow's Ladder

The original philosophical theory behind the idea of an EKC must come from Maslow's Hierarchy of Needs (1943). In the same thinking of Maslow, it would seem that a desire of any individual or a society would be a clean environment. However individuals will not attempt to achieve such clean environment if it comes at the expense of more necessities. Nevertheless, as with any limited resource, demand will go up as less of it becomes available, and as its rate of substitution is increased because of it being less available. In the early stages of a country's development, basic individual wants are not securely met. Additionally, there are typically plenty of clean environments within the country's borders. Therefore, the demand to increase wealth to ensure basic needs will be a greater concern than a clean environment. So, if pollution is necessary for greater levels of wealth, then pollution will be tolerated. Although not inherently demanded. However, as individual wealth rises and basic needs are met, greater attention to a cleaner environment will be given. Additionally, as a developing country pollutes it is simultaneously creating greater demand for clean environments since less is available to enjoy. Imagine Maslow's hierarchy as a ladder where during the initial stages of development a clean environment is 85 percent of the way up. Then imagine a "demand level" were the closer to a need or desire on the ladder the level is at, the more it is demanded. So at initial stages basic needs are highly demanded, where environmental cleanliness it not so much. However, as a country obtains its basic needs it begins to demand goods that are higher up the ladder, bringing it closer to the clean environment good. This is what I will refer to as the "upward demand force". At the same time, the country is polluting as it acquires more wealth and therefore more goods on the ladder. This increased amount of pollution removes the amount of clean environment available to enjoy. Therefore, with a decreasing amount of clean environment the demand for a clean environment is increased (substitution rate). This increased demand for clean environments lowers the relative position of the environmental good on the ladder, bringing it closer to the demand level which increases its demand. This lowering of the relative position I will refer to as the “downward demand force”. Eventually, the demand level and the level of the environmental good will become equal. This is the point where a clean environment is demanded above all else not yet obtained. It is here were net environmental pollution is halted, so long as it does not come at a cost that reverses the level of wealth in the country. This phenomenon is exactly why sustainable energy is increasingly demanded relative to pollutant energy. Because society requires energy for continued economic growth, however, they are willing to pay the higher price for it since they have effectively reached all needs and desires below the clean environment good on Maslow’s ladder.

The Green Solow Model

The Green Solow Model developed by Brock and Taylor (2004), is a Solow growth model that incorporates technological progress in abatement. Brock and Taylor explain that as an economy converges to a sustainable growth path an EKC relationship emerges between pollution emissions and income per capita, and between environmental quality and income per capita.

The present thesis differs from other EKC research in that it does more than to simply attempt to replicate the EKC relationship, and then offer an explanation of some external change. Brock and Taylor point to prominent explanations such as environmental policies that are in line with the incentives of the marketplace, or a move from historically dirty industries to less polluting industry, as well as technological advances that make cleaning and maintaining the environment relatively inexpensive.

Brock and Taylor point out that while each one of these explanations is able to predict an inverted-U relationship, they are less able to match other key features of the income and pollution data, particularly the timing of pollution reductions. The authors relay that threshold models suggest that for some initial period no pollution policies exist, followed by a period of active regulation. During when these pollution policies are inactive, emissions are produced in parallel with output. And when the policies become active, emissions per output unit begin to drop along with aggregate emissions. Thus, both emissions per unit of output and total emission levels fall simultaneously at the time pollution policies are enacted. Still, Brock and Taylor claim the *temporal correlation is strongly contradicted by the data*.

To show this contradiction, Brock and Taylor gave a graphical representation of emissions per unit of output and then again with aggregate emissions, over a fifty year period. Five different emissions were measured including: sulfur dioxide, nitrogen dioxide, particulate matter, carbon monoxide, and volatile organic compounds. The authors point out that the emissions per output levels have been declining at a constant rate since the initial period. In the second graph of total emission levels over the same period, aggregate emissions initially rose to a peak and then began a steady decline. Brock and Taylor note that this trend is nearly identical in time and pace to that of per capita income growth. The parallel inverted-U shape of both emission levels and per capita income over fifty year lends strong support for an EKC relationship. If the threshold theories were correct and the decline in emission levels were due to new pollution policies, then emissions per output would tend to be constant over the initial period until policy were enacted. However, that is not what is observed; emissions per output unit decline steadily over the entire fifty years.

Another result that works against certain threshold theories is the lack of increased abatement costs. Brock and Taylor give the example of sulfur dioxide emissions which fell in half between 1973 and 2001. However, as a portion of GDP, the costs associated with sulfur dioxide abatement showed a negligible change. According to the authors, "Theories that rely on tightening environmental policy predict ever increasing costs of abatement, since emissions per unit of output must fall faster than aggregate output to hold pollution in check. In a world without technological progress in abatement this requires larger and larger investments in pollution control."

Taking the U out of Kuznets

Caviglia-Harris, Chamber, and Kahn (2009), initiate their thesis by stating that *If the EKC is valid for all types of environmental degradation, the sufficient economic development alone will solve environmental problems…* However it appears that this statement jumps the gun by being unwavering and overarching. There is no real argument that claims the EKC exists under any and all circumstances. First, there are certain economic behaviors that must be taken for granted before the EKC relationship can be understood. One of those economic behavioral assumptions makes use of Maslow's hierarchy in which at some point in the accumulation of wealth, people care about the environment in which they live. Integrated into that assumption is the relative cost of energy to a society. This is because the use of energy obviously requires wealth expenditures, and the relatively higher the cost of pollutant energy as compared with clean energy, the less likely an affluent society which faces those costs is to purchase pollutant energy. So for Caviglia-Harris, Chamber, and Kahn (2009), to imply an absolute relationship between economic development and the EKC for the easy attempt to show that the relation does not exists in some cases, is to misunderstand why the EKC exhibits the shape it does, and to neglect certain standard economic behaviors that help explain the EKC.

The authors point out in their introduction that in the existing literature on the EKC, there are no examples that relate an aggregate measure of environmental quality to per capita income by a nation. All of the papers cited by Caviglia-Harris, Chamber, and Kahn (2009) on previous EKC research are mainly concerned with specific measures of environmental quality, such as levels of air and water pollutants, deforestation, toxic waste, and greenhouse gases. And it is only a portion of these studies that present the classic inverted U shape of the EKC. The reason that the authors point this out is because although individual pollutant levels as they compare to development are of concern to society, it is not prudent to build overall policy on the basis of singular effects. And this is essentially the primary concern for Caviglia-Harris, Chamber, Kahn (2009). that no example of the EKC relationship exists using an aggregate measure of environmental quality.

Caviglia-Harris, Chamber, Kahn (2009), make the argument for the use of The Ecological Footprint (EF) as an aggregate measure of environmental quality. The strength of the EF is that it combines a large variety of environmental data into a single standard measure and is easily compared from nation to nation. However, it is not simply one big index of individual pollutant indicators. Caviglia-Harris, Chamber, Kahn (2009), do note that there do exist criticisms of the EF (Ayers 2000; Van Kooten and Bulte 2000; Nijkamp, Rossi, Vindigni 2004). However, the authors state that they choose to use the EF as their aggregate measure of environmental quality because its limitations are well-known, and according to them, it is a widely referenced measurement of sustainability (Nijkamp, Rossi, Vindigni 2004; Haberl, Erb, Krausmann 2001), plus, it has been adopted by a growing number of government authorities, agencies, and policy makers as a measure of ecological performance (Wiedmann, Minx, Barrett, Wackernagel 2006). For these same reasons, EF is used in this paper, as well as to correctly contrast the results presented here to those shown by Caviglia-Harris, Chamber, Kahn (2009). The calculation specifics and methodology of the EF is to be presented in a section of its own.

The authors then shift their focus on the necessary conditions for sustainability. They explain the differences in weak and strong sustainability, and how they relate to the degree to which natural resources can be substituted for human and physical capital (Cabeza, Gutes 1996). The question is whether the current production paths are sustainable. The authors cite Solow 1974; Stiglitz 1974 which basically claim that as long as the reproducible factors of production are sufficiently substitutable for non-renewable factors of production, a balanced long-run growth path is achievable. However, these studies do not take under consideration the impact that production has on the quality of the environment. The authors point to Stokey 1998 who builds a model with pollution generating output and a government that requires increasingly stringent emissions regulations. She (Stokey 1998) finds that even in this context, sustainable balanced growth is possible providing a sufficiently high rate of return on capital, giving rise to an output path of pollution that follows an inverted ‘U’ shaped pattern consistent with the EKC. Caviglia-Harris, Chamber, Kahn (2009) begin an explanation of the long-run trajectory of the EF if strong sustainability and balanced growth are to be achieved.

In order for strong sustainability to hold, total demands placed on the ecosystem or use of natural resources (N) in a given period cannot exceed the planet's regenerative capacity or the total stock of natural resources R(t) during the same period:

$$N(t) \geq R(t) \qquad [1]$$

Building on this necessary condition, assume that natural capital can be partitioned into two components: natural capital used in environmental services, including necessary life support and ecological services, N^{env} , and the natural capital required to produce current output (expressed as the product of N^{Y} (natural capital per real dollar of output) and Y(t) (GDP)). In other words, at any time period, natural capital can be divided as follows:

$$N(t) = N^{env}(t) + N^{Y}(t) * Y\ (t) \qquad [2]$$

Holding natural capital used in non-production activities constant, N^{env} (t) = N^{env} (which is consistent with strong sustainability), and expressing Eq. (2) in per capita terms yields the following identity:

$$\frac{N(t)}{pop(t)} = N{-}{-}^{env} + N^{y}(t) * \left(\frac{Y^{t}}{pop(t)}\right) \qquad [3]$$

It is straightforward to demonstrate that a necessary condition for strong sustainability and balanced economic growth is that $N^Y(t) \rightarrow 0$ as t approaches infinity. Suppose not, i.e. $N^Y(t) \rightarrow \check{N}^Y > 0$ in the limit, then Eq.(3.3) becomes unbounded:

$$\lim_{t\to\infty}\left\{\frac{N(t)}{pop(t)}\right\} = N^{env} + N^{Y}(t) * \lim_{t\to\infty}\left(\frac{Y(t)}{pop(t)}\right) \rightarrow \infty \qquad [4]$$

Thus, strong sustainability and balanced growth require that progressively less natural capital be used per unit of output, a result which clearly echoes Solow (1974), Stiglitz (1974), and Stokey (1998). The empirical implications are clear: the Ecological Footprint (EF) must follow an inverted “U” shaped pattern if both strong sustainability and sustained economic growth are being simultaneously achieved. ---- Caviglia-Harris, Chamber, Kahn (2009).

Caviglia-Harris, Chamber, Kahn, (2009) use the EF of 146 countries over 40 years between 1961 and 2000, and real per capita GDP in PPP-adjusted 2000 international dollars. The panel consists of eight, 5-year time periods or blocks. The authors estimate a baseline quadratic EKC model using OLS. Following previous EKC literature, the Caviglia-Harris, Chamber, Kahn, (2009) decide to use log GDP in their estimation model.

