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Measuring Environmental Regulatory Stringency

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Abstract

Measuring Environmental Regulatory Stringency

by

Claire Brunel and Arik Levinson

Researchers have long been interested in whether environmental regulations discourage investment, reduce labour demand, or alter patterns of international trade. But estimating those consequences of regulations requires devising a means of measuring their stringency empirically. While creating such a measure is often portrayed as a data-collection problem, we identify four fundamental conceptual obstacles, which we label multidimensionality, simultaneity, industrial composition, and capital vintage. We then describe the long history of attempts to measure environmental regulatory stringency, and assess their relative success in light of those obstacles. Finally, we propose a new measure of stringency that would be based on emissions data and could be constructed separately for different pollutants.

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Abbreviations

EPER	European Pollutant Emission Register
E-PRTR	European Pollutant Release and Transfer Register
IPPS	Industrial Pollution Projection System
$\mu g/m^3$	micrograms per cubic metre
NAAQS	National Ambient Air Quality Standards
NAICS	North American Industry Classification System
NIMBY	"not-in-my-backyard"
OECD	Organisation for Economic Co-operation and Development
PACE	Pollution Abatement Costs and Expenditures
PPF	production possibility frontier
SIC	Standard Industrial Classification
SO_2	sulphur dioxide
TEAM	Trade and Environment Assessment Model
UNCED	United Nations Conference on Environment and Development
UNCTAD	United Nations Conference on Trade and Development
US EPA	United States Environmental Protection Agency
WEF	World Economic Forum

Measuring Environmental Regulatory Stringency

Introduction: Obstacles and approaches

For over 40 years numerous policy debates have centred on measures of jurisdictions' environmental regulatory stringency. The EU has long debated whether "harmonization" of regulatory stringency should be a prerequisite for more European unification (Bhagwati and Hudec, 1996). The 1970 and 1977 amendments to the US Clean Air Act were enacted in part to prevent individual US states from competing against one another to attract investment by lowering their local environmental standards in a "race to the bottom" (Portney, 1990). Opponents of strict regulations have cited their costs in terms of lost productivity, lower labour demand, and reduced investment. Proponents cite Porter's (1991) hypothesis that strict regulations encourage innovation and investment. More subtle arguments note that lax environmental regulations can serve as a substitute for protectionist tariffs (Ederington and Minier, 2003). Most recently, international climate negotiators have struggled with concerns that greenhouse-gas emissions capped in one country will be emitted instead by non-participating countries. The jargon has proliferated along with the policy debates: pollution havens, industrial flight, environmental dumping, race-to-the-bottom, NIMBY,[1] harmonization, and leakage.

These varying policy concerns share a unifying feature: assessing them requires measuring the relative stringency of environmental regulations over time or across different countries or states. Do firms relocate to less strict locations? Do countries compete with their neighbours by lowering standards? Do regulations reduce labour demand and investment, or do they stimulate innovation and growth? Knowing the answer requires first measuring environmental regulatory stringency.

What would the ideal measure of environmental regulatory stringency look like? It would be relatively easy to calculate based on data governments already collect or should collect towards other policy objectives. It would be available annually so as to facilitate panel data models that address some sources of simultaneity. It would be cardinal, enabling assessment of magnitudes. It would be available for various pollutants and media or combinable as one overarching measure of multidimensional stringency. It would be theoretically related to the costs facilities incur when they abate pollution, but it would not be mechanically determined by industrial composition.

Much of the research in this literature reads as though the chief obstacles to measuring stringency involve data collection, as though if we gave the appropriate agencies large enough budgets they could simply collect the right information. In truth, the obstacles involve a much deeper set of conceptual problems. Broadly speaking, there are four of these: (1) *multidimensionality* — environmental regulations cannot easily be captured by one measure of "stringency"; (2) *simultaneity* — countries with strong

1. Shorthand for selfish "not-in-my-backyard" objections to nearby pollution but not pollution that harms others.

economies or bad pollution problems may impose the most stringent regulations; (3) *industrial composition* — countries where the mix of industries is on average more pollution intensive have higher average abatement costs and measured regulatory stringency; and (4) *capital vintage* — regulatory standards are typically tighter for new sources of pollution, with implications for the environment, the economy, and measures of regulatory stringency.

Perhaps because these questions are so important, the number of papers in this literature is vast. And perhaps because the conceptual problems those papers face in measuring stringency are so challenging, the number of different approaches taken is equally vast. In Table 1 and in the discussion below, we break the approaches down into five categories: (1) private sector abatement costs, (2) direct assessments of the regulations themselves, (3) composite indexes meant to compress the multidimensional problem down to one number, (4) measures based on pollution or energy use, and (5) measures based on public-sector expenditures or enforcement.[2]

To be clear, we focus here mostly on regulations and policies that affect production costs and therefore have direct effects on issues such as pollution havens and leakage. These could include a wide range of polices, including liability rules, taxes, emissions limits, and technology standards. We are less interested in policies aimed at the consumer sector, such as household recycling mandates, gasoline taxes, or subsidies for home weatherization, though those types of rules are sometimes used as proxies for a jurisdiction's overall environmental stance.

In the pages that follow we discuss empirical work that has taken each of the five approaches and consider their strengths and weaknesses in light of the obstacles faced. At the end we propose a new measure of our own, a hybrid of the emissions and cost-based approaches. Before commencing that discussion, we describe the four conceptual obstacles to measuring stringency.

Four conceptual obstacles to measuring environmental regulatory stringency

The measures of stringency surveyed in Table 1 are used for many purposes. Some papers ask whether regulations have improved the environment or people's health; others examine the pollution haven story and ask whether regulations alter patterns of trade, foreign direct investment, or new plant locations. A few examine versions of the Porter hypothesis, and a smaller number explore strategic questions such as whether nations implement lax pollution regulations as a substitute for protective tariffs or weaken regulations competitively in a race to the bottom. Each purpose faces different obstacles, as we discuss below, and each therefore uses a different approach to measuring stringency as we will see in the section that follows.

Multidimensionality

The first obstacle confronting researchers is multidimensionality. Governments regulate various environmental media: air, water, and solid and hazardous waste. Different regulations control different pollutants into those media: sulphur dioxide,

2. The literature review began with keyword searches in the digital academic libraries Jstor and EconLit for empirical papers studying the effects of environmental regulations. Table 1 contains a selection of papers that we judged to be either early seminal examples of particular approaches, or recent and innovative.

sewage, toxic chemicals, etc. Some regulations target households while others target industries. Regulations set standards for total emissions, emissions concentrations, ambient environmental quality, or for the technologies employed by producers (Johnstone et al., 2010). Finally, the regulations will only be relevant if they are enforced. In other words, the multidimensionality is itself multidimensional.

Multidimensionality poses problems for measuring stringency. The first and simplest is that some regulations will be irrelevant to some of the policy questions being asked. If we are interested in whether environmental regulations cause industrial flight from strict countries, neither the lead content of automotive gasoline nor the incentives to recycle household waste will be directly relevant to industries' profitability in various locales.

Some regulations will be irrelevant to the question being asked not because they target the wrong sector, but because they target emissions when ambient quality matters or vice versa. The US Clean Air Act sets uniform National Ambient Air Quality Standards (NAAQS) for six criteria pollutants. So in terms of ambient standards, every county in the US faces the same level of stringency. But in order to meet those standards, some counties must impose costly emissions requirements while others do not. In Los Angeles, where the local mountains trap air pollution over the city for days at a time, the NAAQS are costly to meet. In Honolulu, where trade winds quickly blow air pollution out over the Pacific, air quality easily meets the NAAQS. So are air quality regulations in Los Angeles more stringent than in Honolulu? If we want to know the effect of regulations on air quality or health, the ambient standards in both cities are equal to the uniform NAAQS. If we want to know the costs imposed on businesses considering locating in either city, those equal ambient standards impose more stringent regulations in Los Angeles.

A second problem due to multidimensionality is that complex regulations are not easily comparable. The new US standards for toxic emissions from industrial boilers, issued in 2012, are 2.0-3.0 short tons per year of mercury and 580 000 short tons per year of sulphur dioxide. Which is more stringent? In 1987 the US EPA set the NAAQS for particulate matter at 150 $\mu g/m^3$ of particles smaller than 10 micrometers in diameter, averaged over 24 hours, not to be exceeded more than once per year over three years. In 1997 that was changed to *65* $\mu g/m^3$ of particles smaller than *2.5* micrometers in diameter, at the *98th percentile*, averaged over three years.[3] Which is more stringent? The answers are not immediately obvious.

The questions policy analysts ask typically seem to assume there is one measure of stringency that is comparable across countries. Does stringency affect growth? Do countries compete to lower standards? It is hard to imagine using real data on complex regulations to answer those questions if countries have multidimensional environmental programs that are not directly comparable. As a consequence, researchers have dealt with the multidimensionality in one of two ways.

Some avoid multidimensionality by focusing on one particular narrow environmental problem with directly comparable stringency measures. An example of this is Berman and Bui (2001), who examined air pollution regulations as they affect oil refineries in Los Angeles. They used confidential plant-level data from the Census of Manufactures, and a painstaking, line-by-line reading of the local air pollution regulations. Berman and Bui therefore knew the exact dates on which specific regulatory changes affected particular

3. http://www.epa.gov/ttn/naaqs/standards/pm/s_pm_history.html.

refineries, how those refineries responded, and what costs they incurred. Levinson (1999) similarly narrowed the multidimensionality by focusing on taxes on the disposal of hazardous waste, a single dimension along which countries might compete that is easily measurable, comparable, and clearly targeted. The advantage of these focused approaches is clear: accuracy in identifying the appropriate regulations and comparability across regulations. The disadvantage is that the results might not be generalizable. Petroleum refineries and hazardous waste disposal may not be representative of whether regulatory stringency usually reduces productivity or countries habitually compete with each other's standards.

