Economic Freedom and Air Quality

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Contents

Summary

It is well established that economic freedom is one of the main drivers of economic prosperity. Economic freedom is the extent to which you can pursue economic activity without government interference as long as your actions don't violate the rights of others. Pollution is generally given as an example of a situation where the economic actions of one person violates the rights of others, thus justifying government intervention. However, the same economic institutions that contribute to economic freedom may actually lead to a cleaner environment at the same time.

Property rights, open markets, and a vibrant private economy are critically important economic institutions that affect environmental outcomes. Ever since the seminal work of Nobel laureate Ronald Coase, secure property rights and a strong justice system have been recognized for their ability to protect people and their property from pollution. Inappropriate government regulation can impede negotiations between those benefiting from and those being hurt by a polluting activity, preventing an efficient distribution of the right to the environmental resource and causing inefficient levels of pollution. In contrast, openness to trade is key to ensuring that new, cleaner technologies can be adopted across borders. Bureaucratic inefficiency, the influence of special-interest groups, and the prevalence of state-owned enterprises can all hinder the ability of a government to improve the environment effectively. All of these economic institutional factors are captured in the index published in the Fraser Institute's annual report, *Economic Freedom of the World*.

In a dataset giving concentrations of fine particulate matter for 105 countries around the world (taken from the World Bank's *World Development Indicators*), the 20 countries rated the most economically free by the *Economic Freedom of the World* index experience much cleaner air quality than the 20 countries with the lowest scores for economic freedom. Indeed, in 2010 the 20 countries that were most economically free had average concentrations of fine particulate matter that were nearly 40% less than the 20 least-free countries. However, the story is of course more complicated; the freest countries are also richer and per-capita income has long been shown to be correlated with both economic freedom and pollution.

In this paper, we examine a multicountry data set for over a hundred countries spanning a period from 2000 to 2010 to identify the relationship between economic freedom and two environmental indicators (concentrations of fine particulate matter and carbon dioxide emissions). After controlling for the effects of income, political freedom, and other confounding variables, we find that a permanent one-point increase in the *Economic Freedom of the World* index results in a 7.15% decrease in concentrations of fine particulate matter in the long-run, holding all else equal. This effect is robust to many different model specifications and is statistically significant. This effect is in addition to a general 36% decrease over time due to unidentified factors.

The results for carbon dioxide emissions per capita are not as promising. We do find evidence of a short-run negative effect in our preferred statistical model specification; however, this effect disappears under other plausible model specifications. Put simply, we cannot find an effect of economic freedom on carbon dioxide emissions. Ultimately, we can only conclude that economic freedom is indeed important for reducing local environmental problems.

Nevertheless, our results lend support to the proposition that economic freedom creates the incentive to abate local air pollution such as particulate matter. It appears that the same may not be true for environmental issues of a global nature, such as carbon dioxide emissions. Nevertheless, it appears that appropriately designed and managed institutions that promote economic freedom and strong property rights are an integral step in the direction of sustainable development. It is especially notable that this effect is distinct from that of political institutions, income, and other country-specific characteristics.

1 Introduction

For many years, societies have striven to achieve economic growth, continuously increasing their standard of living. In the 1970s, people began showing concern for the strain that free economic growth puts on the environment. A significant voice in this opposition to growth was the Club of Rome's *Limits to Growth*, which claimed that population growth was unsustainable, using computational simulations to make apocalyptic environmental and societal predictions (Meadows, Meadows, Randers, and Behrens, 1972).

Economic analysis suggests a different story than that told by the Club of Rome. Economists have developed the hypothesis that, if plotted against national or per-capita income, the concentration of a particular pollutant, one that can be detected by the relevant population, would exhibit a curve shaped like an inverted U. Starting at a very low income levels, concentration would increase as income grows, but only up to a point. At the peak of the inverted U, the marginal benefits of doing something about pollution overwhelm the incremental cost of pollution control, and concentration levels begin to fall in association with higher levels of income. This relationship has been named the environmental Kuznets curve (EKC) after Simon Kuznets, who studied a similar relationship between economic growth and income inequality (Kuznets, 1955). Starting with Grossman and Krueger (1991), the EKC has become a focal point of research into the economic causes of pollution.

Empirical studies on the EKC are extremely numerous, and not all pollutants follow the EKC pattern just described (Lipford and Yandle, 2010). Yet many studies ignore the central role of economic institutions that include property rights enforcement when estimating the relationship. Property rights, open markets, and a vibrant private economy are critically important economic institutions to consider when evaluating environmental outcomes. At the same time that economic institutions tend to be ignored, a plethora of recent empirical research has highlighted the role of political institutions in improving environmental quality. One consistent finding is that political institutions, corruption, or social structure are instrumental in properly characterizing the relationship between economic activity and environmental quality (Panayotou, 1997; Barrett and Grady, 2000; Bhattarai and Hammig, 2001; Bernauer and Koubi, 2009; Leitao, 2010; Lin and Liscow, 2013). Yet these studies fail to account for the role of economic institutions and freedoms explicitly in their explanatory models despite sometimes acknowledging this inescapable, causal connection.

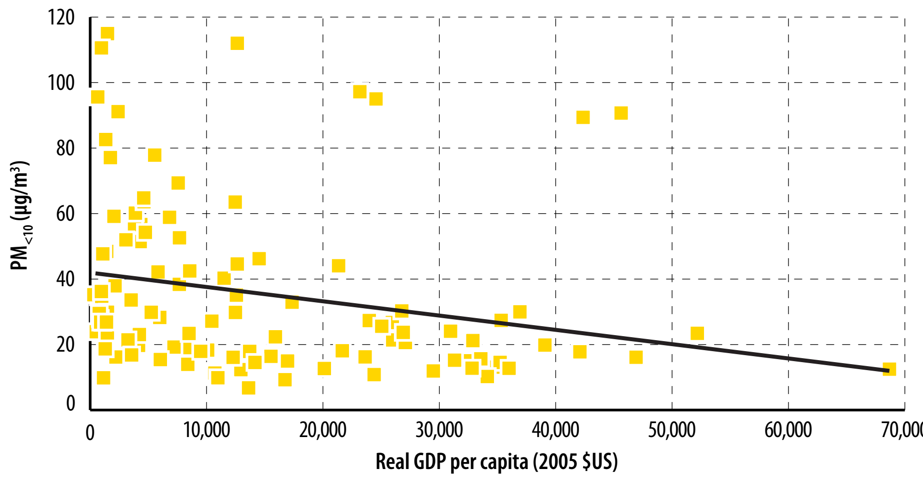
The realization of the importance of property rights and economic institutions to reduce pollution is not a new one. In the most cited paper on the subject in economics and law, Nobel Laureate Ronald Coase (1960) proposed that, in the absence of transaction costs, well defined property rights will always result in the correction of harmful externalities. This would occur as those benefiting from and being hurt by a polluting activity negotiate until they find an efficient distribution of the right to the environmental resource. This negotiation would be impossible without strong property rights. Coase (1960) elaborated upon this argument by noting that, in reality, where assuming that transaction costs do not exist will not make it so, the cost of resolving disputes can be prohibitively high. Well-developed institutions, which make it easier to resolve disputes, must be put in place in order to facilitate a move towards an efficient distribution of environmental resources.