The authors claim to have not found the existence of an EKC between EF and GDP per capita, or by using any of the EF subcomponents, with the exception of the Agricultural Land subcomponent. The authors also attempted to pinpoint exactly what aspect of the EF is most responsible for preventing the EKC relationship. They found that energy consumption is by far the biggest culprit, and that energy use would need to be reduced to approximately half its current level for developed countries in order to witness a significant EKC inverted-U. Caviglia-Harris, Chamber, Kahn, (2009) conclude that when using a comprehensive indicator of a nation's environmental quality, no EKC relationship exists over time, and that environmental quality will be corrected simply as a residual effect of economic growth.

The biggest difference between the results presented here and those of Caviglia-Harris, Chamber, Kahn is the addition of EF and GDP per capita data after 2000. The data here includes observation up to 2008, the most recent measure of EF for most nations. This matters because, it is during these final years that advanced countries earned a high enough income that reached a turning point where these countries began to revert on environmental degradation. This turning point has created the beginning of what appears to be the down sloping pattern of an inverted-U.

Economic Growth and the Environment

Grossman and Krueger 1995 asked weather continued economic development and increased wealth would bring about continued environmental deterioration, or would the advances that created such economic growth (technology) be used to mitigate further ecological harm?

They point out that if output and the methods of production were immutable, then economic activity would be forever linked to environmental harm. This is to say that a firm's production of goods and services would not be able to use their inputs more efficiently, as technology advances, so as to reduce costs. However, this is not the case. The methods of production do become more efficient, particularly with inputs that are relatively scare and therefore more expensive. The obvious example is petroleum fuel. Transportation vehicles have greatly increased their fuel mileage compared to a vehicle of equal weight half a century ago. Plus, the extraction efficiency of petroleum also has been greatly improved. This is a simple conclusion: demand pressures lead to innovation pressures. So it can be said with certainty that economic activity and environmental degradation are *not* inextricably linked. It may be possible that the forces behind changing production patterns and techniques are enough to counter any environmental degradation caused by newer economic activity.

Grossman and Kruger used the available panel data in the Global Environmental Monitoring System's (GEMS) tracking of urban air quality in cities of developed and developing countries around the world. Plus, they used the panel data monitoring of the water quality of river basins around the world.

Grossman and Krueger reason that in order to compare across nations, a standard environmental measure must be used for research. At the time the most widely used and readily available data c came from the GEMS which had monitored the air and water quality in several nations for the two decades prior to the paper being written. “Concentrations of sulphur dioxide (SO_2) and suspended particulate matter” …in urban cities… “are measured on a daily basis and the raw data are used to calculate the median, 80th percentile, 95th percentile, and 98th percentile observation in a given year”.

Grossman and Krueger note the absence of other forms of air quality pollutants, including those that contribute to ozone depletion and greenhouse gases. The reason for using SO_2 and suspended particulate matter is their known links to lung damage and respiratory disease.

The elected water quality data that was collected from GEMS focused on major water sources that supplied municipalities, irrigation, livestock, and other selected industries between 1979 and 1990. The monitoring included 287 river stations in 58 different countries. Grossman and Krueger use three indicators of water quality as they relate to anthropogenic constituencies. First of the three indicators is the level of dissolved oxygen in the water. The reasoning behind this indicator comes from the fact that industrial runoff and human sewage increase the concentration levels of organic carbon used by bacteria. These additional bacteria require more dissolved oxygen which then leaves less for fish and other complex aquatic life, and reduces population levels. The same is true in agricultural areas that use excessive fertilizer that increase algae concentrations, and then reduce dissolved oxygen levels. The second water quality indicator is pathogenic contamination. Pathogens in sewage are the cause of multiple diseases including: gastroenteritis, typhoid, dysentery, cholera, hepatitis, schistosomiasis, and giardiasis. The third pollutant monitored by GEMS used in the paper is heavy metals. Heavy metals that are typically discharged by industry, mining, and agriculture, settle at the bottom of river basins and are released over time, ending up in human drinking water. Also, fish and shellfish ingest these heavy metals which then find their way to the dinner plate. The most typical of the heavy metals monitored are lead, cadmium, arsenic, mercury, and nickel.

These are not perfect indicators of environmental quality by a long shot, and the specific nature of each indicator does not give a complete picture. But that is the tragedy in limitations, and it is nevertheless valuable to see what effect economic activity has on these indications of the environment.

The authors first present the results from the air quality pollutants. Sulfur Dioxide and smoke both exhibit the inverted-U relationship against GDP per capita. The “peak” or turning point of the graph exists at approximately $10,000 and $12,000 (1985 USD) respectively. The third air quality indicator, heavy particles, did not show the inverted-U relationship, but rather a monotonically decreasing relationship at all levels of income.

For the dissolved oxygen water quality indicators, the inverted-U relation is seen, and the turning point is estimated at about $7,500. The relationship with total fecal coliform in river basins however is somewhat different. It does initially rise with income and then falls sharply, but does not continue to decrease along with increased income, and by $10,000 per capita this indicator begins to rise again. The heavy metal indicators don't reveal the same patterns across the different metals. Lead shows a downward sloping relationship, while cadmium is flat throughout all levels of income. Arsenic, on the other hand, does in fact show the inverted-U relation and peaks around $5,000 per capita income.

The authors remark that although the not every indicator represents the inverted-U pattern suggested, there exists no evidence that pollutants rise steadily with economic growth. Rather typically there is an initial period of rising pollution, followed by a period of reduced net pollution after some peak that is seen usually before $8,000 per capita income.

In conclusion the author admit that the research does cover a relatively few environmental indicators. Nevertheless, by 1992 this was the most comprehensive study of the relationship between environmental quality and national income. And from this study began the tense debate that as to whether economic growth must come at the expense of the environment.

Global Footprint Network

The Global Footprint Network (GFN) was established in 2003 as a nonprofit organization directed to enabling sustainability by informing and through research. One of the primary goals of GFN is to measure the impact humans have on the planet as it pertains to resource sustainability. That goal has come about through the use of the Ecological Footprint (EF) which is developed by the National Footprint Accounts (NFA), a program within GFN. The EF is a data-driven metric that reveals exactly how close a specific nation, region, or the planet is to sustainable living. The NFA tracks our consumption of nature's resources and compares that to the total ecological budget and reveals whether or not a society is consuming resources at a higher pace than the regenerative ability of the planet.

The president of the Global Footprint Network is Mathis Wackernagel, who is the co-creator of the Ecological Footprint. He along with William Rees at the University of British Columbia created the EF as a measure of sustainability and an aggregate indicator of environmental quality. It has become a highly regarded and widely used measure by governments, non-profit organizations, and many international institutions.

Ecological Footprint

The GFN recognizes that humanity requires ecosystem from which to draw resources from, absorb waste, and provide space for our expansive existence. However, the planet that we use and from which we draw these resources is finite. This means that humans have the potential to exhaust the planets resources, flood it in pollution, cover its entire face with human productive infrastructure, and by extension kill of a majority of other life forms. Therefore, some reliable system of accounting for the human use of the planets resources is prudent, if future sustainability is of any concern. The GFN defines The Ecological Footprint as:

A measure of the demand that populations and activities place on the biosphere in a given year – with prevailing technology and resource management of that year.

Ecological Footprint accounting is based on six fundamental assumptions (adapted from Wackernagel 2002):

--The majority of the resources people consume and the wastes they generate can be quantified and tracked.

--An important subset of these resource and waste flows can be measured in terms of the biologically productive area necessary to maintain them. Resource and waste flows that cannot be measured are excluded from the assessment, leading to a systematic underestimate of humanity‘s true Ecological Footprint.

--By weighting each area in proportion to its bioproductivity, different types of areas can be converted into the common unit of global hectares, hectares with world average bioproductivity.

--Because a single global hectare represents a single use, and each global hectare in any given year represents the same amount of bioproductivity, they can be added up to obtain an aggregate indicator of Ecological Footprint or biocapacity.

--Human demand, expressed as the Ecological Footprint, can be directly compared to nature‘s supply, biocapacity, when both are expressed in global hectares.

--Area demanded can exceed area supplied if demand on an ecosystem exceeds that ecosystem‘s regenerative capacity.

The 2011 Edition of the National Footprint Accounts (NFA) calculate the Ecological Footprint and biocapacity of more than 200 countries and territories, as well as global totals, from 1961 to 2008 (Global Footprint Network, 2011). The calculations in the NFA are based primarily on data sets from UN agencies or affiliated organizations such as the Food and Agriculture Organization of the United Nations (FAOSTAT, 2011), the UN Statistics Division (UN Commodity Trade Statistics Database – UN Comtrade 2011), and the International Energy Agency (IEA 2011).

Calculation Methodology

The Ecological Footprint measures biocapacity across five distinct land use types. For comparability across land use types and countries, Ecological Footprint is expressed in units of world-average bioproductive area known as global hectares (gha). Global hectares provide information on how much ecological production is associated with a particular land (Borucke, Moore, Cranston, Gracey, Iha, Larson, Morales, Wackernagel, Galli). The following is a step by step approach to the calculation of the Ecological Footprint as described by the Nation Footprint Account's underlying methodology and framework.

For a given nation, the Ecological Footprint of production, EF_P, represents primary demand for biocapacity and is calculated as:

$$EF_P = \sum_i \frac{P_i}{Y_{N,i}} * YF_{N,i} * EQF_i = \sum_i \frac{P_i}{Y_{W,i}} * EQF_i \qquad [5]$$

where P is the amount of each primary product i that is harvested (or carbon dioxide emitted) in the nation; $Y_{N,I}$ is the annual national average yield for the production of commodity i (or its carbon uptake capacity in cases where P is CO_2); $YF_{N,i}$ is the country-specific yield factor for the production of each product i; $Y_{W,i}$ is the average world yield for commodity i; and EQF_i is the equivalence factor for the land use type producing products i (Borucke, Moore, Cranston, Gracey, Iha, Larson, Morales, Wackernagel, Galli).

Total Economy Database

The economic data for all countries analyzed here was retrieved from The Conference Board *Total Economy Database*^{tm} (TED). This database is downloadable directly from their website. The following is a description of The Conference Board and TED:

> The Conference Board *Total Economy Database*™***,*** (TED) is a comprehensive database with annual data covering GDP, population, employment, hours, labor quality, capital services, labor productivity, and total factor productivity for about 123 countries in the world. TED was developed by the Groningen Growth and Development Centre (University of Groningen, The Netherlands) in the early 1990s, and starting in the late 1990s, it was produced in partnership with The Conference Board. As of 2007, the database was transferred from the University of Groningen to The Conference Board, which has maintained and extended the database since then. The Conference Board *Total Economy Database*™ is published every year in January, providing preliminary estimates for the previous year and projections for the current year.

The GDP per capita for each one of the individual countries has been translated into real terms, by TED, using The Elteto-Koves-Szulc (EKS) method. The output measures in the database represent Gross Domestic Product at market prices, which are obtained from national accounts sources from international organizations and national statistical institutes. The post-1990 measures are obtained from a variety of sources, including the OECD National Accounts. Pre-1990 measures are mostly obtained from historical series, collected by Angus Maddison (2007).

