Supplementary Appendix

Measurement of Losses in Economic Output due to Pollution

A. Output Losses Associated with Pollution Mortality

We estimate the present discounted value of the loss in GDP attributable to mortality associated with various sources of modern and traditional pollution in 2000 and 2019 for China, Ethiopia, the European Union, India, Nigeria, and the United States.[1] The loss in GDP in country *i* in year *y* ($y \in \{2000, 2019\}$) if a worker dies is equal to labor's share of GDP (α_{iy}) multiplied by GDP (Y_{iy}), divided by the number of persons who are employed (L_{iy}). We assume that workers of all ages in a country produce the same output per worker. Because not all persons of age *j* are working, the expected value of GDP per worker for a person of age *j* (W_{ijy}) is equal to ($\alpha_{iy}Y_{iy}/L_{iy}$) times the ratio of the number of workers of age *j*, L_{ijy}, to the population of age *j*, N_{ijy},

$$W_{ijy} = (\alpha_{iy}Y_{iy}/L_{iy})*(L_{ijy}/N_{ijy}) \quad (1)$$

To calculate the loss in market and non-market output we modify equation (1) to allow for household production. Ignoring household production understates the losses associated with pollution. While some of the countries we study produce satellite National Income Accounts that value household production, not all do. A recent OECD study (Ahmad and Koh 2011) estimates the value of household production for 13 of the EU 15 countries in 2008. The median value of household production as a percent of GDP is 31%, the mean is 33%. Estimates are 30% for India (Pandey 2001), 26% for China in 2004 (Wang 2020) and 25% for the United States (Kanal and Kornegay 2019). In the interests of transparency we choose a value of 30% for all countries. We therefore calculate W'_{ijy}

$$W'_{ijy} = (\alpha_{iy}Y_{iy}/L_{iy})*(L_{ijy}/N_{ijy}) + \lambda_j(\alpha_{iy}Y_{iy}/L_{iy})*[1-(L_{ijy}/N_{ijy})] \quad (1')$$

where λ_j represents the fraction of output attributable to household production for a person of age *j.*

If a person of age *j* dies in the current year, their contribution to GDP will be lost for all future years of their working life. To compute the value of GDP lost in future years we assume that GDP per worker in country *i* grows at rate g_i. If labor's share of GDP and the fraction of population of working age (L_{ijy}/N_{ijy}) remain constant for all *i* and *j*, this implies that lost GDP at age *t* of a person currently of age *j* will equal $(\alpha_{iy}Y_{iy}/L_{iy})*(L_{ity}/N_{ity})*(1+g_i)^{t-j}$. This must be weighted by the probability that an individual would have survived to age *t*, where $\pi_{ijy,t}$ is the probability that a person of age *j* in country *i* in year *y* survives to age *t*. We therefore weight the loss in GDP

[1] In terms of the European Union, we calculate the loss in GDP attributable mortality associated with PM2.5 for each of the following 15 countries---Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden and United Kingdom. Then, we sum them up to represent the EU's loss in GDP.

in future years by the probability that an individual who dies this year would have survived to each future year of his working life. We discount the value of GDP lost in the future at the annual rate r_i.

Given the previous assumptions, the present discounted value of lost market and non-market output for a person of age *j* in country *i* who dies in year y, PV_{ijy}, is:

$$PV_{ijy} = \sum_{t=j}^{84} \pi_{ijy,t} \left[\left(\frac{L_{ity}}{N_{ity}} \right) \left(\frac{\alpha_{iy} Y_{iy}}{L_{iy}} \right) + \lambda_t \left(1 - \frac{L_{ity}}{N_{ity}} \right) \left(\frac{\alpha_{iy} Y_{iy}}{L_{iy}} \right) \right] \left(\frac{1 + g_i}{1 + r_i} \right)^{t-j} \qquad (2)$$

We calculate equation (2) for j = 0, . . . ,84. The value of λ_j is set equal to 0 for children (e.g., j = 0, ... , 14) and set equal to 0.3) for larger values of *j*.

The total output lost due to pollution is the product of PV_{ij} and D_{ijy}, the number of deaths due to pollution in year *y* of persons of age *j* in country *i*, summed over all *j*. D_{ijy} is computed separately for each category of pollution—ambient ozone pollution, ambient particulate matter pollution, lead exposure, occupational exposures, household air pollution, unsafe water and unsafe sanitation. Confidence intervals reflect confidence intervals in deaths due to each pollution category as computed by the GBD team (GBD 2019 Risk Factor Collaborators 2020).

B. Data

To compute GDP per worker we use per capita Gross Domestic Product (Y_{iy}) (World Bank World Development Indicators) divided by the size of the labor force in country *i* (L_{iy}) (World Bank World Development Indicators) to compute (Y_{iy}/L_{iy}) for year *y* ($y \in$ {2000, 2019}). Labor's share of GDP (α_{iy}) is obtained from the Penn World Tables (Feenstra, Inklaar and Timmer 2015) for all countries except Ethiopia. The ILO estimates labor income as a share of GDP for Ethiopia to be 0.49 and 0.441 in 2000 and in 2019, respectively

Other parameters that vary by country include the ratio of worker to total population and survival rates. The ratio of worker to total population (L_{ijy}/N_{ijy}) for each country and age group comes from the ILO (2019). Because only aggregate data are reported for ages 65 and older, we determine (L_{ijy}/N_{ijy}) for each age over 65 by assuming that the worker-population ratio declines linearly from age 65 to age 105, becoming zero at age 105. The annual survival rate from age *j* to age *t* in each state, $\pi_{ijy,t}$, is computed from life tables provided by the Institute for Health Metrics and Evaluation (2020).

The present value of lost output depends on the rate of growth in output per worker *(g)* and the discount rate *(r)*. As equation (2) indicates, it is the ratio of (1+*g*)/(1+*r*) that determines the present discounted value of future earnings. Determining appropriate values of r and g for each country is difficult. We therefore use the assumptions underlying the Lancet Commission

Report (Landrigan et al. 2017), viz., that the discount rate exceeds the rate of growth in output per worker by (a) 1.5, (b) 3.0 percentage points.

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