Corruption and the Environmental Kuznets Curve: Empirical Evidence for Sulfur

by

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Abstract

We investigate how corruption alters the relationship between sulfur emissions and income, using a wide cross-national panel of countries, at different levels of development and with different degrees of corruption. Our results support the Environmental Kuznets Curve hypothesis for sulfur. We find evidence that the higher the country’s degree of corruption, the higher the per capita income at the turning point, suggesting different income-pollution paths across countries due to corruption. We build upon a new specification for the EKC developed by Bradford, Fender, Shore and Wagner that avoids using nonlinear transformations of potentially nonstationary regressors in panel estimation.

Keywords: Environmental Kuznets Curve; corruption; turning points; new specification;
JEL classification: O13; Q56; C12; C23

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1 Introduction

Given the current debate on global warming, air quality and other serious environmental problems, a better understanding of the relationship between economic growth and the environment is of great interest to policy making.

Several empirical studies support the evidence according to which the environment at first worsens at low levels of income, but then improves at higher incomes. This is the so-called Environmental Kuznets Curve (EKC) hypothesis. The large body of empirical EKC literature started with the seminal work of Grossman and Krueger [21], [22] who found an inverted U-shape relationship between per capita income and pollution concentrations for some chemicals. Other early contributions are, for example, Selden and Song [41] and Hilton and Levinson [26].

The EKC is, in this literature, typically, taken to be invariant to whether a country relies on coal or hydropower for energy, or whether it is a dictatorship or a democracy. Indeed, under the usual specification, the level of income beyond which emissions or concentrations start to decline while income increases further - the “turning point” - is the same for all countries. However, more recently, several theoretical contributions throw into question empirical methods seeking to estimate a unique income-pollution path, as typically done. In Brock and Taylor [6], economies produce an EKC like relationship between income and environmental quality. In contrast to the previous literature, countries make the transition to active abatement at different income and peak pollution levels. The model predicts different income-pollution paths across countries due to differences in geography, resource endowments or institutions. As well, in Lieb [32] different income levels at the turning point of the EKC can be accommodated, depending on parameters that tend to be different across countries, such as the “greenness” of the utility function or the level of pollution.

Corruption and other institutional weaknesses are highlighted in the lit-
erature as crucially affecting the country’s total factor productivity as well as the government’s concerns and control for environmental quality (Chimely and Braden [9], López and Mitra [35]). There is evidence suggesting that corruption is one of the major causes of environmental degradation in developing countries. Examples of corruption abound in the environmental area. For example, in the forestry sector, it includes political parties granting harvesting concessions in return for payments from logging interests, falsifying harvesting records to exclude protected species, under-reporting harvesting volumes or facilitating illegal transportation of timber. In Indonesia, licenses to conduct environmentally damaging activities were typically granted to interest groups supportive of the Suharto regime, with significant negative impacts in the environment. The World Bank estimates that the global value of resources lost from public lands because of illegal activities range between $US10 and $US15 billion per annum (Wilson and Damania [48]).

The importance of institutions has not yet been taken into account on the empirical work of the EKC as, in general, the existence of different income pollution paths between countries has not been considered. The environmental consequences of government corruption have been analyzed in the literature by Damania, Fredriksson and List [12], Fredriksson and Svensson [18], Fredriksson, Neumayer, Damania and Gates [19] and Wilson and Damania [48]. However, neither of these studies focuses on the implications of corruption for the EKC.

The purpose of this paper is to test empirically how corruption alters the relationship between pollution and income, using a cross-national panel of data on emissions of sulfur. Sulfur is among the most commonly used indicators of air pollution and it has severe effects on human health and the natural environment. Moreover, previous studies suggest that sulfur emissions are a likely candidate for finding an inverted U-shape EKC.2 Our sample includes 85 countries with different levels of development and corruption.

This paper contributes to the empirical literature on EKC by investigating the possibility of different paths for the income-sulfur relationship due to corruption, as suggested by the theoretical literature. We empirically test whether to a higher per capita income at the turning point corresponds a

\[ \text{See e.g., Grossman and Krueger [22], Selden and Song [41], Cole [10] and Halkos [23].} \]
higher degree of corruption, as suggested by López and Mitra [35], corrobo-
ratting the theoretical result of Brock and Taylor [6] that countries make the
transition to active abatement at different income levels.

To investigate the existence of an inverted U-shaped relationship between
sulfur and income, and how it is altered by corruption, we build upon a new
specification for the EKC developed by Bradford, Fender, Shore and Wag-
ner [5]. Their specification avoids a major unresolved econometric problem
in the existing empirical literature of the EKC. The usual formulation of
the curve involves nonlinear transformations of potentially nonstationary re-
gressors in panel estimation (squares and cubes of per capita GDP), and no
estimation techniques for panel regressions with nonlinear transformations of
integrated processes are available so far (Wagner and Müller-Fürstenberger
[47]). Therefore, our results can also be seen as a robustness test to the new
specification of the Kuznets curve with respect to the sample composition.

The results obtained support the EKC hypothesis for sulfur. Moreover,
we find evidence that the country’s degree of corruption is related to the
peak of the curve and that corruption is positively related to the income
level beyond which pollution declines.

The paper is organized as follows. Section 2 reviews the literature. Sec-
tion 3 presents the specification of the EKC. The data is presented in Section
4. Section 5 discusses the results. Section 6 summarizes the main conclusions.
Technical details are presented in the appendices.

2 Literature overview

In this section, we review several theoretical contributions that throw into
question empirical methods seeking to estimate a unique income-pollution
path across countries. Also, we focus on some of the serious econometric
problems that have not been appropriately handled in the empirical literature
so far.

Economic background

Several competing explanations for the inverted U-shaped relationship
have been considered in the literature.\(^3\) Copeland and Taylor [11] identify at

\(^3\)The list of references cited below is by no means exhaustive.
least four possible explanations for an EKC: threshold effects in abatement that delay the onset of policy;\textsuperscript{4} income driven policy changes that get stronger with income growth; structural changes towards service intensive industries and increasing returns to abatement that drive down costs of pollution control.\textsuperscript{5} In Dinda [17], the base for an inverted U-shaped relationship between pollution and income is a change from insufficient to sufficient investment in abatement activity.

