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Investigating the relationship between petroleum product subsidies and particulate matter concentrations: An empirical approach

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ABSTRACT: The aim of this paper is to examine how petroleum product consumer subsidies affect concentrations of the air-pollutant small particulate matter (PM10) through excessive consumption. An empirical cross-sectional approach is adopted to test the hypothesis that petroleum product subsidies increase concentrations of PM10. PM10 is known to cause adverse health effects and previous research show that fossil fuel subsidies are often inefficient and come with adverse economic, social and environmental consequences. Petroleum products, including gasoline, diesel and kerosene, are heavily subsidized. With international oil prices being low, now is a time of opportunity for petroleum product subsidy reform. The subsidization of petroleum products for consumers is not a problem limited to developing countries even though the issues differ in character and in terms of severity. The sample used in this study includes 100 countries, both developing and developed, in 2011. Due to issues of endogeneity in the model, instrumental variables are introduced for petroleum product consumer subsidies and per capita GDP. Our model yields approximately unbiased and consistent estimates. A coefficient of 0.3158 for the natural logarithm of petroleum product consumer subsidies is found to be statistically significant at a 1 % significance level. The practical significance can be discussed, since the model predicts an increase in PM10 concentrations by 0.3158 percentage units from a one percentage unit increase in the billion dollars spent on petroleum product consumer subsidies. However, no threshold of PM10 concentrations without adverse health effects has yet been identified.

Keywords: petroleum product consumer subsidies, fossil fuel subsidies, particulate matter, PM10, subsidy reform

JEL Classification: C21, C26

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1. Introduction

1.1 Background

For decades fossil fuel subsidies have encouraged wasteful spending and harmful emissions. They put a strain on national budgets and international efforts to combat climate change are undermined. Except damaging effects on the environment through emissions and reducing investment available for clean energy, fuel subsidies crowd-out public spending (i.e. on health, education and infrastructure) and benefit mostly highly-income groups.[1] [2] In 2011, the International Monetary Fund (IMF) estimates of pre-tax producer- and consumer subsidies reached $480 billion, which reflects 0.7 % of global GDP. Adjusting for corrective taxation to account for negative externalities of their consumption, the subsidy[3] estimates amounted to $1.9 trillion[4]. In comparison, the total sum of fossil fuel subsidies was more than four times the sum invested in improving energy efficiency globally and over four times the value of subsidies to renewable energy.[5]

Problems with energy subsidies arise in both developed and developing countries although the underlying cause of the problem is somewhat different. In many developing countries, consumer prices are directly controlled by governments, which results in the volatility of

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1 Christopher Beaton et al., "Untold billions: fossil-fuel subsidies, their impacts and their path to reform", *IISD*, (working paper, 21 April 2010), <https://www.iisd.org/gsi/sites/default/files/synthesis_ffs.pdf>, accessed 15

2 Christian Ebeke and Constant Lonkeng Ngouana, "Energy subsidies and public social spending: Theory and Evidence", *International Monetary Fund*, (working Paper No. 15/101, May 2015) <http://www.imf.org/external/pubs/ft/wp/2015/wp15101.pdf>, accessed 15 April 2015.

3 The IMF defines post-tax subsidies as the sum of pre-tax and tax subsidies. Post-tax subsidies are four times larger than pre-tax subsidies, and advanced economies account for 40 % of post-tax subsidies. But post-tax subsidies as a share of gross domestic product are roughly eight times larger in the Middle East and North African regions than in developed countries.

4 Carlo Cottarelli, Antoinette M. Sayeh, and Masood Ahmed, "Energy Subsidy Reform: Lessons and Implications", *International Monetary Fund*, (executive summary, 28 Jan. 2013) <http://www.imf.org/external/np/pp/eng/2013/012813.pdf>, accessed on 25 April 2015.

5 Dave Sawyer and Seton Stiebert, "Fossil Fuels - At What Cost? Government support for upstream oil activities in three Canadian provinces: Alberta, Saskatchewan, and Newfoundland and Labrador", *IISD*, (working paper, Nov. 2010) <https://www.iisd.org/GSI/fossil-fuel-subsidies/fossil-fuels-what-cost>, accessed 28 April 2015.

domestic energy prices being reduced and affecting the state budget instead of the consumer.[6] Governments in developed countries do not set fossil fuel prices and they subsidize fossil fuels to a lesser extent by more sophisticated methods.[7]Apart from inducing fiscal costs for governments another possible economic consequence of fossil fuel subsidies in developing countries is the crowding out of public social spending.[8] Although advanced economies have mostly phased out generalized consumer fossil fuel subsidies that are frequent in the developing world, other forms of subsidization and the under-taxation of fossil fuels in both developing and developed countries is economically inefficient in the sense that it distorts market signals, leading to inefficient resource allocation and a lower long-run economic growth.[9]

Considering the many adverse effects of fossil fuel subsidies, one may wonder why they are still in place. The main reasons concern their definition, polity, transparency and the economy. A fossil fuel subsidy is generally defined as *any government action that lowers the cost of fossil fuel energy production, raises the price received by energy producers or lowers the price paid by energy consumers*.[10] Fossil fuel subsidy programs especially targeted at the poor fall under this classification and even engaged activists for fossil fuel subsidy reform would probably not agree that all of those should be removed.[11] The adverse effects versus any possible benefits can vary a lot between subsidies even though they, by definition, fall in the same category. However, subsidies designed to alleviate poverty frequently fail to meet

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6 David Coady and Baoping Shang, "Energy Subsidies in Developing Countries: Treating the disease while symptoms abate", *VOX*, (published article, 13 Jan. 2015) <http://www.voxeu.org/article/energy-subsidies-developing-countries>, accessed 20 April 2015.

7 Ambrus Bárány and Dalia Grigonytė, "Measuring Fossil Subsidies", *European Commission*, (working paper, March 2015) <http://ec.europa.eu/economy_finance/publications/economic_briefs/2015/pdf/eb40_en.pdf>, accessed 23 April 2015.

8 Ebeke and Lonkeng Ngouana, "Theory and Evidence".

9 Bárány and Grigonytė, "Measuring Fossil Subsidies".

10 Laura Merrill, "Fossil-Fuel Subsidy Reform Mitigating emissions through getting the price right", *Global Subsidies Initiative, International Institute for Sustainable Development*, (working paper, 2014) <https://www.iea.org/media/workshops/2014/cop20/Merrill.pdf>, accessed 23 April 2015.

11 Robert Rapier, "The surprising reason that oil subsidies persist: Even liberals love them", *Forbes*, (published article, 25 April 2012) <http://www.forbes.com/sites/energysource/2012/04/25/the-surprising-reason-that-oil-subsidies-persist-even-liberals-love-them/>, accessed 23 April 2015.

that goal.[12] Coady et al. show that there is substantial leakage of benefits from fossil fuel subsidies to other income groups.[13] [14] On average, the richest 20 % of households in low- and middle-income countries receive six times more in fuel subsidies than the poorest 20 %. In spite of the observed progressivity of fuel subsidies, it is important to note that low-income groups are vulnerable to the removal or decrease of such subsidies and reforms should be carefully evaluated before executed.

The politics surrounding fossil fuel subsidies represent another important reason for their persistence. Attempts of removal of the consumer subsidies often face political resistance. In multiple occasions subsidy reforms have resulted in, sometimes violent, protests by the public.[15] Governments in resource-rich countries are subject to political pressure by the public to share the country's endowments with its inhabitants.

Regarding transparency, current overview of the magnitude of fossil fuels is insufficient. It is necessary to develop an accurate image of the level and nature of global fossil fuel subsidies in order to enable further and more valid research of their impacts and facilitate monitoring of the development towards or away from de-subsidization.[16] David Victor's work on fossil fuel subsidies, *The Politics of Fossil Fuel Subsidies*, points out the importance of transparency and more public information and how this will help broaden public support and enable successful subsidy reforms.

Due to the energy intensity in the process of industrialization and growth, many developing countries see fossil fuel subsidies as a mean to encourage economic activity. Worry of decreasing economic activity and a lowered GDP is another counter-argument for

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12 Beaton et al., "Untold billions: fossil-fuel subsidies, their impacts and their path to reform".

13 David Coady et al., "Petroleum product subsidies, costly, inequitable, and rising", *International Monetary Fund*, (working paper, 25 Feb. 2010) <https://www.imf.org/external/pubs/ft/spn/2010/spn1005.pdf> accessed 5 May 2015.

14 Javier Arze del Granado, David Coady, and Robert Gillingham, "The unequal benefits of fuel subsidies: a review of evidence for developing countries", *International Monetary Fund*, (working paper, Sep 2010) <http://www.imf.org/external/pubs/ft/wp/2010/wp10202.pdf>, accessed 15 April 2015.

15 Richard Anderson, "Fossil fuel subsidies growing despite concerns", *BBC*, (electronic article, 29 April 2014) <http://www.bbc.com/news/business-27142377>, accessed 18 April 2015.

16 Beaton et al., "Untold billions: fossil-fuel subsidies, their impacts and their path to reform".

governments to remove fossil fuel subsidies and a factor that further increases public resistance. However, the research findings regarding the removal of fossil fuel subsidies and its aggregate effects on GDP in OECD and non-OECD countries agree that the relationship is positive. Even with those findings in mind, worry about decreases in GDP from subsidy removal might not be unfounded. Some single country modelled and empirical analyses indicate a slight short-term decline in economic output.[17] The prioritizing of short-run economic output, together with the definition aspect previously discussed, is probably the most explanatory reasons subsidies are persistent in the developed countries as well as the developing ones. A discussed topic in environmental economics is naturally the relationship between environmental quality and economy. A frequently used hypothesis regarding this relationship is that of the Environmental Kuznet's curve which implications will be presented and discussed in the literature review of this thesis.

