Is there an Environmental Kuznets Curve for Mercury in Non-industrialised Countries with Small-Scale Gold Mining?

by

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Abstract

Mercury has negative health and environmental impacts. Although its usage is being phased out in most industries and countries, gold mining remains the largest use and source of pollution globally. This paper explores the correlation between GDP per capita and mercury imports for non-industrialised countries where mercury is used for gold mining. These countries have identified artisanal and small-scale gold mining and are the predominant direct users of mercury. I estimate a fixed effects model on panel data with GDP per capita as the independent variable of interest and net mercury imports as the dependant variable. Treating mercury imports as a proxy for mercury pollution, I find that with pooled data across countries there exists an Environmental Kuznets Curve for mercury where mercury use initially increases with income per capita in low and middle income countries but then declines to a lower level for countries with higher income per capita. However, this relationship is not significant when the estimation allows for country fixed effects.

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1. Introduction

On January 19th 2013 The Minamata Treaty was agreed upon by the Intergovernmental Negotiating Committee in Geneva, Switzerland. The moment signified a collective global awareness of the dangers surrounding mercury use and its emissions. Not to say that the perception of mercury has not been shifting even before that. In the last two decades efforts to find alternative technologies that do not use mercury have succeeded. Such changes include the shift from incandescent and fluorescent bulbs to LEDs, and mercury-cell process in chlor-alkali plants to alternative chlor-alkali production processes. The transition away from mercury use is not entirely a global phenomenon. In more developed countries, the major industries driving demand for mercury are shifting to alternative technologies, whereas demand for mercury in developing countries for the purpose of Artisanal and Small-scale Gold Mining (ASGM) does not appear to be decreasing (UNEP, 2006).

Mercury usage in the ASGM sector is the focus of this paper for a number of reasons. The main reason is related to pollution generated by this sector. The Global Mercury Assessment 2013 released by UNEP stated that annual emissions from ASGM accounted for an estimated 37% of total anthropogenic mercury emissions in 2010, the largest source (Appendix 2 Figure 2.2). This figure is more than double that of anthropogenic mercury emissions in 2005, indicating considerable growth of the sector. The growth of emissions stems from ASGM concentrated in lesser developed regions. ASGM is most commonly found in East and Southeast Asia, South America, and Sub-Saharan Africa, contributing to the majority of the global anthropogenic mercury emissions through ASGM (UNEP, 2013). Many of the issues surrounding ASGM are directly related to developmental challenges such as formalization of the sector, institutional ability to enforce regulation, and poverty.

The literature linking pollution and development is that of the Environmental Kuznets Curve (EKC). The general EKC theory states that as income rises, pollution first increases then decreases following an inverted-U path. In the ASGM context, pollution is specific to mercury emissions which, due to its potentially expansive impact, can be regarded as a public bad but with relatively localized negative effects. The EKC theory provides this paper with the motivation to explore the relationship between per capita income and mercury use within the ASGM sector. Does there exist an Environmental Kuznets Curve for direct use of mercury in ASGM countries? By posing the question with direct use of mercury, I am drawing a connection between direct use of mercury in the ASGM sector and mercury emissions.

To explore the relationship between per capita income and direct mercury use, analysis is carried out on panel data constructed for a sample of low income, non-industrialised countries with identified ASGM operations. Further conditions are applied to the sample to best capture the relationship between income and mercury emissions. A Fixed Effects (FE) model is applied to the data with *net mercury imports* as the independent variable and *GDP per capita* as the dependant variable of interest. In the model, *net mercury import* is used as a proxy for direct use of mercury. An additional covariate of population is added to the FE to observe changes in the dependant variable of interest, *GDP per capita,* when conditioned on country specific time-varying observation that may directly influence the ASGM sector.

I find that there is little evidence for an EKC when using the FE model, but significant results when the data is pooled. When the data is pooled, there is little support for an EKC that can be applied to all countries. To better understand the methodology of this paper, I have included sections detailing the Environmental Kuznets curve, followed by the supply and demand story of mercury and its role as a pollutant in the ASGM sector.

2. Environmental Kuznets Curve

As stated above, the approach to examine the correlation between mercury imports and income is motivated by the adoption of the *Environmental Kuznets curve*.

The original Kuznets curve attempts to describe the relationship between economic development and income inequality, hypothesising that as income per capita increases, income inequality will initially increase, peak at the turn-around point, then decline in further stages of development (Kuznets, 1955). The same path is attributed to the relationship between economic development and environmental degradation in the EKC. It follows the rationale that at low levels of GDP there is greater development and industrialization occurring, resulting in higher levels of pollution and waste from production. The general path is driven by several mechanisms which differ between pollution types. The mechanisms relevant to ASGM are formal regulation, technology, and to a lesser extent income elasticity of environmental quality demand and outside employment opportunities. With regards to formal regulation, economic growth should see the improvement of institutions which can better regulate and enforce environmental regulation, thus driving the downward sloping portion of the EKC. For technology, as income rises more efficient technology is invested in through research and development or the technology simply becomes more accessible. It is assumed that more efficient technology decreases negative environmental impacts of production, driving the downward slope of the EKC. Income elasticity of environmental quality demand is the theory that as incomes increase and standards of living increase, people place greater value on the environment. This theory is altered to fit the context of ASGM. Finally, as income rises, alternative employment opportunities in the formal sector increase resulting in a decline of informal sector employment.

Empirical analysis of the EKC is generally carried out on cross-sections of countries and cross-sectional panel data. The analysis in the literature predominantly focuses on air quality and water quality indicators, these of which are further broken down into several categories. Of the water quality indicators, the heavy metal category is the most relevant to my topic. The literature shows that pollutants with short-term and localised effects are more likely to exhibit an EKC in the data. In industries like ASGM, the resulting pollution from mercury use shares these characteristics. In Brazil, Zimbabwe and Indonesia, mercury from the whole ore amalgamation process (where all of the ore mined is combined with mercury) occurring at mining sites was found in aquatic systems with serious harmful effects on the aquatic life, soils, and sediments (Spiegel & Veiga, 2006). Negative health repercussions from direct use and handling of mercury have been identified as well. In some cases, mercury intoxication levels of over 50 times the maximum exposure limit, as defined by the World Health Organization, have been found (Spiegel & Veiga, 2006). This is of particular concern due to the high proportion of women and children employed in the sector, 4.5 million women and 1 million children out of the estimated 10-15 million employed (Spiegel & Veiga, 2006). Infants in ASGM communities are at risk as well due to high concentrations of mercury found in breast milk (Spiegel & Veiga, 2006).

2.1. Environmental Kuznets Curve and Artisanal and Small-scale Gold Mining

Fitting the EKC to mercury imports for non-industrialized ASGM countries relies on first defining the narrative that the mercury follows – from imported commodity to local pollutant. To do that, I treat a particular country as if ASGM is the only industry driving demand for mercury. It is also assumed that the country does not have an internal supply of mercury. In the basic story, when the country imports mercury, it is consumed within the ASGM sector rather than being stock piled for future use. This can be expanded on in the event that a proportion of the mercury is recycled by saying that imports of mercury indicate a lower bound level of consumption (Spiegel & Veiga, 2006). We assume rate of recycling is constant.

The mechanisms driving the EKC mentioned above can be applied to the ASGM narrative.

Regulation in the context of ASGM is the limiting or prohibition of mercury use in gold mining. Regulation is closely linked to formalization of the commonly informal ASGM sector. As income rises, social institutions will have greater resources to formalize the ASGM sector or simply enforce regulations within the informal sector. The strengthening of social institutions or establishment of environmental regulatory institution has greater relevance in less developed countries where these institutions are either weaker or absent (Dinda 2004). With the formalization of the sector, regulations can be more effectively enforced. For example, large scale gold mining operations no longer use mercury as a means of separating gold from the ore extracted.

Increased income resulting in greater investment in research and development, yielding more efficient technologies, is not directly applicable to the ASGM sector. ASGM is predominantly found in the lowest income countries, so increased income at that level would not be reinvested into research and development. Rather, increased income may result in accessibility to existing technologies. Higher income can present the opportunity to put capital towards more efficient technologies such as retorts to recover mercury, or even alternative small-scale gold mining technologies. Both options drive down mercury consumption and emissions.

