Is Free Trade Good For The Environment?
TECHNICAL APPENDIX

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Contents

A Capital Intensity and Pollution Abatement

We argue in our paper that capital-intensive industries are also pollution-intensive. To support this claim, figure A-1 illustrates the relationship between capital intensity and the pollution abatement costs (per unit of output) for a set of U.S. industries in 1988.[1]

A regression through the 122 data points based on the logarithmic transformations of abatement cost ratio and capital intensity reveals a positive relationship with an R^2 of 0.3, indicating that a 1% increase in the capital intensity increases the abatement cost ratio by 0.7%. Data were only available for manufacturing industries. Thus, a particularly interesting industry—electricity generation—is not included in the sample. From other sources it is known that pollution abatement costs and capital intensity are both extremely high in that industry.

Pollution abatement data are as reported in Patrick Low "Trade Measures and Environmental Quality: The Implications for Mexico's Exports", chapter 7 in: Patrick Low (ed.) "International Trade and the Environment", World Bank Discussion paper 159, The World Bank, Washington/DC, 1992, pp. 113-114. Additional capital and labour figures for the 3-digit SIC manufacturing industries were taken from the U.S. Annual Survey of Manufacturing. The i123-type labels next to each data point indicate the 3-digit US-SIC industry.

B Data Set Description

B.1 Dependent Variable

The dependent variable in our study is the concentration of sulphur dioxide at observation sites in major cities around the world as obtained through the GEMS/AIR data set supplied by the World Health Organization. Measurements are carried out using comparable methods. Each observation station reports annual summary statistics of SO_2 concentrations such as the median, the arithmetic and geometric mean, as well as 90th and 95th percentiles.

We have chosen to use a logarithmic transformation of the median SO_2 concentration as our dependent variable. Figure B-1 shows that the distribution of concentrations is highly-skewed towards

1. See also Mani and Wheeler (1997).

Figure A-1: Pollution Abatement and Capital Intensity in the U.S. (1988)

Figure B-3: Composition of GEMS/Air Data Set (Observations per Country)

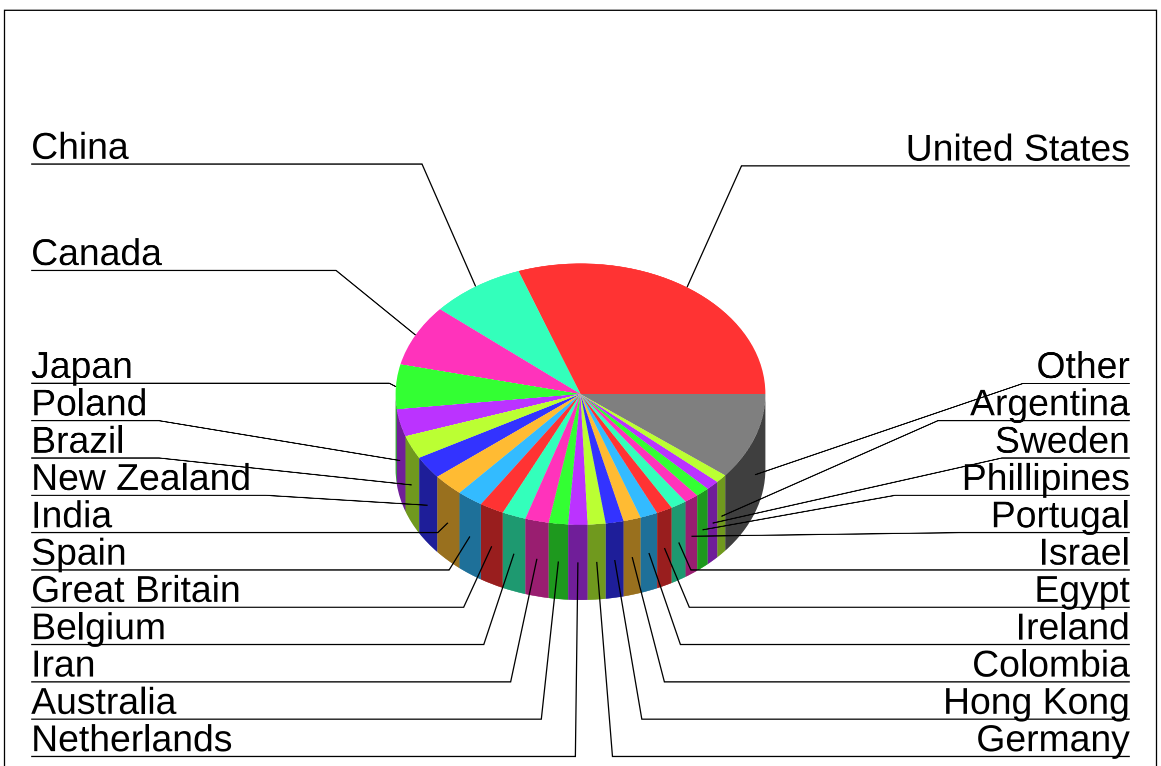


Figure B-1: Distribution of the Dependent Variable (linear scale)