A probable consequence of fossil fuel subsidies universal in all countries, irrespective of development status, is air pollution and its effect on human health. As opposed to producer subsidies, consumer subsidies encourage excessive consumption of energy. The current high levels of fossil fuel consumer subsidies (in both absolute and relative terms) favour the use of fossil fuels. Fossil fuel combustion is known to be a major contributor to air pollutants. In recent years awareness about particulate matter as the component of air pollution that affects more people than any other pollutant has reached consensus.[18] There is a close relationship between increased mortality and high exposure to concentrations of small particles (particulate matter of 10 microns in diameter or less, denoted PM10). An increase of 10 μg/m3 in PM10 is estimated to increase daily mortality by 0.2 – 0.6 %.[19] Particulate matter also seems to be the air pollutant most closely related to increased cancer frequency,

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17 Beaton et al., "Untold billions: fossil-fuel subsidies, their impacts and their path to reform".

18 Regional Office for Europe Joint WHO/Convention Task Force on the Health Aspects of Air Pollution and World Health Organization, "Health risks of particulate matter from long-range transboundary air pollution", *World Health Organization*, (working paper, 2006) <http://www.euro.who.int/__data/assets/pdf_file/0006/78657/E88189.pdf>, accessed 15 April 2015.

19 World Health Organization and Regional Office for Europe, "Health Aspects of Air Pollution with Particulate Matter, Ozone and Nitrogen Dioxide", *World Health Organization*, (working paper, 15 Jan. 2003) <http://www.euro.who.int/__data/assets/pdf_file/0005/112199/E79097.pdf, accessed 15 April 2015.

especially lung cancer[20] and exposures from human sources is expected to lower average life expectancy by 8,6 months. In the European Union PM10 concentrations in most cities are in line with the WHO Air Quality Guidelines of 20 μg/m^3 as an annual mean of PM10.[21] [22] The exposure in fast-developing countries are however often far higher than in developed countries.

Outdoor air pollution was expected to cause 3,7 million premature deaths worldwide in 2012, 88 % of these occurred in low- and middle-income countries. It is estimated that deaths related to air pollution can be cut by around 15 % if particulate matter (PM10) pollution is reduced from 70 to 20 micrograms per cubic metre (μg/m).[23]

The International Monetary Fund (IMF) estimated that the petroleum product consumer subsidies amounted to ca 50 % of total fossil fuel subsidies in 2011. Being the most heavily subsidized fuel, we deem it to be of interest to assess the relationship between petroleum product consumer subsidies and the level of PM10 concentrations in the air. Considering the currently low oil prices, this is a time of opportunity for many countries to go through with petroleum product subsidy reform. Gathering public support is easier than in times when the immediate threat of high international oil prices being passed through, and fiscal costs are lower. As the oil price increases the strains on the government budgets will tighten and the public's grip of their wallet might as well, decreasing the likelihood of success in attempted reforms.[24]

1.2 Previous Research

One of few studies available that considers the impacts of product consumer subsidies on PM10 is *What are the effects of fossil fuel subsidies on growth, the environment and*

[20] World Health Organization and Regional Office for Europe, "Health Aspects of Air Pollution with Particulate Matter, Ozone and Nitrogen Dioxide".
[21] The European commission reports the somewhat higher 40 μg/m3 as a directive limit value for PM10.
[22] World health organization, "Ambient (outdoor) air quality and health", *World Health Organization*, (fact sheet, March 2014) < http://www.who.int/mediacentre/factsheets/fs313/en/>, accessed 3 April 2015.
[23] WHO, "Ambient (outdoor) air quality and health".
[24] Coady and Shang, "Energy Subsidies in Developing Countries: Treating the disease while symptoms abate".

inequality?.[25] In relation to our paper, this one investigates if and how fossil fuel subsidies cause negative environmental externalities. When the dependent variable is the natural logarithm of PM10 the coefficients of gasoline- and diesel subsidies are positive and significant at a 5 % significance level. The results indicate a 0.06 % increase in PM10 concentrations (μg/m) from a one dollar increase in per litre gasoline subsidy and a 0.05 % increase in PM10 concentrations resulting from a one dollar increase in per litre diesel subsidy. When using instrumental variables, only gasoline subsidies are significant (5 %) with the coefficient being 0.1163. As in other studies considering the area of subsidies, some issues regarding the subsidy estimates are commented on.[26]

Despite the evidence of potential severe health effects from PM10, scarce public resources in developing countries have limited their monitoring of particulate matter. Thus, some policymakers in developing countries remain uninformed about their residents exposure to PM10. The study *Air Pollution in World Cities (PM10)* attempts to decrease this information gap by predicting PM10 levels using the The Global Model of Ambient Particulates (GMAPS), using data from the World Health Organization and other reliable sources. The study find the main causes of PM10 to be the scale and structure of economic activity, the energy mix, the strength of local pollution controls and geographic and atmospheric conditions that affect pollutant dispersion in the atmosphere.[27] Further, the United Nations provides case studies of several countries in a report using local Air-Pollution modelling, Global Climate Change Modelling and Natural Resource Depletion.[28] The relationship generally established between energy subsidies and PM10 is positive. Among others, the countries included in the report are Iran, Chile and Indonesia. In the case study of Chile where the particular relationship between petroleum product consumer subsidies and PM10 is

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25 Christopher J. Holton, "What are the effects of fossil-fuel subsidies on growth, the environment, and inequality?", MSc thesis (The University of Nottingham, 2012), p. 60.

26 Holton, "What are the effects of fossil-fuel subsidies on growth, the environment, and inequality?".

27 David R. Wheeler et al., "Air pollution in world cities (PM10)", *The World Bank*, (published paper, 2006) <http://econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTRESEARCH/0,,contentMDK:20785646~pagePK:64214825~piPK:64214943~theSitePK:469382,00.html>, accessed 2 May 2015.

28 Igor Bashmakov et al., "Energy subsidies: lessons learned in assessing their impact and designing policy reforms", *The United Nations Foundation*, (working paper, 2003) <http://www.unep.ch/etu/publications/energySubsidies/Energysubreport.pdf>, accessed 14 April 2015.

assessed, the findings indicate that when a direct subsidy is removed, the level of PM10 decreases with 4.7 % due to consumers switching to less polluting fuels.

In spite of the shortage of investigation of the particular relationship we are interested in, research undertaken that is related to our research question can provide us with valuable knowledge and a foundation on which to build our empirical model.

Transport has been deemed to be a large contributor to PM10 levels in the air due to fuel combustion and coarse dust particles stirred up by vehicles on, in particular, paved roads [29] The *Study on the Particulate Matter PM10 composition in the atmosphere of Chillán, Chile* measures the concentration of PM10 in urban sites of the city Chillán. It is concluded that the urban traffic is the most essential source to the higher concentrations of PM10 in the downtown areas.[30] Their chemical analysis show that carbonaceous substances is one of the most abundant components of PM10 together with crustal material.

Another study; *Macroeconomic factors for sustainable growth: Analytical framework and Policy Studies of Brazil and Chile*, uses the ECOGEM model to analyze emission taxes on PM10 which is shown to lead to reductions in the emissions of other pollutants as well. They continue by investigating the impact of raising fuel taxes until a 10 % decrease in PM10 ug/m3 is reached. The authors find that an increase in fuel VAT and corporate taxes by 150 % is needed to reduce PM10 levels by approximately 10 %. It should be noted that the ECOGEM model has some data limitations that should be overcome in order to improve its analytical capabilities. Nevertheless, these results indicate a rather inelastic demand for fossil fuels. Related to our work, this implies that we should expect a low coefficient of petroleum product consumer subsidies.

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[29] Dennis R. Fitz and Charles Bufalino, "Measurement of PM10 emission factors from paved roads using on-boards particle sensors", MSc thesis (University of California, 2004), 18.

[30] Jose E. Celis Hidalgo, "A study of the particulate matter PM10 composition in the atmosphere of Chillán, Chile", *Chemosphere*, 02 (published work, 2004), <http://www.researchgate.net/publication/9038282_A_study_of_the_particulate_matter_PM10_composition_in_the_atmosphere_of_Chilln_Chile>, accessed 5 May 2015.

Since our study is of how petroleum product consumer subsidies affect PM10 levels through the mechanism of increased petroleum product consumption, we are interested in research on the price elasticity of demand of these products. A study summarizing price elasticities suggest price elasticities to range between nearly zero and -0.25 (short-term) and between -0.21 to -0.86 (long-term).[31] Based on a review of 124 developed and developing countries, a range of values are estimated for the demand price elasticity - between -0.11 and -0.33 for gasoline, and between -0.13 and -0.38 for diesel. Long-run price elasticities are estimated to be larger than those found for the short-term.[32] For developed countries, mean price elasticity for fuel consumption is found to be ranging from -0.25 (short run) to -0.64 (long run).[33] Thus, the demand for oil seems rather inelastic and very inelastic in the short-run which is intuitive. Intuitive a priori reasoning predicts these elasticities to be low since there are few direct substitutes for oil.[34] Intuition can also explain why the short-term elasticities are lower than the long-term elasticities and why country studies on- or including developing countries yield larger price inelasticities. Mileage is typically likely to be more price-responsive in developing countries.[35]

Various researchers have studied emissions of other air pollutants than PM10 and their potential relationship with fossil fuel subsidy reform. Most of the research regards greenhouse gases and C02 in particular. *The Environmentally harmful subsidies: Barriers to sustainable development* by David Pearce concludes that the removal of fossil fuel subsidies would give

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31 John C. B. Cooper, "Price elasticity of demand for crude oil: estimates for 23 countries", *Organization of the Petroleum Producing Countries*, (published paper, March 2003) <http://15961.pbworks.com/f/Cooper.2003.OPECReview.PriceElasticityofDemandforCrudeOil.pdf>, accessed 10 May 2015.

32 Carol Dahl, "Measuring global gasoline and diesel price and income elasticities", (working paper, Colorado School of Mines, 2012).

33 J. Dargay, M. Hanly and P. Goodwin, "Elasticities of road traffic and fuel consumption with respect to price and income: a review", *Transport Reviews*, 24(3), 275-292 (published work, 2004), accessed 15 May 2015.

