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# How Economic Development Influences the Environment

Seema Jayachandran

Department of Economics and School of Public and International Affairs, Princeton University, Princeton, New Jersey, USA; email: jayachandran@princeton.edu



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## Abstract

Reducing global poverty and addressing climate change and other environmental crises are among the most important challenges facing humanity today. This review discusses one way in which these problems are intertwined: how economic development affects the environment. I synthesize recent micro-empirical research on the environmental effects of economic development in low- and middle-income countries. The studies that I discuss identify the causal effects of specific aspects of economic development, such as greater household purchasing power, expanded access to credit, more secure property rights, technological progress, and stronger regulatory capacity. I conclude by outlining some gaps in the literature.

## 1. INTRODUCTION

Reducing global poverty and halting climate change and environmental degradation are two of the most important challenges facing humankind today. These problems are intertwined. Climate change threatens economic prosperity, especially in low-income countries, where it endangers the livelihoods and health of vulnerable populations. Also, just as environmental changes can have economic effects, economic changes can affect the environment. For example, as average household income rises, more people can afford cars and large homes, and thus their carbon footprints expand.

This review focuses on one of the two directions of causality connecting these challenges: how economic development affects the environment. It would be fortuitous if the choices that maximize economic prosperity also maximized environmental quality. The inconvenient truth is that such a perfect alignment rarely occurs. Thus, individuals and societies often have to make a tradeoff between economic growth and environmental protection. This does not imply, however, that economic development is always bad for the environment. Development can expand the set of choices available to us—for example, if a new, cleaner way to generate energy is invented. Economic prosperity can also strengthen people's willingness to forgo a part of their income to achieve a cleaner environment. No one maximizes solely their economic prosperity, and as people achieve a higher standard of living, they can prioritize the environment without sacrificing basic needs.

Further, economic development is not a monolithic force. It manifests in myriad ways and influences a wide range of behaviors. Therefore, it does not have a uniform effect on environmental quality. Manufacturing-led economic growth often increases air pollution, whereas expansion of the service sector might not. For the purposes of this article, I take economic development to mean a constellation of phenomena that typically bring about greater economic prosperity or accompany it, such as higher average household income, more developed capital markets, and better physical infrastructure. Each element of development could theoretically accelerate or slow down environmental degradation; even element by element, the relationship between economic development and the environment is nuanced.

A large body of research at the intersection of development economics and environmental economics has studied how the different elements of economic development influence the environment. This literature collectively provides an understanding of how and in what circumstances economic development helps or hurts different dimensions of environmental quality. In this article, I review this research, focusing on micro-empirical studies from the past decade that use design-based inference. By design-based inference, I mean that the variation in the explanatory factors that is used to estimate effects is random or as-if random, arising from an experiment, discontinuity, or other specific source that the researchers discuss and justify as exogenous. This inclusion criterion narrows the scope of the review; for some topics, there are almost no studies that meet it. For example, I omit discussion of how population growth affects the environment, even though fertility decline is an important force through which economic development could alleviate pressure on the environment. Similarly, I do not discuss the effects of urbanization. That said, within the topics I do discuss, I relax the inclusion criterion on a few occasions to discuss studies that represent the most compelling evidence on an important question.

In Section 2, I present descriptive evidence on the link between economic development and environmental quality and discuss the environmental Kuznets curve (EKC) hypothesis. In Section 3, I discuss evidence on the effects of income growth and access to capital on the environment. Section 4 focuses on technological progress and infrastructure. In Section 5, I turn to institutional changes that often accompany economic development, specifically strengthening of property rights, improved regulatory capacity, trade openness, and market competition. I conclude by discussing some of the open research questions in the literature.

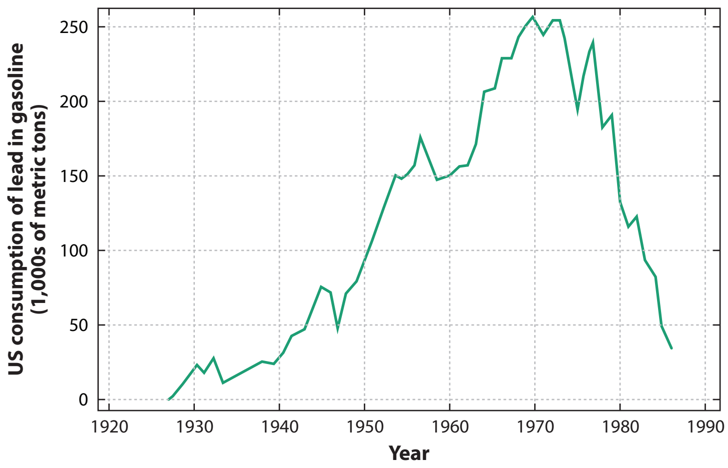


**Figure 1**

Lead from gasoline in the United States. Adapted with permission from Nriagu (1990).

