Air pollution, seen here over Mexico City, has many effects that are detrimental to the economy.

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ENVIRONMENTAL ECONOMICS

Air pollution's hidden impacts

Exposure can affect labor productivity and human capital

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Nearly every country in the world regulates air pollution. But how much pollution control is enough? Answering that question requires considerable information about the costs as well as the benefits of regulation. Historically, efforts to measure benefits have focused on averting major health insults, such as respiratory or cardiovascular events that result in hospitalizations or death, which typically only afflict the most vulnerable segments of the population. These health episodes are clearly consequential—e.g., the U.S. Clean Air Act Amendments of 1990 avert an estimated 160,000 deaths and 86,000 hospitalizations annually (*1*)—but may only represent the tip of the proverbial iceberg, compared to the number of cases of respiratory impairment and other health insults that affect many healthy people every day but do not require hospitalizations or even formal health care encounters. The ubiquity of these less lethal impacts, revealed by emerging economic research on labor productivity and human capital accumulation, suggests that even modest impacts at the individual level can add up to considerable, society-wide impacts across the globe.

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Our understanding of these less-severe health impacts is hampered by two factors. First, the number of potential channels through which pollution could affect human functioning is large, as pollution can alter the function of several organ systems and even genetic expression (*2*). Because these are difficult to assess, only a relatively small number have been well studied, leaving large gaps in our understanding of basic physiological relationships. Second, among channels that have been studied, it is often difficult to discern how the physiological and cognitive impacts that have been identified translate into meaningful effects outside of the controlled laboratory setting in which they were assessed. Does a 10% drop in forced expiratory volume, for example, influence the performance of daily life activities?

An emerging literature has begun to overcome these challenges with a new focus on the effects of acute exposure on measures of great economic importance, which, in turn, can easily be monetized for regulatory purposes.

LABOR MARKET PERFORMANCE

Although hospitalized individuals are unable to attend work, and others who are severely ill may also miss workdays, the impacts from less-severe pollution-induced illness on work hours are less well known. Research in Mexico City found that reductions in sulfur dioxide pollution led to sizable increases in work hours per week by individuals in the local labor market (*3*). Of course, the degree of infirmity that necessitates a shortened workday is still nontrivial. It may require some type of health care encounter and at a minimum is obvious to the person experiencing it.

A handful of recent studies attempt to capture even subtler health impacts by focusing on the productivity of workers while they work. The premise behind these studies is that even minor impairments of respiratory and cardiovascular function can increase fatigue, decrease focus, and impair cognition (*4*), even in seemingly healthy populations, thus diminishing the ability to perform one's job. For example, agricultural workers in the Central Valley of California produce less as ozone increases, even though daily pay directly depends on how much fruit they harvest (*5*). These effects arise at ambient concentrations of ozone that are well below regulatory standards and at levels at which obvious health symptoms are not generally present in healthy populations.

Although agricultural employment is important in developing countries, it represents a small fraction of the labor force in more developed ones. Moreover, because agricultural work takes place outdoors, it is not a priori obvious that these results are germane to indoor work, which contributes most of the value in most economies. But a recent study and some preliminary findings suggest impacts of particulate matter pollution on indoor worker productivity in the manufacturing sector (*6*, *7*).

The aforementioned studies focus on physically demanding work, and thus perhaps represent the most logical place for the impacts of minor respiratory and cardiovascular insults to manifest themselves. But findings from a study in China suggest that the information economy is not inoculated against these effects (*8*). Productivity of call center workers in two Chinese cities is negatively affected by fine particulate matter (particles with diameters less than 2.5 μm). These impacts are not limited to extreme pollution days, but emerge at pollution levels that regularly obtain in several major cities within the United States.

HUMAN CAPITAL ACCUMULATION

Human capital, a measure of the intangible resources an individual possesses, such as knowledge, skills, and judgment, plays a fundamental role in labor market outcomes and other aspects of life, including health, civic participation, and criminal activities. A fairly new body of literature focuses on latent impacts of in utero and early-childhood exposure to pollution on later-life outcomes. Although health insults from pollution may indirectly affect human capital accumulation through channels like school attendance and other educational investments, this focus is motivated by the "fetal origins hypothesis" and literature that documents impacts of stimuli during these critical periods of human development (*9*).