34 U.S. Energy Information Administration, "Oil crude and petroleum products", *U.S. Energy Information Administration*, (electronic article, 21 April 2015) <http://www.eia.gov/energyexplained/index.cfm?page=oil_home>, accessed 25 April 2015.

35 J. Rogat, "The determinants of gasoline demand in some Latin American Countries", (working paper, Technical University of Denmark, 2001).

results that far exceed what the Kyoto Protocol would deliver.[36] Research on the subject of fossil fuel combustion and its effects on air quality has been carried out by several influential institutions. Estimates from the IEA's 2010 World Energy Outlook indicate that an absolute removal of fossil fuel consumption subsidies could reduce CO2 emissions by 5.8 % by 2020. In a joint report from 2010 (IEA, OPEC, OECD and the World Bank) the global greenhouse gas emissions was estimated to decrease by 10 % by 2050 if fossil fuel subsidies were phased out. In 2013, using their own estimates of tax-inclusive subsidies, the IMF reported that raising energy prices to levels eliminating these would reduce CO2 emission by 4.2 billion tons and SO2 emissions by 10 million tons. A 13 % reduction in other local pollutants is also predicted.[37] These local pollutants are undefined in the report but can be assumed to include PM10. The most recent estimation comes from a new report by the Nordic Council of Ministers and the Global Subsidies Initiative released in february 2015.[38] Using IEA subsidy estimates their prediction is that the removal of fossil-fuel subsidies to consumers and to society could reduce global greenhouse gas (GHG) emissions by between 6 - 13 % by 2050.

1.2.1 Economic aspects and the Environmental Kuznet's Curve

Previous research has shed light on economic consequences of fossil fuel subsidies. With significant variation in magnitude, a review of six modelling and empirical studies on the effect of fossil fuel subsidy removal on GDP show that the studies yield similar results. The results indicate that the effect of subsidy reform is positive in both OECD and non-OECD countries. Broken down into blocks, the results for the two country groups were similar and increasing.[39] Findings of Burniaux et al uncover significant GDP or real-income declines in some non-OECD countries. Some single country modelled and empirical analyses also

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[36] David Pearce, "Environmentally harmful subsidies: barriers to sustainable development", (working paper, *University College London and Imperial College London,* 2002), 18.

[37] Cottarelli, M. Sayeh, and Ahmed, "Energy Subsidy Reform: Lessons and Implications", *International Monetary Fund*.

[38] Laura Merrill, "Fossil fuel subsidy reform can reduce greenhouse gas emissions globally by 6-13 %", *Global subsidies initiative*, (working paper, 10 Feb. 2015) <https://www.iisd.org/gsi/news/fossil-fuel-subsidy-reform-can-reduce-greenhouse-gas-emissions-globally-6-13>, accessed 1 May 20.

[39] Beaton et al., "Untold billions: fossil-fuel subsidies, their impacts and their path to reform", *Global Subsidies Initiative*.

indicate a slight short-term decline in economic output as a result of fossil fuel subsidy reform. However, aggregate effects on GDP in OECD and non-OECD are found to be positive.[40]

The paper *Energy Subsidies and Public Social Spending: Theory and Evidence* by IMF investigates whether high-energy subsidies and low public social spending can emerge from a political game between the elite and the middle-class. They implement a cross-section analysis of low-income countries and emerging markets and address the possible simultaneity bias in the OLS estimators that occurs when subsidies and social spending are jointly determined in budget planning. They account for this endogeneity by using IV estimations and find that public expenditures on education and health are on average 0.6 percentage points of GDP lower in countries where energy subsidies were one percentage point of GDP higher.[41]

Environmental quality and its relationship with GDP is hypothesized to be U-shaped by the Environmental Kuznets curve. Derived from the original Kuznets curve of economic inequality, it has been a standard feature in environmental economics research since 1991.[42] The theory of the EKC is that market forces initially decreases environmental quality but at a certain level of income, the environmental quality start to increase. This inverted U-shape is explained by a higher demand for environmental quality at higher income levels and a structural shift away from a dominance of the manufacturing industry as income increases. However, the theory has been strongly contested, critics meaning that there are problems of heteroscedasticity, simultaneity, omitted variable bias and co-integration issues when using the EKC. Recent evidence shows that environmental issues are addressed in developing countries, sometimes adopting standards from developed countries with a short time lag and

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40 Jean-Marc Burniaux and Jean Chateau, "Background Report: An Overview of the OECD ENV-Linkages model", *OECD*, (May 2010) <http://www.oecd.org/env/45334643.pdf>, accessed 29 April 2015.

41 Ebeke and Lonkeng Ngouana, "Energy subsidies and public social spending: Theory and Evidence", *International Monetary Fund*.

42 David I. Stern, "The environmental Kuznets curve", *International Society for Ecological Economics*, (working paper, June 2003) <http://isecoeco.org/pdf/stern.pdf>, accessed 28 April 2015.

sometimes performing better than wealthy countries.[43] Arrow et al. (1995) criticize the EKC meaning that it only represents the relationship of economic output with some measures of environmental quality and that. They also argue that if there was an EKC type relationship it might be partly or largely a result of the effects of trade on the distribution of polluting industries. Under free trade the Heckscher-Ohlin theory imply that developing countries specialize in producing goods that are intensive in labor and natural resources since these are factors that they are endowed with. Since developed countries are endowed with human capital and manufactured they will specialize in activities that are intensive in the use of these. A part of this specialization may be reflected in the decrease of environmental deprivation levels in developed countries at the expense of an increase of these levels in middle-income countries[44] by more stringent environmental regulations in developed countries encouraging polluting activities to gravitate towards developing countries.[45] This theory is called the Pollution Haven Hypothesis of which critics mean there is no clear evidence for. A few researchers who have tested this hypothesis recently are Frankel & Rose and Neumayer who find no and weak evidence respectively for the pollution haven hypothesis.[46] Frankel and Rose also look specifically at the relationship between trade and PM10 and find the coefficient to be insignificant. In their study, Frankel and Rose also test the EKC in predicting emissions and find that it is moderately significant in the case of PM10. In addition to the quadratic function they use a spline function of per capita GDP with cut-off points at the 0.33 and 0.66 percentiles. The adverse effect of economic output is found to be highly significant in the low-income range and significant in the high-income range, thus supporting the theory of the EKC. However, the quadratic specification is far more common in the literature and thus more useful for comparison with previous studies. Frankel and Rose argue that it is less arbitrary than the spline function in its cut-off points, more sparing in degrees of freedom and thus probably better.

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43 David I. Stern, "The rise and fall of the environmental Kuznets curve", *World Development*, (Volume 32, Issue 8, August 2004), 21.

44 Stern, "The environmental Kuznets curve", *International Society for Ecological Economics*.

45 Ibid.

46 Jeffrey A. Frankel and Andrew K. Rose, "Is Trade Good or Bad for the Environment? Sorting Out the Causality", *The Review of Economics and Statistics*, (Voulume 87, No.1, Pages 85-91, February 2005).

1.3 Purpose

Qualitative and quantitative research on the subject of subsidies on carbon emissions has found negative effects on the environment and socio-economic parameters such as health, education and infrastructure. However, to our knowledge, large scale multi-country quantitative research on the direct impact of fossil fuel subsidies on particulate matter is scarce. The reason might be the insufficiency of data.

Building on previous research, the purpose of this paper is to examine how petroleum product consumer subsidies affect the level of particulate matter (PM10) in the air through the mechanism of excessive energy consumption. We chose petroleum product consumer subsidies as our independent variable because the majority of fossil fuel subsidies tend to go to oil (petroleum) products rather than coal and gas.[47] Choosing to look at petroleum product subsidies was also a matter of data availability. Since the health effects of exposure to PM10 are proven to be severe and more pernicious than any other air pollutant, we deem it to be of importance to identify and assess its relationship with petroleum product consumer subsidies. As the economic theory of subsidies state, a subsidy of a good changes its price and therefore the amount of its consumption. Petroleum product subsidies encourage the use of petroleum in energy production and transport etc., and combustion of petroleum is proven to be a major source of PM10. Although intuition therefore argues that there is a significant relationship between petroleum product subsidies and PM10, the lack of empirical assessments of the existence of such a relationship and its magnitude constitutes a void in current research.

By attending to this void, the purpose of this study is to cater to the information needs for policy making. Research by the Global Subsidies initiative (GSI) show that one of the most essential ingredients for a fossil fuel subsidy reform to be successful is building support from the public by communication.[48] Informing the public by employing policies and first-stage

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[47] Beaton et al., "Untold billions: fossil-fuel subsidies, their impacts and their path to reform", *Global Subsidies Initiative*.

[48] Global Subsidies Initiative and International Institute for Sustainable Development, "Supporting countries to reform fossil-fuel subsidies", *Global Subsidies Initiative*, (published article, 2015) <http://www.iisd.org/gsi/supporting-countries-reform-fossil-fuel-subsidies>, accessed 19 April 2015.

communication strategies is crucial to diminish the risk of political resistance when reforming fossil fuel subsidies.

Regarding international agreements on air pollution, the widely recognised game theoretician Scott Barrett argues that agreements on specific gases and pollutants are more likely to be effectively enforced than a comprehensive one for all.[49] Which is another reasons we should gain more knowledge about causes of specific pollutants. He also highlights the importance of full participation of countries in order to achieve an effective climate agreement. One of the reasons the U.S. complied to the Montreal Protocol (on substances that deplete the ozone layer) was the results of a study by the Environmental Protection Agency presenting estimates that a continuation of the growth of CFC at 2.5 % a year until 2050 would cause an additional 150 million skin cancer cases, resulting in more than 3 million deaths in the U.S. population born before 2075.[50] Clearly, evidence of adverse health effects can affect policy decisions regarding consumption of their source. Even though developed countries often provide better healthcare than developing countries, no one can escape air pollution. With this in mind we aim for this investigation to contribute to the current knowledge by unveiling the relationship between petroleum product subsidies and PM10. We hope that our results can serve as comparative measures for previous and further studies in this field.