## 2. DESCRIPTIVE EVIDENCE ON ECONOMIC DEVELOPMENT AND ENVIRONMENTAL QUALITY

According to EKC hypothesis, at low levels of per capita income, the negative effects of economic progress on the environment are dominant, but eventually the beneficial effects become the stronger force. This influential hypothesis predicts that environmental degradation exhibits an inverted-U, or hump-shaped, relationship with income per capita (Grossman & Krueger 1995).[1]

When the hypothesis was first formulated, it aimed to describe the effects of international trade. Trade openness might encourage the expansion of dirty industries in poor countries alongside the growth of less polluting industries in richer countries, for example. But beyond trade, other elements of economic development, or a combination of them, could generate an inverted-U. For example, lead pollution from gasoline rose and fell in the United States over the second half of the twentieth century (see **Figure 1**). The first step in the trajectory of lead use was a technological advance: the discovery in the 1920s that adding lead to gasoline reduces the so-called engine knock. As cars became more powerful, they used more gasoline per mile. Rising incomes meant that more households could afford cars, and the rapid expansion of the road and highway network made travel by road a cheap and convenient option for many. Then, the United States reached a turning point. In response to a growing awareness of the health effects of air pollution, the federal government enacted the 1970 Clean Air Act, which led to regulation that phased out the use of lead in gasoline. Lead pollution from gasoline fell steadily over the next two decades. In short, the emergence of a new technology, rising income levels, improved infrastructure, advances in health knowledge, and improvements in regulatory capacity caused the rise and fall of lead use in gasoline in the United States.

Although the case of leaded gasoline maps perfectly to the predicted EKC trajectory, it represents an exception. In the data, we sometimes observe a monotonic positive correlation between GDP per capita and environmental damage. Carbon emissions per person exhibit this pattern, as

[1]The name is based on the Kuznets curve, or economist Simon Kuznets' hypothesis that there is an inverted-U relationship between inequality and economic development.