In the context of an overlapping generations model with a flow and a stock pollutant, Lieb [32] offers a possible explanation for the inverted U-shape relationship between pollution and income for flow pollutants, but monotonically rising relationship for stock pollutants. Since the positive effects of abating emissions of the stock pollutant would only be felt in the future, myopic governments abate flow pollution only, in order to keep aggregate pollution at a reasonably low level.

In Kelly [28], as income rises, both the marginal benefits and the marginal costs of pollution control rise, since it is assumed that environmental quality is a normal good and that costs are convex. The stronger effect determines the slope of the Kuznets curve. If, at a given income level, the marginal benefits outweigh the marginal costs, the emissions-income curve has a negative slope at that income, and vice versa.

Pfaff, Chaudhuri and Nye [40] provide an alternative theoretical explanation, assuming that the degradation of environmental quality is a by-product of households’ activities. Households can reduce degradation by substituting more expensive cleaner inputs to production for less costly dirty inputs, as they become richer. However, such substitution holds only for middle income households and not for the poorer ones. Therefore, as income rises from low to middle levels a U-shape for environmental quality can arise.

Smulders and Bretschger [43] explain the EKC by policy-induced technology shifts. With growing information about ecological problems and once pollution becomes a serious problem, regulation is introduced, which forces

\textsuperscript{4}For example, Stokey [46] develops a model where the incentive to reduce pollution arises only beyond some threshold, generating an inverted U-shaped relationship between pollution and income.

\textsuperscript{5}For example, Andreoni and Levinson [1] show that economies of scale in abatement activity are sufficient to generate an EKC.
the economy to make a transition to cleaner production processes. However, Brock and Taylor [7] in the Green Solow model show that the EKC is also compatible with pollution policy remaining unchanged in face of ongoing growth. Their explanation for the EKC is entirely distinct from those discussed in the rest of the literature. From a Solow growth model augmented by an abatement technology that experiences exogenous technological progress over time an EKC is derived. The curve is derived from the interplay of technological progress, convergence properties of the neoclassical model and natural rate of regeneration.

Technological progress in abatement is also considered in the Kindergarten Rule model of Brock and Taylor [6]. The model relies on the role of technological progress in staving off diminishing returns to capital formation and abatement, generating first a worsening and then improving environment. Growth is initially rapid because there is no pollution regulation: the environment deteriorates. But, once active regulation begins, it lowers the net marginal product of capital and growth slows. The environment’s regenerative capacity restores its quality slowly over time. In contrast to previous studies, assumptions ensuring that the demand for a clean environment rises rapidly with income are not imposed.7

However, in contrast to the methods employed in the empirical EKC literature, the model predicts that the path for income and pollution differs across countries. Differences across countries in geography, resource endowments or institutions have impact on initial productivity levels. This difference leads to the model’s Environmental Catch-Up hypothesis, relating income and pollution paths to countries initial income levels. Poor countries experience the greatest environmental degradation at their peak, but once regulation begins environmental quality across both rich and poor countries converges. However, at any income level, an initially poor country has worse environmental

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6Brock and Taylor [8] is an excellent survey paper on the new theoretical literature linking environmental quality to income levels. See also the survey of Dasgupta, Laplante, Wang and Wheeler [13].

7López [34], for example, shows that the inverted U-shaped relationship may arise because of a rapidly declining marginal utility of consumption with rising income. A high curvature of the utility function implies that consumers are willing to give up a proportionally greater additional income as they become richer, in order to have a better environment.
quality than an initially rich country. Moreover, since both rich and poor countries start with pristine environments, the qualities of their environments at first diverge and then converge over time.

Therefore, although Brock and Taylor [6] obtain that economies produce an EKC like relationship between income and environmental quality, their prediction is different from the standard EKC result. Countries make the transition to active abatement at different income and peak pollution levels.

In Lieb [32] different income levels at the turning point of the EKC can also be accommodated. As the location of the turning point of the EKC for the flow pollutant depends on parameters that tend to be different across countries such as the level and harmfulness of the stock pollution, the level of the flow pollution, the “greenness” of the utility function or abatement costs, the result follows.

These results may explain why Harbaugh, Levinson and Wilson [24] demonstrate that the EKC is very sensitive to new data, alternative functional forms and additional covariates. This may question empirical methods seeking to estimate a unique income-pollution path.8

Chimely and Braden [9] investigate how differences in total factor productivity (TFP) - which follow from the country’s regulatory and legal constraints, cultural values, corruption, violence, sabotage, relative power of labor unions, etc. - affect environmental quality in different countries. They develop a theoretical model where heterogeneity in TFPs produce a U-shaped relationship between environmental quality and income in a cross-section of countries, even if the dynamic path of environmental quality to its steady-state in individual countries is monotonic. Their results suggest that there is a critical value for TFP, such that higher TFP means better environmental quality.

Also, governments may have in mind other than social welfare considerations. Evidence suggests that corruption and lobbying are important sources of environmental degradation in developing countries. To use the estimated EKC relationships to predict the pollution performance of developing countries depends on the assumption that governments in developing countries are as effective in controlling pollution as governments in developed coun-

8However, when pollution dissipates instantaneously, initial conditions do not matter (Brock and Taylor [6]).
tries. However, governmental institutions in developing countries are often weaker, less effective and more corrupt than in developed countries (López and Mitra [35]).

López and Mitra [35] examine the implications of corruption and rent-seeking behavior by the government to the relationship between pollution and growth. According to their model, actual pollution trajectories are above the socially optimal levels for any level of per capita income due to non-optimal government decisions. Moreover, the higher the degree of corruption, the greater will be the deviation from the social optimum. Yet, despite of corruption, there exists an inverted U-shaped relationship between pollution and income, although the turning point of the curve will occur at a higher per capita income and at a higher pollution level than in the social optimum.

There is increasing recognition that corruption and other aspects of poor governance and weak institutions have substantial adverse effects on economic growth. Malfunctioning government institutions constitute a severe obstacle to investment, entrepreneurship and innovation. Several studies typically conclude that the economic costs of corruption and weak governance are substantial (for example, Knack and Keefer [29], Mauro [36], Shleifer and Vishny [42]) and that richer countries tend to be perceived as having lower corruption. Corruption is found to lower investment and thereby reducing economic growth. Moreover, the countries’ degree of corruption has been quite persistent and some countries appear to be stuck in a vicious circle of widespread corruption and low economic growth (Mauro [37]). Moreover, efficient government institutions efficiently provide public goods and services. However, because of self-seeking behavior of public officials, less public goods are provided and at a higher price relative to the social optimum (Barreto [3]).