The income elasticity of environmental quality demand mechanism is altered to fit the context of ASGM. As income increases, standards of living increase which encompass education. Through education, the negative effects of mercury are better understood and actions are taken to minimize its use, driving down consumption and emissions. The mechanism here is income elasticity of health quality demanded. As income increases, miners demand a higher level of health quality and therefor decrease use of mercury, reducing consumption and emissions.

Employment opportunities in the formal sector can increase with economic growth. As formal sector employment opportunities increase, those employed in the informal sector will migrate to the formal sector, whether it be due to higher wages, job security, or otherwise. The application of the theory is questionable due to the very lower income level of ASGM countries, and alternative employment growth may be negligible. The wage differential may be slight as well.

These mechanisms drive the downward slope of the inverted-U relationship. The upwards sloping portion of the inverted-U can be partially understood by looking to the demand for mercury in ASGM. The increase in gold prices over the past 15 years apparently reflects the growth ASGM mining, driving an increase in mercury demanded and thus anthropogenic emissions (UNEP, 2006). A rise in population can drive growth in the sector as well. This is especially relevant for the countries in the sample as most are low income countries with high population growth rates.

3. Mercury Uses and Pollution

The distinction should be made between direct and indirect sources of pollution. For my paper, I focus on direct sources of mercury pollution to motivate my analysis of the specific sector of ASGM and to truncate my sample. Direct sources of mercury pollution are a result of the intentional use of mercury as an input to production. Indirect sources are mercury emissions as a by-product of other production. For example, coal combustion and zinc refineries can result in mercury emissions but do not use mercury as an input. Figure 2.2 in Appendix 2 shows that coal combustion, primary non-ferrous metal production, and cement production are three other major sources of mercury emissions in 2010. These are all indirect sources of mercury pollution, leaving ASGM as the single major source of direct mercury pollution as well as the major source of all anthropogenic mercury emissions.

3.1. Supply and Demand for Mercury

To better understand the relationship of imports and GDP per capita, it is helpful to understand the supply of mercury and the driving demands for its use.

There are five major sources of mercury supply: Mercury recovered from mercury cell chlor-alkali plants that convert or close, primary mining, accumulation of stocks (originally from previous two sources), mercury captured as a by-product of other production or refining of non-ferrous metals, and finally mercury recycled from products or waste.

Mercury recovered from chlor-alkali production has been an increasing supply of mercury on the world market in the past decade, although efforts by such bodies as the European Commission have proposed legislation to store recovered mercury safely and out of the world market. The decommissioning of such plants leads to considerable stocks of mercury. In the European Union alone, the decommissioning of roughly 6 million metric tons of mercury cell capacity will free over 11,000 metric tons of mercury. Although not all mercury cell chlor-alkali production is ceasing around the world, in the last decade there has been a push for coordinated closure of these plants through organizations like the UNEP Chlor-Alkali Partnership.

The mining and processing of primary mercury ores has also been diminishing within the last decade and earlier. The three dominant sources of primary mercury come from Spain, mined by MAYASA, Kyrgyzstan, and Algeria. China is a large source as well, but mainly operates to support its internal demand for industrial material production such as vinyl chloride monomer production (which represents 80-90% of global capacity) (UNEP see reference list VCM). Mining in both Algeria and Spain has stopped completely since 2004, although large stocks still remaining in Spain. Kyrgyzstan continues to mine mercury, but a recent UNEP report shows that Kyrgyzstan was producing 300 metric tons of mercury in 2008, down from about 600 metric tons in 2000 (Kirby, 2009).

Mercury as a by-product contributes relatively little to the total supply, but is worth noting. For example, mercury recovered from zinc ore is an almost negligible amount. A ratio of mercury exports to zinc production is calculated for Finland, the largest producer of by-product mercury from zinc. In 2001, it was 0.000372 (82.8 metric tons mercury) and has been declining since. Mercury recovered from large scale gold mining is predominantly supplied by the United States, Peru and Chile (amounting to 80 – 100 metric tons recovered annually), and Argentina (UNEP, 2006). The act of recovering mercury is perceived as a positive practice, but it does provide a domestic supply of mercury.

Finally, recycled mercury is closely linked to industries where large amounts of mercury can be recovered, chlor-alkali and vinyl chloride monomer production being the primary source of recycled mercury. In 2005, an estimated 90-140 metric tons of mercury was recycled in the global chlor-alkali industry. Maxon (2006) estimates that globally, an average of 15% of mercury product waste may be recycled, although the data available is very limited

I am only interested in the demand for mercury driven by artisanal and small-scale gold mining (ASGM), but outlining the alternative major demands helps situate ASGM in a broader context and draw a tighter connection between mercury imports and emissions.

In 2005, the ASGM sector was estimated to have the highest demand for mercury at 650-1000 metric tons, followed by VCM production at 600-800 metric tons, chlor-alkali production at 450-550 metric tons, and batteries at 300-600 metric tons demanded. Other demands such as dental use, measuring and control devices, lighting, and electrical devices make up a smaller proportion of total demand with quantity demanded ranging from 150-300 metric tons (UNEP, 2006). It should be noted that since 2005, demand in industries like mercury cell chlor-alkali production has been diminishing considerably. This is especially true regarding the smaller industries mentioned above as there are accessible mercury-free alternatives.

An estimated 60% of mercury consumption in the chlor-alkali industry comes from Europe and 12% from the United States, with the remaining 28% composed of plants from around the world (UNEP, 2006). Here, mercury consumption is defined as net mercury releases to products, emissions, and disposal of mercury.

The ASGM sector supports upwards of 100 million people globally and based on a 2007 report, it represents 20-30% of the global production of gold (Spiegel & Veiga, 2006). Although not all artisanal and small-scale gold miners use mercury, it is the most commonly practiced method due to its low cost and ease of use. There is an apparent increase in demand for mercury from the ASGM sector due to increasing gold prices resulting in increased mining activity observed in many countries (UNEP, 2006). This is consistent with the estimated increase of anthropogenic emissions stemming from mercury use in the ASGM sector (UNEP, 2013). The highest estimated consumption levels are in China with 200-250 metric tons mercury released, then Indonesia with 100 to 150 metric tons, followed by Brazil, Bolivia, Columbia, Ecuador, Ghana, Peru, Philippines, Venezuela, Tanzania, and Zimbabwe each with 10-30 metric tons released (Spiegel & Veiga, 2006). This is not an exhaustive list, but gives us an informative snapshot. Looking at the change in estimated anthropogenic mercury emissions due to ASGM from 2005 to 2010, we see a considerable increase in East and Southeast Asia, Sub-Sahara Africa, and South America, consistent with the increasing demand (UNEP, 2013). In many cases, even though mercury may be imported to a country for use in a formal sector such as chlor-alkali production or dental amalgams, evidence suggests that the majority of mercury imports are allocated to artisanal and small-scale mining (Spiegel & Veiga, 2006).

3.2. Net Mercury Imports as a Proxy for Consumption/Pollution: Demand and Supply Complication

The application of net mercury imports as a proxy for consumption in the ASGM sector, and therefor mercury emissions, is complicated by the vastly differing sources of demand and supply for mercury. First, it is important to note that countries with ASGM operations have been identified by a list provided by the Mercury Watch site and cross-referenced with other sources.

Of these countries some have other mercury demanding industries, such as chlor-alkali production and VCM production, and are generally more industrialised. Several countries like Canada are identified as having ASGM sectors and are higher income countries, and again have industries other than ASGM that drive demand. This is true for a few lower income countries such as India with its chlor-alkali production.

Within the list of ASGM countries, there are those with identified internal supplies of mercury and therefor do not need imports to supply the ASGM sector. As mentioned above, these internal supplies can be in the form of accumulated stocks, e.g. United States, or mining, e.g. Kyrgyzstan. I treat the current and past existence of chlor-alkali plants as an internal source of mercury due to the liberation of mercury that is followed by a decommissioning of a mercury cell chlor-alkali plant.

Alternative demands for mercury also poses a difficulty for determining the connection between consumption and mercury emissions. Due to recycling and recovery of mercury in chlor-alkali and VCM production it is unclear how much is emitted into the environment, either through waste or contaminated equipment when decommissioned. Recycling technologies like retorts in ASGM are available, but due to the high accessibility of mercury, its relatively inexpensive price, and cost of retort itself, the technologies are not commonly applied. In some cases, the uses of retorts can have a greater negative impact on emissions and health due to improper use (Moher 2013).