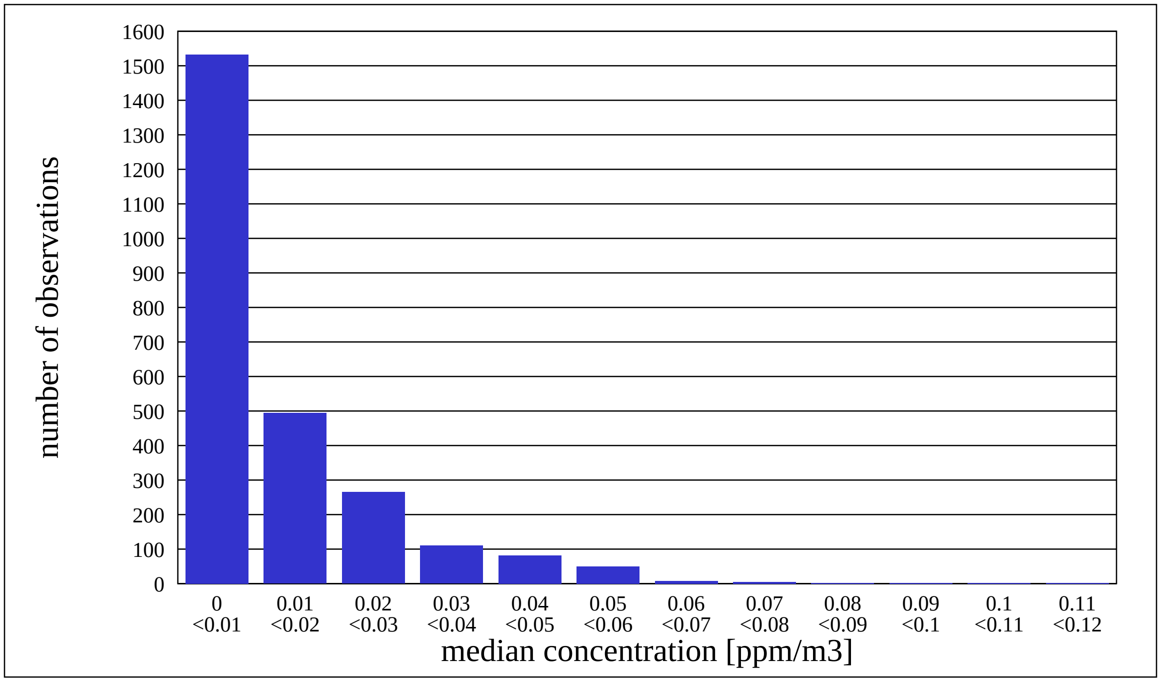


Figure B-2: Distribution of the Dependent Variable (logarithmic scale)

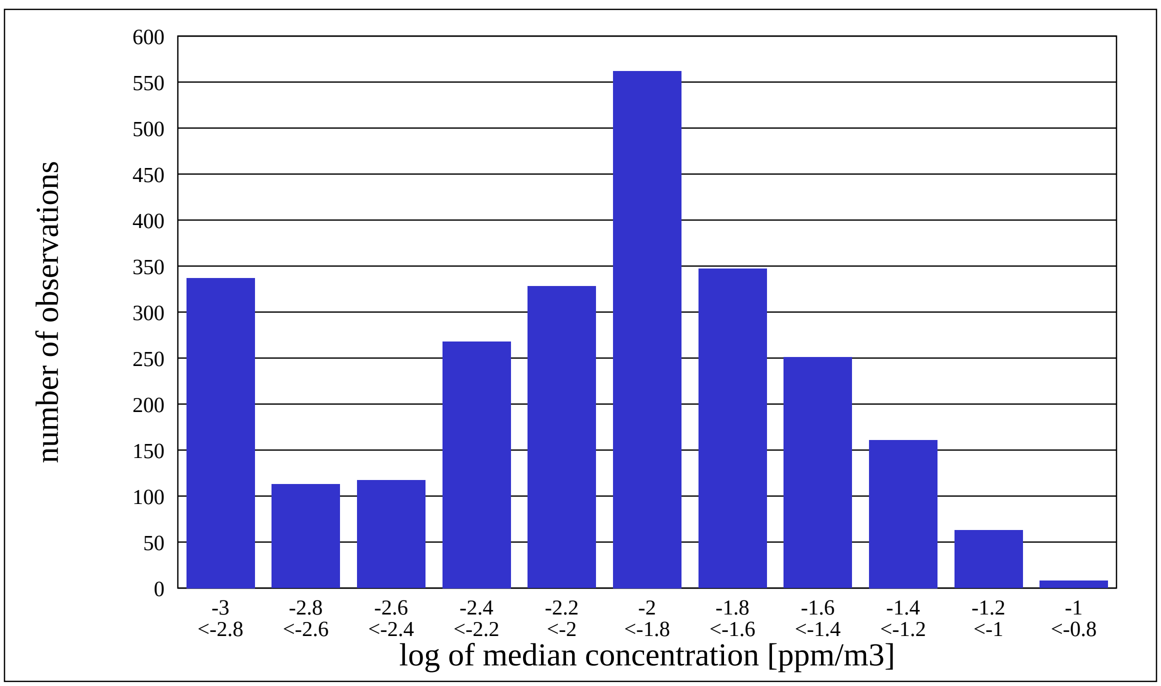
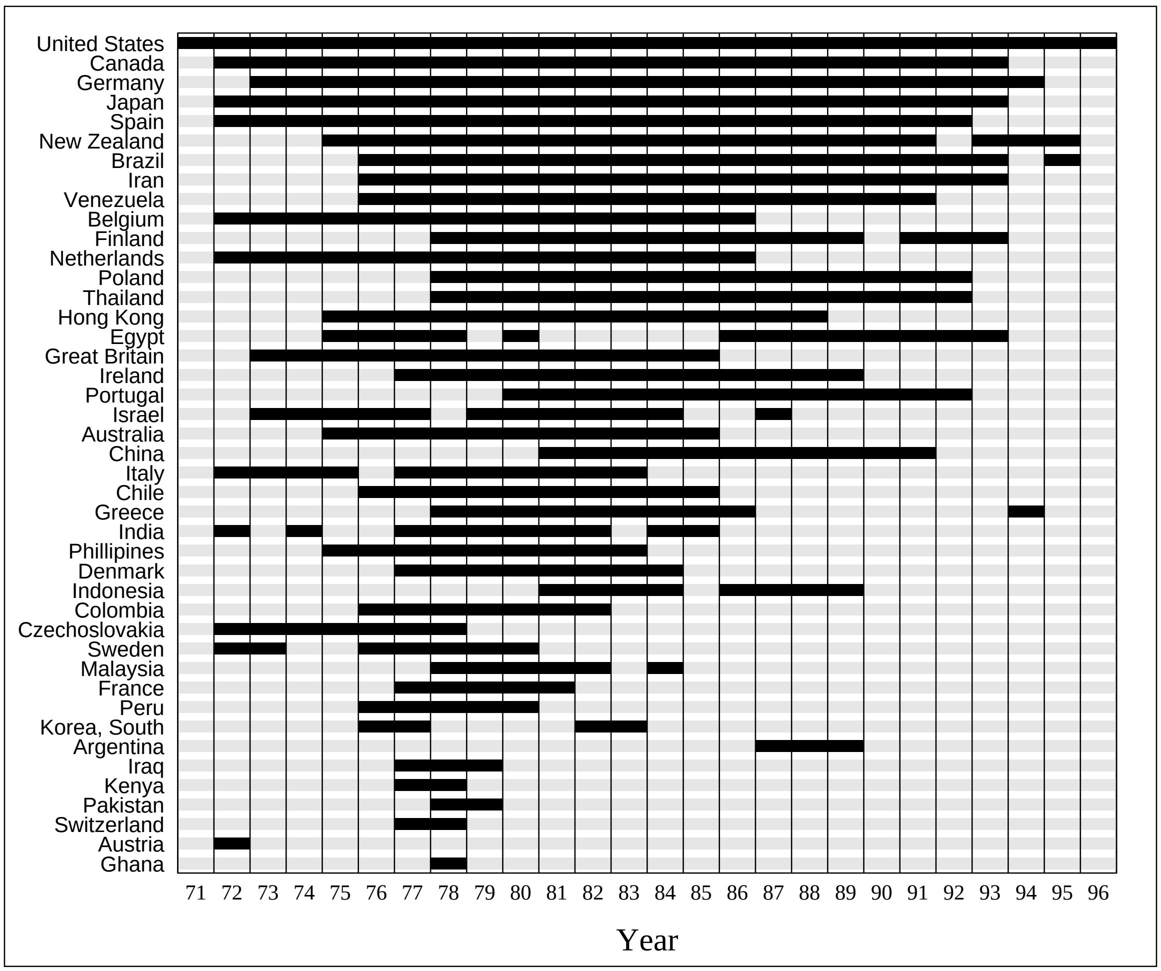