Two gross domestic product (GDP) series are available in the database – GDPEKS and GDPGK. Both are expressed in constant US$ market prices and converted at purchasing power parity covering the period of 1950 - 2010. GDPEKS series are measured in constant 2010 US dollars.1 It is updated from 2005 EKS PPPs with GDP deflator changes. These 2005 EKS PPPs are unpublished estimates from Penn World Tables (to be used in their upcoming version PWT 7), which are benchmarked on 2005 PPPs from the International Comparisons Project (ICP) at the World Bank (World Bank, 2005).2 The adjustments made by PWT reflect: (1) an adjustment for global weighting for individual countries using EKS weights over domestic absorption (DA) for all countries rather than over five main regions as was done in the ICP by the World Bank (2) an adjustment for the net foreign balance using the PPP for domestic absorption (DA) rather than the exchange rate as in ICP (3) a downward adjustment in the PPP for China, which originally was based on relatively high prices for 11 cities, in order to better reflect the impact of lower prices in rural areas in China.3

The effect of the first two adjustments is an upward adjustment in GDP for the global economy (all countries excluding the USA) of 7.6 percent relative to the U.S. in 2005. The China correction adds another 2 percentage points to this global correction. In the case of the China the first two effects lead to an upward adjustment in GDP of 13 percent relative to the World Bank measure, and together with the adjustment for prices even to an upward adjustment of 28.5 percent of the World Bank GDP level for China.

The EKS method, proposed by Elteto and Koves (1964) and Szulc (1964) 1, is designed to construct transitive multilateral comparisons from a matrix of binary/pairwise comparisons derived using a formula which does not satisfy the transitivity property. The EKS method in its original form uses the binary Fisher PPPs (F_{jk}: j,k=1,..M) as the starting point. The computational form for the EKS index is given by

$$EKS_{jk} = \prod_{l=1}^{M}\left[F_{jl} * F_{lk}\right]^{1/M} \qquad [6]$$

where F_{jk} denotes the Fisher price index number for country k with country j as the base. The equation defines the EKS index as an unweighted geometric average of the linked (or chained) comparisons between countries j and k using each of the countries in the comparisons as a link.

Methods – Aggregate Regression

The Ecological Footprints and EKS GDP per capita were collected for 23 countries comprised of European, Asian, USA, South American, and African countries. The countries were chosen on the basis of creating an equal balance between developed and developing countries.

This resulted in a larger amount of European developed countries and South American and Southeast Asian developing countries as this is where there exists a greater density of individual countries of these two groups. The Democratic Republic of Congo was also included, although considered to be underdeveloped, in order to provide a complete spectrum.

The observation points for both variables was collected in 5-year blocks staring in 1960 and continuing until 2008, the latest observation for Ecological Footprint. The furthest back in time that the EF could be calculated for was 1960; therefore it is the initial observation point. Each country gives 11 observations within that 50-year time frame, which results in 253 total observations.

A standard OLS regression is used,

$$EF = b_0 + b_1 GDP + b_2 GDP^2 + \varepsilon \qquad [7]$$

First, and for no particular reason other than organization, the columns of observation were stacked in such a way that each country was grouped with each observation ascending in time, and each country grouping stacked randomly, since the connection between countries has no meaning here. For example, the first observation USA 1960 and the 11th was USA 2008, with the 12th being UK 1960, and so forth. Again this was done as simply an organizational convenience.

After this regression, a test of residual correlation was conducted. The Durbin-Watson test was used to measure any residual correlation between the observations. In order to do so, the residuals of the regression above were tested for correlation against each residual’s lag.

This produces the correlation coefficient (ρ). The DW statistic (Q) is calculated as Q = 2 * (1- ρ), which would mean that a correlation coefficient of ρ = 0 implies no residual correlation. In order to exhibit no residual correlation, the DW stat must fall in between an upper and lower bound. Anything below the lower bound (Q_L = 1.32) results in positive residual correlation and anything above the upper bound (Q_u = 2.60) results in negative residual correlation. The correlation coefficient for this regression was 0.78 which resulted in a DW statistic of 0.44 which lies below the lower bound and therefore suggest that the regression suffered from residual correlation.

In order to alleviate the residual correlation, a simple adjustment in the order of the 253 observations was made. Instead of having the observations stacked according to country, they were stacked according to year in ascending order. So in random order, every observation made for the 1960 was listed first with the observations made for 2008 listed last. This restacked regression resulted in a correlation coefficient of ρ = .062, which does not exhibit residual correlation.

A difference regression was also executed which used the value difference between each year observation for each country. The regression took the following form:

$$\Delta EF_t = \alpha_0 + \alpha_1 \Delta GDP_t + \alpha_2 (GDP_t)^2 + \varepsilon \qquad [8]$$

Methods – Individual Countries

The second half of the overall analysis of the Environmental Kuznets Curve focuses on individual countries instead. The data collected was GDP per capita using the same EKS method and again the Ecological Footprint of Consumption. And again the time span begins with 1960 up to 2008, however, instead of spacing the observation points into 5-year increments, each year was collected which resulted in 48 total observations.

What is also important to note is that the countries were not necessarily selected by random. In fact the focus is primarily on 3 countries: United States, France, and Japan. The reason for selecting these countries as the focus of the individual countries' analysis is because they each are the largest, developed economies in their respective regions. Note, France is in fact the second largest economy of the European Union; however, the EKS PPP conversion for Germany prior to 1988 was not attainable. So for the sack of consistency, France was used instead. 12 other countries were simultaneously analyzed in order to provide context and perspective. And of course all the countries are either fully advanced economies or near advanced. This is because only an advanced economy can provide the full development spectrum required to observe an EKC relationship.

Results

The results from the aggregate regression of all the countries together over the span of nearly 50 years suggests that from a global perspective the developmental effects demonstrated by the Environmental Kuznets Curve is certainly a possibility. The results show an obvious near inverted-U shape for all countries together in the time series. As per capita income increases initially, Ecological Footprint also rises creating a positive relationship. However, at a particular average level of income, EF stops increasing, and even begins to decrease as income continues to grow even further. This very specific point where EF stops increasing is the *Turning Point* on the top of the arch of the EKC. It is calculated

As: $$\frac{\delta EF}{\delta GDP} = \beta_1 + 2\beta_2 GDP^* = 0 \quad [9]$$

Where: $$GDP^* = -\frac{\beta_1}{2\beta_2} \quad [10]$$

And: $\beta_1 = 0.000277$ $\beta_2 = -3.6E^{-09}$

Therefore: $GDP^* = \$38{,}234.82$

One aspect of this finding that must be pointed out against previous papers on the same topic is that this per capita level of GDP is not achieved by any of the observed economies until 2005, which is later than the last observation reported by both Caviglia-Harris, Chamber, Kahn (2009) and Bagliani, Bravo, Dalmazzone (2008). This is significant in that the EKC must have an actual turning point and not simply a leveling off. It is beyond this income level where EF begins to in fact diminish.

The results of the primary individual countries' analysis are consistent with the results from above. However, some of the auxiliary countries that were also analyzed were not so much. First, the primary individual countries were United States, France, and Japan. All three of these countries are consistent with the EKC over the time series of 48 years. Each one showed a positive relationship between EF and GDP in the initial stages of development, only to level off and then begin a negative relationship. The turning point for each of these countries was also calculated as above.

United States: $GDP^* = \$22{,}798.81$
France: $GDP^* = \$30{,}412.18$
Japan: $GDP^* = \$17{,}872.51$

Conclusion

The Environmental Kuznets Curve suggests that as a nation becomes wealthier, the demand for a cleaner environment increases. This demand then lowers the environmental damage in a nation. The EKC relationship is witnessed in many scenarios that involve specific environmental indicators such as carbon emissions, deforestation, and toxin release. However, an inverted-U shape relation is rare when using a general or aggregate environmental indicator such as the Ecological Footprint.

Typical results would suggest a diminishing rate of increasing environmental pressure as a country's income grows. However, previous results do not exhibit a turning point "maximum" at which point a country would begin to reverse its environmental degradation.

Certainly the results presented here are limited. Half of the 23 nations are advanced economies. Still, one notable difference is the inclusion of more recent observations from the past decade. The results presented here show a turning point in Ecological Footprint at approximately $39,000 USD annual income per capita. This level of income has only been reached by a few countries over the last ten years. This means that only now are countries demanding a cleaner environment at a degree that is greater than dirty consumable products and services.

References

Ayres, R. Commentary on the utility of the ecological footprint concept. Ecological Economics. 32. (2000). 347–349.

Azomahou, T. Laisney, F. Nguyen-Van, F. Economic development and CO_2 emissions: a nonparametric panel approach. Journal of Public Economics. 90 (6–7). (2006). 1347–1363

Bagliani, M. Bravo, G. Dalmazzone, S. A consumption based approach to environmental Kuznets curves using the ecological footprint indicator. Ecological Economics. 65. 2008. 650-661.

Barbier, E. Natural Resources and Economic Development. Cambridge University Press. (2005)

Borucke, M. Moore, D. Cranston, G. Gracey, K. Iha, K. Larson, J. Lazarus, E. Morales, J. C. Wackernagel, M. Galli, A. Accounting for demand and supply of the biosphere's regenerative capacity: The National Footprint Accounts' underlying methodology and framework. Ecological Indicators. 24 (2012) 518-533.

Brock, W. Taylor, M.S. The Green Solow Model. NBER Working Paper Series. 2004. No. 10557.

Bruvoll, A., T. Fæhn and B. Strøm. Quantifying central hypotheses on environmental Kuznets curves for a rich economy: A computable general equilibrium study. The Scottish Journal of Political Economy. 50 (2). 2003. 149-173.

Caviglia-Harris, J. Chamber, D. Kahn, J. Taking the "U" out of Kuznets: A comprehensive analysis of the EKC and environmental degradation. Ecological Economics. 68 (4). 2009. 1149–1159.

Cavlovic, T. Baker, K. Berrens, R. Gawande, K. A meta-analysis of Environmental Kuznets Curve studies. Agricultural and Resource Economics Review. 29 (1). (2000). 32–42.

Cole, M. A. Development, trade, and the environment: How robust is the environmental Kuznets curve? Environment and Development Economics. 8. 2003b. 557–580

Copeland, B. Taylor, M.S. Trade growth and the environment. Journal of Economic Literature. 42. 2004. 7–71.

Culas, R. Deforestation and the environmental Kuznets curve: An institutional perspective. Ecological Economics. 61(2-3). 2007. 429–437.

Dasgupta, S. Laplante, B. Wang, H. Wheeler, D. Confronting the Environmental Kuznets Curve. Journal of Economic Perspectives. 16 (1). (2002). 147–168.

Deacon, R.T. and C.S. Norman. Does the environmental Kuznets curve describe how individual countries behave? Land Economics. 82. 2006. 291-315.

Elteto, O. and P. Koves. On a problem of index number computation relating to international Comparison. Statisztikai Szemle 42. 1964. 507-18.

Gawande, K. Berrens, R. Bohara, A. A consumption based theory of the Environmental Kuznets Curve Ecological Economics. 37. 2001. 101–112.

Grossman G.M, and A. B. Krueger. Environmental Impacts of a North American Free Trade Agreement in The US-Mexico Free Trade Agreement P. Garber, ed. Cambridge, MA: MIT Press. 1993.

Grossman, G.M., Krueger, A.B. Economic growth and the environment. Q. J. Econ. 110. 1995. 353–377.

Gutes, M.C. The concept of weak sustainability. Ecological Economics. 17 (3). 1996. 147–156.

Haberl, H. Erb, K. Krausmann, F. How to calculate and interpret ecological footprints for long periods of time: the case of Austria 1926–1995. Ecological Economics. 38. 2001. 25–45.