The connection between consumption and imports becomes clearer if a country does not have an internal supply of mercury and has only ASGM as the industry driving demand. That said, with regards to artisanal and small-scale gold mining, the 2007 Global Mercury Project report states that, “Because some mercury used is recycled, the amount of additional mercury demanded is equivalent to the amount of mercury consumed.” This relaxes the necessity for a country to be without stocks to determine the lower bound of mercury consumed. This is under the assumption that ASGM production levels and technology remains constant. This is not an unreasonable assumption given basic nature of mining with mercury.

4. Data

The data on annual mercury imports has been sourced from the UN Comtrade Database using the tariff code SITC rev. 2 52216. Using SITC rev. 2 as oppose to other classification systems ensures the largest coverage of data available. The tariff code 54416 covers commodity mercury only. This is intentional because statistics on other products and compounds containing mercury may not be as well specified and can be less reliable. The annual import/export data spans from 1976 to 2015. The data I have used for net mercury imports has been constructed by subtracting exports from imports. Due to discrepancies in reporting, the “mirror analysis” method is conducted on the export and import data. The method is suggested by a 2006 UNEP report titled Summary of Supply, Trade, and Demand on Mercury in which it analyzes the same UN Comtrade data used in my sample. The import data has be constructed by comparing self-reported imports by a country to reported exports to said country by its trade partners. The larger of the two is then used, following the rationale that there is greater incentive to underreport than to overreport (e.g. tax avoidance) (UNEP, 2006). The same is done for the available export data. A net mercury imports series is then constructed by simply subtracted exports from imports.

GDP per capita is obtained from the WTO database. GDP per capita for each country has been converted to 2011 US dollars (purchasing power parity). The data spans from the year 1990 to 2014.

Countries with ASGM sectors are identified by various sources, obtained from the Mercury Watch database, which is then cross-referenced with alternative sources such as reports by UNEP. Countries with chlor-alkali production using mercury have been identified through Mercury Reduction Partnership reports that identify current partners as well as non-partner countries that have mercury-cell chlor-alkali production. The list includes those with previously operational mercury cell chlor-alkali plants that have shut down. Again, these lists have been cross-referenced with other sources to ensure all countries with mercury cell chlor-alkali plants have been identified.

I analyze a sample that spans from 1990 to 2013. There are the greatest number of observations over this period. As well, the post-1990 era saw greater consistency of national and economic borders. The analysis is simplified by focusing on observations over this range.

4.1. Sample Construction

The general model of the EKC does not specify a particular sample. In the literature, ideally the EKC is applied to a complete sample containing the full spectrum of incomes to capture the complete picture of the relationship between economic growth and a particular pollutant.

I analyze a particular sample to examine the relationship between GDP per capita and mercury emissions. My focus on countries with ASGM sectors and with no alternative demands allows me to draw a clearer connection between mercury imports and emissions. To do this, the sample was cut down by removing countries where demand or supply was unclear. As mentioned in the Supply and Demand section above, countries with alternative demands were dropped due to a lack of clarity surrounding the level of mercury emissions resulting in other industries. Countries with identified internal sources of supply are dropped as well as mercury imports would not be as informative of levels. These countries are generally net exporters, such as Spain and Chile.

Countries that are net exporters of mercury in the sample but do not have identified stocks are suspect and can be approached in two ways. First, net exporting alludes to a store of mercury that is not being consumed, and thus imports are not necessarily indicative of mercury emission levels. In this case, all observations for a country that exports in one or more years are dropped. The second approach is to drop the particular year and country observation where a net export is observed, while keeping the remaining observations. To do this, I rely on applying to the context of imports, the reasoning that "because some mercury used is recycled, the amount of additional mercury demanded is equivalent to the amount of mercury consumed" (Spiegel & Veiga, 2006). If stocks do exist, additional imports then indicate a lower bound for mercury consumption. It is difficult to apply this theory to countries that do not have identified stocks but are frequently net exporters of mercury with fewer years of net imports such as South Africa, Uzbekistan, Tajikistan, and Mali. These observations are dropped. I will be using the second approach to maintain as large of a sample as I can.

Truncating the sample by income levels is done to focus on non-high income countries that have only the ASGM sector driving demand for mercury rather than alternative industrial demands. This is consistent with ASGM being a lower-income industry. Based on the 2016 fiscal year World Bank definition, countries are partitioned into low, lower-middle, upper-middle, and high income countries by ranges of GNI per capita. Although I use PPP adjusted GDP per capita, the list provides the definition by which I form two samples. One contains all but high income countries. High income is defined as having a GNI per capita greater than $12,

736. Countries below this threshold fall into this sample. A second sample of low and lower-middle income countries contains those with a GNI per capita less than $4, 125.

There are three outliers of reported imports at levels 400,000 kg of mercury. With no observed exports at a comparable level in the subsequent years, I can address these countries in a similar approach as the countries with the infrequent export. I can drop the particular year and country observation while treating the following import data as a lower bound for mercury consumption. Or I can drop the country as it implies that there is now a large stock of mercury rendering the subsequent import data uninformative about mercury consumption. In this case, dropping the country entirely is more desirable because it is highly unlikely that ASGM is the primary demand in these countries to require roughly 80-140 times more mercury than the mean quantity imported of 5000 in the sample. Once I have cleaned my sample by the criteria above, only Malaysia remains to be dropped.

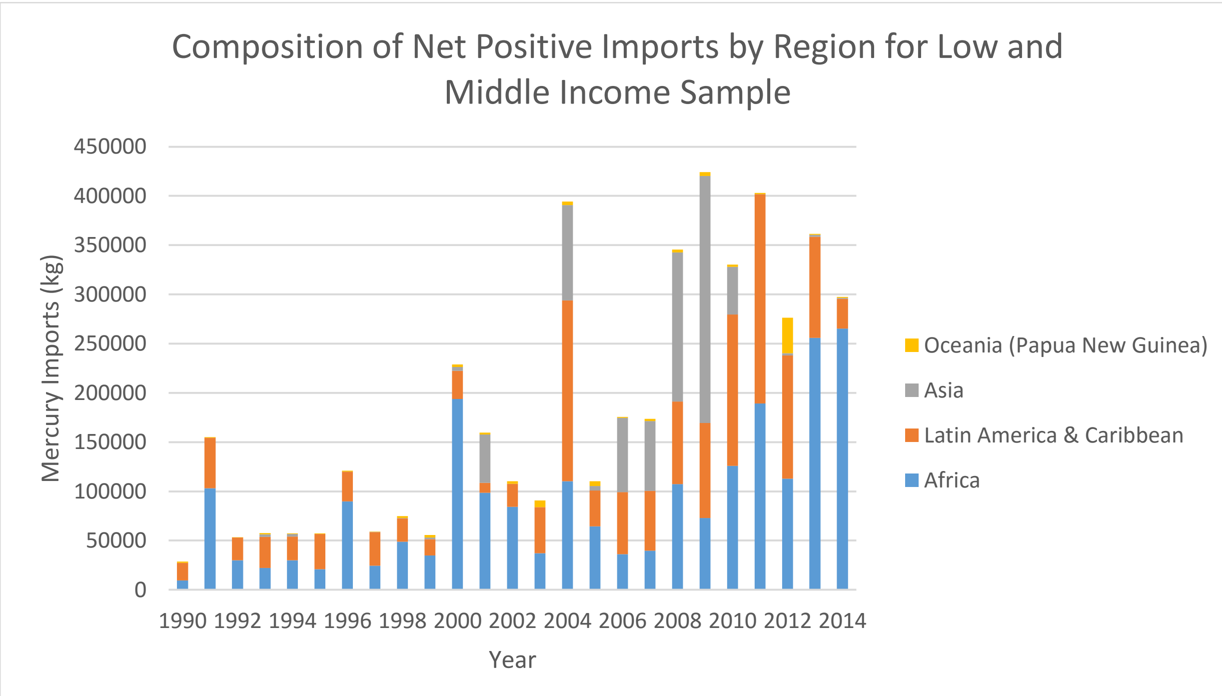
4.2. Summary Statistics

There are two primary samples. First is composed of low and middle income countries. The second is a subset of low and middle countries composed of a lower income group labelled as low and lower-middle income countries. Observations in both samples range from 1990 to 2014.