It turns out that Coase's analysis and the conclusion drawn from it were based on English common-law rules that give rights to uncontaminated water and air to downstream rights holders. At common law, rights holders may contract away their rights to those who value them more highly. But, at common law, no polluter has the right to impose costs on downstream parties without their permission (Meiners and Yandle, 1999). English common law was a property rights institution that mattered. Along these lines, Panayotou (1993) proposed that developing economies could relieve the pressure they put on the environment by eliminating policies that distort markets, ensuring that property rights—particularly those governing natural resources—are strong, and by internalizing any remaining externalities.

More recent research points out that strong property rights are only one of the institutional elements that are relevant to pollution. Inappropriate government regulation might adversely affect the ability of, and incentive for, individuals to engage in Coasian bargaining, which may lead to inefficient levels of pollution. In contrast, openness to trade can allow organizations based in rich nations that adhere to international environmental standards to establish a presence in developing countries, where they may pollute less than local firms. Bureaucratic inefficiency, the influence of special-interest groups, and prevalence of state-owned enterprises can all hinder the ability of a government to improve the environment effectively. All of these economic institutional factors are captured in index (EFW index) published in the Fraser Institute's annual report, *Economic Freedom of the World* (Gwartney et al., 2012).

The purpose of our paper is to investigate more closely the relationship between economic freedom and the environment. **Figure 1** is a scatterplot of concentrations of fine particulate matter and GDP per capita for 105 countries in 2010. The scatterplot suggests a negative relationship; however, as noted by much of the literature discussed above, this relationship may not

Figure 1: Particulate matter and income, 2010

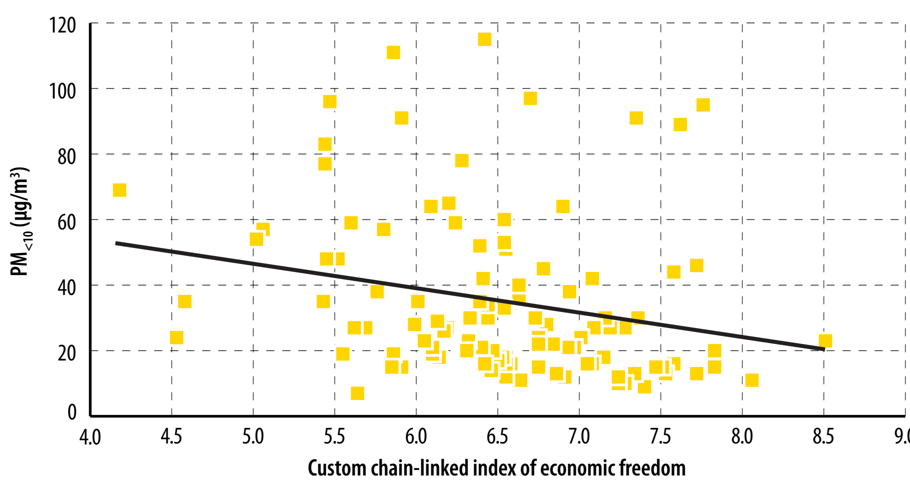


Notes: The figure displays average annual concentrations of fine particulate matter ($PM_{<10}$) plotted against real GDP per capita for 105 countries in 2010. The $PM_{<10}$ are measured in micrograms per cubic metre. The GDP data is adjusted for purchasing power parity and is expressed in 2005 US dollars. The solid black trend line reflects the simple linear relationship between the two variables.

Source: World Bank, 2013.

be linear. Furthermore, in a scatter-plot of fine particulate matter and scores from the EFW index for those same 105 countries in 2010 (**figure 2**), the negative relationship is evident. And, indeed, the 20 countries that rank highest according to the EFW index have concentrations of fine particulate matter that are almost 40% less than concentrations in the 20 countries that rank lowest (authors' calculations). Simply put, the freest countries have cleaner air than the least-free countries.

Figure 2: Particulate matter and economic freedom, 2010



Notes: The figure displays average annual concentrations of fine particulate matter ($PM_{<10}$) plotted against scores from the custom chain-linked index of economic freedom (Sound Money component removed) for 105 countries in 2010. The $PM_{<10}$ are measured in micrograms per cubic metre. A lower score on the economic freedom index represents less economic freedom, and a higher score, more economic freedom. The solid black trend line is the linear relationship between the two variables.

Source: Gwartney et al., 2012; World Bank, 2013.

To complicate matters, economic freedom and GDP per capita are also correlated. The purpose of this paper is to control for these various confounding relationships in order to identify the direct effect of economic freedom on two environmental indicators—concentrations of fine particulate matter (PM_{10}) and emissions of carbon dioxide (CO_2). We use multicountry data from 2000 to 2010 to identify the direct causal effect of property rights and other important economic institutions—as described in an index of economic freedom—on concentrations of fine particulate matter and carbon dioxide emissions while controlling for the effects of gross domestic product, political institutions, and other confounding variables.

The following section lays out the rationale for a relationship between environmental quality and the particular ingredients of economic freedom that interest us. The third section examines the Ukraine's "Orange Revolution" and its associated effects on environmental quality. Our case study focuses on the need for a robust empirical analysis of the effect of economic freedom on pollution. Section four outlines the data and econometric methodology used in our empirical analysis. Section five presents and discusses the empirical results. Section six concludes the paper.

2 The Link between Economic Freedom and the Environment

The link between income and environmental quality has been—and continues to be—extensively studied by those who are primarily interested in the environmental Kuznets curve (EKC). Institutional quality is often treated as a secondary effect on pollution levels. Despite this, there is reason to believe that economic freedom (a measure of the quality of economic institutions) plays a particularly important role in the causal relationship between economic development and environmental quality. Failing to account for it in economic models of pollution can lead to spurious results. In this section, we compile a selection of previous research that reinforces the importance of this role.

2.1 The role of property rights and the legal system

Negotiation between polluters and community groups can control pollution-related externalities, an idea that many attribute to Ronald Coase (1960). Strong property rights over the land being damaged by pollution create the incentives necessary for individuals to engage in informal regulation. Appropriate institutions such as common-law courts or some system for the enforcement of contracts between polluters and communities can further reduce the costs that communities must face in order to ensure that polluters are kept in check.

Strong property rights and a system of courts are not sufficient to harbour effective informal regulation. Formal government regulation is known to inadvertently dismantle informal regulation in favour of inferior outcomes (Meiners and Yandle, 1999). In a legal comparison of formal and informal regulation, Posner (1996) supports several insights into the effects of formal regulation where the government has the same goals as individuals:

- transferring government resources to informal regulators, or simply abstaining from seizing those resources through taxation and regulation, can lead to more efficient regulation than formal government intervention;

- in many cases, government regulation can undo the positive effects of informal regulation;

- government regulation of the interaction among citizen groups appears to severely undermine self-regulation within groups.

Posner's (1996) conclusions implicitly support the proposition that the ability to regulate is held the same way as any other right. When there are many claimants to the right to regulate, the cost of regulating effectively increases as competing regulators step on each other's toes; resulting in ineffective pollution control. At its core, this is an occurrence of the tragedy of the "anti-commons".[1]

In summary, the quality of the legal system and security of property rights can lead in theory to informal regulation of pollution; however, this effect can be crowded out by formal government regulation.

2.2 The role of openness to trade

Implicit in increasing economic freedom is removing unnatural barriers to international trade, treaty, and cooperation. Among the most pervasive—and possibly the most controversial—ideas associated with the relationship between pollution and openness to trade is commonly known as the "pollution haven" hypothesis. This hypothesis simply proposes that, when international barriers are removed, polluting firms will move to countries that have lower pollution standards, the so-called race to the bottom or pollution haven effect. Carson's (2010) review of the EKC literature suggests that the empirical evidence to support this hypothesis is, to be generous, controversial. Wheeler (2001) provides an in-depth critique of the theory supporting the pollutionhaven hypothesis, providing some evidence that:

- pollution abatement and regulatory compliance is a small cost for most polluting firms when compared to an international move;

- informal regulation helps to keep international polluters in check;

- large multinational firms in many industries generally adhere to the same standards regardless of where they operating.