Others address multidimensionality by constructing composite indexes of or proxies for environmental stringency. Smarzynska and Wei (2004) used the number of international environmental treaties signed and the number of active environmental NGOs as indicators of countries' environmental regulatory stringency. Cole and Elliott (2003) used an index based on a survey sent to each UN member country asking for details about its environmental policies, legislation and enforcement. Kellenberg (2009) and Kalamova and Johnstone (2011) used the World Economic Forum (WEF) surveys, which ask business executives in many countries about the stringency and enforcement of the regulations their companies face.

Johnstone et al. (2010) lies between the narrow and broad approaches. That paper examines whether different types of renewable-energy support policies affect innovation in renewable energy. They do not compose a single index, but they allow for multidimensionality by creating dummies and continuous variables for seven different types of policies in each country over 25 years.

The advantages of these composite indexes is clear: they summarize a multidimensional concept in one number, apply broadly to entire economies, and are inherently generalizable. The disadvantage is that while they may successfully rank countries' stringency levels, they cannot assess their magnitude — they are ordinal rather than cardinal. Does signing twice as many treaties or having twice as many NGOs mean a country is twice as stringent? What does it mean that Germany's WEF index is above 6.5 while Argentina's is below 3.5? Research using these indexes can be more general than research that focuses on one narrow problem, and can answer questions about direction and statistical significance of the effect of the regulations, but cannot easily say whether those effects are large or small.

Researchers have circumvented the multidimensionality problem in two ways: using a narrow example that is difficult to generalize, or a broad, comprehensive index of stringency whose magnitude is difficult to assess. As limiting as these workarounds may seem, the multidimensionality may be the smallest obstacle facing measuring stringency. A more difficult conceptual obstacle is simultaneity.

Simultaneity

Researchers need measures of regulatory stringency in order to assess the consequences of those regulations. Unfortunately, those consequences may also simultaneously help to determine regulatory stringency. Countries with high levels of pollution react by imposing stringent standards to solve their environmental problems. Places that are home to lots of polluting industries may do the same. Or, the simultaneity could work in the opposite direction. If pollution-intensive industries have more lobbying power the greater their share of a country's economy, they may pressure their governments to enact less stringent regulations. International trade and economic growth

may influence environmental regulations, even as researchers attempt to measure the causality in the opposite direction. We want to know the effect of regulations on economic outcomes, but cannot easily separate that from the effect of those outcomes on environmental regulations.

If economics were a laboratory science, we could run a controlled experiment and randomly assign some "treatment" jurisdictions to have strict regulations and other "control" jurisdictions to have lax regulations. The outcome would convey the causal effect of regulations because no simultaneity would have determined the treatment. That experiment is not feasible, so researchers deal with the simultaneity of regulations in one of two closely related ways: natural experiments and instrumental variables.[4]

Natural experiments involve situations in which some external force determines the stringency of regulations. The best example of this approach was first taken by McConnell and Schwab (1990) and Henderson (1996) and has been followed by numerous researchers since. They use the US Clean Air Act, which imposed uniform national ambient standards (the NAAQS mentioned earlier) on every county in the US. In the years when the standards were first imposed, and in subsequent years when those standards were tightened, counties whose air quality fell below permitted levels were forced by the federal government to impose strict emissions regulations. Counties whose air quality met or exceeded the standards were exempt from imposing new emissions regulations. While state and local air-pollution emissions regulations may be simultaneously determined by local economic activity, the *changes* in local regulations forced by the federal Clean Air Act were not. Researchers using this measure of stringency can defensibly interpret changes in economic activity that follow federal law changes as causal results of changes in regulatory stringency.

Similarly, Levinson (1999) used the 1992 US Supreme Court ruling that states could not legally set different tax rates for disposing of waste imported from other states. Before 1992 this was common practice. While state tax rates may simultaneously determine waste-disposal levels and be determined by them, the *changes* in tax rates resulting from the 1992 ruling were not the result of any state's decisions. Hence changes in disposal following the 1992 ruling could be reasonably interpreted as being caused by the state tax changes resulting from that ruling.

The problem with these natural experiment solutions to the simultaneity problem is that they are scarce. It is hard to think of examples where jurisdictions have been forced by outside circumstances to adopt regulations with varying levels of stringency. Instead, researchers have turned to a statistical approximation for those natural experiments: instrumental variables. The idea is to find some observable variable that is correlated with regulatory stringency but uncorrelated with the measure of economic activity being researched except indirectly through its relationship to stringency. Unfortunately, examples of such instrumental variables are also scarce and are easily subject to the criticism that they are invalid because they do affect economic outcomes through routes other than indirectly through stringency.

Millimet and Roy (2012) provided a good review of research using instrumental variables for stringency. Xing and Kolstad (2002) used infant mortality and population density. Ederington and Minier (2003) used instruments motivated by political-economy

4. If the source of the simultaneity is some unobserved time-invariant characteristic of jurisdictions, the problem can also be addressed with panel data and fixed effects.

theories: unionization rates, concentration ratios, etc. Levinson and Taylor (2008) instrumented for the US regulatory stringency facing an industry by using the geographic distribution of the industry across US states and the pollution abatement costs incurred by other industries in those states. Kellenberg (2012) instrumented for the WEF index using lagged values of countries' corruption, income, urbanization and education. Jug and Mirza (2005) used prior years' wages and investment in environmental equipment. In addition to their survey of the literature, Millimet and Roy made two contributions. Their first is an instrument that relies on the fact that environmental regulatory stringency imposes higher costs on more pollution-intensive industries, whereas other local business conditions such as market proximity benefit all industries equally. Their second strategy avoids the use of instruments altogether and exploits assumptions about the distribution of the errors in the estimating equations.[5]

Several problems confront these approaches to addressing simultaneity. Most obviously, readers have good reason to question the underlying assumptions. Infant mortality may be a consequence of pollution; industry concentrations may be altered by pollution regulations. This point is highlighted by the fact that the simultaneity could work in either direction. Countries with a lot of pollution from polluting industries could enact strict controls, or concentrated polluting industries could lobby for protection in the form of weak controls. Papers that instrument for regulations using pollution levels risk mistaking one mechanism for the other. Moreover, the assumptions underlying instrumental variables techniques are not easily testable. We cannot tell, except by appeal to theory, whether the geographic dispersion of industries influences standards, or whether assumptions about errors in estimating equations are valid. Third, examples of good instruments — especially ones that vary across jurisdictions and over time — are in short supply. All but one of the papers in Millimet and Roy's survey come from the past 10 years.

In sum, to address simultaneity many researchers have looked for unusual quirks of policy that result in natural experiments or that provide valid instrumental variables. The next two obstacles to measuring regulatory stringency can be thought of as special cases of simultaneity. But they are central to measuring stringency and to the research questions analysts want answered with those measures of stringency, and so it is worth discussing them separately.

Industrial composition

This obstacle involves a fundamental economic principle dating back to Adam Smith and David Ricardo: "comparative advantage." Given the opportunity to trade, countries will specialize in producing and exporting goods that they can produce relatively inexpensively, importing the rest. Those relative costs, or comparative advantages, arise from natural resources, labour skills, proximity to transportation, agricultural conditions, and importantly in this context, regulatory stringency. As a consequence, countries differ in the mix of products they manufacture and export. While some of those differences in industrial composition might depend on regulatory stringency, many of the differences arise from other sources of comparative advantage, some of which may be correlated with stringency but not measurable by researchers.

5. They used the Klein and Vella (2010) estimator, which exploits heteroskedasticity in the error terms of the estimating equation as a non-traditional instrument. If the distribution of the errors is related to the pattern of the exogenous variables, that is enough to identify the effect of the endogenous variable.

Differing industrial compositions across jurisdictions pose especially acute problems for measures of stringency based on pollution abatement costs. We describe those measures below, but for now recognize that countries with relatively more pollution-intensive industries will spend relatively more on pollution abatement, even if every countries has exactly the same regulations. If we measure stringency using industry abatement costs, countries with more polluting industries will appear to be more stringent. A researcher who is not careful about this bias might conclude that environmental standards have no effect on industry location or even attract polluting industry. Grossman and Krueger (1991) find that in some specifications US "imports from Mexico appear to be *lower* in … sectors where US pollution abatement costs are relatively high", a counterintuitive result they attribute to an unnamed omitted variable. A natural candidate for that omitted variable would be some source of comparative advantage that US industries have that is correlated with pollution intensity, such as skilled labour, physical capital, access to inexpensive energy.

In general, the problem posed by differing industrial compositions is a particular example of simultaneity. Suppose a researcher wants to measure the effect of environmental regulatory stringency on, say, net imports of goods from pollution-intensive industries. Those imports will be affected by all of the various sources of comparative advantage. If some unknown measure of comparative advantage attracts polluting industries, the jurisdiction will both (a) have high average pollution abatement costs even if its stringency is the same as elsewhere, and (b) may react to the resulting pollution by enacting more stringent environmental regulations than elsewhere. Both cases represent versions of simultaneity. Industrial activity determines both measured and actual regulatory stringency, whereas researchers want to isolate the effect of the latter — actual stringency — on industrial activity.

Capital vintage

The final obstacle to measuring regulatory stringency involves a particular feature of many environmental regulations: they are "grandfathered" or "vintage-differentiated," meaning they are stricter for new sources of pollution than existing sources. Consider automobile emissions rules. Governments worldwide have imposed standards on allowable vehicle emissions, but the strictest standards apply only to new cars. For obvious practical reasons car owners are not required to retrofit their existing vehicles to control emissions. Ironically, this can result in people keeping their existing cars longer than they would have otherwise, possibly resulting in higher aggregate emissions (Stavins, 2006).

The same grandfathering commonly applies to industrial pollution regulations. The US Clean Air Act prescribes "New Source Performance Standards" for large industrial sources of pollution that are new or significantly modified. This provides both a disincentive for new development and protection to existing industries against new competition.[6] Depending on how we measure regulatory stringency, grandfathering could significantly bias those measurements. For example, suppose our measure is based on pollution-abatement costs incurred. A stringent regulation that grandfathers existing sources may result in no new development and low abatement costs. A less stringent regulation or one that does not grandfather existing sources might result in more new

6. As Buchanan and Tullock (1975) pointed out long ago, environmental regulations can increase the profitability of existing emitters by erecting barriers to entry that protect them from competition.

development and higher abatement expenditures. Perversely, vintage-differentiated regulations might result in lax places appearing stringent and vice versa. Or, suppose our stringency measure is based on emissions, where low emissions are interpreted as the result of strict regulations. A strict vintage-differentiated regulation that deters new investment in cleaner production might be misinterpreted as a lack of stringency because emissions from existing production would remain high.