Heerink, N., Kuyvenhoven, A. and van Wijk, M.S. Economic policy reforms and sustainable land use in developing countries: issues and approaches. Economic Policy and Sustainable Land Use: Recent Advances in Quantitative Analyses for Developing Countries. 2001. 1-20.

Heerink, N. Mulatu, A. Bulte, E. Income inequality and the environment: aggregation bias in Environmental Kuznets Curves. Ecological Economics. 38. 2001. 359–367.

Khanna, N. The income elasticity of non-point source air pollutants: revisiting the environmental Kuznets curve. Economics Letters. 77. 2002. 387 – 392.

List, J. A. Gallet, C. A. The Kuznets Curve: What Happens After the Inverted-U? Review of Development Economics. 3(2). 1999. 200-06.

Maddison, A. Contours of the World Economy 1-2030: Essays in Macro-Economic History, Oxford University Press. 2007.

Maslow, A.H. A theory of human motivation. *Psychological Review, 50*(4), 370–96. 1943.

Merlevede, B. Verbeke, T. Clercq, M.D. The EKC for SO2: Does Firm Size Matter? Ecological Economics. 59(4). 2006. 451-461.

Nijkamp, P. Rossi, E. Vindigni, G. Ecological footprints in plural: a mete-analytic comparison of empirical results. Regional Studies. 38 (7). 2004. 747–765.

Paudel, K. Bhandari, D. Johnson, T. Does Social Capital Have a Role in Environmental Kuznets Curve Estimation? American Agricultural Economics Association. 2005.

Plassmann, F. Khanna, N. Household income and pollution: implications for the debate about the Environmental Kuznets Curve hypothesis. Journal of Environment and Development. 15 (1). 2006. 22–41.

Rees, W.E. Ecological footprints and appropriated carrying capacity: what urban economics leaves out. Environment and Urbanization 4. 1992. 121–130.

Rees, William and Wackernagle, Mathis. Our Ecological Footprint. New Society Publishers. 1996.

Rees, W. Wackernagel, M. Ecological Footprints and appropriated carrying capacity: measuring the natural capacity requirements of the human economy. Investing in Natural Capital. 1994.

Rodriguez-Meza, J. Southgate, D. Gonzalez-Vega, C. Rural poverty, household response to shocks, and agricultural land use: panel results for El Salvador. Department of Agriculture, Environmental and Developmental Economics, Ohio State University. 2003.

Rupasingha, A. Goetz, S. Debertin, D. Pagoulatos, A. The Environmental Kuznets Curve for US counties: a spatial economic analysis with extensions. Papers in Regional Science. 83. 2004. 407–424.

Selden, T. M. Daqing, S. Environmental Quality and Development: Is There a Kuznets Curve for Air Pollution Emissions? Journal of Environmental Economics and Management. 27 (2). 1994. 147-162.

Shafik, N. Bandyopadhyay, S. Economic Growth and Environmental Quality: Time Series and Crosscountry Evidence. Background Paper for the World Development Report. The World Bank. 1992.

R.M. Solow. Intergenerational equity and exhaustible resources. Review of Economic Studies. 41. 1974. 29–45.

Stern, D. Progress on the Environmental Kuznets Curve? Environment and Development Economics. 3 (2). 1998. 173–196.

Stiglitz, J. Growth with exhaustible natural resources: efficient and optimal growth paths. Review of Economic Studies. 41. 1974. 123–137.

Stokey, N. L. Are there limits to growth? International Economic Review. 39. 1998. 1–31.

Szulc B. Indices for multiregional comparisons. Przeglad Statystyezny. Statistical Review 3. 1964. 239-54.

Torras, M. and Boyce, J.K. Income, inequality and pollution: a reassessment of the environmental Kuznets curve. Ecological Economics. 25. 1998. 147-60.

Van Kooten, G.C. Bulte, E.H. The ecological foot print: useful science or politics? Ecological Economics. 32. 2000. 385–389.

Wackernagel, M. Tracking the ecological overshoot of the Human Economy. Proceedings of the National Academy of Sciences. 99 (14). 2002. 9266-71.

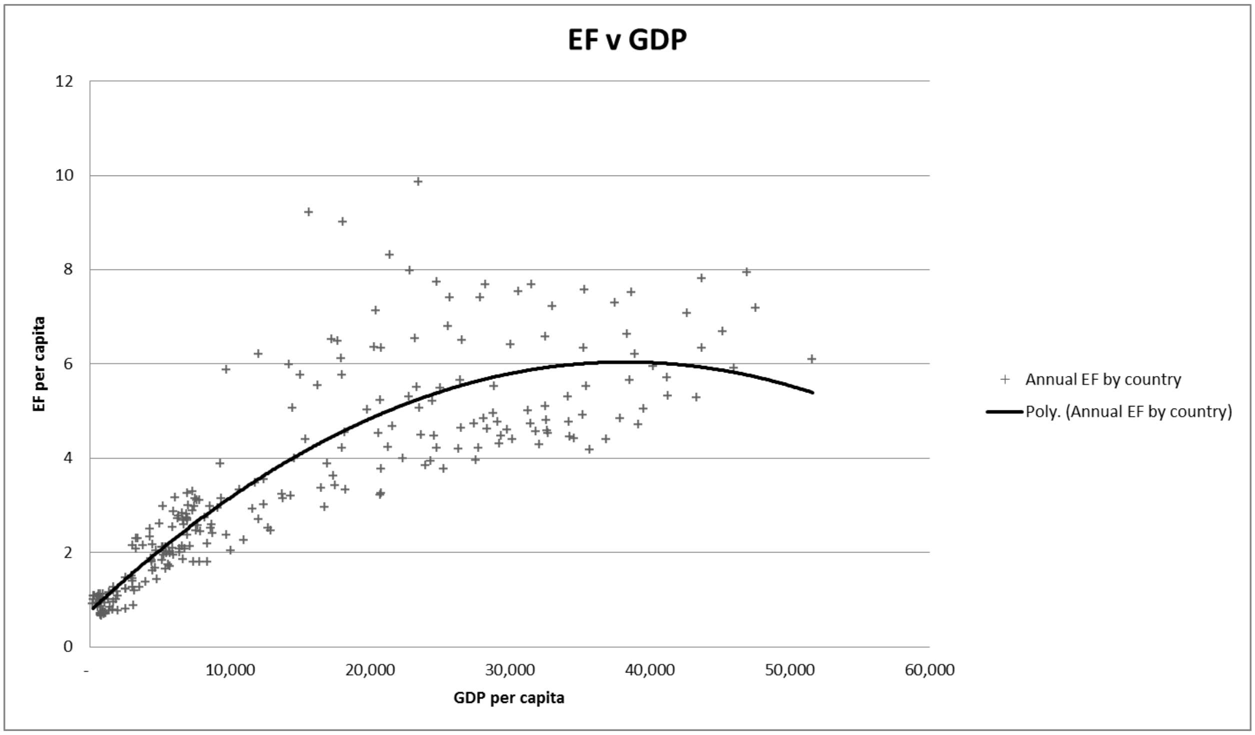
Wackernagel, M. Monfreda, C. Schulz, N. B. Erb, K. Haberl, H. Krausmann, F. Calculating national and global ecological footprint time series: resolving conceptual challenges. Land Use Policy. 21. 2004a. 271–278.

Wackernagel, M. Monfreda, C. Erb, K. Haberl, H. Schulz, N. B. Ecological Footprint time series of Austria, the Philippines and South Korea for 1961–1999: comparing the conventional approach to an ‘actual land area’ approach. Land Use Policy. 21. 2004b. 261–269.

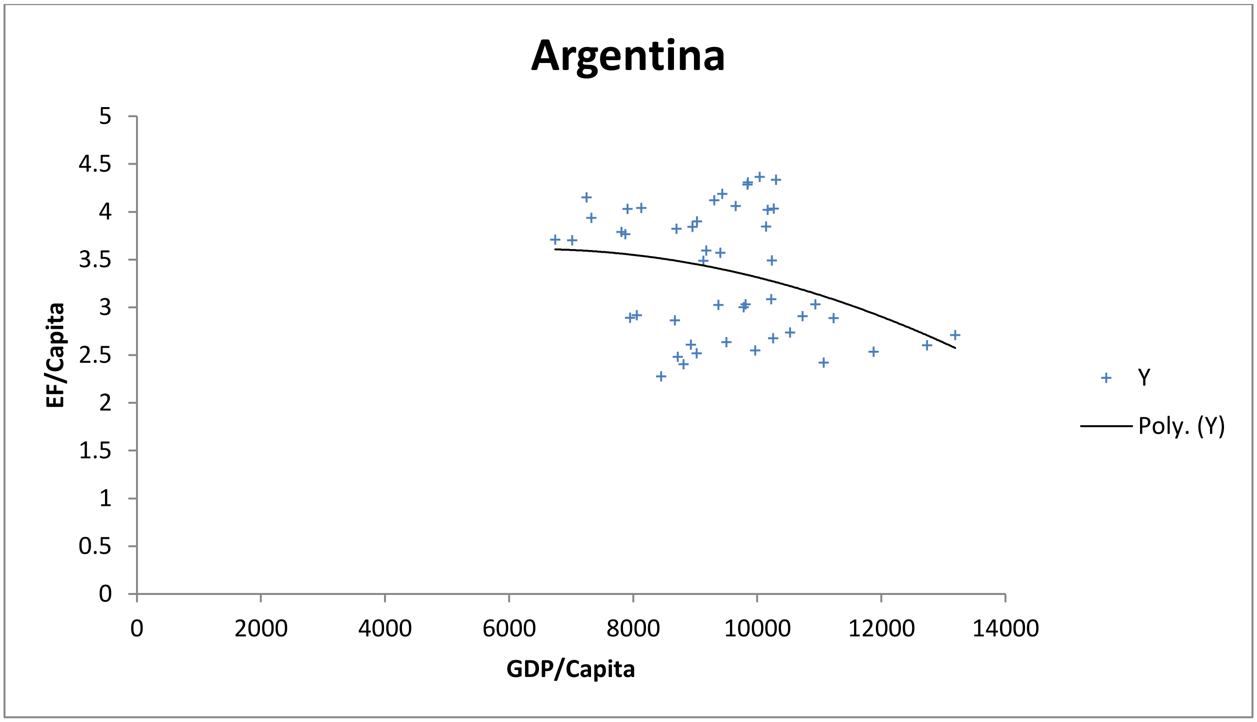
Wiedman, T. Minx, J. Barrett, J. Wackernagel, M. Allocating ecological footprints to final consumption categories with input–output analysis. Ecological Economics. 56 (1). 2006. 28–48.