9 Good economic institutions include, for example, limited government, a relatively benign and uncorrupt bureaucracy, a legal system that protects property rights and enforces contracts, and modest taxation and regulation (La Porta, Lopez-de-Silanes, Shleifer and Vishny [31]).

10 Although fast growers tend to be among the countries with lower corruption, there are a few surprises. In 1980, Thailand was reported to be the most corrupt country, yet its economic performance has been relatively good. Korea has been a fast grower, in spite of the fact that it was reported to have relatively inefficient institutions (Mauro [36]).
Econometric background

The issue of stationarity of the variables is of major relevance for the econometric analysis when using time series or panel data. The properties of many statistical procedures depend crucially upon stationarity or unit root nonstationarity of the variables used. Related to this issue is the question of spurious regression versus cointegration.

Part of the empirical literature on the EKC, in particular the early literature, completely ignores this issue. More recently, some of the literature addresses the stationarity versus unit root nonstationarity issue and cointegration in EKC estimates (see e.g., Perman and Stern [38], [39], Becchetti and Auci [4]).

The paper of Wagner and Müller-Fürstenberger [47] focuses on the econometric analysis of the relationship between GDP and emissions. They point out serious econometric problems that have been ignored so far and have not yet been appropriately handled in the literature.

Three important econometric problems associated with the EKC occur in the presence of unit root nonstationary regressors in panels. First, the use of nonlinear transformations of integrated regressors in the EKC. This nonlinearity issue has not been discussed in the context of the EKC literature, not even in the part of the literature that accounts for the potential presence of integrated processes. The usual formulation of the EKC involves per capita GDP (or its log) and its square as regressors. If this variable is integrated (the macro-econometric literature has gathered evidence suggesting that GDP series are very likely integrated), then nonlinear transformations of it and regressions involving such transformed variables require a different type of asymptotic theory. Regression theory with nonlinear transformations of integrated variables has only been studied recently for the time series case. However, no extension of these methods is available to the panel case. Therefore, no estimation techniques for panel regressions with nonlinear transformations of integrated processes exist. The asymptotic theory for such regressions is fundamentally different from the linear unit root case and it is not yet developed in the panel data context. The usual unit root and cointegration tests can only be applied to the linear case, and are not designed for such problems.
Second, the EKC papers that use panel unit root or cointegration techniques assume cross-sectional independence of both GDP and emissions across countries (“first generation” methods), which is a rather implausible assumption (see e.g., Perman and Stern [38], [39]). Progress has been made in the theoretical literature and panel unit root tests and cointegration methods relying on cross-sectional dependence are available (“second-generation” methods). These methods were applied for the first time in the EKC context by Wagner and Müller-Fürstenberger [47].

Third, although not as crucial as the two previous problems, the unit root and cointegration methods have been used rather uncritically. In particular, the small sample problems of unit root and cointegration methods have been neglected. This stems from the fact that the properties of the panel unit root and cointegration tests crucially depend on the properties of the methods used at the individual country level. Unit root and cointegration techniques perform poorly for short time series. This poor performance translates into poor performance for short panels. So, even ignoring the two previous fundamental problems, and keeping the standard framework that has been applied up to now, there are unsolved econometric problems in the context of the existing empirical EKC literature.

Bradford, Fender, Shore and Wagner [5] present an alternative specification of the EKC.11 Their approach avoids the use of nonlinear transformations of nonstationary variables. Instead, it is based on average per capita GDP and average growth rate of per capita GDP, over the sample period. Moreover, if per capita GDP series are stationary, this alternative specification is also valid. Besides, the other potential econometric problems are avoided.

In this paper we build upon the specification of Bradford, Fender, Shore and Wagner [5], which is summarized in the next section.

11Bradford, Fender, Shore and Wagner [5] use a new specification and reinvestigate the results of the paper of Grossman and Krueger [22], using the same data set. They find weaker evidence for the EKC with their new specification, since they find a statistically significant EKC, although for not as many pollutants as Grossman and Krueger.
3 The model

Consider the following relationship between the rate of change of pollution, the income and the growth rate of income at a given point in time:

\[ \frac{\partial P_t}{\partial t} = \alpha (y - y^*) g \] (1)

According to (1), the rate of change of pollution \( P \) is a function of the growth rate of income, \( g \), and of the distance of income, \( y \), to the turning point, \( y^* \). Assuming that the growth rate \( g \) is positive, and that the coefficient \( \alpha \) is negative then either \( \frac{\partial P_t}{\partial t} > 0 \) when \( y < y^* \), or \( \frac{\partial P_t}{\partial t} < 0 \) when \( y > y^* \). So, pollution increases until \( y^* \) is reached, and decreases after the turning point. Moreover, \( \frac{\partial^2 P_t}{\partial t \partial y} = \alpha g < 0 \). Therefore, as long as \( \alpha < 0 \), this formulation describes an inverse U-shaped relationship between pollution and income.

The growth rate \( g \) is included to allow for pollution dynamics that depend upon the growth regime. This allows for rapid pollution growth in fast growing developing countries.

In the empirical application, \( y \) denotes the average real per capita GDP and \( g \) the average growth rate of real per capita GDP over the sample period, for each country (both time invariant). Instead of using the time-series of income, the estimation is performed using only two statistics of the real per capita GDP time series: the mean and the average growth rate. Further details on how \( y \) and \( g \) are calculated are given in the following section.

The purpose of this study is to test the existence of an EKC for sulfur, based on this new specification, and, simultaneously, to investigate whether the per capita income at the turning point increases with the country’s degree of corruption. In order to answer this last question we build upon the set up of Bradford, Fender, Shore and Wagner [5] and model the turning point, \( y^* \), as a function of the country’s degree of corruption, as follows:

\[ y^* = \delta_1 + \delta_2 I \] (2)

where \( I \) denotes the average of the degree of corruption over the sample period for each country (time invariant).\(^ {13} \) The index of corruption adopted

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\(^{12}\) For simplicity, we omit the country subscript \( i \), for now.