1. The term "anti-commons" refers to situations where there exist multiple rights to exclude. For example, when the approval of multiple regulators is required, underdevelopment will occur. See Buchanan and Yoon, 2000.

Frankel and Rose (2002) use an instrumental-variables approach to estimate the relationaship between pollution and openness to trade. Their results give no support to the pollution haven hypothesis, even suggesting that it may be the case that engaging in trade has a beneficial effect on the environment. This is supported by the micro-level analysis of Dasgupta et al. (2000), which suggests that organizations that are publicly traded or adhere to ISO 14000 production management procedures, which are designed in part to help firms comply with environmental standards, can be expected to pollute less. Dasgupta et al. (2002) provide evidence that the stock prices of publicly traded firms respond negatively to news highlighting their polluting activities. This suggests that international firms face significant pressure to keep pollution in check, regardless of where they are operating.

Antweiler et al. (2001) show that openness to trade can affect the environment in three ways: a scale effect, a technique effect, and a composition effect. The scale effect refers to how freer trade leads to increased output, which in turn leads to more pollution, all else equal. At the same time, freer trade leads to the diffusion across countries of newer, cleaner, technologies that would reduce pollution. Opening up to more trade also leads to a change in the composition of industry, which, depending on factor endowments, can have a positive or negative effect on pollution. Antweiler et al. (2001) do find that the net effect of freer trade on sulfur-dioxide concentrations has been negative.

Freer trade can lead to an overall cleaner environment for some pollutants but there can be locations where polluting activities increase. This occurs through technology diffusion across countries, and through a change in industrial composition in only some countries depending on their factor endowments.

2.3 The role of big government

Government size is often referenced as an indicator of economic freedom. An overly large government may be associated with bureaucratic inefficiency, the influence of special-interest groups, and the prevalence of state-owned enterprises. These factors all have the potential to affect the ability of an overly large government to improve environmental quality.

Bernaur and Koubi (2013) analyze national-level data from 42 countries for the period 1971 to 1996 to examine the effect of government size on sulfur-dioxide concentrations while controlling for the quality of government and other factors. Their results suggest that big government is associated with higher concentrations of sulfur dioxide.

Furthermore, a larger government may have more state-owned enterprises that are immune to informal regulation and are more likely to secure bailouts more easily than their private-sector counterparts since the state has a direct stake in their operations. Wood (2013) builds a theoretical model that predicts that firms that are more likely to receive bailouts when suffering financial distress should be worse polluters than those who have difficulty securing them. Meyer and Pac (2013) compare the environmental performance of energy utilities in Eastern Europe and find that state-owned utilities are indeed dirtier than their privatized counterparts. This is in addition to the findings of Dasgupta et al. (1997), which suggest the state-run firms in China are dirtier than their free-market counterparts. This effect is largely due to distortions of abatement costs and increases in waste production caused by inefficient management.

3 Preliminary Analysis

Before moving on to develop an econometric model to test our hypothesis, we use a case study to demonstrate that a causal relationship between economic freedom and pollution may exist. An ideal case study would be set up much like a scientific experiment. We would ideally observe some event that violently alters economic freedom in a specific country. We could then observe the change in pollution in that country, relative to the change seen in another country that has had stable levels of economic freedom. The "Orange Revolution" is an excellent example of such a case study.

3.1 Data

For the preliminary analysis in this section, we use urban concentrations of particulate matter less than 10 microns in diameter (PM_{10}) from the World Bank's *World Development indicators* (WDI). PM_{10} is used as a proxy for local air quality; its effects are largely tangible and relatively short term. It is essentially an average of measured PM_{10} concentrations (in micrograms per cubic metre) in cities with more than 100,000 residents over the course of a year. It is possible that natural forces may have some effect on this measure of pollution. Despite this, our measure of PM_{10} is a good indicator of the adverse effects of urban air pollution that are borne by individuals.

We use the Fraser Institute's chain-linked index from *Economic Freedom of the World* (EFW chain-linked index) as a measure of economic freedom and the quality of economic institutions. The EFW chain-linked index assigns an annual score out of 10 indicating the degree to which a country's policies and institutions support economic freedom (10 being highly supportive and 0 being poorly supportive of economic freedom). The EFW chain-linked index reflects the size of government; the quality of the legal system and strength of property rights; soundness of money; freedom to trade; and burden of regulation.[2]

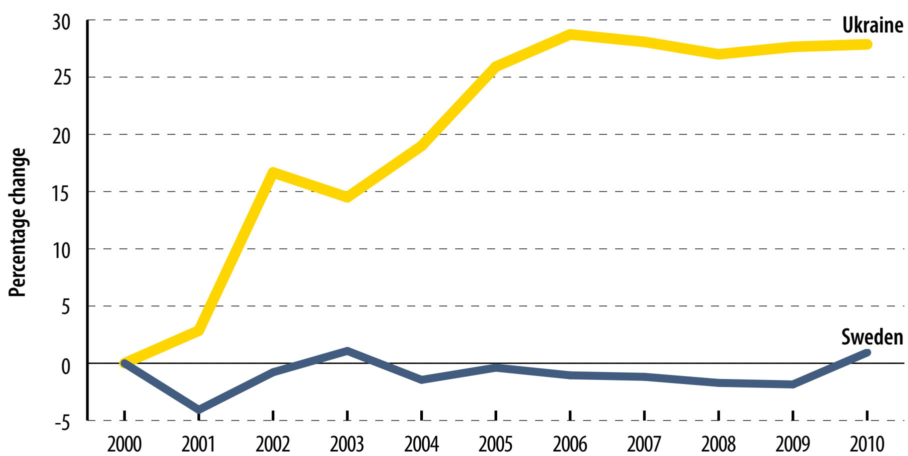
2. More details on how the indexes published in *Economic Freedom of the World* are constructed can be found in Gwartney et al., 2012: chapter 1, appendix.

3.2 The Orange Revolution

Following a fixed election in late 2004, Ukraine saw massive peaceful protests that led to a dramatic political shift (Kuzio, 2010). These protests became known as the Orange Revolution. In the Ukraine, the Orange Revolution represented the start of a drastic shift towards political and economic liberalization. For our purposes, it is an ideal opportunity to investigate the reduction in pollution associated with a discrete change in economic freedom.

Figure 3 shows the percentage change in the EFW chain-linked index from year 2000 levels. At a glance, it is clear that the Ukraine's score on the EFW chain-linked index experienced significant growth starting in 2004, stabilizing in 2006, corresponding—at least chronologically—with the Orange Revolution. The four-year average score on the EFW chain-linked index following this growth was 5.82, an 18% increase from the four-year average preceding 2004 of 4.95. This difference in four-year means is statistically significant at the 5% level according to a Welch two-sample T-test (p-value = 0.0182).