Table B-1: Cities by descending maximum of annual median SO_2 concentration

Country & City	n	min	max	Country & City	n	min	max	Country & City	n	min	max
KOR Seoul	6	25	115	CHE Zurich	1	17	26	USA Houston, TX	3	1	10
ITA Rome	3	2	103	IRL Dublin	3	4	26	USA Long Beach, CA	1	1	10
ITA Milan	2	17	100	MYS Kuala Lumpur	4	1	25	USA Seattle, WA	1	1	10
IRN Tehran	3	7	93	USA Alexandria, VA	1	5	25	NZL Auckland	3	1	9
CHN Shenyang	4	1	89	POL Wroclaw	3	6	24	IRQ Baghdad	3	1	8
AUT Vienna	3	40	80	COL Medellin	3	1	22	USA Chelsea, MA	1	4	8
ESP Madrid	5	2	73	ISR Tel Aviv	5	1	22	USA Tampa, FL	3	1	8
CSK Prague	3	13	65	HKG Hong Kong	6	1	21	COL Cali	3	1	7
BEL Brussels	4	9	64	CAN Hamilton	5	1	20	GHA Accra	3	4	6
EGY Cairo	4	1	61	CAN Montreal	4	1	20	THA Bangkok	4	1	6
GBR London	3	11	58	SWE Stockholm	5	1	20	USA Allen Park, MI	1	2	6
JPN Tokyo	3	5	58	USA Philadelphia, PA	5	1	20	USA St Ann, MO	1	4	6
JPN Osaka	4	5	56	USA St Louis, MO	3	3	20	USA River Rouge, MI	1	3	6
CHN Guangzhou	4	2	55	CAN Vancouver	7	1	19	DEU Munich	1	5	5
BRA Sao Paulo	5	8	51	PAK Lahore	2	15	19	IDN Jakarta	3	1	5
PHL Manila	3	2	50	DNK Copenhagen	3	3	18	PER Lima	3	1	5
CHL Santiago	3	11	49	USA Detroit, MI	2	2	18	USA Atlanta, GA	2	2	5
BRA Rio De Janeiro	2	20	46	KEN Nairobi	2	7	17	USA Waltham, MA	1	1	5
CHN Beijing	5	1	44	USA Chester, PA	1	6	17	PHL Davao	2	1	4
CHN Xian	4	3	41	NZL Christchurch	4	1	16	ARG Buenos Aires	1	1	3
CHN Shanghai	4	1	40	FRA Paris	3	2	15	ARG San Lorenzo	1	2	3
USA Boston, MA	2	3	40	SWE Oxelosund	1	11	15	USA Chula Vista, CA	1	1	3
DEU Frankfurt	3	5	38	USA Washington, DC	2	7	15	USA Dallas, TX	1	2	3
FRA Toulouse	4	19	38	USA Cicero, IL	1	2	14	USA Livonia, MI	1	1	3
NLD Amsterdam	3	6	37	VEN Caracas	3	3	14	USA St Petersburg, FL	1	1	3
IND Bombay	6	3	36	SWE Nykoping	2	5	13	USA Adams Co, CO	1	1	3
COL Bogota	3	1	35	USA Chicago, IL	3	1	13	USA Burbank, CA	1	1	2
PRT Lisbon	3	1	35	USA East St Louis, IL	1	5	13	USA Los Angeles, CA	1	1	2
IND Calcutta	3	4	33	POL Warsaw	3	3	12	USA San Diego, CA	1	1	2
GBR Glasgow	3	11	32	USA Camden, NJ	1	5	11	USA Tarpon Springs, FL	1	1	2
ARG Mendoza	3	10	30	USA Wood River, IL	1	2	11	ARG Cordoba	2	1	1
AUS Melbourne	1	1	30	CAN Toronto	5	1	10	ARG San Miguel de Tucuman	7	1	1
IND New Delhi	3	1	30	FIN Helsinki	3	1	10	ARG Santa Fe	1	1	1
GRC Athens	5	7	29	USA Baytown, TX	1	1	10	ISR Ashdod	2	1	1
USA New York City, NY	2	7	28	USA Blue Island, IL	1	1	10	USA Azusa, CA	1	1	1
AUS Sydney	3	2	27	USA Denver, CO	1	2	10	USA El Cajon, CA	1	1	1