The low and middle income sample contains 618 observations in total. There are 43 countries in the sample with 29 from Africa, 10 from Latin America and the Caribbean, 3 from Asia, and only Papua New Guinea from Oceania.

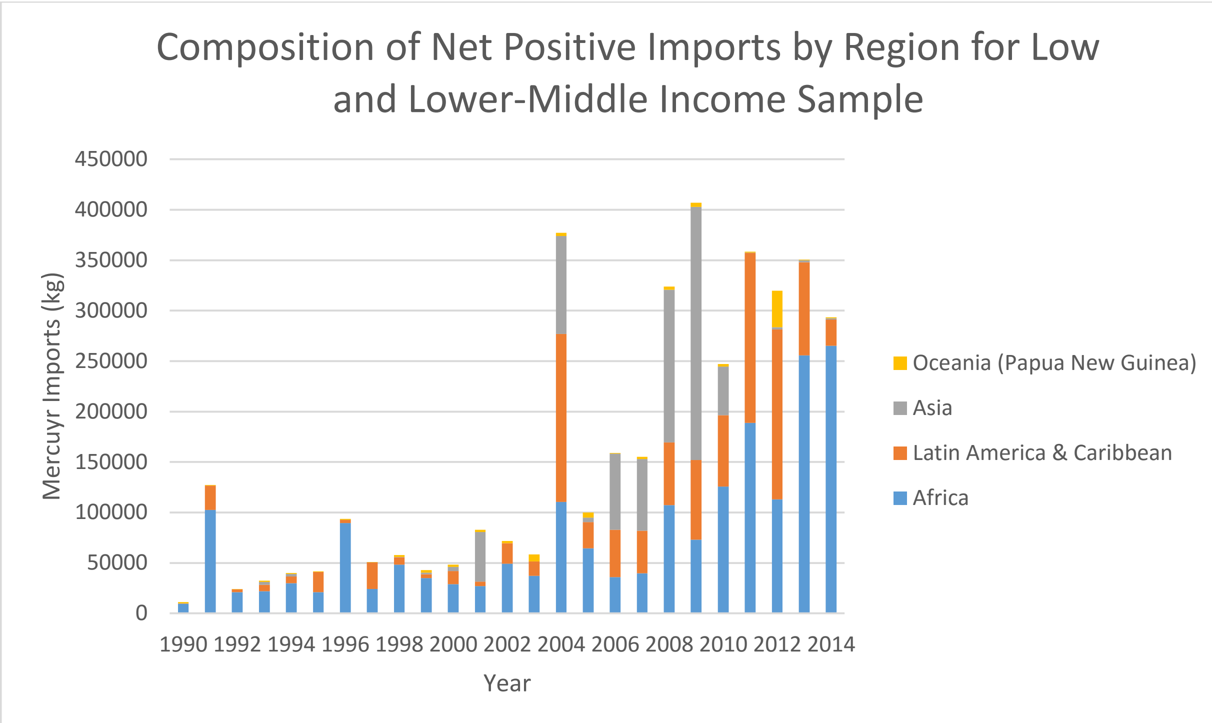
The low and lower-middle income sample contains 490 observation in total. There are 35 countries in the sample with 27 from Africa, 5 from Latin America and the Caribbean, 2 from Asia and only Papua New Guinea from Oceania.

Figure 1.



By observing figure 1, we see that in the low and middle income sample, African countries and Latin American and Caribbean countries see an increasing level of total imports. Asia appears to increase drastically, then diminish between 2000 and 2010. Due to the larger proportion of African and Latin American and Caribbean countries in the sample, there total imports contributes to a large proportion of the sample total each year. The increasing trend is consistent with the Summary of Supply, Trade, and Demand on Mercury report by UNEP.

Figure 2.



The total level of imports for the sample of low and lower-middle income countries does not change drastically from the low and middle income sample.

Figures displaying the distribution of observations are found in Appendix 1, where GDP per capita is plotted against net mercury imports. From observing the figures, we see that there is a greater amount of net mercury imports happening at the lower end of the income spectrum. This is consistent with the ASGM industry supporting a poor population. When focussing on the sample of African countries, the majority of imports occur in the low and lower-middle income bracket where most of the African countries are situated. Latin America and the Caribbean similarly have a higher level of imports occurring at a lower income, although higher than Africa.

Table 1.

Sample	Total Observations	Countries	Mean Income	Mean Net Mercury Imports
Low and Midle Income Countries	618	43	4234.643	7412.319
Low and Lower-Middle Income Countries	490	35	2479.053	7731.541
Africa	366	29	2844.191	5927.328
Latin America & Caribbean	206	10	7074.521	7587.184
Asia	21	3	3226.713	36383.24
Oceania	25	1	2036.942	3376.12

Table 1 displays the mean income and net mercury imports for each sample as well as the specific figures for each region in the sample.

After narrowing the sample to ensure that imports capture mercury consumption as closely as possible, only the regions of Africa, Latin America and Caribbean, Asia, and Oceania remain. The majority of countries in the full sample are from Africa and Latin America and Caribbean. This is consistent with the figure in Appendix 2 figure 2.1 which depicts the estimated levels of anthropogenic mercury emissions in 2010 by sector for each region. The figure shows that in 2010, East and Southeast Asia, South America, Caribbean and Central America, and Sub-Saharan Africa contribute the largest amounts of emissions in 2010. What is apparently missing from my sample is a greater number of East and South East Asian countries. Some of these countries have been omitted due to alternative demands for mercury, such as chlor-alkali production. That said, observing total net imports of mercury in 2010 in figure 1 and 2 above, Asia contributes a significant amount to total imports.

5. Empirical Analysis

5.1. Model

I use an individual-specific effects model with *Net Mercury Imports* as the dependant variable, and *GDP per capita* (PPP) as the independent variable of interest to explore the time-invariant relationship between the two variables. A time dummy is included to capture specific year effects, and individual-specific effects are included to capture country-specific effects.

Let *i* – country, *t* – time (year)

Environnemental Kuznets Curve Model:

$$Environmental\ Indicator_{it} = Country\ Fixed\ Effects_i + Year_t + GDP\ per\ capita_{it}\beta_1 + GDP\ per\ capita_{it}^2\beta_2 + \boldsymbol{X\beta} + \varepsilon_{it} \qquad (1)$$

The model above follows the structure that is commonly found in the EKC literature. Equation 1 states that net mercury imports are quadratic function of GDP per capita. To capture an inverted-U relationship, we would expect that the coefficient on GDP per capita is positive while the coefficient on GDP per capita squared is negative. The turn-around point, as mentioned above, would be found with the equation $\frac{\beta_1}{2*-\beta_2}$ which yields an income level that is associated with the point where pollution begins to decrease. Another common functional form is the cubic function of GDP per capita. The common shape attributed to this cubic function is an N shape relationship found in pollutants such as fecal coliforms in river water; the signs are positive, negative, positive (Shafik, 1994). Control variables are sometimes included as well although GDP per capita remains as the variable of interest. It is common to subsequently add additional regressor while observing the change in the estimated coefficients for GDP per capita.

ASGM Sample Countries with Fixed Effects:

$$Net\ Hg\ Imports_{it} = Country\ Fixed\ Effects_i + Year_t + GDP\ per\ capita_{it}\beta_1 + \varepsilon_{it} \quad (2)$$

$$Net\ Hg\ Imports_{it} = Country\ Fixed\ Effects_i + Year_t + GDP\ per\ capita_{it}\beta_1 + GDP\ per\ capita_{it}^2\beta_2 + \varepsilon_{it} \quad (3)$$

Equation 2 and 3 are applied to the sample of countries. The model is estimated with an additional regressor of $Population_{it}$ in subsequent iterations. For an EKC inverted-U relationship to exist, the coefficients on GPD per capita in equation 3 must be positive for β_1 and negative for β_2. The individual-specific fixed effects indicates a level change. In this case, the shape and therefor the level of income at which mercury emissions begins to decrease is assumed to be the same for all countries.

By looking at the model, it is clear that net mercury imports is used as a proxy for mercury emissions. The nature of panel analysis requires another assumption for net mercury imports to be a proxy for mercury emissions. The equation states that net mercury imports, or mercury emissions, in one year will be partially explained by the GDP per capita function (either linear or quadratic) in the same calendar year. For this to hold, I make the assumption that net mercury imported is consumed and therefor emitted into the environment within the year. This assumption must hold for the additional regressor. That is, net mercury imports must react to a change in population within the same calendar year. This can be relaxed by lagging the regressor.