Figure 3: Ukraine and Sweden, change (%) in economic freedom, 2000–2010

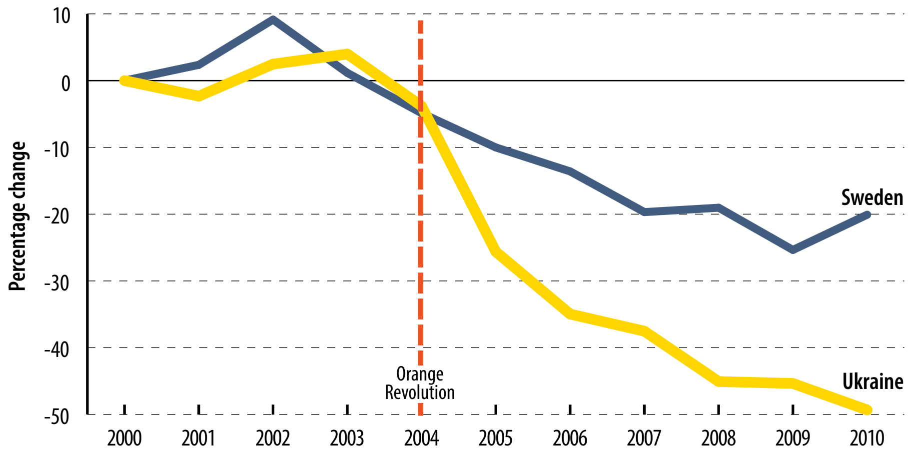


Note: The figure displays the cumulative percentage change since 2000 in the scores from the custom chain-linked index of economic freedom (Sound Money component removed) for the Ukraine and Sweden.

Sources: World Bank, 2013; calculations by authors.

This period of time is also associated with a dramatic decrease in average Ukrainian PM_{10} concentrations (figure 4). The four-year average PM_{10} concentration was over 41% lower following 2005 than it was before 2004. This difference in four-year means is statistically significant at the 1 % level according to a Welch two sample T-test (p-value = $6.573 \cdot 10^{-5}$) More importantly, this represents a change from a mean PM_{10} concentration of 30.7 to 18 $\mu g/m^3$, which is below the World Health Organization's (2006) Air Quality Guideline of 20 $\mu g/m^3$. By including data from 2010, we calculate a 5-year mean PM_{10} concentration of 17.5 $\mu g/m^3$.

Figure 4: Ukraine and Sweden, change (%) in concentrations of fine particulate matter, 2000–2010



Note: The figure depicts the cumulative percentage change in concentrations of fine particulate matter since 2000.

Sources: World Bank, 2013; calculations by authors.

To see a change in Ukrainian PM_{10} associated with the Orange Revolution is compelling, but unsatisfying evidence of a possible link between the induced increase in economic freedom and the observed drop in pollution. It is particularly useful to observe a nearby country that experienced little or no change in economic freedom as a comparison. Sweden is an ideal example of such a country. While culturally and politically different from the Ukraine, Sweden provides good insight into changes of PM_{10} concentrations in a relatively stable country over the course of the 2000s. As seen in **figure 3**, Sweden shows very modest variation in economic freedom. In fact, the difference in the four-year mean of Sweden's EFW chain-linked index before and after Ukraine's Orange revolution is statistically indistinguishable from zero according to a Welch two-sample T-test.

The unobservable and cultural differences between Sweden and the Ukraine are not a major concern since it is reasonable to assume that those differences were the same before and after the Orange Revolution. In this case, we have the makings of a natural experiment. Data from Sweden and the Ukraine prior to the Orange Revolution act as a control for innate differences between these countries. Data from the Ukraine after the Orange Revolution is the treatment group. If the difference between PM_{10} reductions in Sweden and the Ukraine increased after 2004, this may indicate a causal effect as only the Ukraine experienced the Orange Revolution. If we are satisfied with the propositions that PM_{10} concentrations in Sweden and the Ukraine were following the same trend prior to 2004 and Sweden was not affected by the Orange Revolution, we can say that the trend observed in Sweden is what would have occurred in the Ukraine if there had been no shock in economic freedom.

Leading in to the Orange Revolution, Sweden has lower levels of PM_{10} concentration than the Ukraine but appears to be exhibiting a relatively parallel trend. Both countries experience a similar spike in PM_{10} in the early 2000s, likely due to some global event that occurred around that time. Sweden did experience a decrease in 4-year mean PM_{10} concentrations of 22%[3] following 2005, barely more than half the reduction in PM_{10} seen in the Ukraine.

Data from Sweden indicate that the Ukraine may have seen some reduction in PM_{10} even without the increase in economic freedom associated with the Orange Revolution, but it would not been as drastic as what did occur. If the disparity in PM_{10} concentrations seen before 2004 persisted, we estimate that the Ukraine would have reached a minimum concentration of about 27.0 $\mu g/m^3$ in 2009 (a 95% confidence interval of this result spans from 26.4 to 29.1 $\mu g/m^3$) before slightly rising again in 2010. This infers that without the increase in economic freedom brought on by the Orange Revolution, the Ukraine's PM_{10} concentrations would not have met WHO guidelines by the end of this millennium's first decade.

However, we must add the caveat that this simple analysis does not control for many confounding factors, such as unrelated changes in industrial composition. A more detailed econometric analysis is conducted in the remainder of the paper to identify more clearly the relationship between economic freedom and air quality.

3. This difference in four-year means is statistically significant at the 1% level according to a Welch two-sample T-test (p-value 0.0004223)

4 Econometric Methodology

While the case of the Orange Revolution draws attention to the connection between economic freedom and pollution, the evidence we see is hardly robust. We know that changes in economic freedom are accompanied by changes in income, which are associated with changes in pollution. We are left with the question of whether the freedom generated by the Orange Revolution reduced pollution directly, or simply increased income. Or, perhaps it is political rather than economic freedom that leads to reductions in pollution. It is also natural to be unsatisfied with the size of our sample. Surely, there are more events of changing economic freedom that can be observed.

Modern econometrics provides a toolkit that allows us to address these shortcomings. As long as we can develop a model that adequately specifies the relationship between economic freedom and pollution, we can separate out the direct effect from the noise that surrounds it. This is done using linear regression techniques that allow us to estimate the unique effect of economic freedom while controlling for other important factors.

Leveraging the extensive attention that economists have given to the environmental Kuznets curve (EKC) provides insight to how we might control for the effects of income. We build an econometric model that treats income in a very general way, by including a cubic form of the natural logarithm of gross domestic product. This generality makes it difficult to directly interpret the parameters that specify the relationship between income and pollution but enhances our ability to control for its complexity when assessing the effect of economic freedom.

We also realize that income might be endogenous not only to economic freedom but also to pollution as well. In other words, there may be reverse causation between the variables or the variables may be to some extent simultaneously determined. To address this, we develop a model that has two stages:

1. a first stage in which variation in income is theorized to be caused by economic freedom, pollution, and other important controls;

2. a second stage in which variation in pollution is theorized to be caused by economic freedom, income. and other controls.

Using the method of instrumental variables we find the portion of the variance in income that is associated with economic freedom and other instrumental variables that we posit are only related to pollution through their effect on income. This allows us to consistently estimate the parameters on the second stage of our model, revealing the relationship between economic freedom and pollution.

A final concern is the simple fact that there are many things about specific countries and specific years that cannot be observed. As our data set comes from many different countries over several years, we are able to control for many of these unobservable differences. To study the case of the Orange Revolution, we considered only variation seen within Sweden and the Ukraine over time. The differences between these countries are caused by unobservable factors that are constant within each country, and are uninformative in determining the relationship between economic freedom and pollution. Economists refer to the effects of these factors—which may include things like culture or geography—as fixed effects. We can control for these fixed effects using regression techniques—known as fixed effects regressions—that are fundamentally the same as our approach to the analysis of the Orange Revolution. They only observe within-country variation.