Note: The column n is the number of observation stations in each city. The columns min and max show the lowest and highest measured level of the annual median SO_2 concentration in each city, measured in parts per billion. Note that a maximum or minimum concentration of "1" is equivalent to the measurement threshold of the measurement device. Countries appear with their ISO-3166 codes.

Figure B-4: GEMS/Air Participation by Country and Time Period
(Countries are sorted by decreasing number of contributing years)



zero when viewed on a linear scale. In this diagram, the horizontal axis shows ranges of median SO_2 concentrations in parts per million per cubic metre [ppm/m3]. As was pointed out in the WHO (1984) report about the GEMS/AIR project, concentrations are more suitably described by a log-normal distribution with a number of observations concentrated at the measurement threshold of the measurement devices. These instruments cannot measure arbitrarily low concentrations. This is apparent in figure B-2 where the horizontal axis is logarithmic. There is also an ambient level of SO_2 in the air that has natural causes.

The composition of the data set by contributor countries is shown in the pie diagram of figure B-3. A large share of observations were from the United States due to this country's extensive network of air quality measurement stations. Other large contributor countries were China, Canada, and Japan. Many of the other observation stations provided short or discontinuous streams of data while participating in the GEMS/AIR project. All in all, our analysis is based on over 2,555 observations from 290 observation stations in 108 cities around the world; these cities are located in 43 countries.

Figure B-4 reveals the time period during which individual countries participated in the GEMS/AIR project. The countries are ranked by length of participation. Numerous countries provide more than fifteen years of observations, among them the United States, Canada, Germany, and Japan. In addition, table B-1 lists the cities in which the observation stations were located along with the number of stations in each city and the minimum and maximum concentrations measured at any of the stations in a given city.

The primary source for our data is the *AIRS Executive International database* that contains information about ambient air pollution in nations that voluntarily provide data to the GEMS/AIR program sponsored by the United Nations World Health Organization.[2]

We had problems with the identification of several observation stations. The longitude and latitude information provided in one of the ancillary files was in some cases incorrect and was corrected case-by-case based on the the description of the location. Furthermore, distinctive location types (urban, suburban, and rural) were only contained in the observations from the United States and China. The remainder are all urban observation stations, or are potentially misclassified as such.

B.2 Regressors

Additional data sources for our regressors include the *Penn World Tables*[3] for macroeconomic data, the *World Investment Report*[4] for inward FDI stock data, the CIESIN *Global Population Distribution Database*[5] for population density data, the World Resources Insititute *World Resources Database*[6] for natural resources and physical endowments, and data from the *Global Historical Climatology Network*[7] (GHCN) for weather conditions at the observation stations. Yet more time series were obtained for tariff and non-tariff trade barriers,[8] and educational attainment.[9] For some of our specification tests (not discussed in the paper) we also made use of real world

2. This package is available from the United States Environmental Protection Agency (US-EPA) at http://www.epa.gov/-airs/aexec.html. The US-EPA kindly provided a much more complete version of this dataset that included not only averages but also median and other percentiles of SO_2 concentrations. We would like to express our gratitude to Jonathan Miller of the US-EPA for providing additional GEMS/Air data not contained in the public release of the database, and for patiently answering our numerous technical questions.

3. Robert Summers and Alan Heston, "The Penn World Table (Mark 5): An Expanded Set of International Comparisons, 1950–1988", Quarterly Journal of Economics, Vol. 106, May 1991, pp. 327–368. Available in revision 5.6 from the Center for International Comparisons at the University of Pennsylvania at http://pwt.econ.upenn.edu/.

4. United Nations Centre on Transnational Corporations, 1992 and 1999 volumes.

5. This data set from the Consortium for International Earth Science Information Network (CIESIN) is only available for 1990. It can be obtained freely from the United Nations Environmental Programme server maintained by the U.S. Geological Survey at http://grid2.cr.usgs.gov/globalpop/1-degree/-description.html.

6. World Resources 1998-1999: A Guide to the Global Environment", Oxford University Press, Oxford: 1998.

7. Information is available on monthly average temperatures, monthly precipitation, and atmospheric pressure. The raw data and description file are available from the National Climatic Data Center of the U.S. National Oceanic and Atmospheric Administration at ftp://ftp.ncdc.noaa.gov/pub/data/ghcn/v1/.

8. See Sachs and Warner (1995).

9. These figures were obtained from Robert J. Barro and Jong-Wha Lee 1994 study, available from the NBER web site at http://www.nber.org/pub/barro.lee/ZIP/.

oil prices.[10]

Summary statistics for the major variables appear in table B-2. Some of the variables warrant further explanation. First, our scale measure of economic activity GDP per square kilometre is calculated by multiplying a country's real per-capita GDP ($/person) with each city's population density (people/km^2). Extrapolations for per-capita GDP were carried out for the years past 1993 based on real growth rates obtained from the IMF/IFS statistics. Population densities were available only for 1990.

The capital abundance (K/L) of countries was obtained from the physical capital stock per worker variable in the Penn World Tables. We have adjusted this series for human capital by applying a 0–1 average education index (in which 1 represents 16 years of schooling) obtained from the Barro/Lee data set. While this measure is preferrable in our view to the unadjusted series, we note the practical problem with proxying educational attainment through the number of schooling years when considering cross-country differences in the quality of education. Relative capital abundance is obtained by dividing each country's capital abundance by the corresponding world average for the given year, where "world average" is defined by all the countries in the Penn World Tables. Because education data were unavailable for Yugoslavia, we lost the observations from this country. This reduced our dataset from 2621 to 2555 observations.