5.2. Empirical Strategy

The individual-effects models, equations 2 and 3, are applied to the samples containing low and lower-middle income countries with identified ASGM as the demand for mercury. The coefficients are estimated with a fixed effects (FE) model. The primary samples contains the full set of countries as specified above. The FE model is applied first in reduced form with country fixed effects, time dummies, and GDP per capita as a linear function of net mercury imports. Then, GDP per capita is regressed as a quadratic function to test for the EKC. Population is added subsequently for both the quadratic form of GDP per capita.

The FE model is applied using the Newey West method for calculating standard errors corrected for heteroskedasticity and autocorrelation for up to three lags.

A Hausman test is carried out to determine whether the country fixed effects are in fact random. If the individual fixed effects are random, then a random effects (RE) model will provide consistent estimates. The Hausman test compares the coefficient estimates and associated standard errors for FE and RE models. Under the null, the individual effects are random leading to similar estimates because both are consistently estimated with random effects, while under the alternative, the estimates will be different and diverging (Cameron and Trivedi, 2009). The p-value associated with the test was less than 0.10, 0.05, and 0.01 leading me to reject the null of random individual effects. An issue with running a basic Hausman test is that it relies on the RE estimator to be efficient. Results are found in Appendix 3.

Further narrowing of the sample is done due to a common critique in the EKC literature which argues that there lacks a focus of country-specific EKC analysis (Dinda 2004). That is, applying the same inverted-U relationship to a group of diverse countries is suspect. The critique stems from the common practice in EKC literature of running EKC analysis on a single panel composed of multiple panels of a cross-sectional dataset that has been pooled into one. My inclusion of country fixed effects only alters the level of the EKC, not the shape of the inverted-U. Although I do not have a large enough sample to carry out analysis of country-specific or even region-specific EKC. For example, by truncating the full sample into regions, Africa, Latin America and Caribbean, Asia, and Oceania, I examine region-specific EKC and explore how the coefficients on GDP per capita change. I only analyse these two regions in the low and middle income sample due to Oceania and Asia have a small number of observations.

6. Results

The empirical results are found in Appendix 5. Tables 5.1. through 5.4. provide the output for the samples low and middle income countries, low and lower-middle income countries, African countries, and Latin American and Caribbean countries.

The across all samples the general result indicates little support for an Environmental Kuznets Curve when using a FE model. When estimating GDP per capita using the quadratic form, in the low and middle income sample, the coefficients on GDP per capita and GDP per capita squared are positive and negative respectively. The coefficients estimates are 6.726 and -3.037×10^{-4} respectively alluding to a turn-around point at a level of $9979 GDP per capita. When estimated with a FE model with robust standard errors and a FE model with Newey West standard errors, the standard errors are large and remain large when correcting for autocorrelation using the Newey West estimators. The coefficient estimates using the FE model with robust standard errors are both insignificant. The p-value for the joint significance test is 0.258 leading us to accept the null that they are both zero. Using Newey West standard errors, the coefficient for GDP per capita was insignificant, where the coefficient for GDP per capita squared was significant at the 10% level. The coefficient estimates with Newey West standard errors were jointly insignificant with a p-value of 0.178 again leading to a rejection of an EKC. The results are the same with the inclusion of population. Population itself is positive, but insignificant. Both models estimated with GDP per capita as a linear function were positive but insignificant.

The results for the FE model estimations are similarly insignificant for the sample of low and lower-middle income countries. The coefficients on the quadratic form of GDP per capita were 10.382 and -3.843×10^{-4}, but insignificant, indicating a turn-around level of income at $13508 GDP per capita. This level of GDP per capita is larger than the maximum of $6855. One can infer that the countries in the sample are on the upward sloping portion of the EKC. The positive coefficient for the estimated linear GDP per capita model implies the same. Again, the coefficient is insignificant. As are the joint tests for GDP per capita and GDP per capita squared.

The results are equally disappointing when applying the FE model for the subsamples of African countries and Latin American and Caribbean countries. One notable result is that for the subsample of Latin American and Caribbean countries, the coefficient on population enters negatively (-0.00938) and significantly at the 5% level. This says that as population increases by 1000, net mercury imports will decrease by 9.38 kg. This is relatively insignificant amount compared to the mean quantity of net mercury imported of 7587.184. On the other hand, population may be picking up a downward linear trend, while the time effect captures everything else.

Results when using Driscoll and Kraay standard errors are found in Appendix 4. The results indicate the existence of an EKC with high significance for the full sample of low and middle income countries. A turn-around point of about $11000 GDP per capita is found. As detailed in the appendix, these results are suspect.

To the right of the FE model using Newey West standard errors in the table, the Pooled model using Newey West is used. As stated above at the end of the Empirical Strategy section, this method for estimating an Environmental Kuznets Curve as it is defined is often critiqued. The critique is about the assumption made when pooling different countries together. The inclusion of individual-specific effects corrects for the level rather than the shape of the EKC so an estimated peak or turn-around point is assumed to be applicable to all in the sample. There is also the issue of assuming that the error term is not correlated with the regressors. The reason for using a FE model is to relax that assumption. That said, I have included pooled estimation for all samples with and without time-specific effects yielding significant results.

For the full sample of low and middle income countries, GDP per capita in the linear form is not significant, while it is significant in its quadratic form. The coefficients are 2.314 and -1.369×10^{-4}, significant at the 5% and 1% level respectively. This results in a turn-around point of $8451 GDP per capita. The inclusion of time-specific effects and population does not change the results greatly with consistent joint significance at the 5% level. Population is positive and significant at the 10% level although still small. For the low and lower-middle sample of all countries, only GDP per capita as a linear function positively and significantly at the 1% level. It follows that the lower income sample is on the upwards sloping portion of the inverted-U. When focusing on African countries, the model with GDP per capita as a quadratic yielded results significant at the 10% level with a turn-around point at $9268 GDP per capita.

Due to the insignificant results of the FE model, all we can say is that there is a relationship between income and net mercury imports for this particular sample as a whole. This is informative, but does not provide strong evidence for an Environmental Kuznets Curve.

7. Conclusion:

The sample of low income countries with direct use of mercury in the ASGM sector does not appear to exhibit an Environmental Kuznets Curve when using the individual-specific fixed effects model. When panels are pooled, an inverted-U relationship for the full sample of low and middle income countries is found. In an attempt to estimate a more country applicable EKC the sample was truncated into regions, but the results remained insignificant with the FE model.

A critique of the EKC is its ultimate goal to forecast the level of pollution as a country's economy grows. For the EKC to have predictive power, the relationship between economic growth and environmental quality that determined the specific shape of the inverted-U must hold into the future, as economic progress may take time. That is, the mechanisms driving the EKC must have a consistent effect on the EKC through time for all countries in the sample. The benefit of analyzing ASGM is that it is a sector that has remained relatively consistent. Unfortunately, the sample of ASGM still contains a diverse set of countries and a shared EKC does not appear to exist.

Further extensions may include the use GDP per capita of the lower quartile or decile of the population. With respect to the ASGM sector, this may more accurately capture changes in income of the population most dramatically affected by mercury use. The inclusion of gold prices as an additional regressor would be ideally included, as well as the exchange rate, to capture individual countries' mercury import elasticity to gold prices.