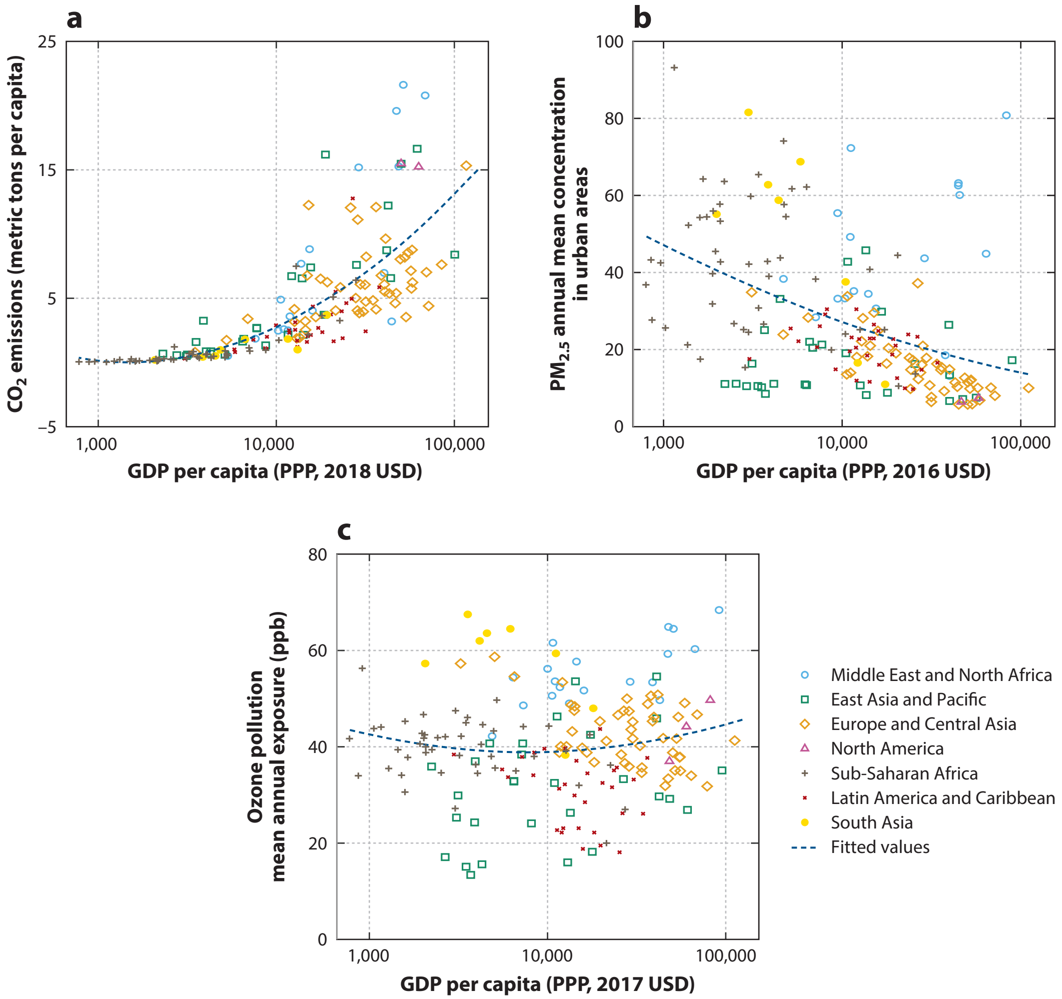


**Figure 2**

Relationship between environmental damage and GDP per capita. The dashed line in each panel is the best-fit quadratic line. (*a*) $CO_2$ emissions per capita. Data from World Bank (2018, 2020). (*b*) Urban particulate matter. $PM_{2.5}$ concentrations are measured regularly at fixed-site monitors within metropolitan areas. The country-level measure is a population-weighted average of the city-level measures. Data from WHO (2016). (*c*) Ozone. Data from Health Eff. Inst. (2020). Abbreviations: $PM_{2.5}$, fine particulate matter; ppb, parts per billion; PPP, purchasing power parity.

shown in **Figure 2*a***: The carbon footprint per person is systematically higher in richer countries than in poorer countries. The relationship is mostly linear, and the best-fit quadratic curve is U-shaped rather than an inverted-U. In other cases, we observe a negative correlation. For example, particulate matter levels in cities follow this pattern, as shown in **Figure 2*b***. For other environmental measures, such as ozone levels, there is no clear correlation between countries' pollution levels and GDP per capita (**Figure 2*c***). These patterns do not necessarily falsify the EKC hypothesis. Perhaps at this point in history, all the countries in the world are on the rising part of the Kuznets curve for $CO_2$ emissions, i.e., the turning point is at a higher income level than any country has reached yet. Moreover, these are raw correlations and not causal effects. Nonetheless, it seems very likely that the relationship between development and the environment will differ across pollutants and will not have a simple, generalizable link with economic development.

The descriptive evidence I have presented matches the consensus view in the literature, which is that there is limited empirical support for the EKC hypothesis (Stern 2017). In part, we lack convincing tests of the hypothesis due to the difficulty of isolating exogenous changes in GDP per capita. In addition—and perhaps more importantly—there is no a priori reason to assume that when we account for all the forces that constitute economic development, the detrimental ones prevail at low levels of development and the beneficial ones at higher levels of development.

Indeed, the overarching view in this review is that we should not expect to give a blanket answer to the question, Does development help or hurt the environment in low-income countries? In fact, the question is ill-posed because it disregards how development came about. Most micro-empirical studies aim to answer the narrower but well-defined question of how a particular cause or feature of economic development influences environmental outcomes (in a particular context). I now turn to discussing these studies.

## 3. INCOME AND ACCESS TO CAPITAL

I divide my discussion of the different facets of economic development into three sections. In the first one, I discuss how rising household income and both households' and firms' greater access to capital affect the environment. The next section focuses on advances in two types of public goods: technology and physical infrastructure. Finally, I discuss institutions, which can be thought of as a more intangible type of infrastructure—that is, the formal and informal rules that underpin economic activity.

### 3.1. Changes in Consumption from Income Growth

When households have more income, they consume more of most goods. The production and use of goods can deplete natural resources and generate pollution. Not only does the scale of consumption increase with income, but the composition of what people consume also changes, which could either exacerbate or offset their environmental footprint.

**3.1.1. Energy use.** Richer people are more likely to have electricity connections in their homes. Although electricity might sometimes displace a more environmentally harmful energy source (e.g., firewood), often it increases total energy use, as households purchase energy-intensive appliances such as refrigerators and air conditioners. Unless the electricity is generated from solar, wind, or other renewable sources, powering these devices depletes natural resources and causes pollution. Similarly, households begin to buy automobiles as they become richer, which also taxes the environment. **Figure 3** shows the steep positive cross-country relationship between motor vehicle ownership and GDP per capita.