These four obstacles do not necessarily mean that measuring environmental regulatory stringency is impossible. Multidimensionality means that narrow non-general measures or broad composite indexes may be all we can hope for. Simultaneity means that researchers should look for circumstances that result in natural experiments or instrumental variables. And researchers should always be cognizant of the bias imparted by industrial composition and vintage differentiation. But as is clear from the range of papers sampled in Table 1, these challenges have not discouraged researchers from the attempt. What the obstacles do mean is that we must interpret results from that research carefully.

Lessons from applications

What can we learn from the research to date that has tried to surmount these obstacles? Early work, surveyed in Jaffe et al. (1995) relied largely on cross sections of data — differences in measures of stringency across countries at a single point in time. This approach has the most difficulty addressing omitted variables and simultaneity, and as a consequence largely finds environmental regulatory stringency has no measurable effect on economic outcomes, or even beneficial effects in some cases. Starting in the mid-1990s, about the time that Jaffe et al. concluded that "there is relatively little evidence to support the hypothesis that environmental regulations have had a large adverse effect on competitiveness," studies began using panel data on country or industry-level measures of regulatory stringency. This allowed researchers to include country or industry fixed effects and control for unobserved attributes of countries or industries that might be correlated with both regulatory stringency and economic activity: comparative advantage, industrial composition, geography that traps air pollution, etc. This approach addresses *some* of the obstacles listed above, but it only allows for controlling unobserved omitted variables that are fixed in time. If a country finds itself increasingly attracting a polluting industry, its abatement costs will rise automatically even if its government does not react by enacting stricter regulations. If a country finds itself becoming more polluted, it might react by tightening regulations. These unobserved time-varying sources of simultaneity can only be resolved using natural experiments or instrumental variables.

Recently, research using those techniques has demonstrated some success measuring statistically significant but moderate effects of regulatory stringency on things like trade flows, foreign direct investment, and new plant locations (Brunnermeier and Levinson, 2004; Millimet and Roy, 2012). These recent papers face a high hurdle, however. They require a measure of stringency that varies across jurisdictions and over time, and they need an instrument for that measure of stringency that similarly varies across places and time.

The next section describes how researchers have constructed measures of stringency, and evaluates their success at surmounting the four obstacles we have identified: multidimensionality, simultaneity, industry composition and capital vintage.

Five approaches to measuring stringency

Table 1 splits research in this field into five categories based on the methods used to measure stringency: (1) private-sector pollution abatement expenditures; (2) direct assessments of the regulations themselves; (3) composite indexes meant to compress the multidimensional problem down to one number; (4) measures based on ambient pollution, emissions, or energy use; and (5) pollution-control efforts by governments. Under each heading we have described examples of the approach taken, and representative research using that approach.

These categories overlap. Some of the composite indexes use measures drawn from other categories such as public expenditures or emissions. Some researchers use measures that fall into multiple categories, either in combination or in separate estimations, so some papers appear multiple times in Table 1. Because the literature is so extensive we have limited the selection in Table 1 to samples of each approach that are either relatively new or provide noteworthy examples of older work. In our choice of papers, we have not focused on the particular application — pollution havens, trade, labour demand, etc. — but rather on the measurement of stringency.

The listing in Table 1 is not chronological. Instead, it is based on how often the approaches have been used by researchers in recent years. Hence we start with one of the newest: measures that use industries' reported expenditures on pollution abatement.

Private-sector cost measures

These measures are based on surveys of industries about their pollution abatement expenditures. The earliest and most comprehensive of these data come from the US Pollution Abatement Costs and Expenditures (PACE) survey, conducted annually by the US Census Bureau from 1973 until 1994, when it was discontinued. Modified versions of the survey have been conducted infrequently since then, in 1999 and 2005.

Numerous researchers have used the PACE survey to construct measures of regulatory stringency in US states. Levinson (1996) used the establishment-level PACE data to estimate how much more or less manufacturers spent on pollution abatement in each state, controlling for other characteristics of the states' manufacturers. That paper regresses the log of pollution-abatement operating costs on characteristics of the manufacturer, including the book value of capital, the number of production workers, value added, an indicator for new plants, industry dummies, and dummies for each US state.

$$\ln(PACE) = \alpha + \beta_1 lnK + \beta_2 lnL + \beta_3 lnVA + \beta_4 New + \sum_i \beta_5^i Ind_i + \sum_s \beta_6^s State_s + \varepsilon \qquad \textbf{(1)}$$

The state coefficients (β_6^s) are the key. A high state coefficient indicates that manufacturers that are observably similar in all other dimensions spend relatively more on pollution abatement in that state. With care those coefficients can be interpreted as a measure of state environmental regulatory stringency. This measure controls for states' industrial compositions and the effects of grandfathered regulations by including the industry dummies (β_5^i) and the new-plant indicator (β_4). But as constructed it does not vary over time, only across states. A version of equation (1) could be estimated using annual cross-sections of establishment-level pollution abatement cost data, and by including state dummies, year dummies, and the interactions between the two. In that case, the state coefficients would capture differences in overall average levels of stringency across states, the time coefficients would capture national trends in abatement

costs over time, and the coefficients on the interaction terms would indicate whether each state became more or less stringent relative to the national trend.

Because most researchers do not have access to establishment-level census data necessary to estimate that equation, Keller and Levinson (2002) constructed a time-varying version of that index using published average PACE costs by industry and state. They calculated the total costs per dollar of gross state product: $S_{st} = P_{st}/Y_{st}$, where P_{st} is the pollution abatement cost in state *s* in year *t*, and Y_{st} is the gross state product in state *s* in year *t*. They then compared that with the *predicted* abatement costs, $\hat{S}_{st}$, which is simply a weighted average of the national pollution abatement costs for each of 20 two-digit SIC industry codes, where the weights are the industries' shares of output in state *s*, Y_{sit}/Y_{it}. Levinson and Keller's measure of stringency is just the ratio $S_{st}/\hat{S}_{st}$.

$$R_{st} = \frac{S_{st}}{\hat{S}_{st}} = \frac{[P_{st}/Y_{st}]}{\left[\frac{1}{Y_{st}}\sum_{i=1}^{20}\frac{Y_{sit}P_{it}}{Y_{it}}\right]} \quad \textbf{(2)}$$

Pollution abatement costs in states and years in which this ratio is greater than one are larger than would be expected given those states' industrial compositions. When this ratio is smaller than one, manufacturers have lower-than-expected abatement costs.

On the surface, the PACE survey might appear to be exactly the data one would need to measure stringency because it reports the costs establishments incurred to abate pollution. In practice, however, it collects those data by asking managers at industrial firms to provide that information, and those survey questions have become increasingly difficult to answer. In the 1970s, when the survey was launched, pollution regulations were relatively new and many industries were reacting to strict standards for the first time. These standards were often met by "end-of-pipe" solutions: scrubbers on smokestacks, filters on wastewater outlets, and proper disposal of hazardous waste. Engineers probably could make a reasonable assessment of how much they were spending for new capital equipment and operating costs due to these new environmental efforts.

Today, after 40 years of regulation, environmental objectives have become integrated into the design of products and processes. Industries have made wholesale changes in order to comply with regulations. Firms have altered their manufacturing technologies, switched energy sources, increased recycling, and even changed the design of their products. Consider the instructions accompanying the 1994 PACE survey:

> *For this survey, only expenditures with the primary purpose of protecting the environment are included. This survey does not collect expenditures intended to meet worker safety and health requirements. It also does not include expenditures that abate pollution when the primary purpose is to increase profits or cut costs, and the environmental protection is a side benefit.*[7]

This type of survey question might be relatively easy to answer for end-of-pipe technologies that modify existing production processes. It is much less clear how survey respondents can answer these questions when process or product changes have evolved over decades driven partly by environmental concerns. If a manufacturer installs capital equipment enabling it to begin using recycled materials, is that an environmental

7. Current Industrial Reports, Pollution Abatement Costs and Expenditures: MA200(94)-1. US Census Bureau. Washington, DC, 1994.

investment? Does it matter if doing so increases profits? How can the manager know what the firm would have done absent environmental considerations without knowing what the prices of raw and recycled materials would have been absent environmental policies? If an electricity generator switches from coal to natural gas and saves money partly because environmental regulations have made burning coal more costly and partly because natural gas prices have fallen, how much of that process change should be counted as environmentally motivated? These are difficult theoretical questions.

To answer the abatement cost questions properly, respondents would have to report how much less their businesses would have spent on capital equipment and operating expenses if there had been no environmental considerations. This question is unlike any other asked by manufacturing surveys. Typical questions ask for information about what the firm actually did: how many workers it employed, how much energy it used, how much equipment it purchased, and suchlike. Respondents can look those numbers up in their accounts. Questions on pollution abatement costs ask respondents to speculate about what the firm might have done if its objectives had been different. Estimating counterfactual, "in the alternative" behaviour like that is a complex and abstract job that is a central task of economics. Just because a government agency asks survey respondents those questions does not mean researchers can accept their answers as meaningful.

Several studies have attempted to assess the accuracy of the PACE survey. Joshi et al. (2001) interviewed accountants at 55 US steel mills and concluded that for every USD 1 increase in visible environmental costs that were reported, USD 9-10 were concealed in other accounts and not reported. The missed costs are not intentionally hidden; they are the incremental costs of materials, utilities, overhead expenditures, and integrated process changes that are difficult to separately identify as being primarily directed towards environmental purposes. Morgenstern et al. (2001) added to this list, suggesting that new-source bias from grandfathered regulations means that surveys based on existing firms will understate regulatory costs faced by new firms. If grandfathered regulations are more stringent for new sources of pollution, reported abatement costs may understate the costs that would be faced if manufacturers chose to expand existing facilities or open new factories. That unreported cost may have substantial implications for economic outcomes. But Morgenstern et al. also identified several reasons why surveys may *overstate* costs, including complementarities between environmental objectives and other purposes such as economies of scope, recycling, or other non-environmental production process changes.