Recent studies provide compelling evidence that early-life exposure to pollution can have lasting impacts on cognitive abilities later in life. Children born in Texas when airborne total suspended particulates (TSPs) were atypically low (due to decreases in industrial production during a brief economic recession) went on to have higher high school test scores (*10*). Children born in Santiago, Chile, with higher exposure to fetal pollution, such as carbon monoxide and particulate matter, went on to perform worse on high-stakes national exams that determine access to secondary schools (*11*). Another study makes the linkage between the labor productivity and human capital literatures more transparent, demonstrating that higher TSP levels in the year of birth lead to lower labor force participation and lower earnings in adulthood (*12*).

INCENTIVES AND DESIGN

Much of what is currently known about benefits from environmental protection in the United States is a result of measurement incentives embodied in Section 812 of the 1990 Clean Air Act amendments and other executive orders that require cost-benefit analyses. U.S. Environmental Protection Agency (EPA) procedures virtually ensure that those incentives remain focused on nationally representative evidence of impacts on high-visibility health endpoints, leaving the investigation of a wide range of other impacts to the idiosyncratic curiosities of the research community. These new forms of evidence could be incorporated into the formal structure of EPA cost-benefit analyses (*13*), while recognizing that forgone earnings due to diminished labor productivity or human capital attainment will not capture all the welfare losses experienced.

More can be done to transform opportunistic study of individual firms into systematic study of productivity impacts. Existing national surveillance systems can be augmented to collect data from industries in which productivity measures are standardized, such as local, state, and national employment data collected from the U.S. Bureau of Labor Statistics. Such data will facilitate calculations of benefits, play a critical role in assessing the generalizability of the results thus far uncovered, and provide a database through which new channels of influence can be explored. For industries in which productivity measures are not standardized, national data on worker hours and absences that could be matched to environmental data could prove useful in uncovering morbidity impacts and how they affect labor markets.

The ideal data collection effort would provide rich spatial and temporal resolution at the level of individual workers. Because such data would provide valuable intelligence on the state of the economy more generally, it would naturally fall in the United States under the jurisdiction of the Departments of Labor or Commerce. Absent resources for substantial new data collection efforts, some of these data could be collected through supplements to existing efforts by the Census Bureau, including the Annual Survey of Manufacturers and the every-5-year Economic Census for industries outside of manufacturing.

The impacts of pollution on labor markets and human capital suggest that policy implications extend beyond the EPA, transforming part of this problem into an occupational safety issue. As such, the Occupational Safety and Health Administration, both in the United States and European Union and in similar agencies in many other countries, may have a role to play in improving indoor air-quality monitoring in the workplace and fostering solutions to mitigate these impacts. If made public, these indoor air-quality measures could help overcome an important obstacle in current research and help deepen our understanding of the relationships between pollution, health, and worker productivity.

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The long-lived impacts of pollution exposure during a brief window in early life also suggest a potential role for public health interventions that target pregnant mothers and underscore the need for more epigenetic research to uncover the mechanisms through which these impacts manifest themselves. Although the science is not completely settled, this relatively brief and well-identified period of vulnerability appears particularly ripe for small-scale interventions that can minimize exposure with large-scale returns. Health care providers and public health officials can play a more prominent role in disseminating relevant information and in facilitating access to technologies, such as home air filters, designed to eliminate harm.

Advances in information technology and measurement have allowed examination of a wide range of pollution impacts that were not visible even a decade ago. Yet, in many respects, these studies just begin to scratch the surface. Much is still unknown about how far these impacts might reach. If pollution can affect reasoned judgment and decision-making, as some recent preliminary findings suggest (*14*), then perhaps every aspect of daily living may be altered by our contaminated environment. Whether these effects of acute exposure to pollution are compounded by chronic exposure is also of great importance and is largely unknown.

Deepening our scientific understanding of these relationships is constrained by the nature of the exercise, which tends to fall between the conventional silos of major research funding agencies. The EPA spends relatively little money on external research. The health-centric focus of the National Institute of Environmental Health Science (NIEHS) has generally viewed this more expansive view of health with a skeptical eye. The Dynamics of Coupled Natural and Human Systems Program at the National Science Foundation (NSF) remains focused on a much broader scale than the studies outlined above. Broadening the scope of what constitutes health at the NIEHS, a more human-scale focus on environmental impacts at the NSF, and a more robust extramural research program at the EPA could help advance scientific understanding of these relationships.

The societal harm generated by these more subtle and pervasive impacts should be reflected in the calculus that helps to determine regulatory standards. Whether they are large enough to justify further revisions to those standards is an important question worthy of more effort and attention. ■

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