[49] Jorge Salazar, "Scott Barrett on crafting a successful climate agreement in Copenhagen", *Earthsky*, (published article, 30 Nov. 2009) <http://earthsky.org/earth/scott-barrett-on-crafting-a-successful-climate-agreement-at-copenhagen-climate-summit>, accessed 2015-04-03).

[50] Peter M. Morrisette, "The Evolution of Policy Responses to Stratospheric Ozone Depletion", *Natural Resources Journal*, (Volume 29: 793-820, 1989) <http://www.ciesin.org/docs/003-006/003-006.html>, accessed 24 April 2015.

2. Research focus

This paper seeks to untangle the relationship between petroleum product subsidies and PM10. Thus, our research question is the following:

Is there a significant relationship between petroleum product subsidies and PM10 concentrations? If so, what are the characteristics of this relationship?

As a basis for the formulation of our hypothesis we consider the following:

1) As according to the economic theory of subsidies, subsidies increase the demand for fossil fuels, resulting in higher quantities of fossil fuels consumed. This larger amount consumed increase fossil fuel combustion contributing to increased levels of PM10.[51]

2) With respect to price, demand for oil is relatively inelastic. The lack of few direct substitutes for oil can serve as an explanation for this.[52] Previous research suggests that consumers are generally more price-responsive in developing countries. Due to the low price elasticity of demand for oil, we expect a modest change in consumption, and thus PM10 concentrations, from a change in the spending on petroleum product subsidies.

4) Given the right institutions, public demand for environmental quality as a result of economic growth can translate into environmental regulation at higher levels of income per capita. The reason for this is people's increased tendency to include environment as well as GDP when valuing their standard of living. The causal relationship between effective environmental regulations on a cleaner environment is assumed to be well-established.

3) A theory that we will test in our study is the Environmental Kuznets curve (EKC). Economic growth increases air pollution at the initial state of industrialization. As mentioned in 3), the demand for environmental quality is assumed to increase as income grows. The

[51] Holton, "What are the effects of fossil-fuel subsidies on growth, the environment, and inequality?".
[52] U.S. Energy Information Administration, "Oil crude and petroleum products".

EKC hypothesize that this demand together with a structural industry shift from manufacturing to services[53] and the development and use of cleaner technologies[54] is predicted to decrease air pollution at higher levels of GDP. We will investigate the applicability of this theory to our model.

With this background, our main hypothesis could be stated as follows:

Petroleum product consumer subsidies increase concentrations of small particulate matter

53 Rachel A. Bouvier, "Air pollution and per capita income", *Political economy research institute*, (working paper seriers, No.84, June 2004) <http://www.peri.umass.edu/fileadmin/pdf/working_papers/working_papers_51-100/WP84.pdf>, accessed 9 April 2015.

54 Stern, "The environmental Kuznets curve", *International Society for Ecological Economics*.

3. Method

Our study will be conducted empirically using a cross-sectional approach. Starting out with observations for 169 countries in our sample, these observations are scaled down to 100 observations in the empirical model we use as a consequence of missing values in our independent variables. The cross-section covers the year 2011 and provides a snapshot of the relationship between current fossil fuel subsidies and levels of PM10 that particular year. The countries included in the study form a balanced mix of both developing and developed countries. We deliberately include both groups to investigate the general effect of consumer petroleum product subsidies on PM10 levels since the outcome should be of interest for developing as well as developing countries.

The choice of adopting a cross-sectional approach is based on data availability and a strong indication of low variation in PM10 and subsidies over time, observed using available IEA subsidy estimates of 20 countries over the period 2007 - 2011. The between variation of the variables of interest was significantly larger than the within variation. Given this observation regarding variation, comparing between adding a time dimension to the model using panel data of 20 countries over 5 years and using a sample of cross-sectional data covering 100 countries for one year we chose the second option. The cross-sectional approach is likely to contribute more in explanatory value to our model. In addition, the within variation of the data over time might represent changes in the benchmark price if domestic prices are sticky in the short-run. As stated by Ebeke and Lonkeng (2015), a consequence of this being the case for some countries is that there is a risk of identifying impacts of shocks to energy prices on levels of PM10 instead of identifying the impact of subsidy levels. Worth mentioning is the measurement errors that are likely to be present in the subsidy data, leading to attenuation bias when using country-fixed effects.[55]

[55] Ebeke and Lonkeng Ngouana, "Energy subsidies and public social spending: Theory and Evidence", *International Monetary Fund*.

3.1 Model specification

To investigate the causality of petroleum product subsidies and PM10 we propose the following empirical model:

$$ln(PM10)_i = \beta_0 + \beta_1 ln(petprodsubs)_i + \beta_2 ln(pcGDP)_i + \beta_3 ln(pcGDP)_i^2 + \delta_1 democracy_i + \beta_4 PPSINC_i + \beta_5 ln(sqkmperpop)_i + \beta_6 urbanpop_i + \beta_7 oilrents_i$$

where $ln(PM10)_i$ is the natural logarithm of PM10 concentrations and $ln(petprodsubs)_i$ is the natural logarithm of petroleum product subsidies. Per capita GDP serves as an indication if a country is richer or poorer and implies a richer or poorer government with more or less resources for subsidy spending. Output, measured in per capita GDP, has been proven to be a relevant determinant of PM10 levels in previous research yielding different signs of its coefficient. An increase in output is predicted to increase air pollution through the scale effect. The square of per capita GDP is included to test the applicability of the Environmental Kuznets curve and to account for the composition- and technique effect, which are effects through which the square of per capita GDP is predicted to affect air pollution.[56] The composition effect entails that at higher levels of income, following the theory of Heckscher-Ohlin, the increasing abundance of human capital make countries move from the physical capital-abundant manufacturing industry toward the service industry which is more abundant in human capital. The technique effect reflects the development in technologies at higher levels of income, as a result of human capital formation and the assumed higher environmental quality demand. The Environmental Kuznets curve is presented in the literature review and mentioned in the research focus section of this paper. The bottom line is that the EKC predicts a positive coefficient on per capita GDP and a negative coefficient on squared per capita GDP. In order for the higher demand for environmental quality to translate into effective environmental regulation Frankel and Rose (2005) argue that there is a need for "the right" political institutions. By "the right" institutions, transparent and accountable

[56] Frankel and Rose, "Is Trade Good or Bad for the Environment? Sorting Out the Causality".

institutions are the ones referred to.[57] [58] This brings us to the next control variable in the model: democracy. Polity is a measure of democracy ranging from -10 to 10 and from this variable we generate a variable of democracy when polity takes on a value over 5 since. Values over 5 as a polity measure classifies the country as democratic, according to the Polity IV database and the literature has found significance in democracy's effect on air pollution. Hence, the generated variable democracy will test whether countries being democratic or not has any impact on their levels of PM10, assuming democracy improves the quality of institutions. This causal relationship is rather intuitive since institutions are more likely to be transparent and accountable when corruption is scarce and the power is not concentrated to a few. PPSINC stands for petroleum product subsidy intensity in neighbouring countries. Since the pollutants considered in this study are airborn and according to our hypothesis, petroleum product subsidies increase levels of PM10, small particulate matter caused by average levels of subsidies in neighbouring countries is likely to affect national concentrations of the pollutant. The proposed correlation between energy subsidy intensity in neighbouring countries and national petroleum product subsidies is reinforced by the literature on spatial spill overs in fiscal decisions and subsequent studies.[59]

$ln(petprodsubs)_i$ is included in the model to control for country size and population density. A larger country for example, comes with greater distances to travel within the country, which implies an increase in the distance driven, by vehicles and consequential emissions. If a large number of people share a smaller surface of land concentrations of particulate matter per cubic meter is certainly likely to be higher. In previous research, this variable was found to be significant as a determinant of PM10.[60] We allow for urbanpop, the percent of the population living in urban areas, as a control variable in the model. Economic activities of urban regions are known to be a major source of PM10 and by including this variable, we control for the effect of these. Including urbanpop also controls for the potential

[57] Frankel and Rose, "Is Trade Good or Bad for the Environment? Sorting Out the Causality".
[58] Scott Barrett and Kathryn Graddy, "Freedom, growth, and the environment", *Environment and Development Economics*, (published, Volume 5, Issue 04, pages 433-456, 2000).
[59] Ebeke and Lonkeng Ngouana, "Energy subsidies and public social spending: Theory and Evidence", *International Monetary Fund*.
[60] Frankel and Rose, "Is Trade Good or Bad for the Environment? Sorting Out the Causality".

higher pressure on the government to introduce subsidies. Finally, we control for oilrents as a percent of GDP in the model since a higher natural resource dependency puts higher pressure on the government to share this revenue by for example, subsidizing the people's use of this natural resource. Ebeke and Lonken Ngouana estimates that the extent of energy subsidies in neighbour countries accounts for one quarter of the variation in energy subsidies across countries and for up to half of the variation among the net oil exporters. The reason for taking the natural logarithms of some of the variables is to linearize the model and to account for skewness. These transformation decisions have been made in an orderly fashion based on exploration of the data and will be covered further in the analytical section of this paper.

Considering possible criticism of our control variables, it can be argued that the subsidy intensity in neighbouring countries only captures common shocks affecting countries, but as we control for a range of variables this risk is limited. The risk could be more severe if we would have used yearly panel data, assuming short-run fiscal policy reactions can be triggered by a common oil price shock. An example of a possible policy reaction could be the introduction of subsidies at some level.[61]

3.2.1 Addressing endogeneity in the model

Making a cross-sectional analysis, the need to address potential endogeneity in the model is of great importance to avoid getting biased and inconsistent estimators. We will use instrumental variables (IV) to solve the identified problems of endogeneity and given the characteristics of our data, we estimate the model using two Stage Least Squares (2SLS) with robust standard errors due to the characteristics of the data. This method has been employed in studies with similar data and with research question similar to ours.

[61] Ebeke and Lonkeng Ngouana, "Energy subsidies and public social spending: Theory and Evidence", *International Monetary Fund*.