In addition to the difficulty separating out costs by their environmental intent, and the fact that cost surveys only include costs for existing firms, researchers must keep in mind a third limitation of using reported expenditures as measure of regulatory stringency. Even if respondents can accurately report environmental costs, those costs will differ from place to place for many reasons unrelated to regulatory stringency. Environmental engineers may require higher salaries in some regions. Low-sulphur coal is more readily accessible in others. Strict ambient standards are easier to meet where winds or water currents disperse pollution more quickly. For these reasons, even states facing the same regulations might incur very different costs.

About the time the US stopped collecting PACE data, Canada and the EU began their own surveys. Pasurka (2008) documented these efforts around the world, including Canada's Survey of Environmental Protection Expenditures (SEPE) and the joint OECD/Eurostat Questionnaire on Environmental Protection Expenditure and Revenues.

But as he notes, it is sometimes difficult to compare surveys across countries.[8] Country surveys differ in their years surveyed and in the pollutants or media they include. Germany's capital expenditure data focused on end-of-pipe expenditures from 1996 to 2002, while other countries' surveys included all abatement costs. The US's discontinued survey included capital depreciation while Canada's on-going one does not. Country surveys differ in their industry classification systems and industry coverage, making it difficult to account for countries' differing industrial compositions. As Pasurka notes, even within the same country reported abatement costs frequently change sharply from one year to the next.

But, more fundamentally, these surveys all face the same deeper conceptual problem in that they ask respondents to separate expenditures according to their environmental intent. The US, Canadian, and EU survey questions all ask environmental managers to describe counterfactual situations — to imagine what their costs would have been in an alternative world without environmental objectives. The EU survey poses the right questions, by asking manufacturers to separate "end-of-pipe" investments from "integrated technologies." But that does not mean respondents are capable of answering those questions. It is becoming increasingly difficult to separate environmental motives from profit motives when manufacturing processes have been designed with both in mind.

Lest this all sound overly negative about the merits of the PACE, SEPE, and OECD/Eurostat surveys, we would note that in aggregate those surveys' responses do make intuitive sense. Abatement costs vary over time, across industries, and across jurisdictions in ways that comport with intuition. The industries we expect to have high abatement costs come out on top of the list; countries and US states we expect to have low abatement costs given their industrial compositions rank towards the bottom; and changes in pollution regulations appear to be reflected in reported abatement costs. In other words, the surveys may do a reasonable job of ranking countries, but the magnitude of differences across countries or states or over time need to be treated cautiously. They are speculative answers to increasingly difficult abstract questions that are not limited to regulatory costs and are not necessarily applicable to new sources.

Several researchers have avoided the conjectural nature of cost survey responses by using a production function or "shadow price" approach. They use economic theory and choices made by firms to calculate pollution abatement costs indirectly rather than relying on answers to survey questions. Van Soest et al. (2006) defined the shadow price of an input as "the potential reduction in expenditures on other variable inputs that can be achieved by using an additional unit of the input under consideration (while maintaining the level of output)." The intuition for this definition can be seen in Figure 1. The curved isoquant depicts all the combinations of inputs that can be used to produce output Y_1. We could plot trade-offs between any two inputs: capital and labour, materials and energy, etc. For graphing convenience, only two inputs are drawn, emissions (E) and one other generic input (X), ignoring trade-offs among other factors.[9] When there is no regulation,

8. Figure 4 of Johnstone et al. (2012) shows that European pollution costs as a share of GDP seem uncorrelated with business executives' assessment of the stringency of their countries' regulations.

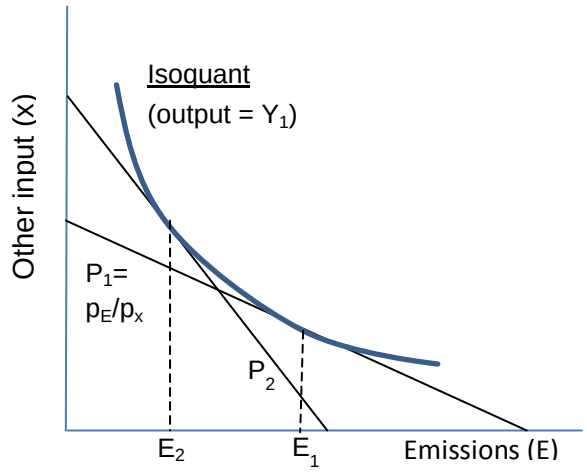
9. People are sometimes confused by economists' treatment of pollution emitted as an "input" to production because it physically emerges from smokestacks or wastewater pipes. But it is an activity undertaken in order to generate the main product of the firm. Call it "disposal services of the environment" if that helps.

the price of emissions (p_E) is zero, or at least very low. When this emissions price is low and the prices of other inputs (p_X) are high, as depicted by price ratio P_1, profit maximising firms will choose to use relatively more emissions (E_1) and less of other inputs. When the price of emissions is higher, maybe because regulations are stringent, the firm will choose lower emissions (E_2).

There is no directly observable "price" of emissions; that is what this analysis seeks to estimate. That price is determined in part by regulatory stringency in various countries. It could be an explicit tax, but it is more likely to be a hidden cost resulting from the various direct and indirect regulations imposed in each country. That is why it is called the "shadow price" of pollution. But it is exactly what most of the research described in Table 1 would like to establish: a measure of environmental regulatory stringency.

The key to this approach is that all of the prices and quantities in Figure 1 *except* the price of emissions can be looked up in government statistical tables and reports. If firms are profit maximizing, and if we know the output of the firm or industry (Y), the amounts of all inputs used including the amount of emissions (X and E), and the prices of all the other inputs (p_x), then we can calculate the implicit or "shadow" price of emissions (p_E).

Figure 1. The shadow price approach



Coggins and Swinton (1996) used a version of this approach to measure the shadow cost of sulphur dioxide (SO_2) emissions at 14 coal-fired electric power plants in Wisconsin in the early 1990s. They combined detailed federal regulatory filings of those power plants along with emissions data from the Wisconsin Department of Natural Resources to estimate a production possibility frontier (PPF) for the industry. The slope of that PPF, like the slope of the isoquant in Figure 1, reveals the shadow price of emissions given the known price of the other inputs. Their best estimate of that shadow price of SO_2 emissions was USD 293. During the early 1990s, the US EPA was in the process of establishing its SO_2 trading program, and actual SO_2 permits traded among utilities at prices between USD 170 and USD 400. Van Soest et al. (2006) used industry-level data from nine European countries from 1978 to 1996 to derive the shadow cost of energy use. Their presumption was that the cost of energy varies across countries and over time because of differences in environmental regulations. Although they measured

the shadow price of energy use, they intended for their approach to be used to measure the shadow cost of pollution.

This shadow-cost approach to measuring environmental regulatory stringency has a number of advantages. It appeals to economists, who do not typically estimate demand for products by surveying customers; instead, economists use a "revealed preference" approach, studying actual choices made in response to real price changes. This method does the same: it studies actual production decisions made by firms and infers the emissions price under which those decisions would be profit-maximizing. The approach incorporates all of the various regulations and incentives, and summarizes them into one cardinal measure of costs. And it can be used to generate the shadow cost of pollution, a measure of regulatory stringency, across countries, industries, years, and pollutants.

Of course the shadow price approach also has drawbacks. It is more complicated than merely surveying environmental managers and asking about the costs of complying with environmental regulations. Shadow prices will depend in part on the functional forms chosen for cost functions or production functions, and on the set of other inputs used in their estimation. Like the abatement expenditures reported to cost surveys, shadow prices measure expenditures that are not necessarily the result of regulatory stringency. Environmental costs might be higher, for example, if environmental engineers demand higher salaries or if low-sulphur coal is less available. Like the cost surveys, shadow prices also measure costs for existing firms, which may be very different than the costs that would be faced by new firms. So if the goal is to study the effect of regulatory stringency on new plant openings, both cost surveys and shadow prices may understate the costs those new plants would face.

An alternative to using the costs imposed by the regulations as a measure of stringency is to use some direct assessment of the regulation itself.

Regulation-based measures

Assembling a regulations-based measure of stringency is difficult for two main reasons. The first is multidimensionality. There is no one measure of national regulatory stringency. Accordingly, most of the studies in Table 1 that use this approach ask very narrow questions. The second obstacle is simultaneity. Most studies that have developed or adopted measures of stringency do so for a purpose. They estimate the effect of stringency on some economic outcome: pollution, health, employment, investment, trade, pollution, etc. As most researchers recognize, those outcome variables may be affected by regulatory stringency, but they also might simultaneously determine regulatory stringency through the political process. Perhaps because of this, very few studies have tried this approach.

One widely-used strategy in this category takes advantage of the US Clean Air Act as a natural experiment, because its standardized air quality standards (the NAAQS) solve both problems. They apply generally to six common air pollutants, and so can be seen as a general measure of multidimensional stringency. They are set by the federal government and apply to every county in the US, so they can be seen as not being simultaneously determined by any one county's economic or environmental conditions. Counties that fail to meet the NAAQS are required to impose more stringent regulations than attainment counties. Numerous studies have used this binary measure, whether or not the county is in compliance with the NAAQS, as an indicator of regulatory stringency.

McConnell and Schwab's (1990) application of this approach found that automobile manufacturers, which contribute to ozone pollution in the process of painting cars, are not less likely to locate new facilities in counties that fail to meet the U.S. federal ozone standard. Henderson (1996) broadened the approach to examine the effects of county nonattainment status on pollution and on the location decisions of other ozone-emitting industries, including plastics, chemicals, steel, and petroleum refining. In contrast to the earlier work he found that regulations improve air quality but reduce the number of new polluting manufacturing plants. Similarly Becker and Henderson (2000) found that there had been relatively fewer new plants being sited in nonattainment counties, including manufacturers of automobiles and wood furniture, and commercial printers. Among the most recent adopters of this approach has been Greenstone, who used it to study industry location and employment (Greenstone, 2002), housing prices (Chay and Greenstone, 2005), pollution (Greenstone, 2004), and mortality (Chay et al., 2003).