The use of country-level fixed effects is of critical importance using our country-level data set. Consider economic freedom in Canada. Canada's level of economic freedom is quite high but lacks variation. So Canada's high level of economic freedom is probably a result of something unobservable and unchanging about Canada. Using standard—also referred to as pooled—regression we would see any data point coming from Canada as a point of high economic freedom and view any associated level of pollution as being caused by this level of freedom. Really, it may have been caused by the same unobservable fixed effect that created Canada's persistently high level of freedom in the first place, causing the pooled regression to report a spurious relationship between pollution and economic freedom. Using a fixed-effect regression to focus on within-country variation avoids this source of bias.

Our preferred approach to controlling for unobservable characteristics in our model is using what are known as two-way fixed effects. Essentially, we transform our data so that we only observe within-country variation before controlling for the individual fixed effects of time using a set of parameters that indicate what year an observation came from. These year-fixed effects control for things such as global weather patterns or economic trends that occur in every country in a given year. In a two-way fixed-effects regression, the relationship between economic freedom and pollution is determined based on co-variation of these variables that is unique to specific countries and years. An extreme event that occurs in Canada in 2006 is only considered to be noteworthy if it is extreme relative to the average across countries in 2006 and across years in Canada.

Combining the methods of two-way fixed effects and instrumental variables, we are able to estimate our two-stage model in order to identify the relationship between economic freedom and pollution in a setting that is as similar as possible to that of a controlled experiment.

4.1 Data

For our analysis we have compiled a panel dataset spanning 11 years from 2000 to 2010 and 111 countries. This panel is chosen due to the availability of our measures of economic and political freedom and is further constrained based on the measure of pollution used.

We use urban concentrations of particulate matter less than 10 microns in diameter (PM_{10}) and carbon dioxide (CO_2) emissions as environmental indicators. PM_{10} is used as a proxy for local air quality; its effects are largely tangible and relatively short term. CO_2 is viewed by many as a global externality[4] and has roused quite a bit of concern amongst scientists and the general public, especially in developed countries. Reliable data on both of these indicators are available from the World Bank's *World Development Indicators* (WDI). In practice, the natural logarithms of these variables are used to correct for severe skewness in their distributions.

Our measure of CO_2 is reported by the WDI as carbon dioxide emissions (in metric tons per capita) from the burning of fossil fuels and the manufacture of cement. This measure of CO_2 only captures emissions caused by human action since it is calculated based on economic activity instead of being measured. The possibilities of carbon sequestration and CO_2 emissions from alternative sources such as deforestation or agricultural fertilizers are omitted. Data for CO_2 is currently unavailable after 2009 and a limited number of countries are missing (seemingly random) years of data, causing our panel to be unbalanced.

Our measure of PM_{10} is reported by the WDI as the average exposure of urban residents of a given country to outdoor particulate matter in a given year. It is essentially an average of measured PM_{10} concentrations (in micrograms per cubic meter) in cities with more than 100,000 residents over the course of a year. It is possible that natural forces may have some effect on this measure of pollution. Despite this, our measure of PM_{10} is a good indicator of the adverse effects of urban air pollution that are borne by individuals.

We use a special version of the Fraser Institute's chain-linked index from *Economic Freedom of the World* as a measure of the quality of economic institutions. Our version of the chain-linked economic-freedom index

4. An externality is a situation where some of the costs or benefits of a private action are incurred by third parties.

(custom chain-linked index) excludes Area 3: Sound Money,[5] since we use inflation as an instrumental variable in some model specifications in our empirical analysis. With Area 3: Sound Money excluded, the chain-linked index of economic freedom reflects the size of government; the quality of the legal system and strength of property rights; freedom to trade; and the burden of regulation. These elements account for the three arguments we discussed in section 2.

The index published in *Economic Freedom of the World* considers a wide range of both developed and developing countries, assigning a score out of 10 indicating the degree to which its policies and institutions support economic freedom (10 being highly supportive and 0 being poorly supportive of economic freedom).[6]

Many authors, including Lin and Liscow (2013) and Bernauer and Koubi (2009), recognize the importance of political structures in determining levels of pollution. Such studies typically use an aggregate index of political rights or structure as a proxy for the political institutions in place in a country at a given time. In our study, controlling for political setting is of critical importance as certain political environments are more conducive to economic freedom than others. Omitting such controls could lead us to mistake the effect of political institutions for that of economic freedom. As indicators of the political system in place we use data from the Polity IV data set (Marshall, Gurr, and Jaggers, 2013).[7] As a primary measure, we include the Polity2 variable, which we will refer to simply as "polity". Polity is a comprehensive aggregate of several political indicators and ranges from –10 (mostly autocratic) to 10 (mostly democratic). We also create a political event dummy variable that indicates the occurrence of a period of serious political collapse, interruption, or transition of any kind.

As a measure of standard of living and level of economic development of a country, we use purchasing power parity adjusted gross domestic product (GDP) measured in 2005 US dollars, as reported by the WDI. We consider the natural logarithm of GDP as well as its square and cube in order to appropriately model the relationship between economic development and pollution. This functional form was preferred by the early work of Shafik and Bandyopadhyay (1992), the logarithm of GDP continues to be used in the EKC literature (Panayotou, 1993; Stern, 2002; Halkos, 2003; Hung and Shaw, 2002). It specifies the EKC in the context of the changing income elasticity of pollution while correcting for skewness in the sample GDP distribution.

5. The customized version of the chain-linked index from *Economic Freedom of the World* excluding Area 3: Sound Money was provided by Robert Lawson upon request.

6. More details on how the indexes published in *Economic Freedom of the World* are constructed can be found in Gwartney et al., 2012: chapter 1, appendix.

7. We have also tried the Freedom House Index but our empirical results are insensitive to which indicator of the quality of political institutions is used.

Also from the WDI dataset, we add data on population density (people per km[2] of land), manufacturing value added as a percent of GDP, annual growth rate of the GDP deflator, and the percentage of population between the ages of 15 and 64. As a proxy for inflation, we use a logarithmic transformation of the growth rate of the GDP deflator (more details are included in the Technical Appendix). Summary statistics for all variables are displayed in table 1.

Table 1: Summary Statsitics

Variable	Observations	Mean	Standard Deviation	Skewness	Max	Min
$\ln(PM_{10})$	1221	3.5824	0.68	0.1722	5.3174	1.8904
$\ln(CO_2)$	1110	0.7306	1.7075	−0.745	3.6138	−3.958
$\ln(GDP)$	1211	8.8618	1.3119	−0.371	11.2121	5.513
freedom	1211	6.43	0.8849	−0.312	8.51	3.57
manufacturing	1211	0.1476	0.0643	0.1827	0.3574	0.0063
density	1211	4.1469	1.3741	−0.0458	8.8891	0.8341
polity	1211	5.5095	5.3981	−1.2263	10	−9
PoliticalEvent	17	—	—	—	1	0
workingAge	1211	62.8881	6.5267	−0.3746	82.5421	48.5505
inflation	1211	−1.0885	0.2727	−0.2575	1.6929	−4.511

Notes: *politicalEvent* is a dummy variable that is equal to one for 17 observations in our sample; it is never missing.
Source: Authors' calculations.