Democracy, being a proxy for transparent and accountable institutions, could have a causal effect on GDP.[62] To avoid getting distorted as a result of this endogeneity, we use neoclassical factor accumulation variables as instrumental variables for per capita GDP and squared per capita GDP. These variables are often used in the literature as instruments for GDP.[63] In our model, gross capital formation per worker and average education will serve as instruments for GDP.[64] This variable was previously denoted gross domestic investment by the World Bank. In the absence of data on national capital stocks, we use gross capital formation divided by labor force as a proxy for capital stock divided by labor force, the original variables used in the neoclassical growth equations.[65] [66] This variable is denoted capitalformpw. Average years of education in adults over 25 years old will be used as a measure of human capital formation.

There is a possibility that democracy could be endogenous, meaning richer countries tend to be more democratic. However, there are several studies suggesting the causality of that relationship goes from democracy to GDP.[67] [68] Based on this literature, exogenous treatment of the democracy variable in previous similar studies and the fact that GDP is not our primary variable of interest, we do not judge this potential issue to be an obstacle of great importance in our study.

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62 Tang Qinga and Liu Yujieb, "The Study of Relationship between China's Energy Consumption and Economic Development", *Physics Procedia*, (Volume 24, Part A, pages 313-319, 2012).

63 Frankel and Rose, "Is Trade Good or Bad for the Environment? Sorting Out the Causality".

64 The estimate on gross capital formation by the World Bank contains outlays on additions to the fixed assets of the economy plus net changes in the level of inventories. The fixed assets include land improvements, equipment purchases (i.e. plant and machinery) and infrastructure (i.e. construction of roads, railways, schools). Inventories include stocks of goods held by firms to meet unpredictable fluctuations in transactions. Net acquisitions of valuables are also included in capital formation, according to the 1993 SNA.

65 The neoclassical growth model puts stress on capital accumulation and its related decision of saving as an important determinant of economic growth. The model consider two factor production functions with capital and labour as determinants of production. Technology is also added to the production function as an exogenously determined factor.

66 William Easterly and Ross Levine, "It's not factor accumulation: stylized facts and growth models", *World Bank Economic Review*, (Volume 15, Issue 2, pages 177-219, 2001).

67 Qinga and Yujieb, "The Study of Relationship between China's Energy Consumption and Economic Development".

68 Madeeha Gohar Qureshi and Eatzaz Ahmed, "The Inter-linkages between Democracy and Per Capita GDP Growth: A Cross Country Analysis", *PIDE*, (Volume 85, 2012).

Petroleum product consumer subsidy estimates only provide a snapshot of the true magnitude of such subsidies. The estimates are likely to suffer from some measurement errors even though they are carefully calculated by reliable sources. The reasons for these potential measurement errors are mentioned in the data section of this paper. In short, the estimates should be interpreted with caution since it relies on many assumptions in both calculation of pre-tax subsidies and the corrective taxes included in the final tax-inclusive subsidy estimates that are used in this study. Also, our estimated model most probably differs from the true model of PM10 determinants. We have excluded all meteorological and natural sources of PM10. In "National carbon dioxide emissions: geography matters" the author points out the importance of climatic and spatial conditions in determining cross country differences in CO2 emissions since this has an effect on fuel use.[69] Climatic factors are generally not accounted for in the economic literature, and indeed it does not feature in the environmental equation used by Frankel and Rose[70] from which our model is inspired. For the purposes of our model which seeks to isolate the effect of subsidies, it is sufficient to omit such factors and natural PM10 sources from explicit inclusion and to account for their potential correlation with petroleum product subsidies or GDP through instrumental variables.

However, it is possible that we might have omitted other variables correlated with petroleum product subsidies. In order to still attain a consistent estimate of our variable of interest and solve the measurement error issue, we instrument for petroleum product consumer subsidies. The instrument we use is average fiscal deficit/surplus the last five years, denoted avgdefsurp5years. Average results for the previous five year period (2006 - 2011) give an indication of the financial state of the government budget and what fiscal space is available for subsidy spending. Ebeke and Lonkeng Ngouana find a significant negative interaction between fiscal space and energy subsidies, a narrower fiscal space causing energy subsidies to adjust .[71] This instrument fulfils the relevance criteria since it is significantly related to our endogenous variable petroleum product subsidies. We deem the variable avgdefsurp5years to

69 Eric Neumayer, "National carbon dioxide emissions: geography matters", *Area*, (journal article, Volume 36, Issue 1, pages 33-40, 2004).

70 Frankel and Rose, "Is Trade Good or Bad for the Environment? Sorting Out the Causality".

71 Ebeke and Lonkeng Ngouana, "Energy subsidies and public social spending: Theory and Evidence", *International Monetary Fund*.

be exogenous and unlikely to have a relationship with any variable affecting PM10, except with any of those that are already included in the model. Thus, avgdefsurp5years is likely to be a valid instrument for petroleum product subsidies.

4. Data

This chapter will describe the data used in our model. Our primary data sources are the International Monetary Fund (IMF), International Energy Agency (IEA), World Bank and Knoema, consisting of several original sources[72].

We have been able to find sufficient data for the above-mentioned variables for 100 countries in 2011 from these datasets.

4.1 Dependent variable of interest

We have chosen small particulate matter (PM10) as our dependent variable and the data used in the model covers 100 countries. The data is derived from The World Bank (estimates originally from the World Health Organization and supplemented by data from other reliable sources[73]) and measured in micrograms per cubic metre at a country level. The estimates, being urban-weighted PM10 concentrations in populated urban areas with more than 100,000 residents, represent the average annual exposure level of the average urban resident to outdoor particulate matter. The WHO air quality guidelines for PM10 are 20 μg/m3 (micrograms per cubic metre) as an annual mean exposure.[74]

There are different types of PM10 and their impact on human health differs. The particulates referred to in this study are suspended particles less than 10 microns in diameter (μg/m3) that are capable of getting into the respiratory system, causing adverse health effects.[75]

Particulate matter consists of a complex mixture of solid and liquid particles of organic and inorganic substances suspended in the air. Common chemical constituents of PM include sulphate, nitrates, ammonium, sodium, chloride, black carbon, mineral dust and water.

72 Knoema provides access to over 500 databases. We have mostly been using World Bank data provided by Knoema.
73 Wheeler et al., "Air pollution in world cities (PM10)".
74 The World Bank, "Tackling the global clean air challenge", (news release, 26 Sep. 2011) <http://www.who.int/mediacentre/news/releases/2011/air_pollution_20110926/en/>, accessed 1 April 2015.
75 Wheeler et al., "Air pollution in world cities (PM10)", *The World Bank*.

Biological components such as allergens and microbial compounds are also found in the particulate matter. [76]

The particulate matter can either be directly emitted into the air (primary), or formed in the atmosphere from gaseous precursors (secondary). The sources of primary PM include combustion of fossil and solid fuels, other industrial activities and road traffic causing erosion of the pavement. Chemical reactions of gaseous pollutants in the air cause secondary PM. These products are particularly from atmospheric conversion of emissions from traffic and industrial processes but soil and dust re-suspension (mostly during episodes of long-range transport of dust) is also a contributing source of particulate matter.

4.2 Independent variable of interest

Data on petroleum product consumer subsidies as percent of GDP is derived from the IMF report "Energy subsidy reform: Lessons and Implications".[77] In order to get absolute values of the subsidy estimates these values are multiplied with GDP measured in current $US 2011. The data for petroleum product consumer subsidies used in the model covers 100 countries and includes subsidies for gasoline, diesel and kerosene. Responsible for the collection and provision of the data is the IMF staff, the OECD, and Deutsche Gesellschaft für Internationale Zusammenarbeit GIZ.

Consumer subsidies arise when the price consumers pay is below a benchmark price. This method of measuring subsidies is called the price-gap approach which is a method widely

[76] Christoffer Boman et al., "The Role of Particle Size and Chemical Composition for Health Risks of Exposure to Traffic Related Aerosols - A Review of the Current Literature", *Umeå University Hospital*, (7 Dec. 2012) <http://www.researchgate.net/profile/Bertil_Forsberg/publication/242083990_The_Role_of_Particle_Size_and_Chemical_Composition_for_Health_Risks_of_Exposure_to_Traffic_Related_Aerosols_-_A_Review_of_the_Current_Literature/links/0f31752d6f2c061659000000.pdf>, accessed 7 May 2015.
[77] Cottarelli, Sayeh, and Ahmed, "Energy Subsidy Reform: Lessons and Implications", *International Monetary Fund*.

used by researchers.[78] In this case, the benchmark price is the world market price for oil. The price-gap approach quantifies the gap between the international price of oil and domestic prices paid by consumers. The advantage of this approach (as opposed to for example the inventory approach)[79] is that it captures implicit consumer subsidies that do not appear in the government budget. Examples of implicit subsidies are such subsidies provided by oil-exporting countries that offer petroleum products to their populations at prices below those prevailing in international markets.

Petroleum products subsidy estimates used in this study are tax-inclusive. By tax-inclusive, it is meant that the data is made up of pre-tax subsidies and tax subsidies. Pre-tax subsidies arise when domestic prices paid for oil is below the international price adjusted for distribution costs. Similar transport and distribution margins across countries are assumed. Post-tax subsidies are the difference between the international price adjusted for efficient taxation and the domestic consumer price. Adjustment for efficient taxation is included to correct the current taxation of energy for negative externalities of consumption. Such externalities are pollution, road damage and CO2 emissions. Corrective taxes are often referred to as Pigouvian taxes and the ones used in this study are estimated by the IMF drawing on previous studies and a common assumption regarding expected variation of corrective taxes with country income level[80]. The estimates assume that energy products are subject to the economy's standard consumption tax rate (an ad valorem tax) as well as the corrective tax. The basis for these estimates is VAT rates for 150 countries in 2011. The average VAT rate of countries in the region with a similar level of income is assumed for countries lacking data on VAT.