Our income (I) variable is the three-year average of lagged GNP per capita. This addresses two problems. First, contemporaneous income and the level of pollution may be determined simultaneously. Lagged income, however, is exogenous. Second, it is reasonable to assume that income changes translate only slowly into policy changes. We therefore smooth out some of the variation introduced through business cycles and include three years of data. (We also experimented with longer lags, without much effect on our results.) More concretely, for a given year t we compute $I_t = (y_{t-1} + y_{t-2} + y_{t-3})/3$. Relative income is constructed in the same fashion as our relative capital abundance measure. The monetary figures for income and capital are expressed in constant 1995 US Dollars. GNP figures were obtained by adjusting GDP figures with a GNP/GDP correction factor obtained from the International Monetary Fund's *International Financial Statistics*. However, such correction factors were unavailable for the former Czechoslovakia, Egypt, Hong Kong, Iraq, Pery, Poland, and the former Yugoslavia. Unadjusted GDP figures were used in these cases.

The data on foreign direct investment were obtained as percentages of the stock of inward FDI relative to GDP, and interpolated where necessary. Then these figures were divided by GDP to capital stock ratios obtained from the Penn World Tables in order to obtain the percentage of inward FDI stock relative to a country's entire capital stock.

We have also interacted our FDI and city economic intensity variables with indicator variables that identify rich and poor countries. We define as rich those countries that in a given year belonged to the richest 30% of countries listed in the Penn World Tables, as measured by their per-capita GDP. Likewise, poor countries are those in the bottom-30%. As countries' position change over time, our two indicator variables are in some cases not fixed over time. Based on the 2555 observations used in our regressions, 29% are from rich countries, 11% from poor countries, and the remaining 60% are from the middle-income group.

The suburban and rural location type dummy variables are from the oiriginal GEMS/AIR dataset. The third (default) location type is 'central city'. Our trade intensity measure is calculated as the sum of exports and imports expressed as a percentage of gross domestic product. The communist country dummy used in our study identifies the following countries: China, Czechoslovakia, Poland, and Yugoslavia. The country dummy for the Helsinki Protocol identifies Austria, Belgium, Bulgaria, Canada, Czechoslovakia, Denmark, Finland, France, Germany, Hungary, Italy, Luxembourg, The Netherlands, Norway, and Switzerland, in the years after 1985.

10. This series from the U.S. Energy Information Administration (at http://www.eia.doe.gov/price.html) has been calculated by dividing the landed costs of crude oil imports from Saudi Arabia (Arabian Light) in US$ per barrel by the US GDP deflator (1990=100).

Table B-2: Summary Statistics

Variable	Dimension	Obs.	Mean	Std.Dev.	Min.	Max.
Log of SO2	log(ppm)	2555	-2.112	0.481	-3.000	-0.939
City Economic Intensity	\$m per km^2	2555	0.790	0.878	0.010	5.934
GDP per capita (current)	\$10k	2555	1.478	0.862	0.109	2.718
Population Density	1000p/km^2	2555	0.063	0.055	0.001	0.276
Capital Abundance (adjusted)	\$10k/worker	2555	5.612	2.497	0.829	17.189
Capital Abundance (unadjusted)	\$10k/worker	2555	3.207	1.763	0.130	7.750
Education Attainment	0-1 range	2555	0.540	0.226	0.088	0.799
GNP per capita, 3yr avg.	\$10k	2555	1.396	0.815	0.111	2.635
Communist Country	[—]	2555	0.125	0.331	0.000	1.000
C.C. $\times$ Income	\$10k	319	0.302	0.208	0.127	0.716
Trade Intensity (X+M)/GDP	[—]	2555	0.409	0.322	0.088	2.617
Relative (K/L) (adj.)	World=1.00	2555	1.357	0.605	0.203	4.174
Relative Income	World=1.00	2555	2.500	1.392	0.221	4.138
Inward FDI Stock / Capital Stock	[—]	2525	0.106	0.250	0.001	2.193
Avg. Temperature	°C	2555	14.689	5.600	2.617	28.967
Precipitation Coeff. of Var.	[—]	2555	0.011	0.006	0.001	0.054
Hard Coal Reserves	GJoule/worker	2555	0.040	0.043	0.000	0.146
Soft Coal Reserves	GJoule/worker	2555	0.038	0.052	0.000	0.348

Note: All monetary figures are in 1995 US Dollars. The interaction term for income with the communist countries dummy only shows the case where the the dummy is equal to one; thus the mean for this line is the mean for the communist countries only.

C Sensitivity Analysis

A set of specification checks appears in table 2 in the main body of the paper. In this appendix we provide additional specification and checks to demonstrate additional features of our data and the robustness of our estimation procedure.

C.1 Linear Time Trend

In all of our regressions displayed in tables 1 and 2 we have used time fixed effects to allow for a arbitrary common-to-world effects on pollution concentrations. However, this is probably more rigorous than necessary. When estimated, the time fixed effects trace out a relatively linear trend that can be captured through more simply through a linear time trend variable. When we replace time dummies with such a trend variable, it is in most cases significantly negative.

In a modification of the regressions in table 2, columns (2) and (6), we have allowed for the real price of oil. To identify an effect from the price of oil, a linear time trend had to be used instead of time dummies. We find that the price of oil has a significantly negative effect on pollution concentrations. We are cautious in interpreting the particular numeric result because, in essence, we are estimating a time effect identified in 26 data points with a panel data set almost 100 times the size.