\(^{13}\) Once more, we omit the country subscript \( i \), for simplicity.
is inversely related to the degree of corruption (further details are given in the next section). In other words, the higher the index, the lower the corruption. As long as $\delta_2 < 0$, this implies a lower per capita income at the turning point.

Combining equations (1) and (2), we obtain

$$\frac{\partial P_t}{\partial t} = \alpha(y - (\delta_1 + \delta_2 I))g$$

Integrating equation (3) with respect to time, and taking as constants the average income, the average growth rate and the average degree of corruption, we obtain

$$P_t = \mu + \alpha(y - (\delta_1 + \delta_2 I))gt$$

where $\mu$ is a constant of integration. The equation estimated is obtained from (4) by adding the unobserved country-specific effects ($\mu_i$), the linear time trend ($\lambda t$) and the stochastic error term ($\varepsilon_{it}$).

We estimate the model using the natural logarithm of per capita sulfur emissions as the dependent variable. Inspection thus, we have

$$\ln P_{it} = \mu_i + \beta_0(\gamma_i g_{it}) + \beta_1 (g_{it}) + \beta_2 (I_i g_{it}) + \lambda t + \varepsilon_{it}$$

where the countries are indexed by $i$ ($i = 1, 2, ..., N$) and the time periods by $t$ ($t = 1, 2, ..., T$). $P_{it}$ is per capita sulfur emissions in country $i$ in period $t$, $\gamma_i$ is the country-specific measure of average real per capita GDP over the sample period, $g_i$ is the country-specific average growth rate of real per capita GDP over the sample period, and $I_i$ is the country-specific average of the degree of corruption over the sample period. Hence, this alternative formulation is not subject to the unsolved problems arising in panel regression with nonlinear transformations of potentially nonstationary regressors, as pointed out by Bradford, Fender, Shore and Wagner [5] (p. 5). Finally, notice that $\alpha = \beta_0$, $\delta_1 = -\beta_1/\alpha$ and $\delta_2 = -\beta_2/\alpha$.

The hypothesis of an inverse U-shape can be checked from equation (5) by testing the hypothesis $\alpha < 0$. The hypothesis of a positive relationship

\[14\] We also have estimated the model using per capita sulfur emissions as the dependent variable, instead of its logarithm. We have compared the two alternative specifications, following the procedure in Davidson and MacKinnon [14] (p. 438), and we concluded that the model that better fits the data is the model given by eq. (5) (see Appendix A for further details).

\[15\] Notice that $\frac{\partial P_t}{\partial t} = \alpha(y - (\delta_1 + \delta_2 I))gP_t$, abstracting from the time trend.
between the country’s degree of corruption and the per capita income at the
turning point can be checked by testing the hypothesis $\delta_2 < 0$. Moreover,
a necessary condition for positive per capita income at the turning point is
$\delta_1 > 0$. Therefore, we should expect $\beta_1 > 0$ and $\beta_2 < 0$.

As most empirical studies use panel data, neglecting the role of important
country-specific characteristics in the explanation of the EKC raises poten-
tial econometric problems. For example, climate and geography vary widely
across countries and may well be correlated with emissions. Climate may
affect heating and cooling needs; endowments of fossil fuels and hydroelec-
tric power sites may affect relative energy prices. These factors may cause
the error terms in the estimating equation to be correlated across all periods
for a particular country. Therefore, with panel data analysis, the uncon-
trolled heterogeneity across countries must be accounted for. The effect of
country-specific characteristics can be explored by estimating both the fixed
and the random effects versions of the model. The fixed effects and ran-
dom effects models allow for variation only in the intercept and impose slope
homogeneity.

When choosing between fixed effects and random effects estimation, an
important issue is whether the country effects are correlated with the explana-
tory variables. In the absence of such correlation, random effects estimation
is consistent and efficient. If country-specific characteristics are correlated
with the explanatory variables, then random effects estimation yields inconsis-
tent results. In such a case, the fixed effects estimation should be adopted.

The specification test used to help choosing between these two approaches
is the Hausman test which indicates whether there are omitted variables cor-
related with the explanatory variables. It can be used to test for inconsistency
in the random effects estimate.\textsuperscript{16}

Studies about sulfur, using both random and fixed effects estimators find,
in general, that the random effects model cannot be estimated consistently,
based on the Hausman test (see e.g., Stern and Common [44]). Bradford,
Fender, Shore and Wagner [5] confirm this finding using their new specifi-
cation. We also find that fixed effects are more appropriate than random effects.

\textsuperscript{16}For more details see Wooldridge [49].
fects estimation is the lack of correlation between the unobserved individual
country characteristics and the explanatory variables, which we believe to be
very unlikely in this context.

The time trend is included in the regression to allow for autonomous
changes in pollution that are not directly related to income. There may be a
secular downward trend in sulfur emissions that is independent of income and
which might be due to technological progress (for example, energy efficiency
improvements) or structural change. This can be checked from equation (5)
by testing the hypothesis $\lambda < 0$. If this is the case, emissions decline over
time, even holding income constant.

We also have estimated the model including year effects, $\gamma_t$, common to
all countries. They capture disturbances affecting all countries in the panel
at some point in time, in a similar way. Dummy variables are included to
capture the year effects. Qualitatively similar results are obtained in this
case (see Appendix C).

4 Data

We use a sulfur emissions data set, taken from Stern [45], which includes most
of the countries of the World from 1850 to 2000. Emissions are measured in
giga gramms (Gg).

Sulfur is among the most commonly used indicators of air pollution and
it has severe effects on human health (e.g., lung damage and other respira-
tory diseases) and the natural environment (e.g., it contributes to the acid
rain problem). It is a flow pollutant emitted naturally by volcanoes, decaying
organic matter and sea spray. Economic activities responsible for sulfur emis-
sions include the burning of coal and fossil fuels, the smelting of nonferrous
ores, automobile exhaust and certain chemical manufacturers.