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78 James Cust and Karsten Neuhoff, "The Economics, Politics and Future of Energy Subsidies", *Climate Policy Initiativ Workshop*, (report, posted 21 March 2010) <http://climatepolicyinitiative.org/wp-content/uploads/2011/12/Summary-Report_The-Economics-Politics-and-Future-of-Energy-Subsidies.pdf>, accessed 28 April 2015.

79 Masami Kojima and Doug Koplow, "Fossil fuel subsidies: approaches and valuation", *The World Bank*, (policy research working paper, Vol.1, 23 March 2015) <http://documents.worldbank.org/curated/en/2015/03/24189732/fossil-fuel-subsidies-approaches-valuation>, accessed 2 May 2015.

80 Dirk Heine, John Norregaard, and Ian W.H. Parry, "Environmental Tax Reform: Principles from Theory and Practice to Date", *International Monetary Fund*, (working paper, Vol.12, Issue 180, July 2012) .<https://www.imf.org/external/pubs/ft/wp/2012/wp12180.pdf>, accessed 9 May 2015.

The estimates should be interpreted with caution. Not covering Liquified Petroleum Gas (LPG) and a precautionary methodology in its collection, they are likely to be underestimated. In addition, since the basis of the estimates are prices paid by households and firms at a point in time (average end-of-quarter prices or end-of-year prices), depending on data availability they only provide a snapshot of the true magnitude of subsidies. Due to government transparency issues and an insufficient reporting system of this data, the methods used to estimate the magnitude of fossil fuel subsidies vary and rely on different assumptions. Kojima and Koplow at the World Bank highlight this issue in a very recent publication[81]. However, the IMF estimates construct a broad picture of the magnitude of energy subsidies, are indicative in empirical research and can be used for comparative purposes.

4.3 Control variables

For the data on GDP, we have collected data on GDP (current $US in 2011) from the World Bank. This data represents the sum of gross value added by all resident producers in the economy, all product taxes minus subsidies not included in the value of products. These estimates are calculated without accounting for depreciation of fabricated assets or for depletion and degradation of natural resources. Domestic currencies are converted into current $US in 2011, using single year official exchange rates. An alternative conversion factor has been used for some countries where the official exchange rate does not reflect the rate effectively applied to actual foreign exchange transactions.[82]

The data on GDP is divided by data of total population to get GDP per capita. The data on total population is collected from the World Bank database where the values are midyear estimates counting from all inhabitants regardless of citizenship, except from refugees not

81 Kojima and Koplow, "Fossil fuel subsidies: approaches and valuation", *The World Bank*.

82 The World Bank, "GDP (current US$)", *The World Bank*, (data description, 2015) <http://data.worldbank.org/indicator/NY.GDP.MKTP.CD>, accessed 3 May 2015.

permanently settled in the country of asylum since they are normally considered a part of the population of their country of origin.

Urban population is chosen as one of our control variables. The data is found in the World Bank database where the urban population refers to the share of the population living in urban areas. Originally it is calculated using population estimates from the World Bank and urban ratios from the United Nations World Urbanization Prospects.

The control variable Petroleum Subsidy Intensity in Neighbour Countries (PPSINC) is constructed as the weighted average of petroleum consumption subsidies-to-GDP ratios in all neighbouring countries. More specifically, for each country *i* in the sample, the petroleum subsidy intensity in neighbour countries (PPSINC) is evaluated as the average subsidy intensity in neighbouring countries, measured in billion dollars. For some countries, the measure includes subsidy intensity in countries in the region, even if they are not directly adjacent.

Controlling for country size and population density, square kilometre per total population turns into *sqkmtotpop.*

4.4 Data exploration and transformation of variables

The model we have specified contains the natural logarithms of some of the independent variables. These transformation decisions have been made after exploring the data and in order to fulfil the normality and linear assumption of multiple linear regressions.

Starting out, judging from matrix graphs, the data seem to have problems fulfilling the classical linear model assumption of the model being linear in parameters (MLR.1). To make adjustments in the variables, by for example transforming them or removing outliers, we need to explore the data. We start by looking at our main variables of interest; PM10 and petroleum product subsidies. The relationship between dependent variable PM10 and petroleum product

subsidies (denoted petprodsubs) contains outliers and does not seem to fulfil the linear assumption. The countries with the highest level of petroleum subsidy spending are the rich countries Saudi Arabia and the United States which both have reserves of oil. The PM10 data contains one outlier of 283 μg/m3 representing data from Mongolia. Its capital Ulan Bator is known to be one of the world's most polluted cities.[83] In summary, there is no indication that this outlier or the ones of petroleum product consumer subsidies are due to measurement errors that deviate from other possible measurement errors in the estimates. The exclusion of the outliers does not change the relationship to seem more linear, which we observe by using scatterplots. Thus, we cannot justify the exclusion of them from our data. However, the petroleum subsidy estimates have 55 duplicate values of 0 that cause the data to be skewed to the right. These duplicate values decrease the variation of the data, which can have adverse effects on the precision of the OLS estimator. With this in mind, we use the ladder and gladder commands in STATA and find and illustrate graphically that the most appropriate transformation of these variables, in order to make them more normally distributed, is the natural logarithm. Since it is not possible to take the logarithm of zero, we implicitly exclude petroleum product consumer subsidies of 0 form our model. We think that the explanatory variation gained from removing these values override potential issues of their removal; bearing in mind they are duplicates. Scattering the logged variables against each other now suggests a positive linear relationship, although with rather large residuals.

We explore the data for the other variables in the same manner and do not exclude any outliers on similar basis as when exploring the data for our main variables of interest. For example, Kuwait has a very high value of petroleum product subsidy intensity in neighbouring countries. This seems reasonable, since Kuwait is geographically situated in the midst of many oil-exporting countries in the Middle East, known to subsidize petroleum products.

83 Tania Branigan, "In Ulan Bator, winter stoves fuel a smog responsible for one in 10 deaths", *The Guardian*, (published article, 20 Oct. 2013) <http://www.theguardian.com/world/2013/oct/20/ulan-bator-killer-winter-stoves>, accessed 15 May 2015.

The variables being transformed are square kilometre per capita and per capita GDP in both its present forms. Using the natural logarithms of the above-mentioned variables also seems intuitive for our research question. Since we are expecting a rather low coefficient of petroleum product subsidies it is fitting to be able to say what effect a one unit increase in petroleum subsidy spending has on the percentage unit change in PM10 concentrations. The other natural logarithm variables are all controls for country size and economy variables. For reasons of comparison, the coefficients of these variables are suitably interpreted as stemming from percentage changes. After transformation of the data the relationships between the variables in the model can be illustrated with a graph matrix (see appendix 1).

We deem the random sampling assumption (MLR.2) of the data to be fulfilled. Judging from distribution graphs, the data seems to exhibit sufficient variation and can thus be used to estimate beta. Neither is there an exact linear relationship between the independent variables (MLR.3). Due to indications of some of the variables in the model inhibiting observations with large residuals we will regress the model using the White-Huber robust option in STATA. We do not have reasons to suspect the model to inhibit heteroscedasticity of errors and both the Breusch-Pagan and White test of heteroscedasticity tells us we cannot reject the null hypothesis of homoscedasticity (MLR.5). However, using the robust option in our regression is helpful in dealing with potentially influential outliers and minor possible failures to meet the classical linear model assumptions. The most important condition to avoid omitted variable bias is the zero conditional mean (MLR.4) for which the fulfilment of has been argued for when presenting our model specification. We will also test this and the assumption normality of errors (MLR.6) by scattering the residuals of the model and using a kernel density function to graphically observe the residuals' potential deviation from a normal distribution. A Ramsay model specification test of the OLS regression cannot reject that the model has no omitted variables, indicating that the specification of our model in terms of exponentials is valid. Finally, we will investigate the strength of our instruments by executing a first-stage partial F-test and evaluating the results using the widely used rule of thumb that the F-statistic should be greater than 10 and by looking at Shea's partial R-squared.

5. Results

When instrumenting for the endogenous variables we obtain results displayed in appendix III.

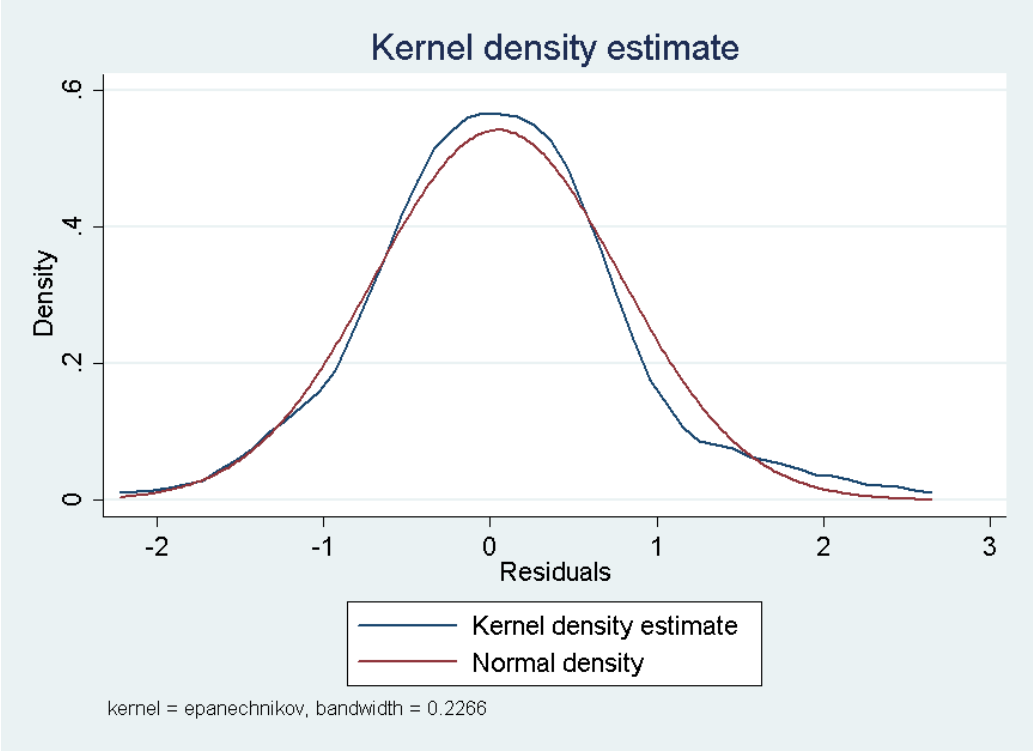
These results confirm our hypothesis, the coefficient of $ln(petprodsubs)_i$ being positive and significant at 1 % significance level. The coefficient $ln(petprodsubs)_i$ of is 0.3158. This means that for a one percentage unit increase in billion $US spent on petroleum product subsidies, the concentrations of PM10 μg/m3 is predicted to increase with 0.3158 percentage units. Illustrating with sample means of per capita GDP and per capita PM10 concentrations, this is equivalent to a PM10 level increase to 45.92 μg/m3, from the mean of 45.78 μg/m3, resulting from an increased subsidy spending of $4.23 billion.