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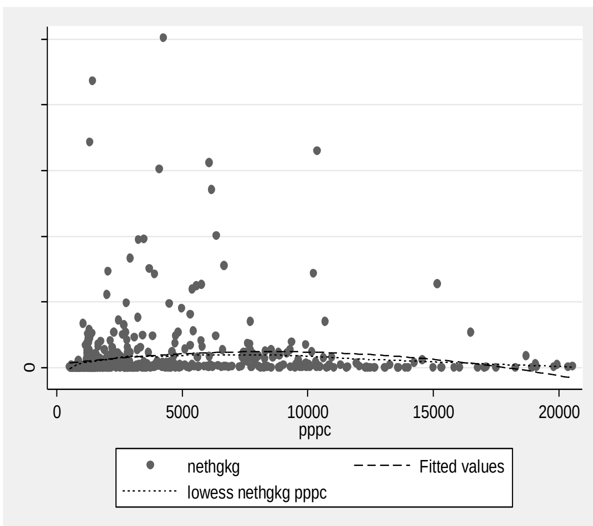
Appendices

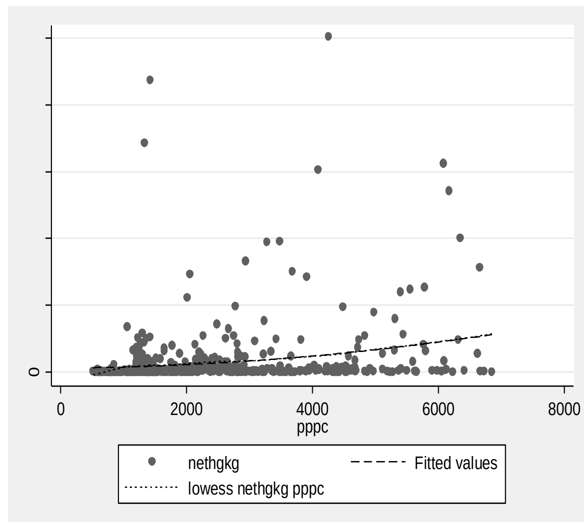
Appendix 1

Net Mercury Imports and GDP per capita

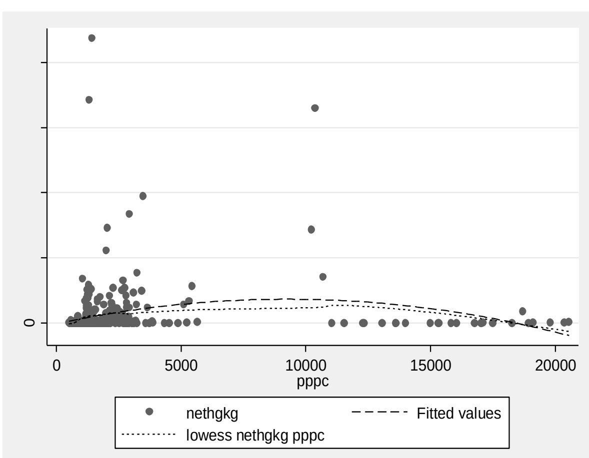
Low and Middle Income Full Sample



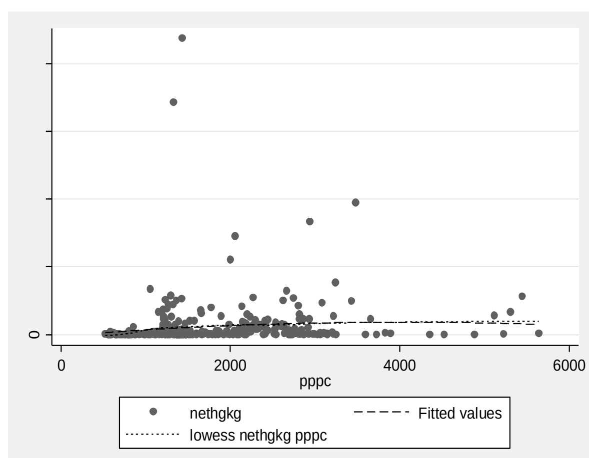
Low and Lower-Middle Income Full Sample



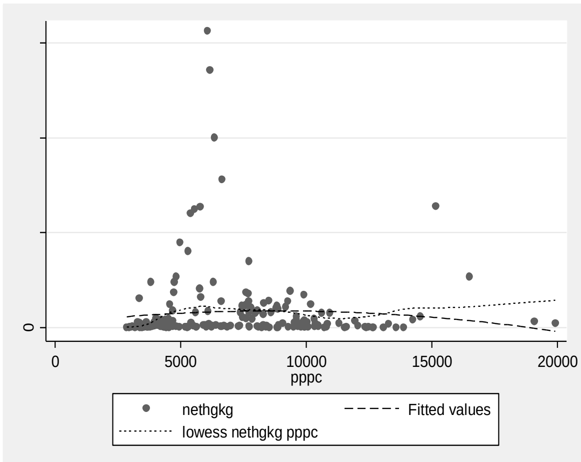
Low and Middle Income Africa



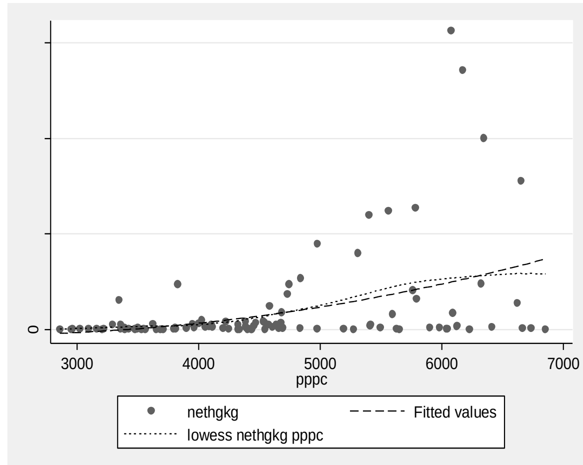
Low and Lower-Middle Income Africa



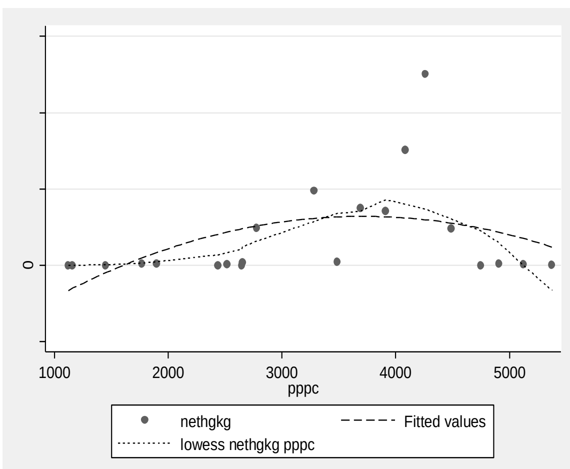
Low and Middle Income L.Amer. & Caribbean



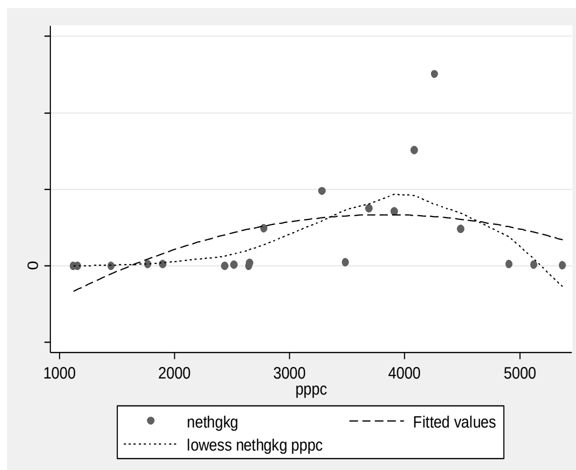
Low and Lower-Middle Income L.Amer. & Caribbean



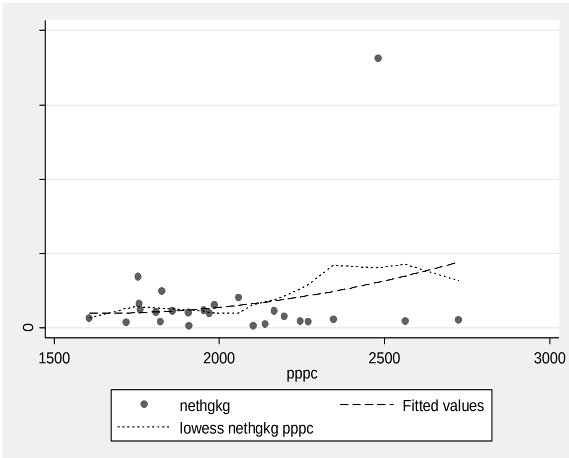
Low and Middle Income Asia



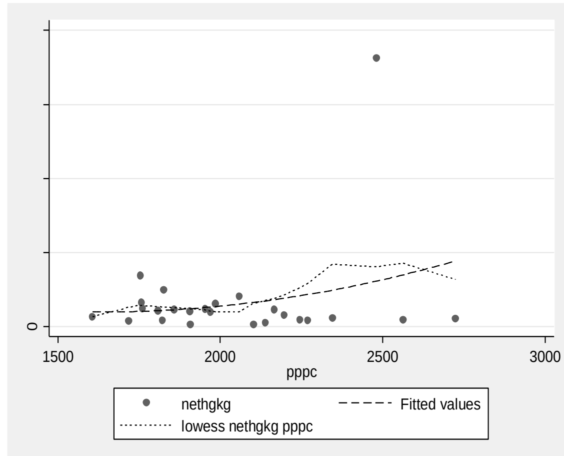
Low and Lower-Middle Income Asia



Low and Middle Income Oceania



Low and Lower-Middle Income Oceania



Appendix 2

Figure 2.1. Anthropogenic Mercury Emission in 2020 by Sector obtained from UNEP. (2013) Global Mercury Assessment 2013: Sources, Emissions, Releases and Environmental Transport