Graphs

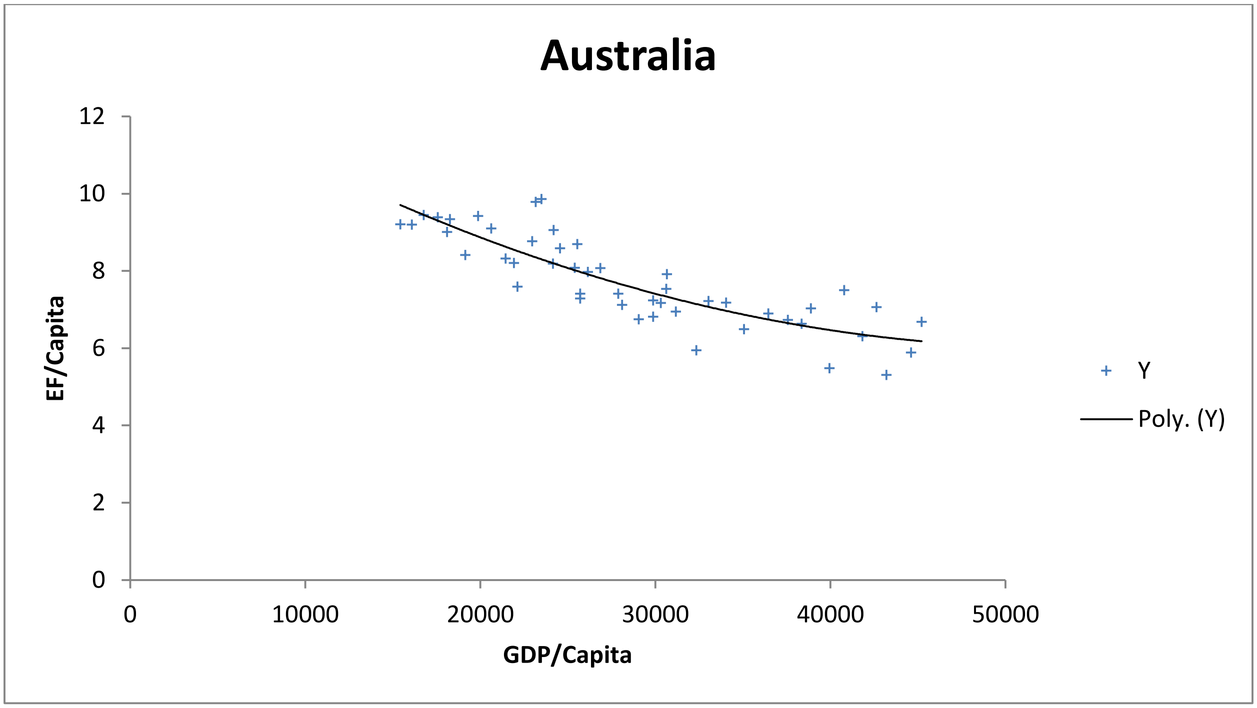
a.


EF v GDP
EF per capita
GDP per capita
12
10
8
6
4
2
0
-
10,000
20,000
30,000
40,000
50,000
60,000
+ Annual EF by country
Poly. (Annual EF by country)

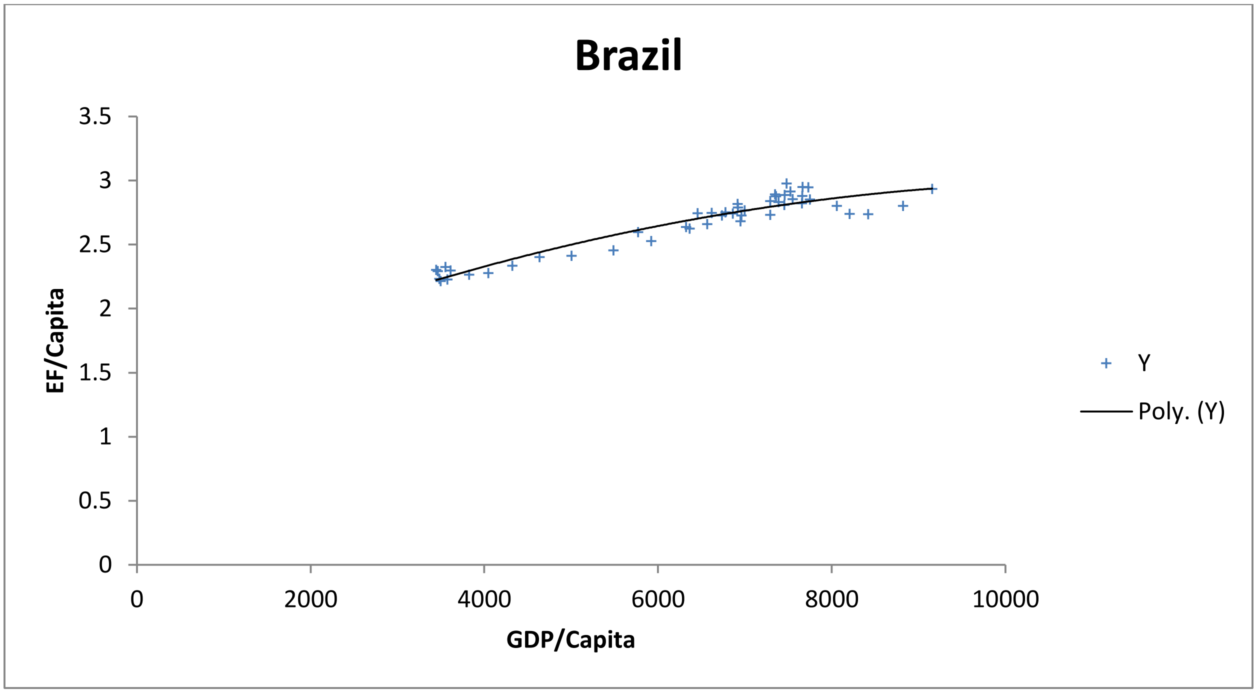
b.


Argentina
EF/Capita
GDP/Capita
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
2000
4000
6000
8000
10000
12000
14000
Y
Poly. (Y)

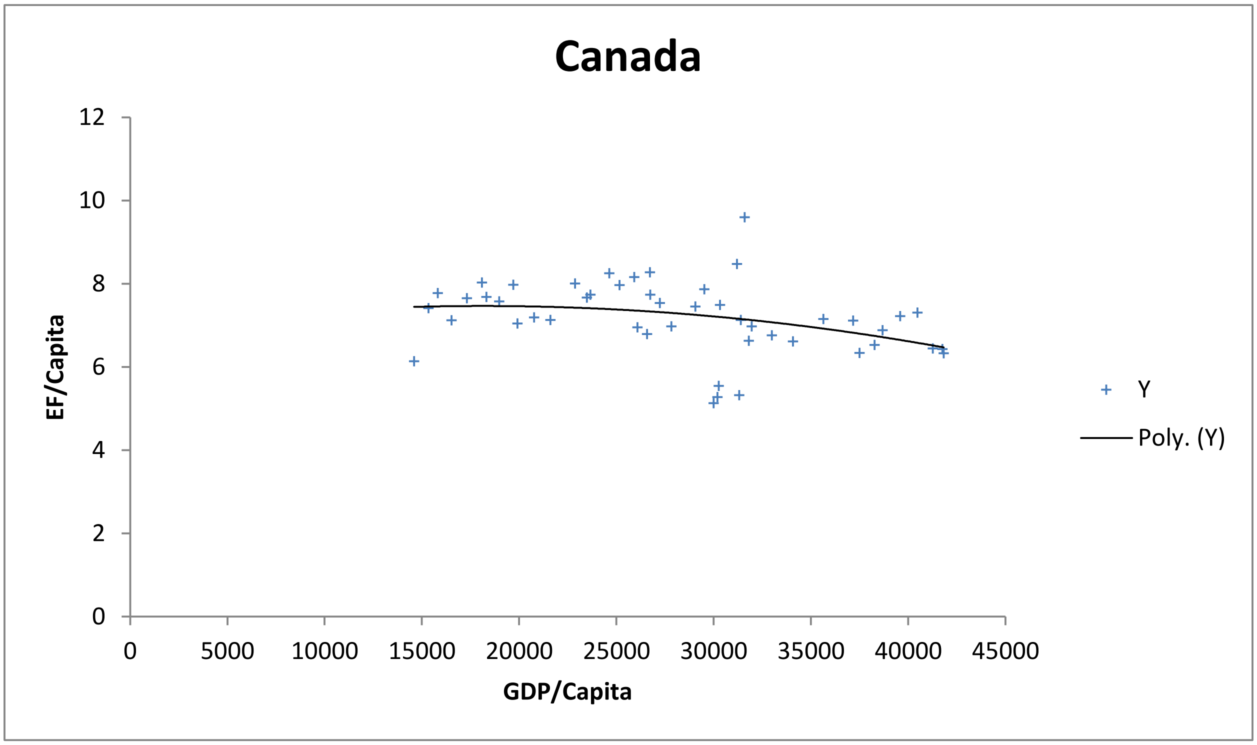
c.


Australia
EF/Capita
12
10
8
6
4
2
0
0
10000
20000
30000
40000
50000
GDP/Capita
Y
Poly. (Y)

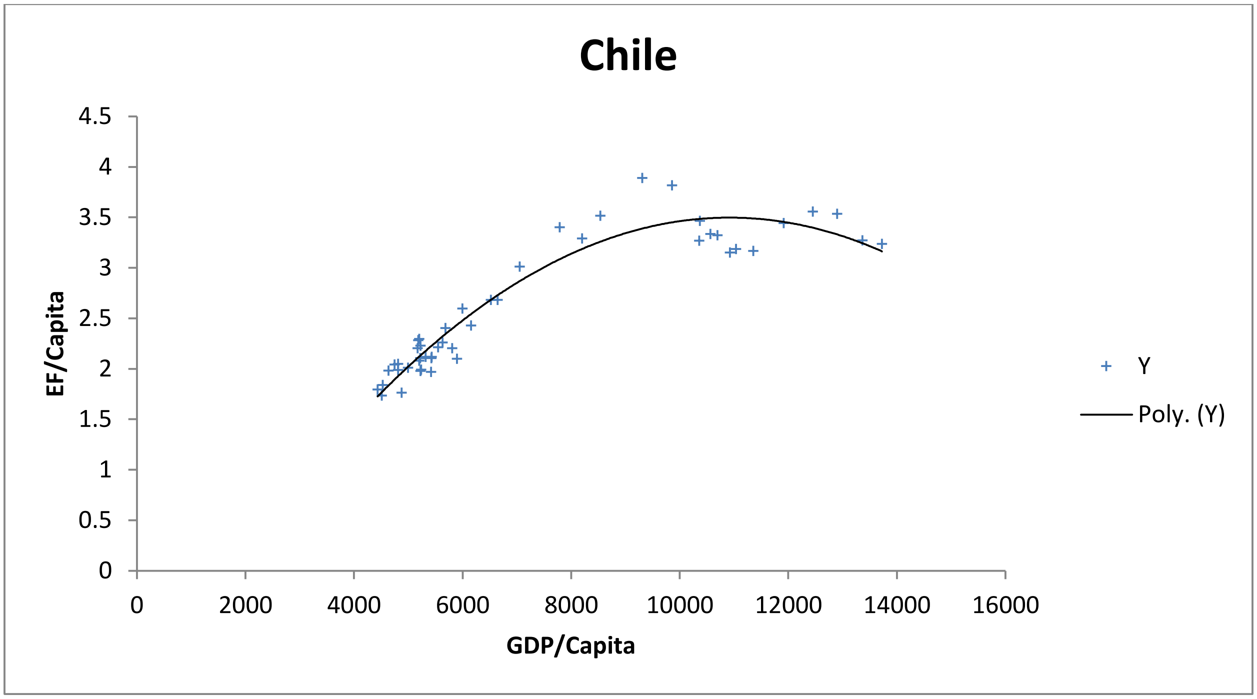
d.