To better understand these trends, several recent studies have used exogenous variation in antipoverty transfers to examine how changes in income affect consumption. For example, Gertler et al. (2016) examined a conditional cash transfer (CCT) program to estimate the income elasticity of energy-intensive appliance purchases. Their study focused specifically on refrigerator purchases among Mexican households who were eligible for the CCT program Oportunidades. They leveraged both the randomized timing of the program rollout in the 1990s and variation in the transfer amount across households based on family composition. They estimated that receiving a transfer of 40,000 pesos, which was the median cumulative transfer between 1997 and 2007 in their sample, increased the likelihood of owning a refrigerator from 4% to 23%. Unsurprisingly, the effect was not uniform across groups. Transfers to initially very poor families or a small transfer to any family was not enough to trigger a large, lumpy purchase. Moreover, once a household bought a

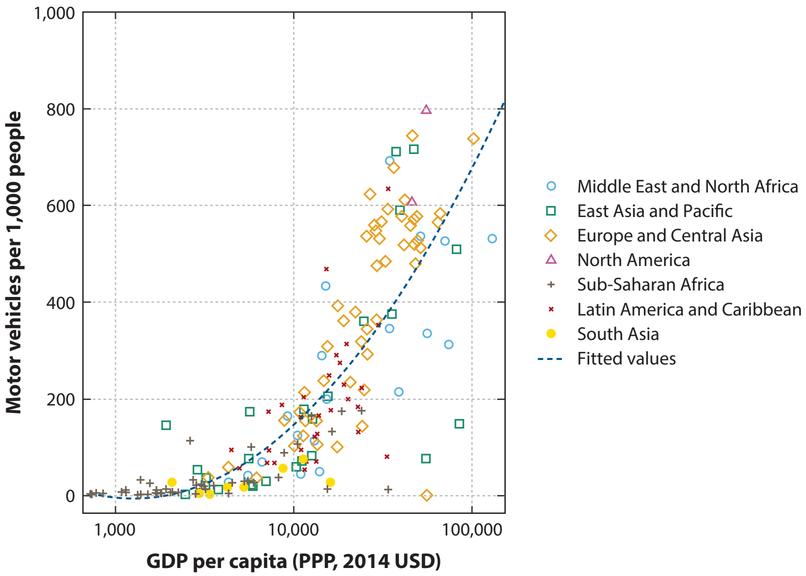


**Figure 3**

Relationship between car ownership and GDP per capita. GDP per capita data are from World Bank (2020). Vehicle data are from NationMaster (2014). The dashed line is the best-fit quadratic line. Abbreviation: PPP, purchasing power parity.

refrigerator, it would rarely want a second one. In line with this, refrigerator ownership followed an S-shape in income: shallow, then steep, and then leveling off.

Hanna & Oliva (2015) used data from the West Bengal, India, site of Banerjee et al.'s (2015) multicountry randomized controlled trial (RCT) of a program targeting ultra-poor households. The multifaceted graduation program consisted of an asset transfer (e.g., two cows, four goats), a stipend, and weekly meetings, among other components, and led to a large and persistent increase in both assets and consumption in the India site. Hanna & Oliva (2015) found that participation in the program led to a 22% increase in fuel consumption. They tested if households transitioned to cleaner or more fuel-efficient technologies (e.g., liquefied petroleum gas stoves) and found no evidence of such a shift.

**3.1.2. Diet.** Another common shift in consumption as people become richer is that meat and dairy start to comprise a larger share of their diet. This transition has environmental consequences, as animal-based foods are more land intensive than grains, fruits, and vegetables.

Haushofer & Shapiro (2016) conducted an RCT to trace how poor households in rural Kenya spent the unconditional cash transfers provided by the nongovernmental organization (NGO) GiveDirectly. The average transfer amount was $700, adjusted for purchasing power parity. They estimated that recipient households increased their food spending by 19% and began consuming relatively more meat and fish; spending on meat and fish rose by 39% compared to a 10% increase for cereals (grains). These findings align with a recent study that used panel data from Ethiopia to study how changes in food consumption correlate with income changes over time (Worku et al. 2017). This study found that meat and dairy comprised 18% of the total food expenditures of the richest quintile of Ethiopian households, compared to 7% for the poorest quintile. These dietary patterns suggest that, as households become richer, food production will require more land.