Typically, the pollutants with inverted U-shaped curves do not involve
international externalities. In the case of sulfur its impact is more local. The
country that emits the pollutant suffers the damage and, therefore, has the
incentive to reduce emissions. In contrast, carbon emissions constitute an
international externality. Each country’s emissions affect the entire planet,
and emissions reduction is a global public good. Countries are unlikely to
impose unilateral carbon regulations, given the incentive to free ride on other countries’ efforts. In other words, cross-border externalities reduce domestic incentives to reduce emissions. Perhaps for this reason, evidence in favor of an inverted U EKC relationship for carbon dioxide is ambiguous. Many studies find that carbon emissions rise monotonically or find an EKC with a turning point which lies far outside the income sample range (e.g. Holtz-Eakin and Selden [27]; Dijkgraaf and Vollebergh [16] question the existence of an overall EKC; Cole [10] finds that the turning point for carbon dioxide occurs at higher per capita income levels than for local air pollutants; Galeotti, Lanza and Pauli [20] find evidence of an inverted U-pattern for the group of OECD countries, with reasonable turning point, but not for non-OECD countries, as the EKC is basically increasing; Azomahou, Laisney and Van [2], using a nonparametric approach, find an upward sloping relationship between CO₂ emissions and GDP per capita).

The income data is taken from the Penn World Table (Heston, Summers and Aten [25]). The Penn World Table contains real¹⁷ per capita GDP in international dollars (I$) in 1996 constant prices,¹⁸ up to 2000. Population data for computing sulfur emissions per capita are also taken from this source. Population is expressed in thousands of inhabitants. Per capita sulfur emissions are obtained by dividing each country’s emissions by its population.

The index of corruption is provided by the International Country Risk Guide (ICRG). This index has been extensively used in the cross-country corruption literature (see e.g., Damania, Fredriksson and List [12], Fredriksson and Svensson [18]). It is based on the opinions of experts and measures the extent to which “high government officials are likely to demand special payments” or to which “illegal payments are generally expected throughout lower levels of government” in the form of “bribes connected with import and export licenses, exchange controls, tax assessment, policy protection, or loans” (Knack and Keefer [29], p. 225). The index ranges from 0 to 6, with 6 being less corrupt. Countries that at some moment in time have an index of 0 are, for example, Bangladesh, Haiti, Indonesia and Philippines. In contrast, countries with an index of 6 are, for example, Australia, Denmark, Finland, Norway and Sweden. This index is only available since the beginning of the

¹⁷In Penn World Table “real” means “purchasing power parity converted”.
¹⁸RGDPL series.
1980s, which determines 1981 as the starting year of our study. However, not all countries have information available for the whole period.

Our EKC estimates use data for all countries with available information about sulfur emissions, real per capita GDP and index of corruption, for the period 1981-2000. Moreover, given the specification of the EKC described in the previous section, we only consider countries with a positive average growth rate of real per capita GDP. In our sample there are 85 countries. The countries include about 93% of the World real GDP and 85% of the World population in 2000 (and about 95% of the World real GDP and 90% of the World population in 1981). The full list of countries is available in Appendix B, and is divided into high, upper middle, lower middle and low income levels, according to the World Bank guidelines. Economies are divided according to 2004 gross national income (GNI) per capita (formerly referred to as gross national product per capita). The groups are: low income, $825 or less; lower middle income, $826-$3255; upper middle income, $3256-$10065; and high income, $10066 or more.

More details about the data set are provided in Table 1. This table also indicates the distribution of observations by income level. We can say that all types of countries are well represented in the sample. Moreover, there is considerable variability within the sample.

To estimate equation (5), we need to obtain for each country the average value of real per capita GDP, $y_i$, the average growth rate of real per capita GDP, $g_i$, and the average of the degree of corruption, $I_i$. We calculate $g_i$ and $y_i$ following Bradford, Fender, Shore and Wagner [5].

Let us denote by $Y_{i1}$ the average of real per capita GDP in country $i$ over the period 1981 to 1984, and by $Y_{i2}$ the average of real per capita GDP over the period 1997 to 2000. The average growth rate $g_i$ is computed from $Y_{i2} = Y_{i1} \exp(16g_i)$ and the measure of average real GDP over the sample period from $y_i = Y_{i1} \exp(8g_i)$, i.e., $y_i$ is the interpolated income at the sample mid-point. The measure of the degree of corruption is the simple average of the degree of corruption over the sample period. The average incomes, growth rates and degrees of corruption are available upon request.

19 For some countries, data are not available for the whole sample period. In such cases, we choose the first and/or the latest available 4-year period.
Table 1 - Sample characteristics

<table>
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<th></th>
<th>Mean (^{a})</th>
<th>Std. dev. (^{a})</th>
<th>Min. (^{a})</th>
<th>Max. (^{a})</th>
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<td>5.28E-05</td>
<td>0.1427</td>
</tr>
<tr>
<td>Real per capita GDP (1996 I$)</td>
<td>9425.99</td>
<td>7955.24</td>
<td>488.88(^{b})</td>
<td>44008.5(^{c})</td>
</tr>
<tr>
<td>Index of corruption (0-6)</td>
<td>3.6</td>
<td>1.5</td>
<td>0</td>
<td>6</td>
</tr>
</tbody>
</table>

Distribution of sample by income level

<table>
<thead>
<tr>
<th>Number of countries</th>
<th>Low</th>
<th>Lower middle</th>
<th>Upper middle</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15</td>
<td>23</td>
<td>17</td>
<td>30</td>
</tr>
</tbody>
</table>

\(^{a}\)Calculated from the pooled cross-section series.
\(^{b}\)Guinea-Bissau, 1992.
\(^{c}\)Luxembourg, 2000.

5 Results

In this section we present the estimation results for (5). This equation has been estimated using both fixed effects and random effects estimation. However, the random effects specification is rejected by the Hausman test. Hence, we only present the fixed effects estimation results.

The strong econometric support in favor of the fixed effects results confirms our intuition, since we believe that it is unlikely that the country unobserved characteristics are uncorrelated with the country’s income and degree of corruption. In contrast to random effects, fixed-effects estimation allows for correlation between the country-specific effects and the explanatory variables. A graphical analysis of the results is presented below.