Brazil
3.5
3
2.5
2
1.5
1
0.5
0
EF/Capita
0
2000
4000
6000
8000
10000
GDP/Capita
Y
Poly. (Y)

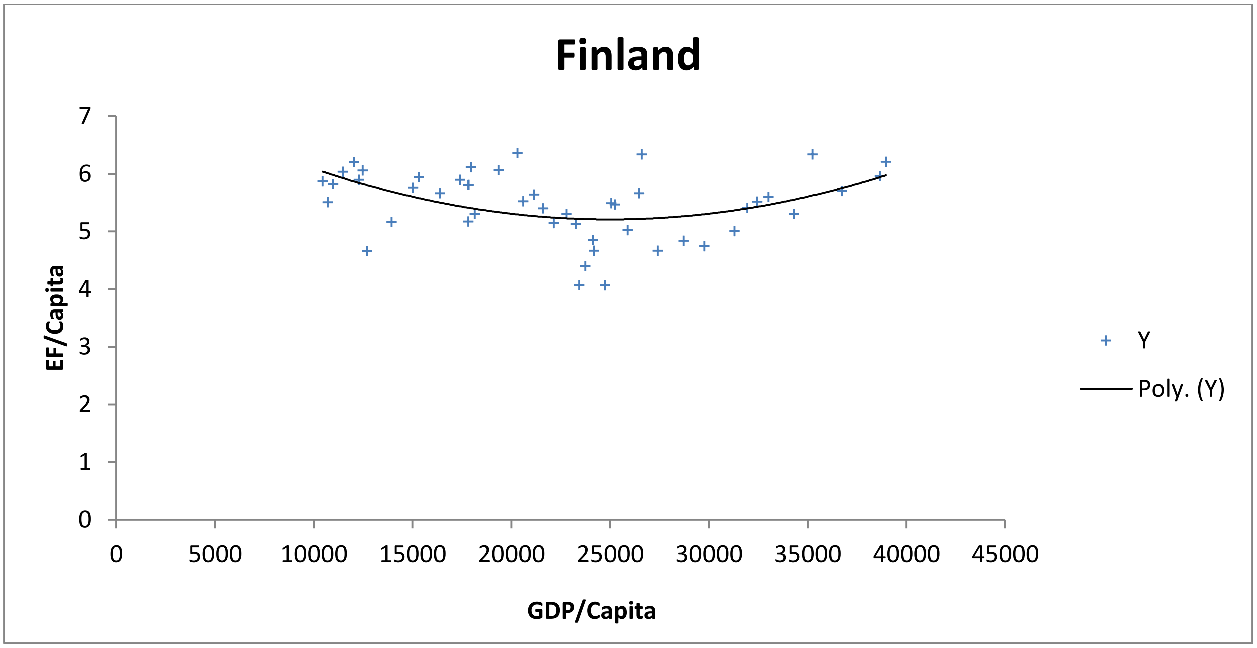
e.


Canada
EF/Capita
12
10
8
6
4
2
0
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
GDP/Capita
Y
Poly. (Y)

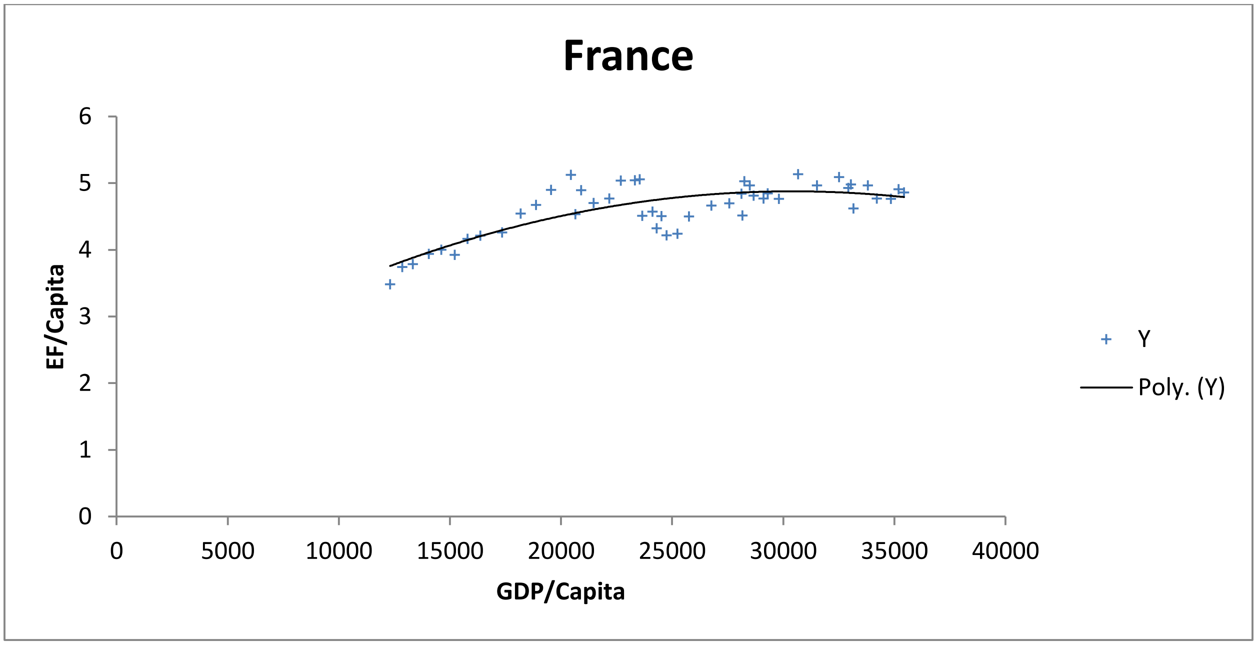
f.


Chile
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
EF/Capita
0
2000
4000
6000
8000
10000
12000
14000
16000
GDP/Capita
Y
Poly. (Y)

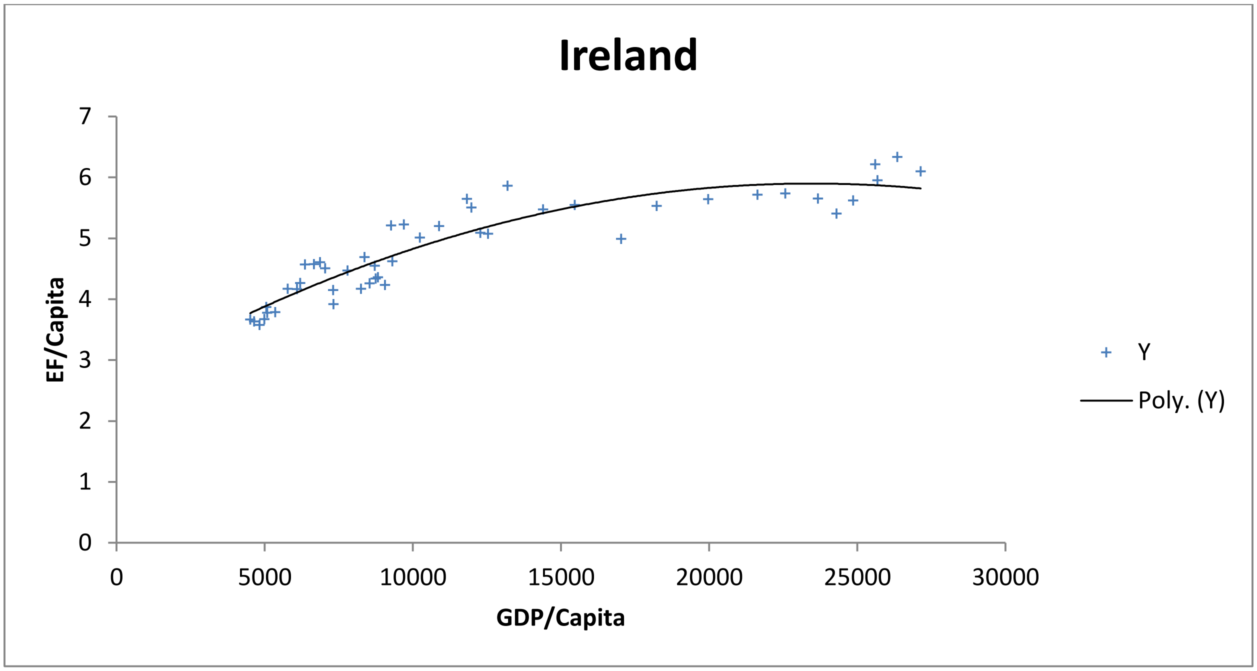
g.


Finland
EF/Capita
GDP/Capita
0
1
2
3
4
5
6
7
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
Y
Poly. (Y)

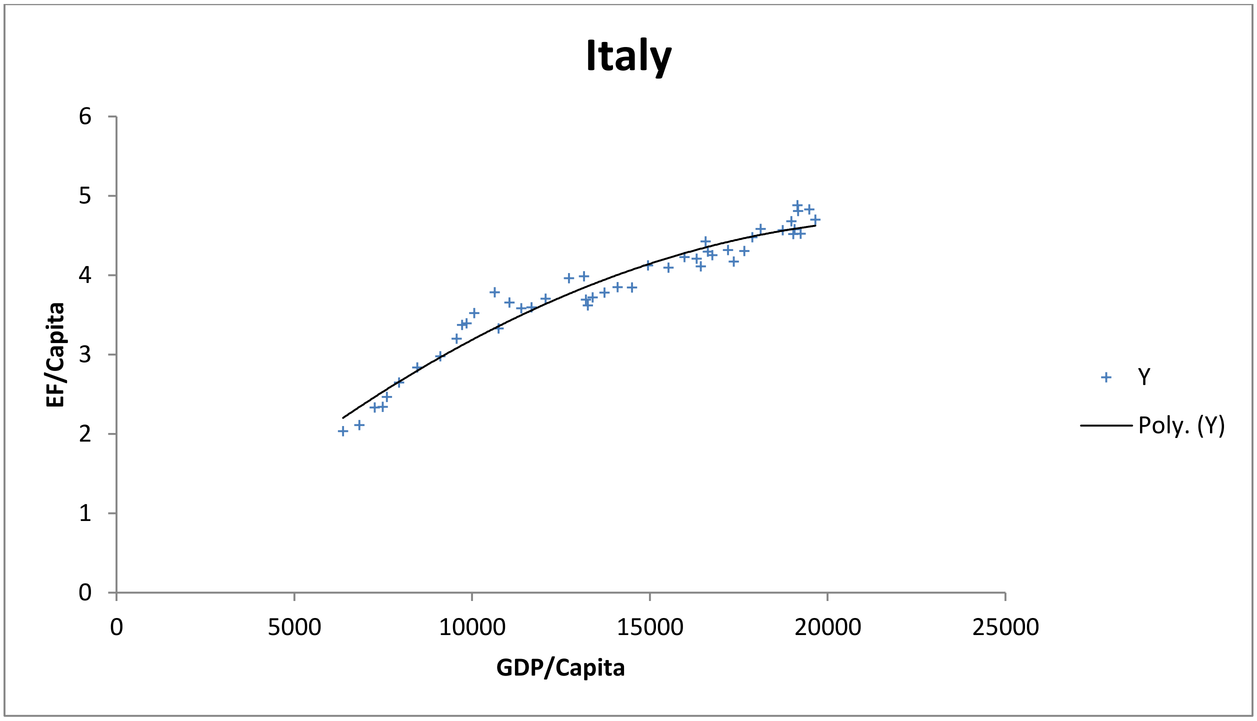
h.