The problem already noted with this approach is that there are few examples around the world of externally imposed broad-based environmental regulations like the NAAQS standards of the US Clean Air Act. As thorough as all of this research has been about the effects of those standards on various economic outcomes, the results cannot be generally applied to standards imposed for other pollutants or by other countries.

An alternative regulation-based approach is to use a narrow regulation-based measure. The best example of this can be found in Berman and Bui (2001), who study the specific regulations that target petroleum refineries in Los Angeles from 1979 to 1992. Refineries not subject to those rules, because they used different technologies or were located elsewhere, were used as a comparison group. Curiously, they found that the regulations increase plant-level productivity, though that may in part be due to the fact that unregulated plants deferred risky investments, waiting to see how they worked out in the regulated plants first. McConnell and Schwab's study of automobile plants, in addition to using counties' attainment of federal ambient standards, used the states' standards for the maximum amount of volatile organic compounds used in automobile paint. Levinson (1999) studied paint manufacturers and commercial printers and used indicator variables for whether or not the states' toxic air pollution rules grandfathered existing sources of pollution. Haščič and Johnstone (2011) examined the effect of fuel taxes and fuel efficiency standards on innovation aimed at alternatively fuelled vehicles. All of these studies suffer from the same shortcoming: results cannot be generally applied beyond the conditions and outcomes of the particular examples they explore.

One final example of these regulation-based measures worth mentioning is the use of the lead content of gasoline as an indicator for overall environmental regulatory stringency. The maximum allowable amount of lead per litre can be easily compared across countries. Researchers using this approach argue that if a country has large quantities of lead in gasoline, it is likely to be lax in other environmental areas as well. Indeed, Damania et al. (2003) show that this measure is correlated with three other composite indexes of regulatory stringency, as discussed below.

Cole et al. (2006) examined whether foreign direct investment is simultaneously determined by this measure of stringency. They found that foreign direct investment leads to less stringent regulations, exacerbating the pollution haven effect of stringent regulations on foreign direct investment. Cole and Fredriksson (2009) showed that this result is reversed if countries' governments have more diverse political structures. Broner et al. (2012) used the same measure, the lead content of gasoline, to examine whether international trade is altered by regulatory stringency. They addressed the simultaneity of

regulatory stringency and trade by instrumenting for the lead content of gasoline with a measure describing countries' atmospheric conditions. Countries with prevailing winds that disperse air pollution do not need stringent regulations to achieve clean air. All of these studies faced the recognized challenge that the lead content of gasoline applies to the transportation sector, which is not necessarily central to decisions about imports or foreign direct investment. They based their approaches on the empirical correlation between lead content and other more relevant measures of stringency. Lead content is convenient and easily comparable, but applies to a sector that is not internationally tradable.

That concern leads us to the next batch of measures: composite indexes meant as comprehensive indicators of countries' overall environmental regulatory stringency.

General composite indexes

Some of the earliest attempts to quantify regulatory stringency were based on simple indexes constructed from counts of regulations, environmental non-governmental organizations, international treaties signed, and similar easily enumerated characteristics. In the United States, researchers have used the voting records of states' congressional delegations (Gray, 1997), and a measure that adds to that the existence of state environmental impact statement requirements and counts of the number of statutes each state has from a list of 50 common laws (Levinson, 1996).

For cross-country comparisons an immense number of these types of indexes have been examined. Among the earliest was a 1976 survey sent by the United Nations Conference on Trade and Development (UNCTAD) to 145 countries, asking government officials details about their environmental policies. Only 40 responded, and the UN ranked their overall responses on a 7-point scale (Tobey, 1990; Walter and Ugelow, 1979).

These cross-country indexes have come a long way since the UNCTAD effort. Dasgupta et al. (2001) constructed a more thorough version of an index in the same spirit as that original study. They randomly selected 31 of the 145 national environmental reports prepared in advance of the first UN Conference on Environment and Development in Rio de Janeiro in 1992. They assessed the answers to 25 questions as they applied to four media (air, water, land, and wildlife) and five economic sectors, resulting in 500 separate scores for each country. This was done separately for five different environmental dimensions: awareness, scope of policies, scope of legislation, control mechanisms, and implementation. This results in a ranking that can be compiled in aggregate or separately for each media, industry, or environmental dimension. Not surprisingly Dasgupta et al. showed that this measure is correlated with economic development. Switzerland ranked first and Mozambique last. Damania et al. (2003) used the Dasgupta approach, along with several others, to try to calculate the causal political-economic relationship between trade policy and environmental policy. Raspiller and Riedinger (2008) used the index to estimate the effect of regulations on the location decisions of French multinational firms.

Two problems arise with this approach to measuring environmental regulatory stringency, even with indexes constructed as comprehensively and thoroughly as the Dasgupta index. First, the UNCED survey was one single cross section for 1990. There is no way to construct a panel of data and include country fixed effects to control for unobserved country characteristics correlated with both regulatory stringency and economic activity. Raspiller and Riedinger tried to address this by using firm-level data.

With multiple firms locating in the same country, they could include country-level fixed effects. But those fixed effects capture unobserved characteristics of the set of firms that choose to locate in a given country, not unobserved characteristics of that country that may be correlated with the Dasgupta index and might be spuriously attributed to the effect of stringency. Damania et al. (2003) tried to convert the Dasgupta index into a panel by predicting its values in 1990 using country characteristics that vary over time, such as GDP, population, urbanization, corruption, and industry's share of the work force. They then used the estimated coefficients and the data for each of the regressors to predict the value of the Dasgupta index for years other than 1990. This method raises a different concern: that the regressors used to predict stringency may themselves be determined by stringency. If stringent environmental regulations slow GDP growth or change industry's share of labour, those variables cannot be used to predict the stringency of regulations.

Second, as sensible and methodical as Dasgupta et al. were in constructing their index, an equally sensible and methodical group of other economists might have looked at those 31 national environmental reports and constructed a different index, with different country rankings. None of the studies we are aware of have attempted this robustness check, examining whether alternative indexes constructed with the same data deliver similar conclusions.

Rather than surveying government officials, a number of papers have used surveys of businesses about their countries' environmental regulatory stringency. Among the most widely used, because it has been asking environment-related questions annually since the mid-1990s, is the World Economic Forum (WEF) survey of business executives. Unfortunately, the surveys conducted in different years are not directly comparable because many of the questions have changed over time, making panel data analysis impossible. Kellenberg (2009) focused on two questions that have been asked consistently since 2000: one asks executives about their countries' environmental regulatory stringency, the other asks about those regulations' enforcement. Each asks executives to rate countries' regulations on a scale from 1 to 7. Two recent studies have used this index to examine whether environmental stringency reduces foreign direct investment and draw conflicting conclusions. Wagner and Timmins (2009) found that outbound foreign direct investment from Germany is strongly negatively associated with high values of the WEF index for one particular industry, chemical manufacturing. Kalamova and Johnstone (2011) found a more broad-based effect that is relatively small and nonlinear; it diminishes above a certain threshold of stringency.

As Kalamova and Johnstone emphasize, this measure of stringency is based on perceptions, not actual hard data on costs or regulations. On one hand, perceptions may be correlated with regulations and an important driver of economic outcomes. On the other hand, perceptions are not necessarily the policy-relevant determinant of either economic or environmental outcomes. What would be the policy implication of learning that perceptions of regulatory stringency were discouraging investment? Change the regulations and hope perceptions follow, or launch a public relations campaign aimed at altering perceptions? Perceptions may be a useful indicator of regulatory stringency, but Kalamova and Johnstone cannot say whether the nonlinear relationship they find reveals a true nonlinear relationship between stringency and foreign direct investment, or a spurious nonlinear relationship between actual and perceived stringency. Finally, we can imagine many situations in which the perception of regulations may be even more simultaneously determined by economic activity than the actual regulations. We know, for example that public support for environmental policies falls when unemployment rates rise (Kahn and Kotchen, 2011). It seems likely to us — though we are speculating here —

that business-sector sentiment that regulations are too stringent may also rise during recessions. If perception of stringency is correlated with economic downturns, that may be misinterpreted as though actual stringency reduces investment.

In the same way that the Dasgupta index improves on the UNCTAD index from the early 1970s, indexes that merely count up the number of regulations have also become more sophisticated. Smarzynska and Wei (2004) counted whether or not each country signed or ratified one of four international environmental treaties, along with the number of environmental NGOs present in the country. Johnstone et al. (2010) were interested in the degree to which policies towards renewable energy have spurred technological innovation. They created a list of policies that included tax incentives, investment subsidies, differentiated tariffs, voluntary programs, quotas, and tradable certificates. Then they documented how many of these policies had been implemented in each of 25 countries from 1978 to 2003. While not technically a measure of regulatory stringency, we could imagine such a measure being constructed with that alternative goal in mind.

One final effort worth highlighting is that of Cole et al. (2010), which uses an index constructed by the Japanese Research Institute of Economy, Trade and Industry. The index calculates a weighted average of 303 four-digit manufacturing industries within each of 41 two-digit sectors that are governed by 3000 broad industrial regulations. The index ranges from 0 to 100, representing the share of each sector that is regulated. While not limited to environmental regulations, such an index could in principle be constructed to eliminate rules that do not pertain to pollution. Like the other indexes, however, we do not know whether slight deviations in its constructions might lead to large differences in its rankings and conclusions. And like all such indexes, this one conveys little sense of magnitude. Regulations are weighed equally regardless of the burden they impose. The index cannot tell us whether a sector with twice the regulatory coverage faces twice the level of stringency.