5.1 Estimation results

In Table 2, we present the coefficient estimates \(\hat{\beta}_0, \hat{\beta}_1, \hat{\beta}_2, \hat{\lambda}\) and the implied \(\hat{\delta}_1\) and \(\hat{\delta}_2\), for the fixed effects estimation of (5). The estimated value of \(\beta_0\) is negative and significant, supporting the existence of an inverse U-shape. Hence, we confirm the finding of Bradford, Fender, Shore and Wagner [5] with respect to sulfur, based on a different sample.
The slope of the linear time trend is also negative and significant. This suggests that there are technological changes taking place not captured by the other regressors, contributing to a decline in emissions over time more than would be predicted by income growth alone. This contrasts to the finding of Bradford, Fender, Shore and Wagner [5], where the time trend is not significant for sulfur, with fixed effects estimation. However, they find it significant for other pollutants in their study.

In the last row of Table 2 we report the Hausman test statistic and its rejection probability. The test confirms the absence of orthogonality between the regressors and residuals, suggesting that the fixed effects estimation is more appropriate.

We also find that the estimated value of $\delta_2$ is negative and significant, supporting the existence of a positive relationship between the degree of corruption and the per capita income at the turning point. Thus, the country’s degree of corruption is related to the peak of the EKC.

Table 3 presents the estimated turning points for each degree of corruption, according to the ICRG index, where the inverse relationship between the estimated turning point and the index of corruption can be observed. The turning points are within the sample range of income.

Our finding can be related to the result of Stern and Common [44]. They use a larger and more globally representative sample than previous sulfur EKC studies. Estimating the EKC using data for only high income countries yields a lower estimated turning point than when the EKC is estimated using data for low income countries, or for the World as a whole. Since, as evidence shows, low income countries are, in general, more corrupt, the positive relationship we find between the degree of corruption and the income at the turning point may explain Stern and Common’s result.

\[20\text{Recall that the index ranges from 0 to 6, with 6 being less corrupt.}
\[21\text{Galeotti, Lanza and Pauli [20] find a similar pattern for CO}_2\text{ emissions.}\]
Table 2 - Estimation results for (5) with fixed effects

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>Dependent variable = ln (sulfur per capita)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_0$</td>
<td>-5.01E-05***</td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>2.0842***</td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
</tr>
<tr>
<td>$\beta_2$</td>
<td>-0.3041***</td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>-0.0320***</td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
</tr>
<tr>
<td>$\delta_1$</td>
<td>41597.43***</td>
</tr>
<tr>
<td></td>
<td>(0.007)</td>
</tr>
<tr>
<td>$\delta_2$</td>
<td>-6068.95*</td>
</tr>
<tr>
<td></td>
<td>(0.054)</td>
</tr>
<tr>
<td>$N$</td>
<td>1550</td>
</tr>
<tr>
<td>F test</td>
<td>103.62***</td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
</tr>
<tr>
<td>Hausman test*</td>
<td>193.71***</td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
</tr>
</tbody>
</table>

Notes: *After random effects estimation.
Significance levels in parentheses.
***Statistically significant at 1%.
**Statistically significant at 5%.
*Statistically significant at 10%.

Also, our results support the theoretical insights about the importance of country-specific characteristics in explaining the EKC, as pointed out by Brock and Taylor [6] and Lieb [32]. We find different income-pollution paths across countries due to corruption. Our findings agree with the idea that corruption and other institutional weaknesses affect the country’s total factor productivity as well as the government’s concerns and control for environmental quality, with important implications to environmental degradation (Chimeli and Braden [9], López and Mitra [35]).
### Table 3 - Estimated turning points

<table>
<thead>
<tr>
<th>$T$</th>
<th>$\hat{y}^* = 41597.43 - 6068.95T$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>41597.43</td>
</tr>
<tr>
<td>1</td>
<td>35528.49</td>
</tr>
<tr>
<td>2</td>
<td>29459.54</td>
</tr>
<tr>
<td>3</td>
<td>23390.60</td>
</tr>
<tr>
<td>4</td>
<td>17321.65</td>
</tr>
<tr>
<td>5</td>
<td>11252.71</td>
</tr>
<tr>
<td>6</td>
<td>5183.76</td>
</tr>
</tbody>
</table>

**Note:** Turning points are in international dollars in 1996 constant prices.

Notice that the estimated turning point of the EKC is in most cases above the mean value of real per capita GDP in the sample. This is not consistent with Selden and Song’s [41] results, who argue that the majority of the countries are in the downward side of the EKC curve as the upward-side of the curve is very small. For example, the real per capita GDP in 2000 in countries with an average degree of corruption smaller or equal than 2 in the sample period, like Bangladesh, Gabon, Indonesia or Pakistan, among others, is still very far away from the income level at the turning point suggested by the model. They are located in the upward-side of the curve. In contrast, countries with low levels of corruption (with an average degree of corruption of 6) like Canada, Denmark, Finland or Iceland, are beyond the peak of the curve suggested by the model, and, thus, in the downward side of the curve.

The estimated turning points should only be interpreted as rough estimates. They only provide evidence of the level of development at which countries in the sample find themselves when per capita emissions begin to fall.

### 5.2 Graphical analysis of the results

Another way of analyzing the results is to illustrate graphically the estimated effects of income on pollution, for different income levels. We present the results assuming different degrees of corruption, and, consequently, different turning points for the EKC.

Figure 1 plots the estimated effects of income on pollution: $\frac{∂\ln P_t}{∂t} = \hat{α}(y - (\hat{δ}_1 + \hat{δ}_2 T))g$. Therefore, the estimated effects are pollution growth
rates. These are obtained from eq. (5). In order to enhance our main results the time trend is neglected.

The income on the horizontal axis ranges from low values to very high. They are chosen somehow arbitrarily, following the estimated turning points (summarized in Table 3). They span the observed sample range in the data rather well.

Following Bradford, Fender, Shore and Wagner [5], we assume a 3% annual growth rate of real per capita GDP, which is considered as a good estimate of the average long-run growth rate.\textsuperscript{22}

Finally, we assume different degrees of corruption (ranging from 0 - maximum corruption - to 6 - minimum corruption -) and, thus, different turning points. In the graph, each block of bars describes the effects of income on pollution for different countries characterized by different levels of the index of corruption. The extreme left bars correspond to a country with an index of corruption of 0, while the extreme right bars characterize a country with an index of corruption of 6.