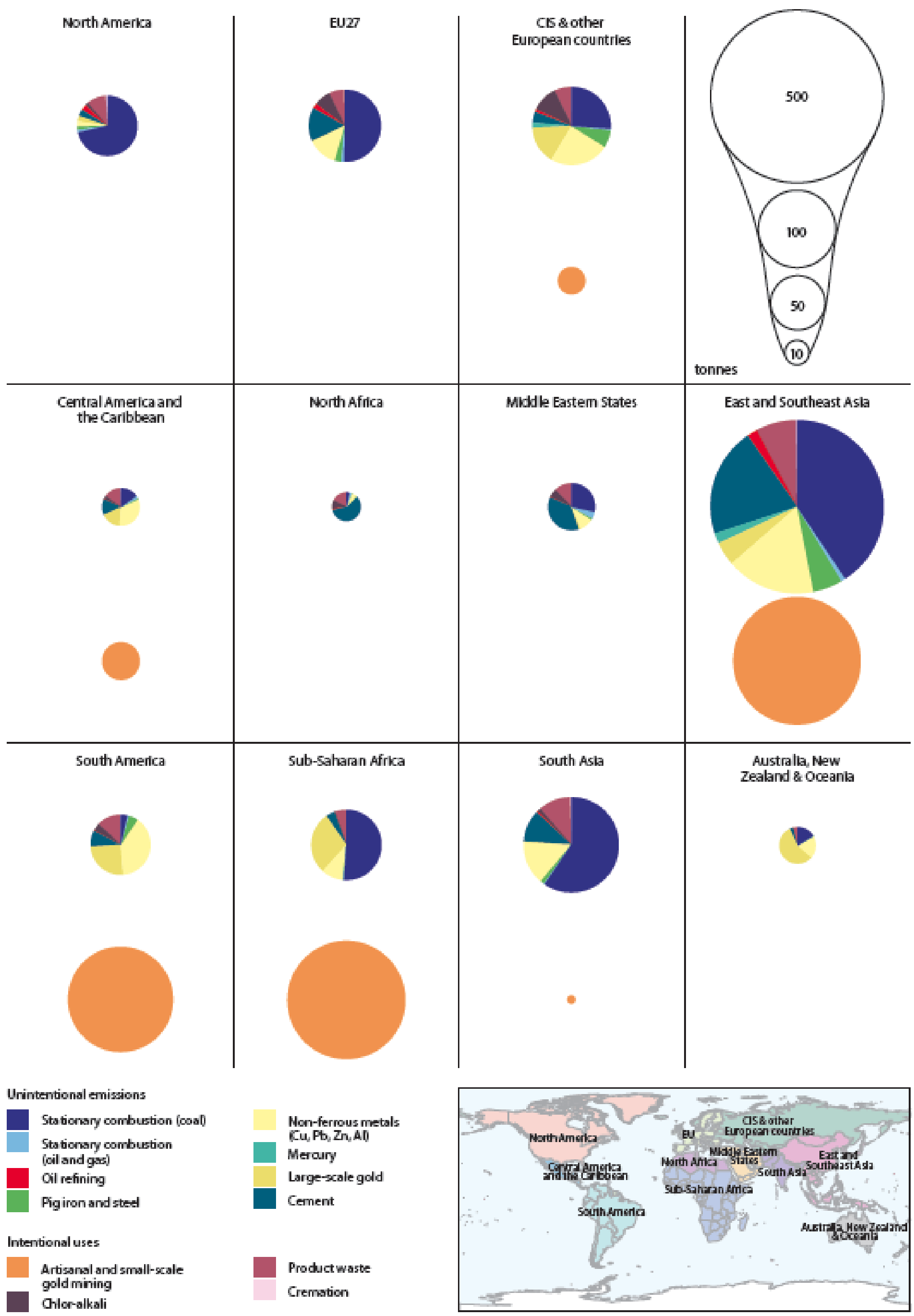
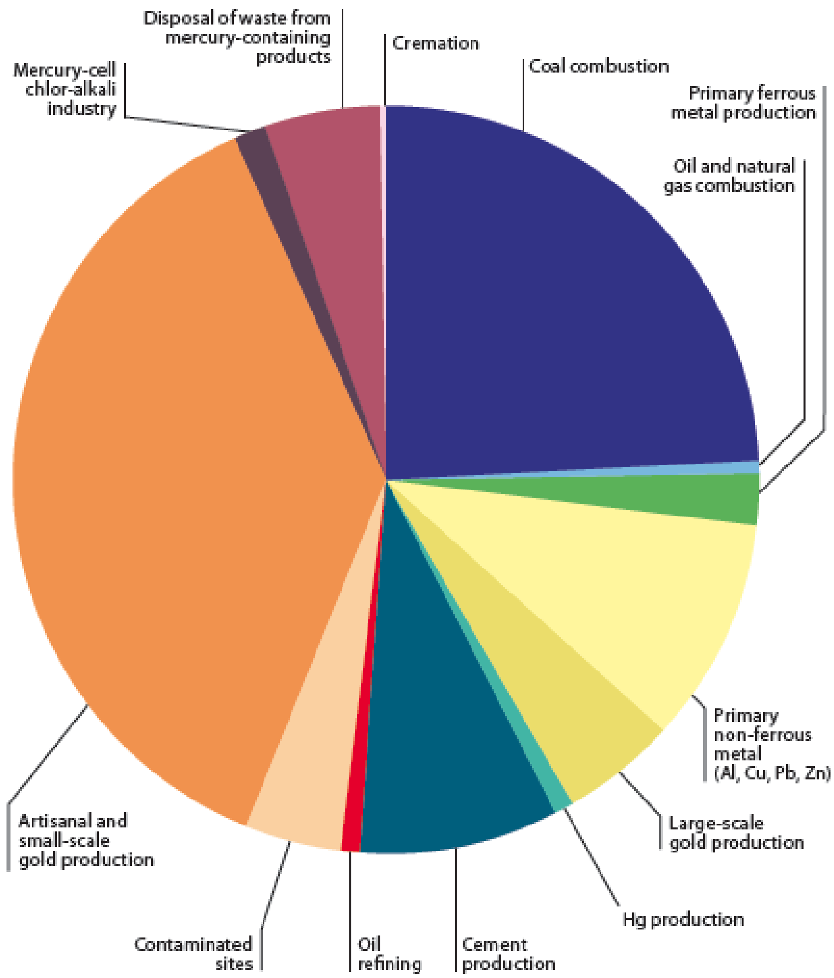


Figure 2.2. Proportion of Anthropogenic Mercury Emissions in 2010 by Sector



Relative contributions to estimated emissions to air from anthropogenic sources in 2010.

Appendix 3

Below are the results for the Hausman Test using low and middle income sample with full set of countries. The result of the test indicates that the RE model is not the correct model to use. From the results, I infer that the FE model will estimates coefficients efficiently. Testing using the low and lower-middle income sample yields the same result. So does removing the time-specific fixed effects.

Table 3.1. Hausman Test Output

Net Mercury Imports (kg)	Coefficients (b) FE	(B) RE	(b-B) Difference	Sqrt(diag(V_b-V_B)) S.E.
GDP per capita	6.726	2.247	4.479377	3.113389
(GDP per capita)^2	-0.0003037	-0.0001397	-0.000164	0.0001162
Year Fixed Effects	-	-	-	-

b = consistent under Ho and Ha; obtained from xtreg

B = inconsistent under Ha, efficient under Ho; obtained from xtreg

Test: Ho: difference in coefficients not systematic

chi2(24) = (b-B)'[(V_b-V_B)^(-1)](b-B)

= 81.49

Prob>chi2 = 0.0000

The null hypothesis, the individual effects are random. I reject the null due to the reported p-value of 0.0000.