C.2 Alternative Dependent Variables

We first turn to our choice of dependent variable. We have argued before—based on the observations expressed in figures B-1 and B-2 that a logarithmic transformation of the dependent variable is appropriate. However, there is a menu of different SO_2 concentrations to choose from. We opted for the median SO_2 concentration because it is more "robust" with respect to outlier observations than the arithmetic mean. The U.S. Environmental Protection Agency kindly supplied us with a variety of concentration statistics. We explore all of them in tables C-1 and C-2 for our fixed-effects and random-effects baseline model. In addition to the median (column

'Base'), we use the arithmetic mean (column 'Mean') and the 90th, 95th, and 99th percentile of SO_2 concentrations (columns 'P90%', 'P95%', and 'P99%'). All of these measures were transformed into logarithms when they were used as a dependent variable.

All four specifications produce results that are broadly in line with our previous findings shown in column (1) of both tables. In particular, there are no statistically significant sign reversals. Judging by the sample-mean elasticities shown at the bottom of the table, the numbers are only slightly different in magnitude, confirming all our qualitative results. We also take these results as a confirmation of the regularity of the distribution of SO_2 concentrations. Recall that these numbers are *annual* summary statistics that tend to mitigate the effect from single-day outliers.

C.3 Box-Cox Transformation

We have argued earlier that the appropriate transformation of the dependent variable is to take the logarithm, based on our observations expressed in figure B-2. However, in table C-3 we explore the possibility of other transformations, notably, a linear transformation and a Box-Cox transformation. All of these are based on our fixed-effects model.

We apply a Box-Cox transformation as a generalization to our fixed-effects model (where ν_i is a site-specific fixed effect). The model can be specified as

$$y_{it}^{(\lambda)} \equiv \begin{cases} y_{it} - 1 & \text{for } \lambda = 1 \\ (y_{it}^{\lambda} - 1)/\lambda & \text{for } 0 < \lambda < 1 \\ \log(y_{it}) & \text{for } \lambda = 0 \end{cases} = \mathbf{X}_{it}\beta + \nu_i + \epsilon_{it} \qquad (1)$$

which assumes that there exists a λ for a transformation of the dependent variable so that $\epsilon_{it} \sim \mathrm{N}(0, 1)$. The transformation parameter λ is determined by maximizing the concentrated log-likelihood function

$$L(\lambda) = -\frac{N}{2} \ln \hat{\sigma}^2(\lambda) + (\lambda - 1) \sum_t \ln(y_t) \qquad (2)$$

where

$$\hat{\sigma}^2(\lambda) = \frac{1}{N} \left(y^{(\lambda)} - \mathbf{Xb}\right)' \left(y^{(\lambda)} - \mathbf{Xb}\right) \qquad (3)$$

With the results from the Box-Cox regression we can also peform two likelihood-ratio tests, $2[L(\lambda) - L(0)] \sim \chi^2(1)$ and $2[L(\lambda) - L(1)] \sim \chi^2(1)$, that allow us to test the Box-Cox transformation against the log-linear (our baseline) model and the simple linear model.

We find that the signs of our estimates remain stable and significant. The optimal Box-Cox transformation parameter is approximately 0.24. When we test this specification against either the log-linear or pure-linear case, the log-likelihood test statistics reject both the log-linear and pure-linear specifications in favour of the Box-Cox transformation. Observe, though, that the pure-linear model is rejected by a much larger margin than the log-linear model. Also note that the interpretation of the parameters change and cannot be easily compared across the three models.

To facilitate comparisons across all three models, the bottom of table C-3 shows the usual set of four sample-mean elasticities. Note that the magnitudes of the composition and technique elasticities tends to increase noticeably when λ increases.

C.4 Simultaneous-Equation Approach

Yet another concern in our work has been the possibility of a simultaneous determination of pollution and the contemporaneous city economic intensity (as this is largely influenced by GDP). In our theory, emissions are determined endogenously, but recursively. Thus there is no a-priori reason to use a simultaneous-equations framework for our empirical analysis. However, here we use such a framework to allow for the possibility of unknown sources of simultaneity that are not captured in our theoretical framework.

Note that there is no endogeneity issue as far as per-capita income is concerned because pollution policy tends to respond slowly to changes in income levels, and we therefore employ a three-year lagged moving average of per-capita income (see section B.2). A further consideration is the likely magnitude of the effect that an increase in pollution has on per-capita income; we believe that this magnitude is small. This belief appears to be supported by Dean (1998), who finds no significant relationship in the estimation of a corresponding simultaneous-equation system.