The information displayed in the graph is based on the point estimates presented in Table 5 (see Appendix D).

If an EKC-like relationship prevails, pollution grows at income levels below the peak of the inverted U and decreases at income levels beyond the peak. Moreover, $\frac{\partial^2 \ln P}{\partial t \partial y} < 0$. Thus, the bars on the graphs represent positive values before reaching the peak and negative ones after the peak, decreasing from left to right. From the graph, there is strong evidence of such pattern. The graphical analysis makes clear the shape of the pollution-income relationship and confirms the strong evidence in favor of the EKC hypothesis for sulfur.

Consider, for example, the case of a country with an index of corruption of 3, as represented in Figure 2 (fourth bar, in each block from Figure 1). According to Table 3, the estimated turning point is $23390.60. From Figure 2, we observe that the bars to the left of the peak represent positive values. However, they decrease as income becomes closer to the turning point. To the right of the peak the bars represent negative values and become more negative as income grows.

\textsuperscript{22}In our sample, the simple mean growth rate over countries is 2.36%, and the population weighted mean growth rate is 3.64%.
Figure 1: Estimated effects from eq. (5)

Figure 2: Estimated effects from eq. (5) - Index of Corruption 3
If the higher the corruption, the higher the per capita income at the turning point, then more corrupt countries must have a larger number of positive bars than weakly corrupt ones. Moreover, for the same level of income, the effects of income on pollution should decrease as corruption decreases. Hence, within each block, bars should decrease from left to right, since countries with a low index are still very far away from the peak, whereas countries with a high index are already close to their peaks.

Focusing again on Figure 1, consider the case of two countries, one with an index of corruption of 0 (first bar, in each block), and another with an index of 6 (seventh bar, in each block). Figure 3 illustrates the two cases. From Table 3, the turning points are $41597.43 and $5183.76, respectively. All bars for the country with a very high degree of corruption represent positive values, except for the last income value considered, $45000, which is beyond the peak. The bars representing positive values decrease as income increases getting closer to the peak. In contrast, all bars for the country with a very low degree of corruption represent negative values, except for the first income value considered, $1000, which is below the corresponding turning point. Moreover, the bars representing negative values increase as income increases beyond the peak. Also, within each block, bars decrease from left to right. For example, in the extreme left block of bars in Figure 1, the first bar is very high when compared to the seventh bar, since the income in the country with high corruption is still very far away from the corresponding peak. In contrast, the income in the country with low corruption is quite close to its peak.

Therefore, the graphical analysis confirms the strong evidence in favor of the positive relationship between the degree of corruption and the peak of the EKC.

6 Conclusions

In this paper we test empirically how corruption alters the relationship between sulfur emissions and income, using a wide cross-national panel of countries. We test whether the per capita income at the turning point of the EKC is positively correlated to corruption. Therefore, we investigate the possibil-
Figure 3: Estimated effects from eq. (5) - Index of Corruption 0 and 6

ity of different paths for the income-sulfur relationship due to corruption.

Our sample includes 85 countries at different levels of development, with considerable variability in terms of income and degree of corruption.

We build upon a new specification developed by Bradford, Fender, Shore and Wagner [5]. This specification avoids using nonlinear transformations of possibly integrated regressors in panel estimation, in contrast to the standard specification of the curve. This is clearly a great advantage of this formulation, since the asymptotic theory for panel regressions with nonlinear transformations of nonstationary processes is not yet developed (Wagner and Müller-Fürstenberger [47]).

Our results support the EKC hypothesis for sulfur. We confirm the existence of an inverted U-shaped relationship between per capita sulfur emissions and income, based on a different sample from that of Bradford, Fender, Shore and Wagner [5]. Thus, the income-sulfur relationship proves to be robust to changes in the estimation sample. Like Bradford, Fender, Shore and Wagner [5], fixed effects estimation is preferred over random effects estimation, as it allows for correlation between the country-specific unobserved characteristics and the remaining explanatory variables.

We also find that the country’s degree of corruption is related to the
peak of the EKC. There is evidence that the higher the country’s degree of corruption, the higher the per capita income at the turning point. Therefore, we find different income-pollution paths across countries.

These results confirm the theoretical developments according to which country-specific characteristics play an important role in explaining the EKC, as pointed out by Brock and Taylor [6] and Lieb [32]. Corruption and other institutional weaknesses affect the country’s total factor productivity as well as the government’s concerns and control for environmental quality, both with important implications to environmental degradation (Chimeli and Braden [9], López and Mitra [35]). Moreover, our finding may also explain Stern and Common’s [44] result that high income countries yield a lower estimated turning point than low income countries, since low income countries are, in general, more corrupt.

We analyze the evidence in favor of the EKC graphically, by plotting the estimated effects from our specification. We evaluate the effects at different income levels. As previously discussed, the EKC hypothesis implies that the effects of income on pollution should decrease as income level increases. There is strong graphical evidence in favor of this monotonous pattern. The graphical analysis also confirms the strong evidence in favor of the positive relationship between the degree of corruption and the peak of the EKC.

While the Environmental Kuznets Curve does not indicate that countries can simply grow out of environmental problems, a better understanding of the relationship between income and pollution can definitely contribute to policy making.
Appendix A - Comparing alternative models

We have compared the two alternative specifications (natural logarithm of per capita sulfur emissions and per capita sulfur emissions, as the dependent variable), following Davidson and MacKinnon [14] (p. 438). The idea is to compare the loglikelihoods of the two alternative models, considered as models for the same dependent variable. We have to compute the loglikelihood function for each of the models, including the Jacobian term $(-\sum_{t=1}^{n} \ln P_t)$ for the model in which the regressand is $\ln P_t$, and pick the model with the highest loglikelihood.