Emissions, pollution, or energy use

Some studies have turned the question on its head and used emissions, ambient pollution, or energy use as measures of stringency. On the surface this seems backwards. The regulations whose stringency is to be measured are designed to reduce emissions, pollution and energy use. So are they indicators of regulatory stringency or laxity? That depends on the situation. Some studies have taken high levels of pollution as evidence that regulations are relatively *lax*. Xing and Kolstad (2002) use national aggregate SO_2 emissions in this way. Others use high levels of pollution as a measure of *stringency*, on the grounds that governments will be forced to tighten regulations to deal with the problem (Constantini and Crespi, 2008). This works well in cases where a central government imposes ambient standards, as with the US Clean Air Act. McConnell and Schwab (1990) used the degree to which a US county was out of compliance with national standards as a proxy for the stringency of the regulations the state would have had to impose to meet those standards. In each of these cases it may not be obvious whether the variable in question, emissions or ambient pollution, conveys regulatory stringency or laxity.

Several research projects have used *reductions* in emissions as indicators of stringency. Smarzynska and Wei (2004) used declines in carbon dioxide, lead, and water pollution as a share of GDP. Gollop and Roberts (1983), in a classic study, conducted a detailed examination of 56 US electric utilities from 1973 to 1979. They constructed a

measure of stringency, R_t, that is based on the emissions reduction forced on the utility as a consequence of the legal requirement and its enforcement.

$$R_t = \left(\frac{E_t^* - L_t}{E_t^*}\right)\left(\frac{1}{2}\sum_{i=t-1}^{t}\frac{E_t^* - E_i}{E_t^* - L_i}\right) \quad \textbf{(3)}$$

Where L_t is the legal standard for SO_2 emissions in pounds per million BTU[10], E_t is the utility's actual emissions rate, and E_t^* is an engineering estimate of what the utility's unconstrained emissions rate would have been absent the regulation. The first ratio just reports the degree to which the legal standard requires a proportional reduction, between zero and one. The second set of brackets contains a two-year moving average of the proportion of the mandated reduction that the utility actually achieves, also between zero and one. The key, naturally, is *E**, the counterfactual unconstrained emissions that is of course unobserved. Gollop and Roberts assumed that, in the absence of regulations, the utility would purchase only high-sulphur fuel and employ no end-of-pipe abatement.

These two approaches represent extremes of aggregation and disaggregation. Smarzynska and Wei used aggregate country-wide emissions reductions. Those could be a consequence of regulatory changes. But they could also result from changes in industrial composition or factor prices involving other trends. Gollop and Roberts used emissions reductions below unconstrained levels for one particular industry in the United States. Their application is an estimate of productivity effects for this one industry and country. It would be difficult to apply their measure to study differences across industries or countries because legal standards (*S*) would be stated in non-comparable terms and unconstrained emissions (*E**) would have to be calculated in different ways for each situation.

The last approach in this category involves energy use as a proxy for regulatory stringency. A number of studies have used energy consumption as an indicator of environmental regulatory stringency. Cole and Elliot (2003) used countries' energy consumption divided by GDP in 1980, along with the change in that variable from 1980-1995. Those two numbers were ranked, the ranks were added together, and the sum was ranked again and divided by the number of countries, resulting in a stringency measure from zero to one. This energy-based measure is highly correlated with the Dasgupta index discussed above (ρ=0.77). Harris et al. (2003) elaborated on this same energy index using two measures of energy (final consumption and primary supply), scaled by population and two alternative measures of GDP (based on purchasing power parity and exchange rates), resulting in six different versions of the index used by Cole and Elliot.

It is hard to tell from these indexes, however, whether the measure of stringency is largely the result of changes in energy use or levels. Both changes and levels could differ across countries for many reasons other than environmental standard stringency, such as differences in energy prices, in industrial composition, and in the degree of trade openness. Furthermore, if environmental regulations drive up the price of energy, it is not clear that energy expenditures will decline as a share of GDP.

The van Soest et al. (2006) paper discussed earlier estimated the shadow price of energy as a proxy for environmental regulatory stringency. Again, the cost to industry of using energy could differ for many reasons, environmental regulations being only one of

10. 1 pound per million BTU (British thermal units) = 1.548 kg/MW-hr or 430 mg/J (*Source*: www.ilga.gov/commission/jcar/admincode/035/035002120A01110R.html).

them. But we believe their approach could be applied to emissions directly, at least partly circumventing that problem.

Enforcement or public expenditures

The final category of measures involves public sector environmental efforts as a proxy for stringency. Not the regulations themselves, which are discussed above in a separate category, but some variable serving as a proxy for governmental effort. For example Gray (1997) uses US states' budgets for environmental and natural resources. This has the advantage that it includes enforcement, which is an important part of stringency, but it requires caution. While some public expenditure imposes costs on the private sector (e.g. regulatory staff and budgets for inspection and enforcement), while others relieve the private sector of costs (think of tax incentives and public clean-up efforts). A tax incentive to abate pollution will have different effects on the various approaches to measuring stringency. It increases the marginal cost of polluting (the opportunity cost of foregone tax rebates), and profit-maximizing firms will respond by abating more. That will make a country appear more stringent by a PACE-type measure, a shadow-cost measure, and a public expenditure measure. But it also increases the profitability of pollution-intensive industries. We should not expect industrial flight from countries with tax incentives to countries without them, for example.

Other papers have used state enforcement and inspection budgets in particular, avoiding the concern that some public expenditure reduces business costs.[11] Gray (1997) and Shadbegian and Gray (2012) used the total number of environmental inspections of manufacturing plants, divided by the total number of such plants in each state. Levinson (1996) used the number of employees at state environmental agencies, scaled by the number of manufacturing plants. But this is at best a remote indicator of stringency. State laws can be made stringent by well-staffed environmental agencies through frequent inspections even without steep punishments for violations, or though infrequent inspections by understaffed agencies if the punishment for violations discovered is sufficiently onerous.

Pearce and Palmer (2001) combined this public expenditure approach with the private cost approach we discussed first. They focused on the mix of the two, and asked whether over time the burden of environmental regulations had shifted from the public sector to the private sector. As they pointed out, this division is not unambiguous.

In general, public-sector effort has not been widely used to measure regulatory stringency, especially recently, probably because its shortcomings outweigh its advantages, and partly because as more emissions and cost data have become available the need for it as a proxy has declined.

11. One could also imagine enforcement efforts being classified with the regulation-based approach. We've placed it here on the grounds that it doesn't measure the stringency of any particular regulation the way a technology standard or emissions limit does, but rather it examines how strictly that regulation is enforced. Both are components of the multidimensional concept of stringency.

A new emissions-based approach

In this final section we propose assembling a new measure that could be used to assess environmental regulatory stringency. The idea rests on the same microeconomic principle behind the shadow-price approach discussed previously, that profit-maximizing firms will use each factor of production until its marginal revenue product is equal to its price. Emitting pollution is a factor of production like any other. Without regulation, the price of emissions is low, and firms will emit pollution until the marginal product they get from emitting extra pollution falls to close to zero. As environmental regulations raise the cost of emissions, firms will emit less pollution. Hence, one could compare emissions of various industries across countries or states, and use emissions per dollar of value added — emissions intensity — as a measure of regulatory stringency. By averaging emissions per dollar of value added across industries, an emissions-based measure of stringency could be constructed. Where emissions intensity in a country is higher, it could be concluded that the cost of polluting is lower because regulations are less stringent. Where emissions intensity is lower, regulations must be more stringent.

The idea behind using emissions intensity as a measure of regulatory stringency originates with the production function approach outlined in van Soest et al. (2006). That approach would ideally employ plant-level data on all factors of production in addition to emissions — labour, capital, materials, etc. But such plant-level data are confidential and difficult to access, and our approach would depend solely on aggregate industry-level emissions data, which more and more countries are beginning to develop and make publicly available. We combine the intuition behind the van Soest approach — that regulated firms will emit less — with the cost-based approach taken by Levinson and Keller (2002).

Let e_j be emissions per dollar of value added in jurisdiction j, averaged across all industries:

$$e_j = E_j / V_j$$

where E_j and V_j denote total emissions and value added in jurisdiction j, summed across all industries. Let e_i be the emissions per dollar of value added in industry i, averaged across all jurisdictions:

$$e_i = E_i / V_i$$

where E_i and V_i denote total emissions and value added in industry i, summed across all jurisdictions. Then denote $\hat{e}_j$ as the *predicted* emissions per dollar of value added in jurisdiction j, assuming each of its industries uses the average emissions intensity for all jurisdictions.

$$\hat{e}_j = \frac{1}{V_j} \sum_i V_{ij} e_i$$

This is a prediction of j's emissions intensity based solely on its industrial composition (the V_{ij}'s) and the average emissions intensities of those industries in other jurisdictions. If a country has a lot of high-emitting industries, we would expect it to have a high value of $\hat{e}_j$. If its mix of industries is relatively clean, we would expect a low $\hat{e}_j$.

Another way to think about this is as follows. The *actual* emissions intensity of a jurisdiction is equivalent to a weighted average of the actual emissions per dollar of value added of each industry *in that jurisdiction* (e_{ij}) where the weights are the industries' shares of total output in that jurisdiction (V_{ij}/V_j), though we won't need or want disaggregated jurisdiction-industry emissions data because we can just use the aggregate equivalent E_j/V_j. The *predicted* emissions intensity of a jurisdiction is a weighted average of the *national average* emissions per dollar of value added in each industry (e_i), where the weights are the same (V_{ij}/V_j).

A measure of the stringency of regulations, R_j, is just the ratio of predicted emissions intensity to actual emissions intensity:

$$R_j = \hat{e}_j / e_j \qquad \textbf{(4)}$$

Countries that impose higher pollution abatement costs on their industries will have smaller-than-predicted emissions, and higher levels of R_j, no matter what their industrial compositions. The index R_j could be constructed for particular pollutants or particular media. Or it could be summed across various pollutants and media to construct a general measure of regulatory stringency. Critically, this measure could in theory also be constructed on an annual basis to observe changes over time.

In addition to data on value added by industry and jurisdiction, constructing the index in equation (4) requires two key variables. The first is E_j, the total amount of pollution emitted in each jurisdiction. This does not need to be industry-specific, though it does need to be limited to the industries that comprise the index. (That is to say, it should not include transportation or household pollution if those are not part of equation (4)). The second variable is E_i, the total amount of pollution emitted by each industry. This does not need to be jurisdiction-specific.