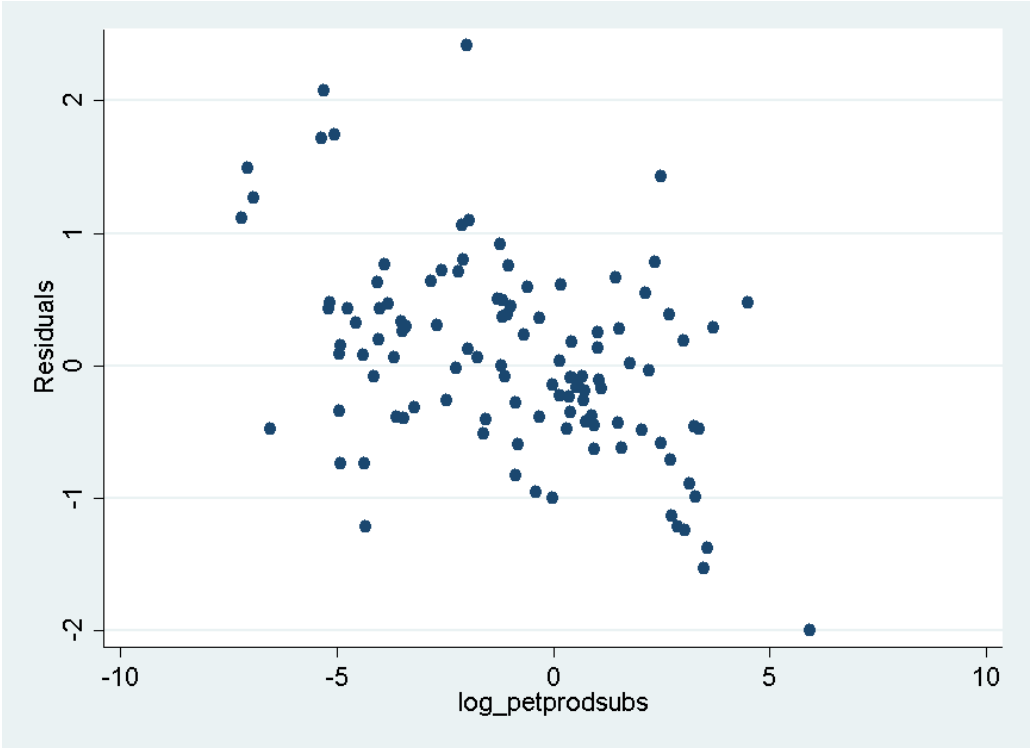
The natural logarithms for per capita GDP are both significant at 1 % and 5 % (squared per capita GDP) significance levels. The coefficient of per capita GDP is -2.3472 and the coefficient of per capita GDP squared is 0.0969. This implies a turning point at $181,944 per capita, at where higher income has an increasing effect on PM10 concentrations. Comparing with the sample mean of per capita GDP $14,431.47 this is much larger. Democracy is significant and has a coefficient of 0.7416. Thus, a democratic country is predicted to have higher concentrations of PM10. The remaining variables; share of population living in urban areas, oil rents to GDP, petroleum subsidy intensity in neighbouring countries and square kilometres per capita are insignificant. The R-square of the model is negative and therefore not displayed. In the first-stage regressions, we observe significant relationships between the instruments and their respective endogenous variable.

VARIABLES	(1) log_pm10
log_pcGDPcurrent	-2.347***
	(0.873)
log_pcGDPcurrentsq	0.0968**
	(0.0446)
log_petprodsubs	0.316***
	(0.107)
democracy	0.742***
	(0.236)
PPSINC	0.0187
	(0.0372)
log_sqkmperpop	-0.0571
	(0.0699)
urbanpop	0.00744
	(0.00531)
oilrents	0.00463
	(0.00625)
Constant	15.50***
	(4.015)
Observations	100

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The kernel density function indicates that the residuals of the model follow a normal distribution. In other words, the classical linear assumption of normality of errors is fulfilled. Plotting the residuals from the model against each of the independent variables, a fairly random scatter centred around zero is displayed for most of the variables. Thus, there is no clear evidence against the normality assumption or violation of the linearity assumption. The residuals however, are rather large. The residuals plotted against the variable PPSINC suggest a linear heteroscedastic relationship. For petroleum product subsidies, our independent variable of interest, the residuals are centred around zero and display a fairly random scatter.


Kernel density estimate
Density
0
.2
.4
.6
-2
-1
0
1
2
3
Residuals
Kernel density estimate
Normal density
kernel = epanechnikov, bandwidth = 0.2266


Residuals
-2
-1
0
1
2
-10
-5
0
5
10
log_petprodsubs

When performing tests of endogeneity, we can reject the null hypothesis that the variables claimed to be endogenous are in fact exogenous. We can reject the null hypothesis of exogeneity at a 5 % significance level both when testing all endogenous variables and when testing a subset for each variable. When executing a first-stage F-test we get that the F-statistic for the natural logarithm of per capita GDP in both its forms are well above 10, at 57.33 for per capita GDP, 65.04 for per capita GDP squared. The F-statistic for the natural logarithm of petroleum product subsidies is 10.37. Shea's partial R-square[84] reports a value of 0.1689 (0.2277) and 0.2157 (0.2711) respectively for per capita GDP and per capita GDP squared. The Shea adjusted partial R-square for $ln(petprodsubs)_i$ is 0.06 (-0.0082).

[84] (The Shea partial adjusted R-square is displayed in parentheses.)

6. Discussion

The regression results confirm our hypothesis that petroleum product subsidies increase pM10 concentrations. The magnitude of the effect petroleum product subsidies is predicted to have on PM10 concentrations seems negligible. However, the coefficient is positive at a significant at 1 % level and a threshold for PM10 concentrations without any adverse health effects have yet not been observed.[85] Thus, from a health perspective calling this effect negligible might be very misleading and is beyond the scope of this study. The low increase in PM10 levels implied by this model does not come as a great surprise. As we previously have discussed, the price elasticity of demand for oil is rather inelastic and very inelastic in the short-run. Our study only covers one year so short-run price inelasticities is the ones in play.

As we have tested for heteroscedasticity in our model and not being able to reject the null hypothesis of homoscedasticity, the heteroscedastic errors in respect to PPSINC should not pose a threat to BLUE characteristics. In addition, we use the robust option in our regression. Overall the plotting of residuals against the independent variables does not imply a violation of the normality assumption or the linearity assumption. The existence of several large residuals does however imply that the fit of the model to the data could be better.

It is not rare to obtain a negative R-square in an instrumental variable regression, as in this case, when the sum of squared residuals is larger than the total sum of squares. However, this really has no statistical meaning when using 2SLS/IV.[86] By this statement, it is meant that the R-square should not be interpreted in the same way as in OLS (see appendix II). If we were strictly interest in projecting the dependent variable OLS is preferable. In our study, we are mostly concerned with investigating if there is any significant relationship between petroleum product subsidies and PM10 concentrations. A negative R-square obtained from 2SLS/IV

85 World Health Organization, "Ambient (outdoor) air quality and health", *World Health Organization*.

86 William Sribney, Vince Wiggins, and David Drukker, " Negative and missing *R*-squared for 2SLS/IV", Data analysis and Statistical Software, (resources and support, FAQs, July 2013) <http://www.stata.com/support/faqs/statistics/two-stage-least-squares/>, accessed 4 May 2015.

need not be a problem and the parameters can be safely interpreted if they are significant with reasonably small standard errors as is the case in our regression.

Regarding the theory of the Environmental Kuznet's curve, the estimates derived in our model oppose its proposed hypothesis. We find statistically significant results that the coefficient of per capita GDP is negative and that the coefficient of per capita GDP squared is positive, indicating that pollution increases at higher levels of income. The turning point of $181,944 per capita is in line with turning points calculated in previous work. However, this level of per capita GDP is higher than the maximum of $113,746 in our sample. These results partly support the findings of Neumayer and Holtz-Eakin and Selden, however regarding CO2 emissions, who conclude that if the hypothesized EKC-relationship exists, the turning points occur at higher levels of per capita GDP than any country has reached yet. [87] On the other hand, even though we observe similarly high turning points both in absolute values and compared to the average in our sample, the coefficients or per capita GDP in our model instead suggest that pollution in an increasing function of income. The results are partly counter-intuitive since they imply that income decreases pollution until per capita GDP is at a very high turning point.

There is no indication that our instruments for per capita GDP and per capita GDP squared are weak. On the other hand, average deficit/surplus the last five years might be a weak instrument for petroleum product subsidies. The validity tests are limited for just-identified models like ours so what we look at is the rule-of-thumb value of and the F-statistic that exceeds 10 but only by 0.37 units. The low value of Shea's partial R-square by itself is a reason to question the strength of the instrument and even more so, together with the rather low first-stage F-statistic. In summary, we cannot reject or confirm that the instrument is weak. However, as Angrischt and Pischke states that with 2SLS, a just-identified Instrumental variable model is approximately unbiased even with a weak instrument. [88] Our results or reasoning do not indicate cosmic weakness (close to zero) of our instrument. This conclusion

87 Neumayer, "National carbon dioxide emissions: geography matters".

88 J. Angrist and J.S. Pischke, "A Note on Bias in Just Identified IV with Weak Instruments", *Mostly Harmless Econometrics: An Empiricist's Companion*, (chapter in published book, April 14, 2009).

is based on the observed significance level and F-statistic from the first-stage regression and that the standard errors in the second-stage regression are not large. Thus if the instrument for petroleum product subsidies is indeed weak, the consequential bias is approximately zero.