For the model using per capita sulfur emissions, $P_t$, as the dependent variable, the loglikelihood function is

$$ll_1 = -\frac{n}{2} \ln 2\pi - \frac{n}{2} - \frac{n}{2} \ln \left(\sum_{t=1}^{n} (P_t - \hat{P}_t)^2\right) = 5.2023$$  \hspace{1cm} (a.1)

The loglikelihood for the model using the logarithm of per capita sulfur emissions, $\ln P_t$, as the dependent variable (given by eq. (5)), understood as a model for the per capita sulfur emissions, is

$$ll_0 = -\frac{n}{2} \ln 2\pi - \frac{n}{2} - \frac{n}{2} \ln \left(\sum_{t=1}^{n} (\ln P_t - (\ln \hat{P}_t))^2\right) - \sum_{t=1}^{n} \ln P_t = 1465.6909$$  \hspace{1cm} (a.2)

The Jacobian term is absolutely critical. If it were omitted, the model in eq. (5) would be a model for $\ln P_t$, and it would make no sense to compare its loglikelihood value with the loglikelihood value for the linear model, which is a model for $P_t$. When the Jacobian term is included, the loglikelihoods for both models are expressed in terms of $P_t$, and it is perfectly valid to compare their values. The model with the largest value (largest (a.1) or (a.2)) is the one that better fits the data. Therefore, the model in eq. (5) is the model that better fits the data.

In order to perform a statistical test and, eventually, reject one of the competing models as incompatible with the data, we must go beyond simply comparing loglikelihood values. Since $2(ll_0 - ll_1) = 2920.9772 > \chi^2(1) = 6.63$, we can reject the linear model for a significance level of 1%.
Appendix B - List of countries

High income
Australia, Austria, Belgium, Canada, Cyprus, Denmark, Finland, France, Germany, Greece, Hong Kong, Iceland, Ireland, Israel, Italy, Japan, Korea Rep., Luxembourg, Malta, Netherlands, New Zealand, Norway, Portugal, Singapore, Slovenia, Spain, Sweden, Switzerland, United Kingdom, United States

Upper middle income
Argentina, Botswana, Chile, Costa Rica, Croatia, Czech Republic, Estonia, Gabon, Hungary, Lebanon, Lithuania, Malaysia, Mexico, Panama, Poland, Turkey, Uruguay

Lower middle income
Albania, Armenia, Azerbaijan, Brazil, China, Colombia, Dominican Republic, Egypt Arab Rep., El Salvador, Guatemala, Guyana, Indonesia, Iran Islamic Rep., Jamaica, Kazakhstan, Morocco, Paraguay, Philippines, Romania, Sri Lanka, Syrian Arab Rep., Thailand, Tunisia

Low income
Bangladesh, Burkina Faso, Ghana, Guinea, Guinea-Bissau, Haiti, India, Kenya, Malawi, Mali, Pakistan, Papua New Guinea, Senegal, Uganda, Vietnam
Appendix C - Alternative specification

A specification that includes year effects, $\gamma_t$, common to all countries, was also performed. They capture disturbances affecting all countries in the panel at some point in time, in a similar way. Dummy variables are included to capture the year effects. We estimate the following equation:

$$\ln P_{it} = \mu_i + \gamma_t + \beta_0 (y_i g_{it}) + \beta_1 (g_{it}) + \beta_2 (I_i g_{it}) + \lambda t + \varepsilon_{it} \quad (c.1)$$

Estimation results for this equation are presented in Table 4. We obtain very similar results to the estimation results of equation (5), both in terms of the magnitude and significance of the coefficients (see Table 2).

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>Dependent variable = \ln (sulfur per capita)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_0$</td>
<td>-5.14E-05*** (0.001)</td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>2.0744*** (0.000)</td>
</tr>
<tr>
<td>$\beta_2$</td>
<td>-0.2983*** (0.002)</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>-0.0362*** (0.000)</td>
</tr>
<tr>
<td>$\delta_1$</td>
<td>40367.01*** (0.006)</td>
</tr>
<tr>
<td>$\delta_2$</td>
<td>-5803.936* (0.053)</td>
</tr>
<tr>
<td>$N$</td>
<td>1550</td>
</tr>
<tr>
<td>F test</td>
<td>19.76*** (0.000)</td>
</tr>
</tbody>
</table>

Notes: Significance levels in parentheses.

*** Statistically significant at 1%.

** Statistically significant at 5%.

* Statistically significant at 10%.
Appendix D - Point estimates displayed in Figure 1

Table 5 summarizes the point estimates displayed in Figure 1.

Table 5 - Point estimates displayed in Figure 1

<table>
<thead>
<tr>
<th></th>
<th>$1000</th>
<th>$10000</th>
<th>$15000</th>
<th>$20000</th>
<th>$25000</th>
<th>$30000</th>
<th>$40000</th>
<th>$45000</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>$41597.43</td>
<td>0.0610</td>
<td>0.0475</td>
<td>0.0400</td>
<td>0.0325</td>
<td>0.0249</td>
<td>0.0174</td>
<td>0.0024</td>
</tr>
<tr>
<td>1</td>
<td>$35528.49</td>
<td>0.0519</td>
<td>0.0384</td>
<td>0.0309</td>
<td>0.0233</td>
<td>0.0158</td>
<td>0.0083</td>
<td>-0.0067</td>
</tr>
<tr>
<td>2</td>
<td>$29459.54</td>
<td>0.0428</td>
<td>0.0292</td>
<td>0.0217</td>
<td>0.0142</td>
<td>0.0067</td>
<td>-0.0008</td>
<td>-0.0158</td>
</tr>
<tr>
<td>3</td>
<td>$23390.60</td>
<td>0.0337</td>
<td>0.0201</td>
<td>0.0126</td>
<td>0.0051</td>
<td>-0.0024</td>
<td>-0.0099</td>
<td>-0.0250</td>
</tr>
<tr>
<td>4</td>
<td>$17321.65</td>
<td>0.0245</td>
<td>0.0110</td>
<td>0.0035</td>
<td>-0.0040</td>
<td>-0.0115</td>
<td>-0.0191</td>
<td>-0.0341</td>
</tr>
<tr>
<td>5</td>
<td>$11252.71</td>
<td>0.0154</td>
<td>0.0019</td>
<td>-0.0056</td>
<td>-0.0131</td>
<td>-0.0207</td>
<td>-0.0282</td>
<td>-0.0432</td>
</tr>
<tr>
<td>6</td>
<td>$5183.76</td>
<td>0.0063</td>
<td>-0.0072</td>
<td>-0.0148</td>
<td>-0.0223</td>
<td>-0.0298</td>
<td>-0.0373</td>
<td>-0.0523</td>
</tr>
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References


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