4.2 The reduced form model of pollution

Our empirical model of primary interest, which we refer to as the second stage of our model, is as follows:

$$\ln(p_{it}) = \beta_0 + \beta_1 \ln(GDP_{it}) + \beta_2 \ln(GDP_{it})^2 + \beta_3 \ln(GDP_{it})^3 + \beta_4 freedom_{it} + \beta_5 freedom_{i(t-1)} + x'_{it}\beta_x + e_{it} \quad (1)$$

Where p_{it} is pollution, $freedom_{it}$ and $freedom_{i(t-1)}$ are the current and lagged values of the freedom index in country i and year t. x_{it} is a vector of control variables that contains our chosen measures of manufacturing value added ($manufacturing_{it}$), political variables ($polity_{it}$ and $politicalEvent_{it}$), the natural logarithm of population density ($density_{it}$) as well as country and year fixed effects depending on the model specification.

We use the natural logarithm of population density (people per km^2 of land), taken from the WDI, to control for the scale of a given economy. This variable is omitted as a control in models of CO_2. Controlling for the scale of an economy in the CO_2 model is redundant since CO_2 is measured in per-capita terms. Manufacturing value added as a percent of GDP is used to control for the composition of industry within a given country. These two controls are necessary since they vary across countries and years, so they cannot be captured appropriately by fixed effects.

4.3 The problem of endogeneity in the reduced-form model

Like Lin and Liscow (2013), we recognize that endogeneity is likely to be present in the relationship between pollution and GDP. This can bias the estimates of all of our model's coefficients. We are primarily interested in the effect that GDP and economic freedom have on pollution, but pollution may in fact have a simultaneous causal effect on GDP. In the case of PM_{10}, it is possible that high levels are associated with issues such as respiratory disease, decreasing labor productivity and, subsequently, GDP.

The argument for simultaneity in the case of CO_2 is more subtle but it is also more applicable to the macroeconomic level of our data. In the early stages of development, increasing CO_2 emissions are expected to be driven by increasing GDP. This is simply the effect of the growing scale of the economy that is not captured by other control variables. However, as a country develops there may be international pressure, from other countries with economic, legal, and social institutions in place that discourage CO_2 emissions, to adopt costly emission reduction targets and policies that negatively affect the economy. Lipford and Yandle (2010) are skeptical of the effectiveness of the peer-pressure since the pressuring countries are unlikely to be willing to offer compensation; they do argue, nevertheless, that the relatively carbon-efficient developed countries do push for emissions reduction targets for the large and carbon-inefficient developing countries (India and China).

This type of simultaneity is more likely to be the case for CO_2 than PM_{10} since CO_2 is more commonly seen as having global implications that transcend many geographical and even intergenerational boundaries. In short, CO_2 emissions are considered an international issue and may affect GDP through costly CO_2 reduction policies implemented at the behest of international pressure.

There may also be endogeneity due to omitted variable bias. While year and country fixed effects are likely to control for a great number of unobservable factors, there are additional variables varying by time and country for which reliable data simply do not exist for a sufficient portion of our data set. An obvious example of such an omitted variable would be a measure of income inequality.

4.3.1 Mitigating potential endogeneity

Proposing that the reduced-form model, specified by equation (1) suffers from simultaneity bias makes it necessary to consider a first stage model:

$$\ln(GDP_{it})^{q} = \delta_0^{(q)} + \delta_2^{(q)} freedom_{it} + \delta_5^{(q)} freedom_{i(t-1)} + z'_{it}\delta_z^{(q)} + x'_{it}\delta_x^{(q)} + v_{it}^{(q)} \quad (2)$$

where the superscript q is an exponent taking the value 1, 2, and 3 and z_{it} is a vector of at least three exogenous variables that can be used to identify equation (1), the second-stage model, by the method of instrumental variables. The first-stage model proposed here is actually three linear equations, one for each polynomial term of GDP. The parameters from the second stage of our model are estimated using an instrumental variables (*IV*) framework that views each of the first-stage equations as independent of each other and simultaneously determined with the second stage. For each instrument that is chosen, its square and cube are also used as instruments.

In addition to the typical instrumental-variables assumptions, equation (2) contains several important theoretical assertions. The most significant is that we explicitly acknowledge that GDP is a function of economic freedom. Under this assumption, the coefficients on freedom in our second-stage model describe only the direct effect of economic freedom on pollution.

We use proxies of inflation, its lag, and a measure of the proportion of the population of common working age or simply working age as instruments for income. In the Technical Appendix, we propose the arguments for the validity of these instruments and discuss the proxies we have chosen.

4.4 Identifying the effect of economic freedom on pollution

In the context of this study, the primary result of interest is the long-run[8] effect of freedom. We calculate this effect as the sum of the coefficients on freedom and its lag by estimating the augmented regression:

8. Our data set has a relatively short time-series dimension so we use of only a single lag of freedom. In this context, "long run" refers to any acknowledgment of dynamic relationship between pollution and freedom.

$$\textbf{(3)}\quad \ln(p_{it}) = \beta_0 + \theta\, freedom_{it} + \beta_5(freedom_{i(t-1)} - freedom_{it}) + \beta_1\ln(GDP_{it}) + \beta_2\ln(GDP_{it})^2 + \beta_3\ln(GDP_{it})^3 + x'_{it}\beta_x + e_{it}$$

where it can be shown that θ is an estimate of the long-run effect of freedom. θ can be interpreted as the percentage change in pollution that is expected to follow from a permanent unit increase in the custom chain-linked index. In practice, θ is only an accurate estimate of the percentage change in pollution associated with small changes in freedom. Since the scale of the custom chain-linked index ranges only from 0 to 10, a one-point change is a relatively large shift. An accurate measure of the change in pollution associated with a one-point change in freedom can be calculated as $\%\Delta p = 100\,(e^{\theta} - 1)$.

5 Results

5.1 Fine particulate matter (PM_{10})

Applying a Durbin-Wu-Hausman[9] test, as explained in the Technical Appendix, for PM_{10} with two-way fixed effects suggests that we cannot reject the null hypothesis of no endogeneity. For this reason, the preferred estimator and model for PM_{10} is fitted by ordinary least squares (OLS) with country and year fixed effects.[10] The results estimated by OLS and by GMM IV are displayed in table 2.[11]

We do find evidence of a significant and negative relationship between economic freedom and PM_{10}. The coefficient on the lagged custom chain-linked index variable is negative and significant in our preferred model and under all other specifications tried. However, the coefficient on current freedom, although negative, fails to be statistically different from zero. This implies that for PM_{10} emissions decisions are sticky, that is, a change in one's incentive to reduce pollution takes time to translate into results. Most importantly, the long-run effect of freedom is negative and statistically significant in all model specifications. Our preferred model estimates that a permanent increase of one point on the custom chain-linked index reduces PM_{10}

9. F (3, 110) = 1.94

10. To test the fixed-effects assumptions of our theoretical model we use a joint significance test that all country-level fixed effects are equal to zero as well as a Hausman test to assess whether the more efficient random effects estimator would yield consistent estimates. We then add year dummy variables to the fixed-effects model and test their joint significance. This procedure empirically justifies our use of country and year fixed effects for both pollutants.

11. We apply Wooldridge's (2002) autocorrelation and a modified Wald test of panel heteroskedasticity test (Greene, 2000) to our full models for PM10 and CO2, with time fixed effects implemented as year dummy variables. Based on these tests we reject the null hypotheses that the models do not suffer from first order autocorrelation and heteroskedasticity. For this reason, we use country cluster robust statistics throughout our analysis. To estimate models with instrumental variables, we use a generalized method of moments (GMM IV) approach with an efficient weighting matrix.