France
6
5
4
3
2
1
0
EF/Capita
0
5000
10000
15000
20000
25000
30000
35000
40000
GDP/Capita
Y
Poly. (Y)

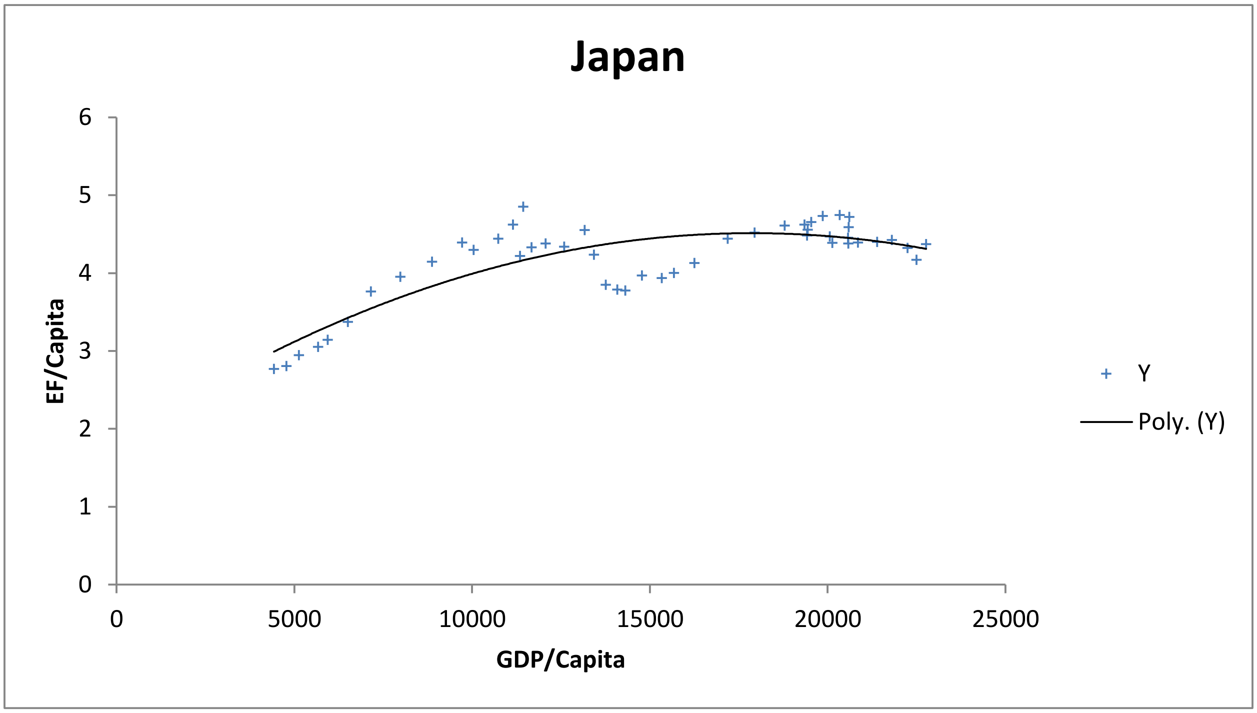
i.


Ireland
EF/Capita
7
6
5
4
3
2
1
0
0
5000
10000
15000
20000
25000
30000
GDP/Capita
Y
Poly. (Y)

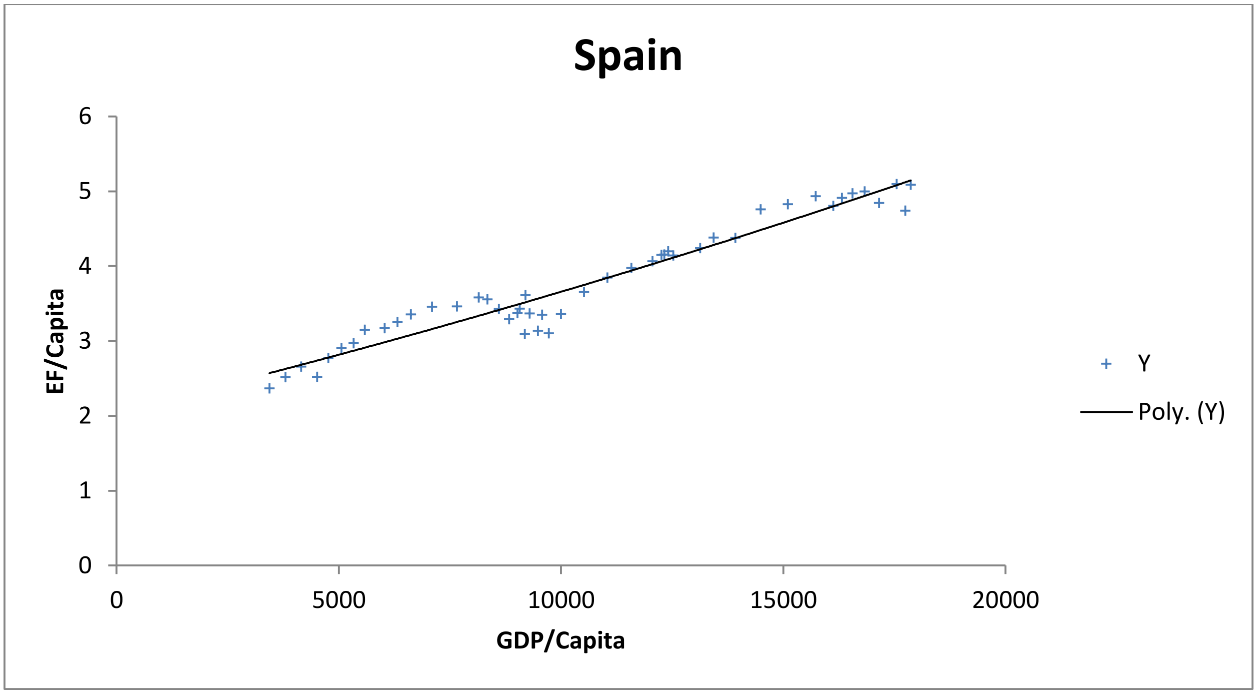
j.


Italy
6
5
4
3
2
1
0
EF/Capita
0
5000
10000
15000
20000
25000
GDP/Capita
Y
Poly. (Y)

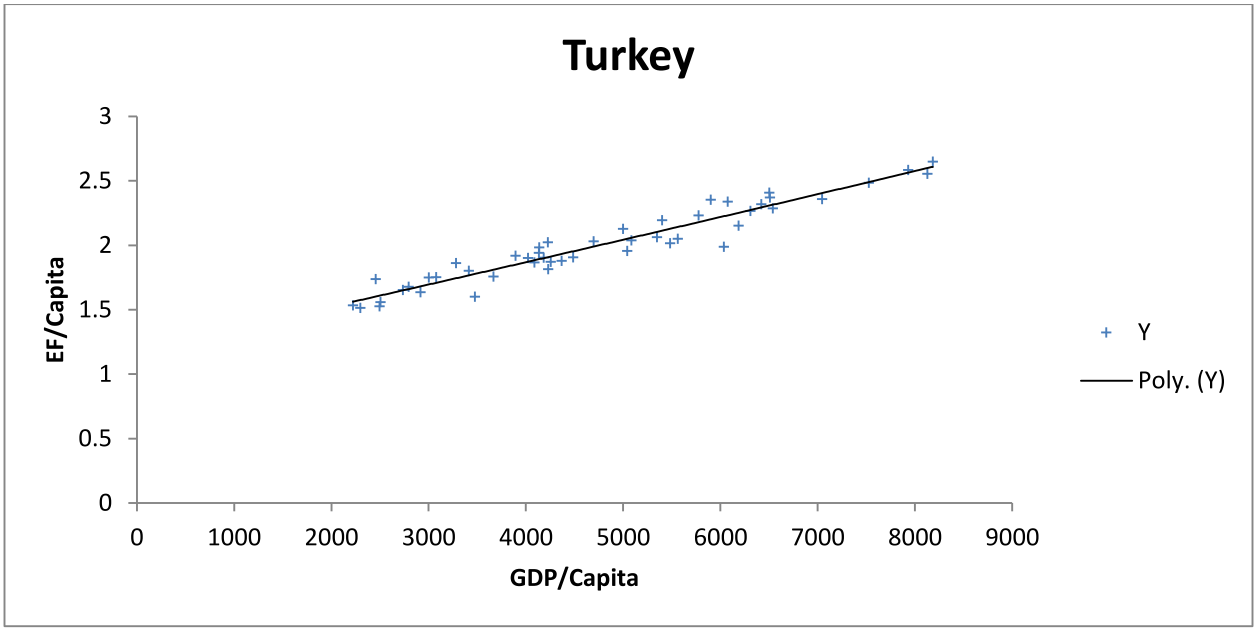
k.


Japan
EF/Capita
6
5
4
3
2
1
0
0
5000
10000
15000
20000
25000
GDP/Capita
+ Y
Poly. (Y)

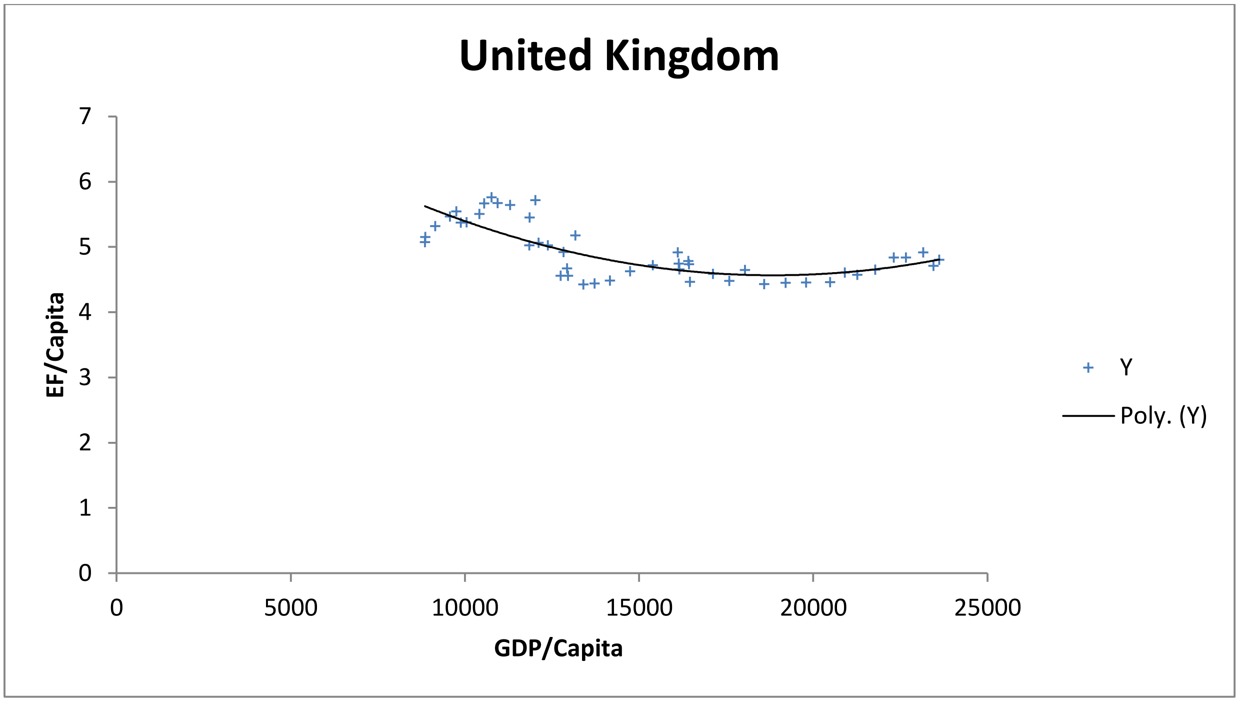
I.