We follow Dean (1998) in using two-stage least

Table C-1: Sensitivity Analysis for Dependent Variable — Fixed Effects

Estimation Method	Fixed Effects				
Model Specification	Base	Mean	P90%	P95%	P99%
Variable / Column	(1)	(2)	(3)	(4)	(5)
Intercept	-4.299^c	-4.297^c	-3.216^c	-2.662^c	-2.394^c
ξ= City Econ. Intensity GDP/km^2	0.089^a	0.102^c	0.120^c	0.100^c	0.079^b
ξ^2/1000	-0.340	-0.386	-0.462	-0.306	-0.226
Capital Abundance (K/L)	0.437^a	0.710^c	0.793^c	0.769^c	0.602^c
(K/L)^2	0.008	-0.009	-0.019	-0.020	-0.002
Lagged per-capita Income	-0.228	-0.182	-0.721	-0.995	-0.395
(Income)^2	0.578^c	0.633^c	0.727^c	0.744^c	0.760^c
$(K/L) \times (I)$	-0.386^c	-0.441^c	-0.429^c	-0.390^c	-0.444^c
Trade Intensity θ=(X+M)/GDP	-3.216^b	-1.397^a	-2.555^b	-2.199^b	-1.792^a
$\theta\times$ Rel. K/L	-2.121	-3.144^c	-3.217^c	-3.143^c	-3.027^c
$\theta\times$(Rel. K/L)^2	-0.176	0.213	0.447	0.521^a	0.043
$\theta\times$ Rel. Inc.	2.614^c	1.203^a	1.590^b	1.309^a	1.876^b
$\theta\times$(Rel. Inc.)^2	-0.584^b	-0.385^b	-0.418^b	-0.323^a	-0.647^c
$\theta\times$(Rel. K/L)$\times$(Rel.Inc.)	0.924^b	1.102^c	1.021^c	0.864^c	1.294^c
C.C. Dummy $\times$ Income	9.639^b	7.428^c	8.844^c	10.198^c	9.252^c
C.C. Dummy $\times$ (Income)^2	-8.806^b	-6.500^c	-6.686^b	-7.762^c	-8.414^c
Average Temperature	-0.056^a	-0.074^c	-0.085^c	-0.091^c	-0.082^c
Precipitation Variation	10.716^a	9.094^b	8.528^a	9.206^b	9.409^b
Helsinki Protocol	0.016	0.132	0.121	0.106	0.171^a
Observations	2555	2555	2555	2555	2555
Groups	290	290	290	290	290
R^2	0.1499	0.1732	0.1829	0.1801	0.1657
Log Likelihood	-3905	-1868	-2502	-2320	-2365
Hausman Test / Wald χ^2(df)	53.663	171.41	554.5	256.24	131.08
Scale Elasticity	0.398^b	0.455^c	0.536^c	0.448^c	0.353^b
Composition Elasticity	0.975^a	1.130^c	1.043^c	1.003^c	1.005^c
Technique Elasticity	-1.266^b	-1.420^c	-1.697^c	-1.715^c	-1.419^c
Trade Intensity Elasticity	-0.882^c	-1.022^c	-1.264^c	-1.247^c	-0.865^c

Note: To conserve space, no standard errors or t-statistics are shown. However, significance at the 95% and 99%, and 99.9% confidence levels are indicated by superscripts ^{a} and ^{b} and ^{c} respectively. The short descriptions in the Model Specification line refer to the following dependent variables: Base = the log of the median of SO_2 concentrations at each observation site; Mean = the log of the arithmetic mean of SO_2 concentrations; P90%, P95%, P99% = the log of the 90th, 95th, and 99th percentiles of SO_2 concentrations. All regressions use time fixed effects.

Table C-2: Sensitivity Analysis for Dependent Variable — Random Effects

Estimation Method	Random Effects				
Model Specification	Base	Mean	P90%	P95%	P99%
Variable / Column	(1)	(2)	(3)	(4)	(5)
Intercept	-3.311^c	-3.607^c	-2.684^c	-2.323^c	-2.145^c
ξ= City Econ. Intensity GDP/km^2	0.070^c	0.061^c	0.062^c	0.054^c	0.047^c
ξ^2/1000	-0.244	-0.033	0.028	0.079	0.033
Capital Abundance (K/L)	0.286^a	0.432^c	0.453^c	0.419^c	0.273^b
(K/L)^2	0.013	0.005	-0.001	0.001	0.018^a
Lagged per-capita Income	-1.312^c	-0.945^c	-1.230^c	-1.199^c	-0.505
(Income)^2	0.669^c	0.710^c	0.774^c	0.787^c	0.808^c
$(K/L) \times (I)$	-0.285^c	-0.347^c	-0.325^c	-0.323^c	-0.392^c
Trade Intensity θ=(X+M)/GDP	-0.510	0.074	-0.484	-0.515	-0.430
$\theta\times$ Rel. K/L	-1.828^a	-2.770^c	-2.917^c	-2.858^c	-2.472^c
$\theta\times$(Rel. K/L)^2	-0.248	-0.032	0.158	0.165	-0.260
$\theta\times$ Rel. Inc.	1.011^a	1.050^b	1.493^c	1.505^c	1.749^c
$\theta\times$(Rel. Inc.)^2	-0.285^a	-0.394^c	-0.454^c	-0.453^c	-0.668^c
$\theta\times$(Rel. K/L)$\times$(Rel.Inc.)	0.822^c	1.046^c	0.937^c	0.898^c	1.242^c
Suburban Dummy	-0.422^a	-0.131	0.021	0.082	0.176
Rural Dummy	-0.631	-0.156	-0.008	0.134	0.308
Communist Country Dummy	-0.257	0.066	0.055	-0.161	0.055
C.C. Dummy $\times$ Income	4.641^a	3.786^a	4.009^a	4.930^b	5.266^b
C.C. Dummy $\times$ (Income)^2	-5.788^b	-4.717^b	-4.587^a	-5.469^b	-6.633^c
Average Temperature	-0.052^c	-0.046^c	-0.054^c	-0.058^c	-0.055^c
Precipitation Variation	6.158	9.774^b	10.840^b	12.038^c	11.961^c
Helsinki Protocol	-0.114	0.055	0.042	0.042	0.115
Observations	2555	2555	2555	2555	2555
Groups	290	290	290	290	290
R^2	0.1499	0.1732	0.1829	0.1801	0.1657
Log Likelihood	-3905	-1868	-2502	-2320	-2365
Hausman Test / Wald χ^2(df)	53.789	264.05	96.43	141.48	115.37
Scale Elasticity	0.315^c	0.281^c	0.289^c	0.253^c	0.218^c
Composition Elasticity	0.993^c	0.959^c	0.822^c	0.735^c	0.661^c
Technique Elasticity	-1.577^c	-1.499^c	-1.536^c	-1.475^c	-1.165^c
Trade Intensity Elasticity	-0.394^c	-0.410^c	-0.449^c	-0.450^c	-0.225^b

Note: To conserve space, no standard errors or t-statistics are shown. However, significance at the 95% and 99%, and 99.9% confidence levels are indicated by superscripts ^{a} and ^{b} and ^{c} respectively. The short descriptions in the Model Specification line refer to the following dependent variables: Base = the log of the median of SO_2 concentrations at each observation site; Mean = the log of the arithmetic mean of SO_2 concentrations; P90%, P95%, P99% = the log of the 90th, 95th, and 99th percentiles of SO_2 concentrations. All regressions use time fixed effects.