Table 2: Two-way fixed effects regression estimates for PM_{10}

Explanatory variables	OLS	(s.e.)	GMM-IV	(s.e.)
$\ln(GDP_{it})$	−2.965	(−2.382)	−9.821	(10.42)
$\ln(GDP_{it})^2$	0.131	(−0.268)	1.189	(1.456)
$\ln(GDP_{it})^3$	−0.00255	(−0.00997)	−0.0451	(0.063)
$freedom_{it}$	−0.0203	(0.0202)	−0.059	(0.0506)
$freedom_{i(t-1)}$	−0.0512***	(0.0154)	−0.0866**	(0.0512)
$manufacturing_{it}$	1.255**	(0.516)	0.939	(0.725)
$\log(density_{it})$	0.0139	(0.158)	0.189	(0.402)
$polity_{it}$	0.00343	(0.00261)	0.003	(0.00317)
$politicalEvent_{it}$	−0.000782	(0.0446)	−0.00383	(0.0508)
Long Run Effect of Freedom	−0.07151***	(0.02447)	−0.14557**	(0.0973)
Joint Significance Test on Income (p-value)	0.00035		0.26854	
Durbin-Wu-Hausman Test (p-value)	—		0.17928	
Observations	1,100		1,100	
Number of countries	111		111	

Notes: $\log(PM_{10it})$ is the dependent variable. Country-clustered standard errors in parentheses. OLS is the preferred estimator by a Durbin-Wu-Hausman test. Details of first-stage regressions available upon request. Year fixed effects are significant at the 1% level for all years. *** indicates statistical significance at the 1%, ** at the 5%, and * at the 10% level.

concentrations by 7.151%[12] in the long run. The coefficient estimate is robust to whether pooled OLS (−7.1%), country fixed effects (−6.6%), or two-way fixed effects are used (−7.151%).

Using a joint significance test of the parameters on our income terms, we find evidence of a relationship between income and PM_{10} when OLS estimation is used. Despite this, our model does not support the existence of an environmental Kuznets curve (EKC) for PM_{10}. In fact, we find evidence of a downward sloping relationship between income and PM_{10}. The preferred estimate of the coefficients on income suggests that there is a local minimum in pollution levels when GDP per capita hits approximately $11,196.[13] The upward trend seen after this local minimum levels off slightly over time due to the negative cubic coefficient in our model and may in fact be a statistical artifact caused by outlying levels of income.

12. The exact percentage change for a one-point change in the long-run effect of freedom is computed as $\%\Delta p = 100\,(e^{\theta} - 1)$.

13. Which is approximately equal to $e^{9.32367}$, the exponential of the root of first derivative of the estimated polynomial in $\ln(GDP)$.

When we estimated a pooled OLS model instead of one with fixed effects, the relationship between income and PM_{10} was N-shaped. However, an L-shape was found under all other specifications tried (OLS country fixed effects, OLS two-way fixed effects, and GMM IV). This suggests that, for the case of local air pollutants such as PM_{10}, notable EKC or N-shaped trends found by previous studies may be statistical artifacts of cross-sectional regressions that are capturing not the effect of economic growth but the unobservable cultural and geographical effects that are correlated with it. Our results indicate that PM_{10} concentrations within a nation should be expected to decrease as it experiences growth. Since economic freedom has been shown to enhance growth (Gwartney et al., 2012), this relationship can be seen as an added benefit of economic freedom.

It is encouraging to note that expected PM_{10} concentrations decrease over time. The year fixed effects (available from the authors upon request) indicate that by the year 2010 the average country's expected PM_{10} concentration had dropped by approximately 36% since the year 2000, holding all else equal.

A surprising result is that the estimated direct effect of political institutions on PM_{10} is very small in magnitude and statistically insignificant. This result is impervious to whether political institutions are represented by the Polity index or the Freedom house index.

5.2 Carbon dioxide (CO_2) per capita

Based on the results of a Durbin-Wu-Hausman test, we cannot reject the null hypothesis of no endogeneity in the model for CO_2. Because of this, we are most interested in the results of the two-way fixed effects model for CO_2 estimated by OLS. The results for the model with two-way fixed effects estimated by both OLS and GMM IV are displayed in **table 3**.

While we do see some evidence to support the hypothesis that economic freedom results in lower CO_2 emissions, it is less compelling than that observed for PM_{10}. We see a negative relationship between lagged freedom and current CO_2 emissions that is significant at the 10% level in fixed-effects specifications estimated by OLS; however, this result is not robust to using pooled OLS or GMM IV estimation. The long-run effect of economic freedom on CO_2, though the coefficient is negative, is indistinguishable from zero, primarily due to the high standard error associated with the coefficient on the current level of the custom chain-linked index. As with PM_{10}, the estimated direct effect of political institutions on CO_2 is very small in magnitude and statistically insignificant in our preferred model. Surprisingly, the indicator variable signaling an extreme political event is positive; we fail to reject that it is different from zero in our preferred model but it is significant when using GMM IV method.

Using a joint significance test of the parameters on our income terms, we find evidence of a relationship between income and CO_2. In fact, the OLS

Table 3: Two-way fixed effects regression estimates for CO_2

Explanatory Variables	OLS	(s.e.)	GMM-IV	(s.e.)
$\ln(GDP_{it})$	2.826	(4.901)	0.384	(8.578)
$\ln(GDPi_t)^2$	−0.15	(0.557)	0.578	(1.237)
$\ln(GDP_{it})^3$	0.00183	(0.0208)	−0.0387	(0.0542)
$freedom_{it}$	0.022	(0.0225)	−0.0523	(0.0555)
$freedom_{i(t-1)}$	−0.0789*	(0.0454)	−0.108	(0.0699)
$manufacturing_{it}$	0.702	(0.585)	0.797	(0.986)
$polity_{it}$	0.000267	(0.00306)	−0.00162	(0.00552)
$politicalEvent_{it}$	0.0831	(0.0746)	0.148**	(0.0627)
Long Run Effect of Freedom	−0.05689	(0.04085)	−0.1598	(0.11438)
Joint Significance Test on Income (p-value)	0.00000		0.0013	
Durbin-Wu-Hausman Test (p-value)	—		0.12384	
Observations	991		991	
Number of countries	111		111	

Notes: $\log(CO_{2it})$ is the logarithm of carbon dioxide emissions per capita and is the dependent variable. Country clustered standard errors in parentheses. OLS is the preferred estimator by a Durbin-Wu-Hausman test. Details of first stage regressions available upon request. Year fixed effects positive and not significant for all years except 2009. *** indicates statistical significance at the 1%, ** at the 5%, and * at the 10% level.

estimates of the coefficients on the income variables loosely predict an EKC, but with a turning point outside our sample income range. This is a similar result to the one found by Lipford and Yandle (2010). They argue that the current positive relationship can be explained by the following: it is more costly for CO_2-intensive developing countries, like India and China, to reduce emissions than for CO_2-efficient developed countries like France or Germany. Lipford and Yandle (2010) argue that, because of this, China and India will not agree to emissions reductions without compensation from developed countries, but the developed countries refuse compensation and many will not commit to substantial reductions without some agreement for reductions by India and China.

The GMM IV estimates suggest a local maximum in pollution levels when GDP per capita hits approximately $29,106.[14] This result appears to be driven by a cluster of countries from Europe and Asia that have made notable reductions in their CO_2 emissions since 2000. Many, but not all, of these countries have made quantified CO_2 emissions reduction commitments under Annex B of the Kyoto Accord (IPCC WG3). Unlike the case of PM_{10}, we do not see a persistent trend among the year fixed effects.