7. Conclusion

Using a fairly large cross-section of developing and developed countries, our results indicate a positive significant statistical relation between petroleum consumption subsidies and particulate matter. These results and the fulfilment of the classical linear assumptions, strongly indicates that there is a positive statistically significant causal relationship between petroleum product subsidies and concentrations of small particulate matter. Thus, our hypothesis is confirmed: petroleum consumption subsidies increase PM concentrations.

The practical significance of these results can be discussed since the effect predicted is very small in magnitude. However, even a slight increase in PM10 concentrations might have severe health effects since no limit value of PM10 has yet been identified as harmless to human health.

Our instrument for petroleum product subsidies, which we include to solve omitted variable bias and possible measurement error in the subsidy data, might be weak. If this is the case, the literature states that it is not a problem since our model is just identified and there is no indication that the potential weakness of the instrument is of great magnitude. The estimators reported from the 2SLS instrumental variable regression would still be consistent and approximately unbiased, if the instrument is indeed a weak one.

We do not find support for the Environmental Kuznet's curve, supporting the critique against it suggesting that it only supports some measures of environmental quality. The high turning point of per capita income and per capita income squared combined with the sign of the proposed function is somewhat counter-intuitive and could be further discussed. The results contradict the ones obtained by Frankel and Rose who find statistical significance for the presence of the relationship hypothesized by the Environmental Kuznet's curve. However, the results from their study show moderate statistical significance and their model is different from ours by for example including trade as a control variable.

Measurement error in the subsidy data could be solved with greater data availability and accuracy. The insufficiency and lack of data available is probably the reason not many researchers have taken an empirical approach investigating the relationship between fossil fuel subsidies and air pollution. More transparency of fossil fuel subsidies and systematic international reporting of subsidy data would be very beneficial for further research. Transparency of the data, often in countries with a lot of energy subsidies, is sometimes poor which also weakens the strength of the inference from this study. For further research, we suggest a cross-sectional approach covering even more countries for many years. Testing the possible lagged effect of subsidies on PM10 concentrations due to stickiness of domestic prices in another matter that could be explored further.

Our contribution to current state of knowledge is an empirically found indication of a highly significant causal relationship between petroleum product subsidies small particulate matter (10 micrometres in diameter or less), using a large sample including both developing and developed countries. We find approximately unbiased, consistent estimators as a basis for comparison. It should be noted that our results provide a snapshot of one point in time in a year with high oil prices, containing several important geopolitical events such as the Arab Spring. A proposition for further investigation of the relationship between petroleum product subsidies and PM10 concentrations would be to test our model with a stronger instrument for petroleum product subsidies and for more countries and years. Investigating the relationship of separate petroleum products with PM10 concentrations can also be an interesting topic for future research.

8. Summary

Building on previous research, the aim of this paper is to examine how petroleum product consumption subsidies affect concentrations of the air-pollutant particulate matter (PM10) through excessive consumption. In order to investigate this relationship, an empirical cross-sectional approach is adopted to test the following hypothesis:

Petroleum product consumer subsidies increase concentrations of small particulate matter.

There are severe adverse health effects caused by small particulate matter and many adverse economic, social and environmental effects of Fossil fuel subsidies have been identified in previous research. Petroleum is heavily subsidized, and consumer subsidies encourage excessive consumption of petroleum products; including gasoline, diesel and kerosene.

In developing countries fossil fuel subsidies put a strain on the government budget, crowd out public social spending and often fail to meet set aims of targeting the poor. With international oil prices being low, decreasing political resistance now is a time of opportunity for petroleum product subsidy reform. The subsidization of petroleum products for consumers is not a problem limited to developing countries. Even though the issues of these subsidies are somewhat different in character and severity, both developing and developed countries fail to tax fossil fuels efficiently and subsidize the use of petroleum products.

To test the hypothesis, this study uses a sample of petroleum product subsidy estimates for 100 developed- and developing countries. The data is from 2011 and represent post-tax subsidies, derived by the International Monetary Fund using the price-gap approach.

Due to issues of omitted variable bias, measurement error and simultaneous equations; petroleum product subsidies and per capita GDP are treated as endogenous variables in our model. To address endogeneity in the model, instrumental variables are introduced. Average government deficit/surplus over the previous five year period is used to instrument for

petroleum product subsidies as fiscal space determines what resources are available for subsidy spending. There are indications that this is a weak instrument for petroleum product subsidies. However, the instrumental variable regression still generates approximately unbiased and consistent estimates since the model is just identified.

No evidence of the Environmental Kuznet's curve is found. Instead pollution is predicted to be an increasing function of income.

A coefficient of 0.3158 for the natural logarithm of petroleum product subsidies is found to be statistically significant at 1 % significance level. Thus, the hypothesis that petroleum product consumer subsidies increase PM10 concentrations if confirmed. The practical significance can be discussed, since the model predicts an increase in PM10 concentrations by 0.3158 percentage units from a one-percentage unit increase in the billion dollars spent on petroleum product subsidies. However, no threshold of PM10 concentrations without adverse health effects has yet been defined.

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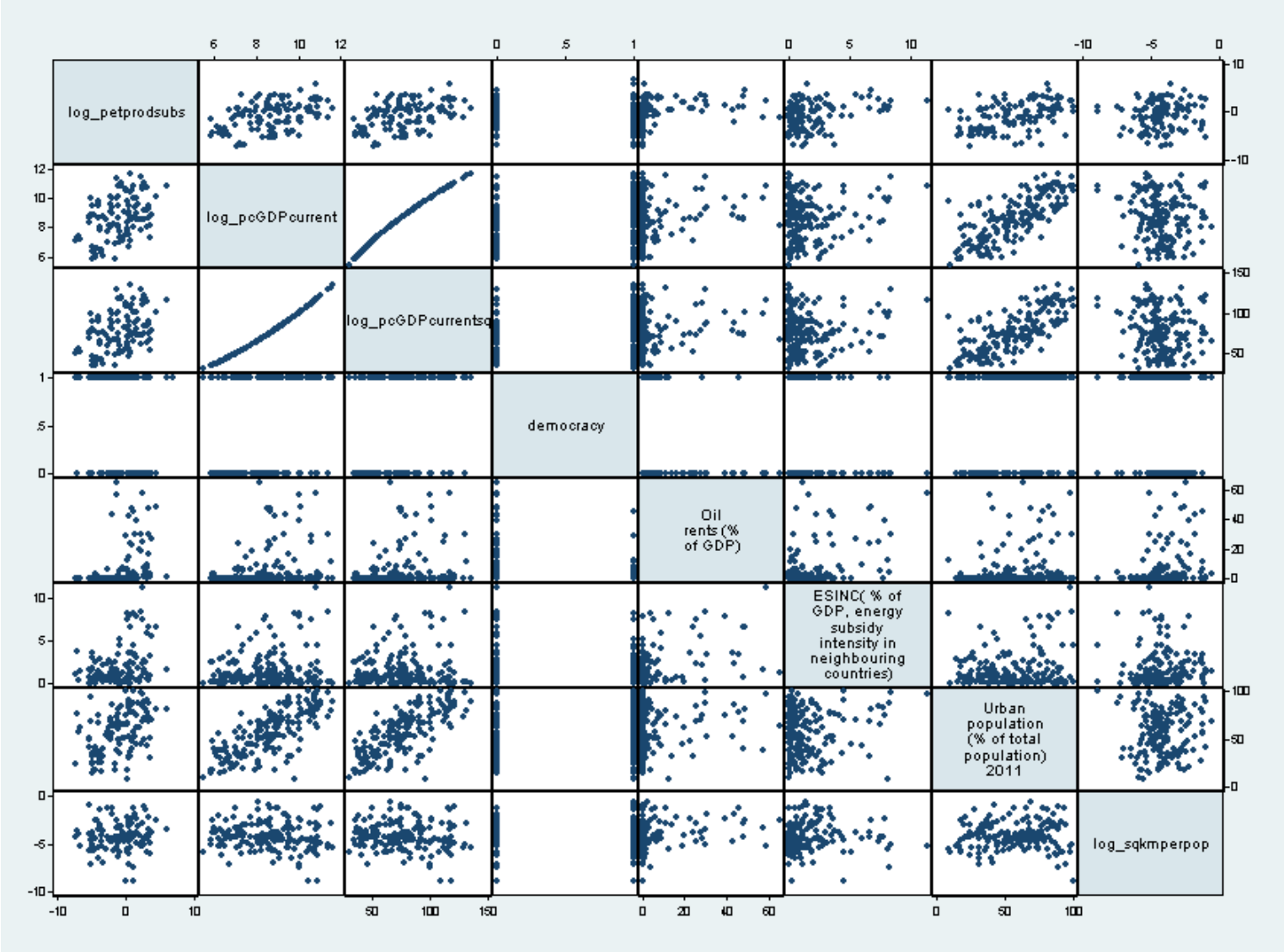
Appendix I – Overview of relationships within the model



Appendix II – OLS regression

VARIABLES	(1) log_pm10
log_petprodsubs	0.121***
	(0.0238)
log_pcGDPcurrent	-0.400
	(0.378)
log_pcGDPcurrentsq	-0.000783
	(0.0210)
democracy	0.272**
	(0.124)
oilrents	0.000489
	(0.00485)
PPSINC	0.0394
	(0.0254)
urbanpop	0.00778**
	(0.00309)
log_sqkmperpop	-0.0247
	(0.0476)
Constant	6.434***
	(1.540)
Observations	112
R-squared	0.432

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1