Spain
6
5
4
3
2
1
0
EF/Capita
0
5000
10000
15000
20000
GDP/Capita
Y
Poly. (Y)

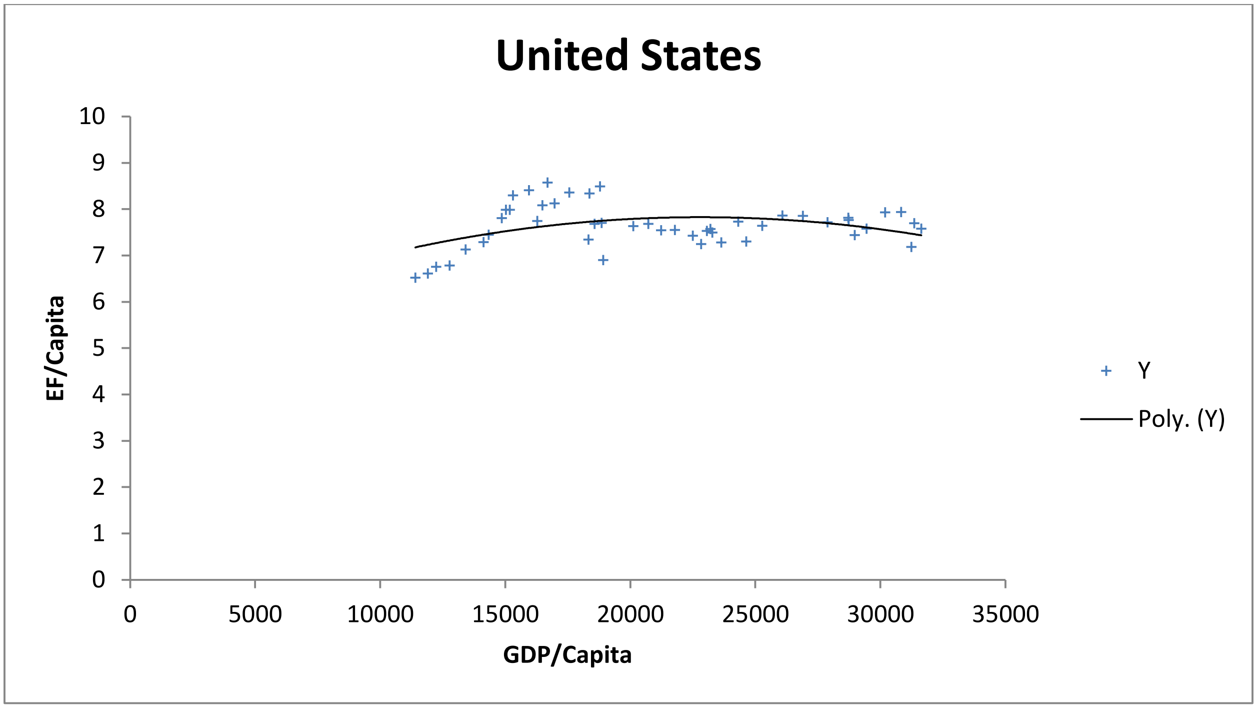
m.


Turkey
EF/Capita
3
2.5
2
1.5
1
0.5
0
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
GDP/Capita
Y
Poly. (Y)

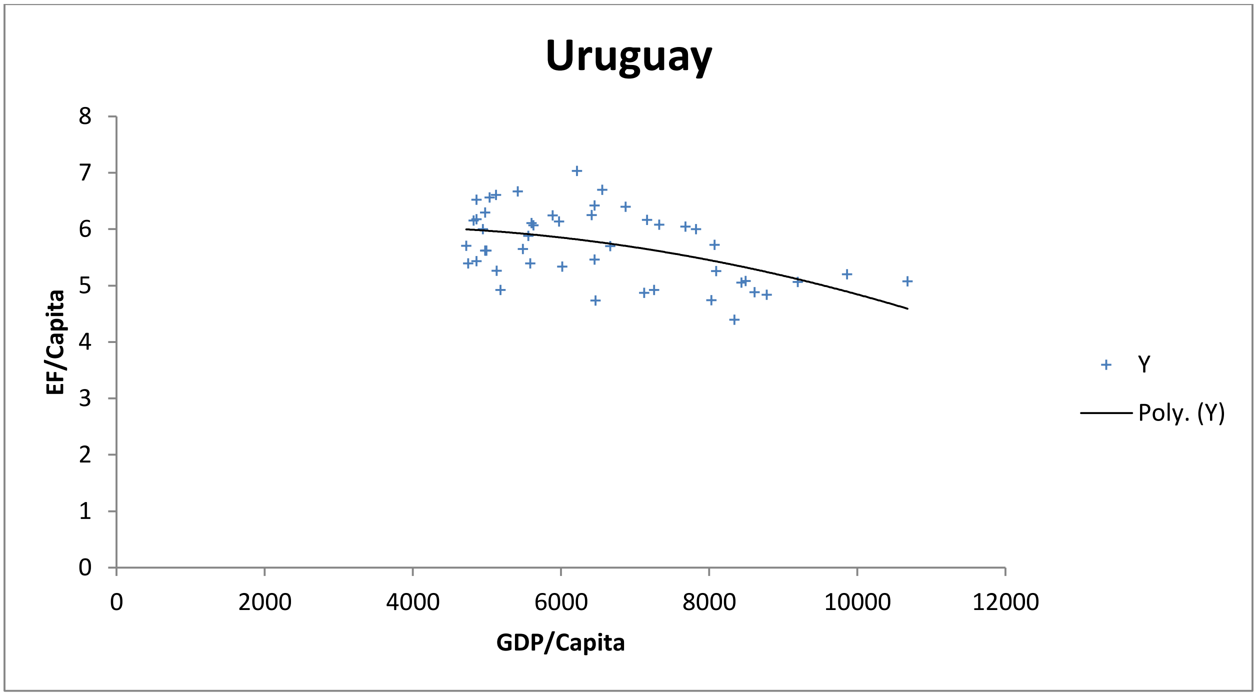
n.

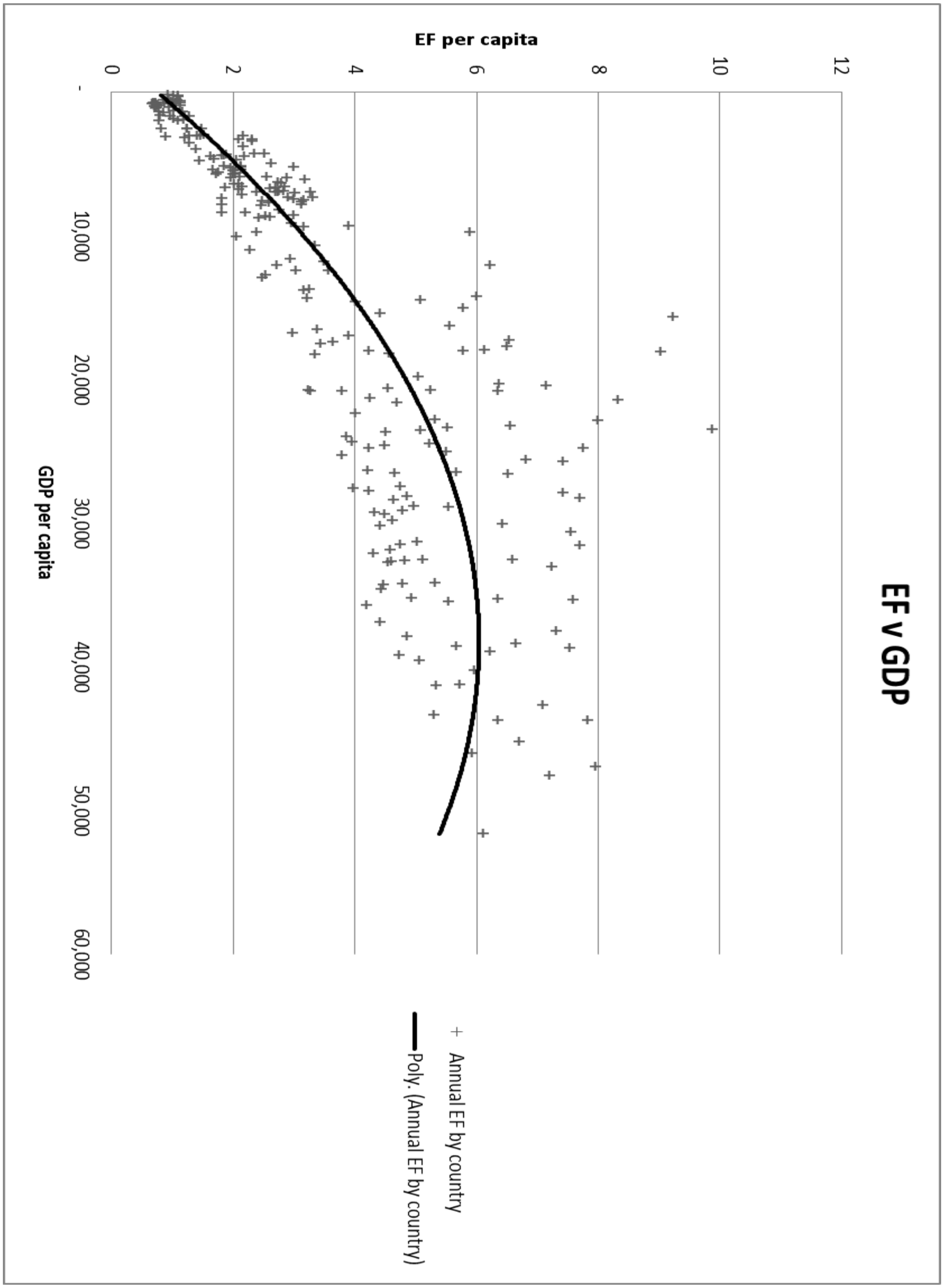

United Kingdom
EF/Capita
7
6
5
4
3
2
1
0
0
5000
10000
15000
20000
25000
GDP/Capita
Y
Poly. (Y)

o.


United States
10
9
8
7
6
5
4
3
2
1
0
EF/Capita
0
5000
10000
15000
20000
25000
30000
35000
GDP/Capita
Y
Poly. (Y)

p.


Uruguay
8
7
6
5
4
3
2
1
0
EF/Capita
0
2000
4000
6000
8000
10000
12000
GDP/Capita
+ Y
Poly. (Y)


EF v GDP
EF per capita
0
2
4
6
8
10
12
GDP per capita
-
10,000
20,000
30,000
40,000
50,000
60,000
Annual EF by country
Poly. (Annual EF by country)