Appendix 4

A Pesaran Test was conducted for cross-sectional dependence with a larger sample. The sample was cleaned, but not to the extent of the final samples used in the panel analysis. The test indicated that cross-sectional dependence was likely present. To counter the problem of cross-sectional dependence, the use of Driscoll and Kraay (1998) standard errors for the coefficient estimates was suggested for FE modelling (De Hoyos and Sarafidis, 2006). Unfortunately, the sample I have used to conduct my analysis on is too small to run a Pesaran test and others like it. I have estimated the full sample with Driscoll and Kraay standard errors. This results are suspect due to a lack of testing with the particular sample. The results in table 4.1 below indicate that an inverted-U relationship may exist although the exact shape, or peak, is not clear due to the relatively large standard errors. Based on the coefficient estimates, there is a turn-around point at $11108 GDP per capita. The coefficients on the GDP per capita regressors are significant at the 5% and 1% significance level. The joint significance also indicates that the coefficients on GDP per capita are not zero. The coefficients do not change when using Driscoll and Kraay standard errors if we compare to the FE model with robust standard errors and Newey West standard errors. The standard errors change significantly, almost by half. The validity of these results should be questioned.

Table 4.1. Low and Middle Income Sample: Full Sample with Driscoll and Kraay s.e.

Net Mercury Imports (kg)	FE Model with Driscoll-Kraay s.e.		
GDP per capita	-0.615 (1.176053)	6.665345** (2.754129)	6.067 (3.823377)
(GDP per capita)^2		-3.0×10^{-4}*** (9.41×10^{-5})	-2.749**$\times10^{-4}$ (1.336×10^{-4})
Population			.0001204 (3.000×10^{-4})
Country-Specific Fixed Effects	Yes	Yes	Yes
Time-specific Fixed Effects	Yes	Yes	Yes
P-value Associated with F-Test of GDP & GDP^2 Coefficients		0.0031	0.0241

Standard Errors are in parentheses *p<0.1 **p<0.05 ***p<0.01

Appendix 5

Tables for empirical results below.

Table 5.1. Low and Middle Income Sample: All Countries in Sample

Net Mercury Imports (kg)	FE Model with Robust s.e.			FE Model Using Newey West s.e.			Pooled Using Newey West s.e.					
GDP per capita	-0.664 (1.452)	6.726 (4.279)	6.147 (4.875)	-0.664 (1.182)	6.726 (4.215)	6.147 (4.618)	0.186 (0.232)	2.314** (0.892)	2.449** (0.951)	0.078 (0.257)	2.247** (0.877)	2.380** (0.937)
(GDP per capita)^2		-3.037×10^{-4} (1.816×10^{-4})	-2.792×10^{-4} (1.963×10^{-4})		-3.037×10^{-4}* (1.671×10^{-4})	-2.792×10^{-4} (1.752×10^{-4})		-1.369×10^{-4}*** (4.96×10^{-5})	-1.301×10^{-4}** (5.23×10^{-5})		-1.397×10^{-4}*** (4.99×10^{-5})	-1.337×10^{-4}** (5.26×10^{-5})
Population			1.193×10^{-4} (5.197×10^{-4})			1.193×10^{-4} (3.8×10^{-4})			1.607×10^{-4}* (9.21×10^{-5})			1.365×10^{-4} (8.86×10^{-5})
Country-Specific Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No
Time-specific Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes
P-value Associated with F-Test on GDP & GDP^2 Coefficients		0.258	0.364		0.173	0.205		0.020	0.036		0.018	0.038

Standard Errors are in parentheses *p<0.1 **p<0.05 ***p<0.01

Table 5.2. Low and Lower-Middle Income Sample: All Countries in Sample

Net Mercury Imports (kg)	FE Model with Robust s.e.			FE Model Using Newey West s.e.		
GDP per capita	7.466 (5.400)	10.382 (18.700)	11.666 (15.911)	7.466 (4.834)	10.38248 (13.760)	11.666 (11.845)
(GDP per capita)^2		-3.843×10^{-4} (2.809×10^{-3})	-4.696×10^{-4} (2.5977×10^{-3})		-3.843×10^{-4} (1.9489×10^{-3})	-4.696×10^{-4} (1.8191×10^{-3})
Population			-1.151×10^{-4} (5.252×10^{-4})			-1.151×10^{-4} (3.969×10^{-4})
Country-Specific Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Time-specific Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
P-value Associated with F-Test on GDP & GDP^2 Coefficients		0.223	0.170		0.198	0.209

Net Mercury Imports (kg)	Pooled Using Newey West s.e.					
GDP per capita	3.423** (1.442)	0.330 (4.293)	-0.532 (4.345)	2.808* (1.428)	0.672 (4.281)	-0.177 (4.305)
(GDP per capita)^2		4.867×10^{-4} (7.499×10^{-4})	5.872×10^{-4} (7.915×10^{-4})		3.377×10^{-4} (7.416×10^{-4})	4.554×10^{-4} (7.733×10^{-4})
Population			1.459×10^{-4} (9.41×10^{-5})			1.279×10^{-4} (9×10^{-5})
Country-Specific Fixed Effects	No	No	No	No	No	No
Time-specific Fixed Effects	No	No	No	Yes	Yes	Yes
P-value Associated with F-Test on GDP & GDP^2 Coefficients		0.032	0.075		0.099	0.160

Standard Errors are in parentheses *p<0.1 **p<0.05 ***p<0.01

Table 5.3. Low and Middle Income Sample: Africa

Net Mercury Imports (kg)	FE Model with Robust s.e.			FE Model Using Newey West s.e.			Pooled Using Newey West s.e.					
GDP per capita	-5.141 (5.239)	0.357 (4.016)	-7.394 (9.013)	-5.141 (3.837)	.357 (3.517)	-7.394 (7.435)	0.158 (0.372)	4.065* (2.285)	3.362 (2.892)	0.086 (0.395)	3.333 (2.597)	2.808 (3.200)
(GDP per capita)^2		-2.451×10^{-4} (2.840×10^{-4})	-2.11×10^{-5} (2.928×10^{-4})		-2.451×10^{-4} (1.884×10^{-4})	-2.11×10^{-5} (1.953×10^{-4})		-2.193×10^{-4}* (1.121×10^{-4})	-1.767×10^{-4} (1.475×10^{-4})		-1.819×10^{-4} (1.282×10^{-4})	-1.496×10^{-4} (1.637×10^{-4})
Population			.0005817 (6.776×10^{-4})			.0005817 (5.394×10^{-4})			.0000698 (8.74×10^{-5})			.0000559 (7.8×10^{-5})
Country-Specific Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No
Time-specific Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes
P-value Associated with F-Test on GDP & GDP^2 Coefficients		0.634	0.6548		0.3491	0.4335		0.0172	0.0266		0.1026	0.5667

Standard Errors are in parentheses *p<0.1 **p<0.05 ***p<0.01

Table 5.4. Low and Middle Income Sample: Latin America and Caribbean

Net Mercury Imports (kg)	FE Model with Robust s.e.			FE Model Using Newey West s.e.			Pooled Using Newey West s.e.					
GDP per capita	-0.973 (1.703)	8.235 (7.810)	3.396 (5.117)	-0.973 (1.066)	8.235 (6.434)	3.396 (4.440)	0.017 (0.400)	1.529 (1.178)	1.976 (1.712)	-0.423 (0.589)	2.304 (1.553)	3.307 (2.324)
(GDP per capita)^2		-3.281×10^{-4} (3.15×10^{-4})	-2.14×10^{-4} (1.974×10^{-4})		-3.281×10^{-4} (2.39×10^{-4})	-2.14×10^{-4} (1.673×10^{-4})		-8.7×10^{-5} (8.09×10^{-5})	-1.16×10^{-4} (1.138×10^{-4})		-1.598×10^{-4} (1.101×10^{-4})	-2.303×10^{-4} (1.664×10^{-4})
Population			-0.0093886 (0.007846)			-0.0093886** (0.0043187)			-5.333×10^{-4} (7.096×10^{-4})			-9.55×10^{-4} (8.6×10^{-4})
Country-Specific Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No
Time-specific Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes
P-value Associated with F-Test on GDP & GDP^2 Coefficients		0.591	0.512		0.357	0.193		0.339	0.454		0.334	0.559

Standard Errors are in parentheses *p<0.1 **p<0.05 ***p<0.01