In the United States, two such emissions inventories have been created. The first was assembled by the World Bank using US EPA emissions data in 1987, and was called the Industrial Pollution Projection System (IPPS) (Hettige et al., 1995). The IPPS listed emissions intensities for various air and water pollutants and for each four-digit Standard Industrial Classification (SIC) code. Unfortunately, that emissions inventory was not repeated in subsequent years, and so although a version of equation (4) could be constructed for 1987, it would not be feasible to construct a panel. Also, the IPPS is not differentiated by state, so aggregate state emissions would have to be estimated from other sources.

A second US source has more promise. In recent years the US EPA has begun compiling its own emissions inventory, called the Trade and Environmental Assessment Model (TEAM). So far the TEAM is available for 1997, 2002, and 2007, and is organized by four-digit North American Industry Classification System (NAICS) codes. This has the advantage that it has been repeated three times, and so a panel can be constructed, and it is available state-by-state, facilitating calculation of both E_j and E_i.

There are two possible sources for emissions data in Europe. The first is the European Pollution Emissions Register (EPER) for 2001 and 2004. In the first reporting year, the database covered air and water emissions for 50 pollutants for 9 400 facilities in the EU-15, Hungary, and Norway. In the second reporting year, the database expanded to include approximately 12 000 facilities in the EU-25 and Norway. The facilities covered are classified into 16 economic sectors, themselves divided into activities. For example, the manufacturing sector includes 14 activities. This level of aggregation poses the

greatest challenge for researchers. An activity as it is defined is still comprised of a variety of industries and products, some of which might be highly pollution-intensive even if the activity appears clean on average. For example, the pulp, paper and paper product activity is polluting in terms of air pollution. However, the envelope manufacturing sub-activity is not. The rough division of economic activities in this database therefore hides important pollution variation within activities.

An alternative possible source of annual EU emissions data, starting in 2007, is the European Pollution Release and Transfer Registry (E-PRTR). This covers 91 pollutants, including water, air, and soil pollutants, for the 27 EU Member States as well as Iceland, Liechtenstein, Norway, Serbia and Switzerland. The E-PRTR classifies the economic activity of facilities at the four-digit level of the NACE classification, including 67 manufacturing activities. Despite progress in the level of detail of the classification, the data still have important shortcomings, specifically with regards to coverage of facilities. Only facilities above a certain capacity and emission threshold — which vary by industry and by pollutant — are required to report emissions.[12] The resulting data are spotty. For SO_2 emissions, more than 80% of EU manufacturing industries do not report data. In contrast, in the US IPPS data only about 35% of manufacturing industries report zero or missing data for SO_2 emissions.

While the international data necessary to calculate (4) may not yet be suitable, assembling such data should be a high regulatory priority for reasons unrelated to measuring stringency. The US EPA began compiling the TEAM data in order to analyse the environmental consequences of trade agreements. Emissions inventories like TEAM are key environmental management tools, helping regulators assess the most important sources of pollution. They are also a key *product* of the regulatory process, as more and more pollution regulations require monitoring the resulting data can be aggregated to create emissions inventories. So it is likely that in the future emissions inventories will improve, in the US, Europe and elsewhere.

Constructing a stringency measure based on emissions ratios as in equation (4) would go a long way towards overcoming three of the four conceptual obstacles outlined in the first section. Such a measure would be theoretically motivated by pollution-abatement costs. It would be divisible by pollutant, and therefore could be used either as a summary measure for all the multidimensional aspects of environmental policy in a country, or disaggregated for particular pollutants or media. It would be a panel, and so examinations of changes in economic outcomes in response to changes in this measure would help ameliorate simultaneity issues. It also inherently controls for industrial composition. But it would only be informative about environmental costs faced by existing sources of pollution. That obstacle may be unavoidable for any empirical cost-based measure of regulatory stringency.

12. The reporting guidelines are available in the annexes of the following document: http://eur-lex.europa.eu/LexUriServ/site/en/oj/2006/l_033/l_03320060204en00010017.pdf (accessed 12 December 2012).

Conclusion and recommendations

From pollution havens and environmental dumping to industrial flight and carbon leakage, many issues in environmental policy revolve around measuring regulatory stringency. The range of approaches taken to construct such measures reveals the complexity of the task. In this paper, we point out that obstacles to measuring stringency are not ordinary difficulties of data collection but involve deeper conceptual issues that we group into four categories: multidimensionality, simultaneity, industrial composition, and capital vintage. While these obstacles do not mean that measuring stringency is impossible, any proposed measurement should be evaluated with them in mind.

Approaches to measuring stringency can be divided into five broad categories, with different strengths and weaknesses. (1) Surveys of businesses' abatement expenditures have the advantage of varying over time, and across industries and countries or states in ways that comport with intuition. But the surveys are not limited to costs stemming from environmental regulations, and they only measure existing industries' costs, which may differ from potential new entrants' costs if regulations are vintage-differentiated. Moreover, the surveys ask respondents to distinguish costs they incur for environmental reasons from costs incurred for other goals, a task businesses may not be capable of accomplishing. (2) Direct assessments of regulations are particularly sensitive to multidimensionality and simultaneity, and so researchers typically narrow their questions to focus on particular case studies and look for natural experiments where regulatory changes have been imposed on jurisdictions by external considerations. (3) Composite rankings compress the multidimensional problem down to one number, but they are inherently ad hoc and make assessing cardinal magnitudes difficult. (4) Indexes based on pollution or energy use are sometimes used as measures of stringency and other times used as measures of laxity, exposing their inherent simultaneity. (5) Finally, measures based on public-sector environmental efforts include enforcement, an important element of stringency, but provide an ambiguous proxy for stringency since some types of public expenditure can decrease private-sector costs.

Recall the goals that an ideal measure of environmental regulatory stringency would achieve: it would be simple to calculate; produced annually; cardinal; available for various pollutants and media; and related to industry costs without being mechanically determined by industry composition. Of the measures we have discussed, most fall far short of these goals. The regulations themselves are too complex and dissimilar across countries to create consistent measures of stringency, except in narrow case studies that are not generalizable. It is hard to imagine surveys of business executives or government officials meeting those standards.

Composite indexes, though numerous, are rarely conducted consistently as panels, are not theoretically grounded in costs, and are typically impossible to disaggregate by pollutant or media. Public-sector efforts as measured by expenditures or enforcement are conducted differently in every state and country and fail to capture key aspects of stringency. Pollution-abatement-cost surveys shift the burden to private-sector managers by asking them to answer difficult conceptual questions they may be incapable of answering. Each of the five approaches we've discusses faces all four obstacles. Researchers using the PACE survey need to consider multidimensionality, simultaneity, industrial composition, and capital vintage. The same holds for researchers using direct regulatory measures, composite rankings, surveys of business executives, or public sector costs.

Finally, we have proposed a new emissions-based measure that could be used to assess environmental standard stringency. The idea hinges on the intuition that regulated firms will emit less. The new method would calculate each jurisdiction's predicted emissions based on its industrial composition and the average emissions intensity of each if its industries. Where actual emissions exceed predicted emissions, we would conclude that environmental regulation is less stringent than average, and vice versa. This new index could be computed for a particular pollutant or media, or it could be aggregated to serve as a general measure of environmental regulatory stringency. Only two sets of data would be necessary to construct this measure: (1) value added by industry and jurisdiction, which is already available, and (2) emissions by industry and jurisdiction, which is beginning to be available and which we believe countries should be collecting anyway towards other worthwhile policy goals. While those data are currently not available across countries, they do exist for US states in 1997, 2002, and 2007 in the form of the EPA's TEAM emissions inventory. Soon we are planning to construct the index in equation (4) for the United States as a test of its usefulness, and to encourage other countries to assemble comparable emissions inventories.

In sum, we hope that this discussion of measuring environmental regulatory stringency provides a sense of realism about the obstacles facing the task and an understanding of where existing methods may fall short, but also some hope that a theoretically-motivated, empirically feasible measure may not be impossible.

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Table 1. Measures of environmental regulatory stringency

Private-sector costs					
Measure	**Data source**	**Countries or industries**	**Time**	**Studies**	**Notes**
Private-sector pollution abatement costs	US Bureau of Economic Analysis (BEA) Pollution Abatements Costs and Expenditures (PACE) US BEA PACE	US states, automobile manufacturers	1972-1983	McConnell and Schwab (1990)	Pollution abatement operating costs per dollar of shipments or as a proportion of new capital expenditures by industry in the state.
		US manufacturing	1982	Levinson (1996)	Pollution abatement operating costs by industry and US state. Coefficient on the state dummy in a plant-level regression of PACE on plant characteristics.
			1977-1994	Keller and Levinson (2001)	Pollution abatement costs adjusted by state industrial composition.
			1977-1994	Millimet and Roy (2012)	
		US pulp and paper, oil refineries and steel mills	1990-2000	Shadbegian and Gray (2005)	Pollution abatement operating costs divided by the plant's capacity
		US pulp and paper, plastics, petroleum and steel	1979 -1991	Morgenstern et al. (2001)	Estimated total burden of environmental regulation using a cost model allowing for interaction between environmental expenditures (pollution abatement operating costs and capital expenditures) and non-environmental expenditures
		United States	1973-1985	Jorgenson and Wilcoxen (1990)	Dynamic CGE model projects growth of US economy with and without environmental regulation
	US BEA PACE, and interviews with plant-level accountants and corporate-level managers	55 US steel mills	1979-1988	Joshi et al. (2001)	Visible costs identified as "environmental" v. estimated hidden environmental costs embedded in other accounts
	US Bureau of Economic Analysis (BEA) Pollution Abatements Costs and Expenditures (PACE) US BEA PACE	Manufacturing sectors in Canada, West Germany, Japan, US	1973-1982	US CBO (1985)	Pollution abatement capital expenditures
	US BEA PACE; Statistical agencies in Germany and Netherlands	US, Netherlands and German manufacturing	1977-1992	Mulatu et al. (2004)	