14. Which is approximately equal to $e^{10.27871}$, the exponential of the root of the first derivative of the estimated polynomial in $\ln(GDP)$.

6 Conclusions

Our results suggest that after controlling for the effects of many important factors including economic growth and political institutions, economic freedom has a significant direct effect on concentrations of fine particulate matter but not on emissions of carbon dioxide. There are several possible explanations for this distinction.

The most obvious possibility is that the relationship between economic freedom and pollution is dependent on the ability of those who are affected by pollution to confront polluters. This follows directly from the role of economic freedom in fostering informal regulation of pollution through property rights and the legal system. It is likely that most of the forecast costs associated with carbon dioxide emissions will be borne by future generations. Furthermore, as argued in Lipford and Yandle (2010), there are many politico-economic factors that make an effective global agreement to reduce CO_2 emissions elusive. PM_{10}, on the other hand, is a very local pollutant. The effects of loading the air with particulate matter are felt quickly and relatively close to the source of pollution.

Technology may hinder the ability of countries to reduce CO_2 emissions by improving economic freedom as well. In Canada, particulate matter was acknowledged to be a problematic pollutant as early as the 1970s by the Clean Air Act (Environment Canada, 2013); CO_2 has come to attention more recently. This means that research and development into technologies for particulate matter abatement had a significant head start on research into ways to reduce CO_2 emissions. So, it may be the case that this disparity in technologies causes PM_{10} to have higher returns to scale from pollution abatement than CO_2. Empirically validating an explanation for the difference in the effect of economic freedom on CO_2 and PM_{10} is a challenge that can be addressed by future research.

Nevertheless, our results lend support to the proposition that economic freedom creates the incentive to abate local air pollution such as that caused by particulate matter. The same may not be true for CO_2, which appears to have a global impact. Nevertheless, appropriately designed and managed institutions that promote economic freedom and the strength of property rights are integral to sustainable development. It is especially notable that this effect is distinct from that of political rights, income, and other country-specific characteristics.

Our results also suggest that, when economic freedom is accounted for, the quality of political institutions has no discernible direct effect on environmental quality. This result is somewhat surprising considering that several other studies, notably Lin and Liscow (2013) and Bernauer and Koubi (2009), have found that political institutions matter a great deal for the environment. Our results do not necessarily negate the effect of political institutions found by other studies as the pollutants considered differ but at the very least they highlight the vital importance of including a measure of economic freedom when examining the relationship between income and pollution.

Technical Appendix

Working age

The use of *working age* (the percentage of the population between the ages of 15 and 64) as an instrument for income follows directly from Lin and Liscow's (2013) use of the age-dependency ratio. *Working age* is a relevant instrument for income as it is directly related to the quantity of labour available in an economy. We feel that it is an ideal measure of the quantity of labour since it:

1. captures the effect of both legal and extralegal, market and non-market labour on GDP;
2. varies over time and across countries, giving it explanatory power beyond that of country and year-fixed effects;
3. is commonly measured, so that reliable data is available for our entire panel.

The first of these reasons is our primary motivation for rejecting the age-dependency ratio, since it is relevant to GDP as substitution from market to non-market labor can occur as society adjusts to care for a large number of children and the elderly. This substitution may be a conscious choice, a would occur when a person quits a job to care for dependents, or it may be inadvertent as when a person simply cannot be as productive in the labor force when responsible for caring for others. In either case, the age-dependency ratio appears to represent a substitution from market to non-market labor.

GDP is calculated based on production (World Bank, 2013), so the non-labor inputs used in non-market production would contribute to GDP. Theoretically, moving from market labour to non-market labor would have a relatively small effect on GDP. This makes the connection between the age-dependency ratio and GDP appear tenuous; the substitution to non-market labor may be offset by the demand for its complements. This is supported by the results of Lin and Liscow's (2013) first stage regression for income.

Their coefficient on age-dependency ratio was indistinguishable from zero, with an estimate of 0.00 and a standard error of 0.61.

We reject the use of a direct measure of the size of the labour force in favour of *working age* for the following reasons:

1 it does not account for extralegal and non-market labour;

2 in areas with extreme levels of pollution, workers may become sick and leave the labour force;

3 such a measure is likely to be unreliable in developing countries.

One argument to suggest that *working age* may itself be endogenous is that high levels of pollution may cause people of working age to leave a country. This seems unlikely since the cost of such a move is likely to be very high for most people.

There is also evidence that high levels of PM_{10} are most hazardous to the old and the young (Ostro, 2004), having relatively little effect on those of working age (Gouvia and Fletcher, 2000; Kan et al., 2008). If these effects on the young and old were widespread and deadly, this would cause an increase in working age. This is not a major concern since the practical significance of the effect of PM_{10} on mortality is somewhat controversial. Gamble and Lewis (1996) assert that, while there is a correlation between PM_{10} concentrations and mortality, it is weak and the compelling evidence of causality in this relationship is not convincing.

Inflation

Inflation and its first-order lag are relevant to GDP as measures of macroeconomic stability and the risk premium of a country. Inflation is expected to be a particularly useful instrument when a full set of time- and year-fixed effects are included in the model. In this case, the model only captures levels of inflation that are more extreme than the world average for that year and what is expected from a given country given sample data. This volatility is the component of inflation that would discourage investment and reduce GDP.

One may argue that inflation is potentially endogenous to any form of environmental damage that can also be viewed as a form of capital, particularly resource extraction. Inflation may cause individuals to reevaluate investments in natural capital such as forest land. This is a concern specifically for measures of environmental quality such as deforestation, where changing investment decisions of stakeholders may cause deforestation as land use changes. For the model we have developed, which is based on air pollution, these concerns are largely irrelevant.

In order to correct for the skewness in the distribution of inflation while appropriately weighting periods of inflation and deflation, we use the following formula:

$$infl_{it} = \ln(\%\Delta gdpDefl_{it} + c)$$
$$\text{where } c = \underset{c}{\text{argmin}}\ skewness(\,|\ln(\%\Delta gdpDefl_{it} + c)|\,) \text{ s.t. } c > \min(\%\Delta gdpDefl_{it} + c)$$

where $\%\Delta gdpDefl_{it}$ is the growth rate of the GDP deflator in country *i* and year *t*. The constant *c* is chosen to minimize the absolute value of the skewness of the distribution of *infl*. This practice causes extreme inflation and deflation events to have similar distances from the mean while allowing the definition of extreme to be chosen by the sample.

Identifying the need for instrumental variables estimation

If there is no endogeneity in our second-stage model, instrumental variables estimation would give us biased results since we would be controlling for only the portion of variation in income that is explained by the first stage of our model, a property that is only desirable when there is some endogeneity that we wish to avoid.

We can test for the endogeneity of income using the instrumental variables we have collected in what is called a Durbin-Wu-Hausman (DWH) test. This test is carried out by estimating the augmented regression:

$$\ln(p_{it}) = \beta_0 + \beta_1 \ln(GDP_{it}) + \beta_2 \ln(GDP_{it})^2 + \beta_3 \ln(GDP_{it})^3 + \beta_4 freedom_{it} + \beta_5 freedom_{i(t-1)}$$
$$+ x'_{it}\beta_x + \gamma_1 v_{it}^{(1)} + \gamma_2 v_{it}^{(2)} + \gamma_3 v_{it}^{(3)} + e_{it}$$

Where $v^{(j)}$ are the residuals from the j^{th} first-stage regression. The Durbin-Wu-Hausman test itself is implemented as a test of the joint null hypothesis that all γ_j are equal to zero.

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