Table C-3: Sensitivity Analysis for Dependent Variable Transformation

Estimation Method	Fixed Effects		
Model Specification	Log	Linear	Box-Cox
Variable / Column	(1)	(2)	(3)
Intercept	-4.299^c	-0.475	2.854^a
City Econ. Intensity GDP/km^2	0.089^a	1.397^b	0.156^b
(City Econ. Intensity)^2/1000	-0.340	-4.781	-0.577
Capital Abundance (K/L)	0.437^a	16.824^c	1.233^c
(K/L)^2	0.008	-0.313	-0.006
Lagged per-capita Income	-0.228	-12.53	-0.622
(Income)^2	0.578^c	9.977^c	1.052^c
$(K/L) \times (I)$	-0.386^c	-6.568^c	-0.728^c
Trade Intensity θ=(X+M)/GDP	-3.216^b	10.254	-3.305^a
$\theta\times$ Rel. K/L	-2.121	-53.07^c	-5.114^b
$\theta\times$(Rel. K/L)^2	-0.176	5.819	0.080
$\theta\times$ Rel. Inc.	2.614^c	4.368	3.516^b
$\theta\times$(Rel. Inc.)^2	-0.584^b	-0.834	-0.817^a
$\theta\times$(Rel. K/L)$\times$(Rel.Inc.)	0.924^b	9.011^a	1.574^b
C.C. Dummy $\times$ Income	9.639^b	-4.739	11.581^a
C.C. Dummy $\times$ (Income)^2	-8.806^b	-3.750	-11.25^b
Average Temperature	-0.056^a	-0.494	-0.088^a
Precipitation Variation	10.716^a	-12.39	12.857
Helsinki Protocol	0.016	2.745^a	0.124
Observations	2555	2555	2555
Groups	290	290	290
R^2	0.1499	0.1459	0.1408
Log Likelihood	-3905	-16520	-3421
Box-Cox λ	0	1	0.2432
Scale Elasticity	0.398^b	0.601^c	0.451^b
Composition Elasticity	0.975^a	3.968^c	1.857^c
Technique Elasticity	-1.266^b	-2.822^c	-1.714^c
Trade Intensity Elasticity	-0.882^c	-1.412^c	-1.072^c

Note: To conserve space, no standard errors or t-statistics are shown. However, significance at the 95% and 99% confidence levels are indicated by * and **, respectively. λ is the transformation parameter of the Box-Cox transformation as defined in equation (1).

squares (2SLS) to estimate a simultaneous-equation system in which the two endogenous variables are the log of city economic intensity and, as usual, the log of pollution concentration. Our additional estimating equation links real economic activity to its determinants: the log of city economic intensity on the logs of pollution concentration, capital stock and labour force, as well as our measure of openness. Deviating from our established practice, we use the log of city economic activity as a single variable instead of the combination of linear and square terms as in table 1. This amounts to estimating a constant elasticity specification of scale. Recall that the fixed effects approach employed here works off the the time variation in variables, which in the case of the city economic intensity variable is due entirely to movements in per-capita GDP.

Results from the fixed-effects 2SLS regression, shown in table C-4, indicate that the parameters in our baseline model remain stable. However, we estimate the scale effect from a city's economic intensity to be much higher than in our baseline model: around 1.3. In the auxiliary regression we find that a higher pollution concentration has a small positive effect on city economic activity. We also employed a variety of alternative specifications of the auxiliary regression, including a 2nd-order Taylor series expansion. We were unable to estimate the repercussion effect from pollution to economic activity robustly: in some specifications the estimate changes sign and/or is statistically insignificant.

The elasticities for the composition and trade intensity effects (as usual evaluated at sample means) are consistent with our other work, while the technique-effect elasticity is somewhat higher in magnitude (around –1.7). Consistent with our other empirical work the sum of scale and technique effect remains negative.

Table C-4: Simultaneity Analysis

Dependent Variable	$\ln(SO_2)$	
log of city GDP/sq.km.	1.32	(1.09)
Capital abundance (K/L)	0.53^{**}	(2.69)
$(K/L)^2$	-0.00	(0.24)
Lagged p.c. income (I)	-1.83	(0.98)
I^2	0.58	(1.58)
$(I) \times (K/L)$	-0.22^{**}	(3.12)
Comm.C. $\times$ (I)	7.92^{**}	(2.66)
Comm.C. $\times$ $(I)^2$	-8.48^{**}	(3.30)
θ =(X+M)/GDP in %	-2.95^{**}	(2.75)
$\theta\times$ relative (K/L)	-2.37^{*}	(2.17)
$\theta\times$ relative $(K/L)^2$	-0.10	(0.25)
$\theta\times$ relative (I)	2.58^{**}	(3.54)
$\theta\times$ relative $(I)^2$	-0.49^{*}	(2.56)
$\theta\times$ relative $(K/L) \times (I)$	0.69^{*}	(1.99)
Average Temperature	-0.06^{*}	(2.36)
Precipitation Variation	13.47^{**}	(3.01)
Helsinki Protocol	-0.08	(0.83)
R^2	0.143	
Dependent Variable	$\ln$(GDP/sq.km.)	
log of SO_2 concentration	0.07^{**}	(6.21)
log of capital stock (K)	0.42^{**}	(22.11)
log of labour fource (L)	-0.97^{**}	(20.87)
θ =(X+M)/GDP in %	0.55^{**}	(20.65)
R^2	0.731	
Elasticities		
Scale	1.320	(1.09)
Composition	1.605^{**}	(4.52)
Technique	-1.890	(1.75)
Trade Intensity	-1.039^{**}	(5.11)

Note: To conserve space, no standard errors or t-statistics are shown. However, significance at the 95% and 99%, and 99.9% confidence levels are indicated by superscripts [a] and [b] and [c] respectively. This regression is a fixed-effects modification of 2SLS (ie, site averages have been subtracted). Time fixed effects were used throughout.