Private-sector costs					
Measure	**Data source**	**Countries or industries**	**Time**	**Studies**	**Notes**
	Statistics Division, Taiwan Ministry of Economic Affairs	Taiwan manufacturing	1987-1997	Tsai (2002)	
	US BEA PACE; German statistical agency; Japan Ministry of International Trade and Industry; Netherlands statistical agency	US, German, Netherlands and Japanese manufacturing	1975-2002	Aiken et al. (2009)	Pollution abatement capital expenditures as a ratio of total capital expenditures
	Dept. of Environment, Food and Rural Affairs (DEFRA)	United Kingdom	1999-2003	Cole and Elliott (2007)	Pollution abatement capital expenditure and operating costs
	German Statistical Yearbook	German industries	1975-1991	Conrad and Wastl (1995)	
	Eurostat Environmental Expenditures and Taxes database	19 countries from the EU and Central and Eastern Europe	1996-1999	Jug and Mirza (2005)	Capital expenditures and operating costs in environmental protection activities
	Statistics Canada, unpublished report	Quebec, Canada manufacturing sector	1985-1988	Dufour et al. (1998)	Pollution abatement expenditures divided by total cost in industry.
	Japan's Research Institute of the Economy Trade and Industry	Japan	1989-2003	Cole Elliott and Obuko (2010)	Waste disposal costs per unit of output
Estimated costs via shadow prices	US Federal Energy Regulatory Commission	14 coal-burning power plants in Wisconsin	1990-1992	Coggins and Swinton (1996)	Shadow price of SO2 emissions: $293. Actual auction futures price in 1992: $170-$400.
	IEA Energy Balances and the OECD International Sectoral Database	9 European countries	1978-1996	van Soest et al. (2006)	High variability within countries. Pattern across industries not consistent across countries.

Regulation-based measures					
Measure	**Data source**	**Countries or industries**	**Time**	**Studies**	**Notes**
US County attainment of Clean Air Act standards	US Environmental Protection Agency	United States	1972-1983	McConnell and Schwab (1990)	County attainment status is determined based on the Clean Air Act environmental standards (NAAQS) for six "criteria" air pollutants; nonattainment counties face tighter regulation.
		US five ozone polluting industries	1977-1987	Henderson (1996)	
		US, new plants in 4 ozone polluting industries	1963-1992	Becker and Henderson (2000)	
		United States	1996-2000	Condliffe and Morgan (2009)	
		US manufacturing	1987-1997	Greenstone (2002)	
		New York State	1980-1990	List et al. (2004)	
Air pollution regulatory strictness	South Coast Air Quality Management District	US oil refineries of the LA basin	1979-1992	Berman and Bui (2001)	Number of new regulations in effect
	State and Territorial Pollution Program Administrators and the Association of Local Air Pollution Control Officials (1987)	US states and automobile manufacturers	1972-1983	McConnell and Schwab (1990)	Whether the state imposed fees for operating and construction permits as of 1978, State requirement for maximum VOC content in topcoat paint.
	US EPA National Air Toxics Information Clearinghouse	Commercial printers and paint manufacturers	1988-1992	Levinson (1999)	Some states grandfather existing sources, others do not. Finds little evidence of new source bias.
Lead per gallon of gasoline	Octel's Worldwide Gasoline Survey	13 OECD countries and 20 developing countries	1982-1992	Cole and Fredriksson (2009), Cole et al. (2006)	
		48 developed and developing countries	1982-1992	Damania et al. (2003)	
		101 countries	1980-2010	Broner et al. (2012)	Lead content instrumented using wind and atmospheric mixing height.

Composite indexes, surveys, and related measures					
Measure	**Data source**	**Countries or industries**	**Time**	**Studies**	**Notes**
Voting records	League of Conservation Voters	US manufacturing	1963-1987	Gray (1997)	Average score of the state's House of Representative members on environmental Issues
	Conservation Foundation Index	US States	1983	Levinson (1996)	Index based on congressional voting records, state environmental impact statement processes, environmental language in state land-use statutes.
Treaties	OECD (1999)	24 countries of Central and Eastern Europe and the former Soviet Union	1990s	Smarzynska and Wei (2004)	Degree of participation in 4 environmental treaties, adjusted by the number of environmental NGOs per million people
Indicators of policy implementation	International Energy Agency database of public policies for renewable energies	25 countries	1978-2003	Johnstone et al. (2010)	Binary and continuous variables based on different environmental policies: R&D support, taxes, voluntary programs, tradable permits etc.
Surveys of regulated firms	World Economic Forum's Executive Opinion Survey	100 countries	2001-2007	Kalamova and Johnstone (2011)	Index based on ranking by CEOs of environmental regulation stringency from 1 (lax) to 7 (strict)
		Germany	1996-2003	Wagner and Timmins (2009)	
		50 countries	1999-2003	Kellenberg (2009)	
Composite indexes	Japanese Ministry of International Trade and Industry (MITI)	Japan	1998-1999	Cole, et al. (2010)	Index based on weighted average of the number of subsectors of each industry governed by 3000 broad regulations.
	OECD Environmental Indicators	21 OECD countries	1992	Van Beers and Van den Bergh (1997)	Index based on: protected areas; unleaded gasoline use; recycling rates; percent of population connected to sewage treatment; energy intensity.
	United Nations Conference on Environment and Development Country Reports (UNCED, 1992)	31 countries	1990	Dasgupta et al. (2001)	Index of environmental stringency and enforcement for air, water, land and living resources
	United Nations Conference on Environment and Development Country	48 developed and developing countries	1982-1992	Damania et al. (2003)	Index of environmental stringency and enforcement for air, water, land and living resources
		France	1993-1999	Raspiller and Riedinger (2008)	Index of air and water ambient and emission

Composite indexes, surveys, and related measures					
Measure	**Data source**	**Countries or industries**	**Time**	**Studies**	**Notes**
	Reports (UNCED, 1992) European Bank for Reconstruction and Development (1997)	24 countries of Central and Eastern Europe and the former Soviet Union	1990s	Smarzynska and Wei (2004)	standards systems adjusted by the number of environmental NGOs per million people
	Environmental Sustainability Index	16 manufacturing industries in 13 European countries	1990-1994	Mulatu et al. (2010)	Index of environmental stringency from the World Economic Forum, Yale Center for Environmental Law and Policy, and the Center for Informational Earth Science of Columbia University
	1976 UNCTAD Survey (Walter and Ugelow 1979)	23 countries (13 developed)	1976	Tobey (1990)	Index of environmental stringency from 1 (not stringent) to 7 (most stringent)
	United Nations Conference on Environment and Development Country Reports (UNCED, 1992)	31 developed and developing countries	1990	Cole and Elliott (2003)	Index of state of environmental policies, legislation, and enforcement
	Fund for Renewable Energy and the Environment (FREE) Index	US States	1980s	Levinson (1996)	Index of the strength of state environmental programs and laws.
	Green Index (Hall and Kerr, 1991)	US States	1963-1987	Gray (1997) Levinson (1996)	Indicators of the state's environmental quality, state laws, and membership in environmental organizations,
	Eurobarometer survey	48 developed and developing countries	1982-1992	Damania et al. (2003)	Per capita membership of environmental organizations for EU member states
	Index of Environmental Sensitivity Performance (IESP)	31 countries (23 developed and 8 developing)	2000	Cagatay and Mihci (2006)	Index based on relative degree of pollution generated during certain industrial activities and related efforts of economic agents to improve environmental quality. Data from Bakkes et al. (1994), Hammond et al. (1995), WB (1995) and MENV (1996)

Emissions and energy use					
Measure	**Data source**	**Countries or industries**	**Time**	**Studies**	**Notes**
Emissions	United Nations Environment Program	15 developed countries and 7 developing	1985-1990	Xing and Kolstad (2002)	Economy-wide emissions of sulfur dioxide
	World Bank World Devel. Indicators	148 countries	1996-2005	Constantini and Crespi (2008)	CO2 emissions.
Ambient pollution	US EPA	US counties	1977 and 1982	MConnell and Schwab (1990)	Actual ozone reading for counties failing to attain national AQ standards.
Emissions reductions	World Development Indicators and OECD (1996)	24 countries of Central and Eastern Europe and the former Soviet Union	1990s	Smarzynska and Wei (2004)	Actual reductions in emissions of carbon dioxide, lead and water pollutants scaled by GDP growth
	Monthly Report Steam Electric Plant Air and Water Quality Control Data; State Implementation Plans for the Clean Air Act	US electric utilities	1973-1979	Gollop and Roberts (1993)	Firm-specific based on stringency, enforcement, and estimated unconstrained emissions.
Energy use	World Bank World Development Indicators.	31 developed and developing economies	1980-1995	Cole and Elliott (2003)	Change in energy intensity (energy/GDP) and level of energy intensity in 1980
	Energy Balances of OECD Countries; International Energy Agency	24 OECD countries	1990-1996	Harris et al. (2003)	Six indexes based on final energy consumption or primary energy supply, normalized by GDP or population
	IEA Energy Balances and the OECD International Sectoral Database	Food and beverages and primary metals industries in Europe.	1978-1996	van Soest et al. (2006)	Difference between a polluting input's shadow price and purchase price.

Public expenditures and enforcement					
Measure	**Data source**	**Countries or industries**	**Time**	**Studies**	**Notes**
Public sector expenditures	OECD (1995)	48 developed and developing countries	1982-1992	Damania et al. (2003)	Public environmental R&D expenditure as a proportion of GDP
	Council of State Governments (1991)	US manufacturing	1963-1987	Gray (1997)	Public spending per capita on each state's programs for environment and natural resources in 1988
	OECD (1999) - and comparison with national EU sources: Eurostat for France and Netherlands, UK Department of the Environment (1992) for the United Kingdom	United States, United Kingdom, France, Netherlands	1985-1997	Pearce and Palmer (2001)	Pollution abatement expenditure per capita by public and private sectors
State monitors and inspections	National Governor's Association (1982)	United States	1982	Levinson (1996)	Number of employees at state environmental agencies divided by the number of existing manufacturing plants
	US Environmental Protection Agency	US manufacturing plants	1963-1987	Gray (1997)	Number of air inspections at manufacturing plants normalized by the number of manufacturing plants for each US state
		US manufacturing plants near 4 US cities	2000-2002	Shadbegian and Gray (2012)	