Less clear-cut is how the changes in food consumption transformed local land use, as the food might have been produced elsewhere. Alix-Garcia et al. (2013) studied the relationship between income and changing land use in Mexico. The authors used a regression discontinuity (RD) design to compare deforestation in communities just poor enough to be eligible for the Oportunidades program and communities that just missed the cutoff. The authors found that access to the cash transfer program led to an increase in deforestation. They provided additional evidence that transfer recipients increased their consumption of land-intensive foods such as beef and milk, which suggests that the forest was cleared to enable cattle farming. Interestingly, the study also showed that market access influenced the effect of the cash transfers on local deforestation. The increase in deforestation was concentrated in communities with low road density, which the study used as a proxy for limited access to trade.[2] An important caveat is that road density could be capturing other dimensions of underdevelopment rather than market access.

Another point to keep in mind when interpreting these findings is that increased demand for meat will lead to more land being allocated for meat production, whether in the same locality or elsewhere. Malerba (2020) used a difference-in-differences (DiD) design to study the effects of Familias en Acción, Colombia's health-and-education CCT, and found that recipients consumed more beef and milk, but, if anything, deforestation decreased. Presumably, land beyond the locality was allocated to cattle grazing to meet this increased demand for animal products. Nonetheless, limited access to trade might exacerbate ecological impacts, because if production and consumption can be decoupled geographically, then it is possible to strategically locate the cattle industry in less ecologically sensitive areas.

Most studies do not quantify the carbon footprint of dietary changes, but an exception is provided by Feng et al. (2020). They examined changes between the 1992 and 2007 rounds of China's Urban Household Income and Expenditure Survey, a period during which average household expenditure on animal-based food increased by over 50%, while spending on cereals decreased. Interestingly, despite this dietary change, they concluded that the carbon footprint of Chinese diets decreased overall because of energy-efficiency gains in the food industry. A related study in China by He et al. (2019) considered what the effect on $CO_2$ emissions would be if all households switched to the dietary quantity and diversity recommended by health experts, and they estimated that it would increase greenhouse gas emissions by 7.5%. This result highlights that the diets of the poor have a lower carbon footprint partly because they are undernourished or have low dietary diversity; there is some tension between better diets and environmental conservation, but only up to a point.

**3.1.3. Willingness to pay for environmental protection.** Although everyone likely values environmental quality, all else being equal, people will be more willing and able to sacrifice some of their income to improve it after they have satisfied their basic needs such as food and health care. Greenstone & Jack (2015, p. 12), who present a simple model that lays out this reasoning, write, "[A]s the budget constraint is relaxed, the value of an additional unit of consumption falls and the trade-off between consumption and environmental quality becomes less extreme, increasing demand for the latter." Moreover, in more economically developed regions, people are more aware of the health and productivity costs of environmental degradation, which offers another reason they might support environmental protection more.

An important distinction is whether people value self-protection—i.e., they perceive the private, instrumental benefits of environmental quality—or they also altruistically value the benefits

[2]A related study, by Lawlor et al. (2020), investigated how market integration influenced the ecological effects of a cash transfer program in Zambia.

enjoyed by others or environmental quality per se. Franzen & Vogl (2013) showed that there is an association between economic development and the more expansive form of environmentalism. They constructed an index of the survey questions about environmental concern in the 2010 round of the International Social Survey Programme, including "How willing would you be to accept cuts in your standard of living in order to protect the environment?" and respondents' agreement with the statement "We worry too much about the future of the environment and not enough about prices and jobs." They found that environmental concern is higher in countries with higher GDP per capita and, within countries, among higher-earning and more educated individuals.

Most work in economics on this topic investigates the demand for self-protection. To my knowledge, none of these studies uses exogenous variation in income. For this reason, and because Greenstone & Jack (2015) nicely synthesized the pre-2015 literature, I discuss this line of research only briefly. Ashraf et al. (2010) and Berry et al. (2020) conducted early studies that examined the willingness to pay (WTP) for water purification, finding no strong link between WTP and household income or wealth. Ito & Zhang (2020b) studied air pollution by analyzing purchase decisions for air filters in China. They found that WTP for clean indoor air is increasing in income. Baylis et al. (2021) offered people face masks at randomly varying prices in New Delhi, India, and also found that WTP is increasing in income as well as in education. The study also reported that less educated individuals were more likely to underestimate the health impacts of exposure to air pollution.

A related literature, which includes the work of Baylis et al. (2021), uses information campaigns to assess whether knowledge about the health impacts of pollution drives the demand for environmental quality. Several experiments try to correct misperceptions and then test if WTP for self-protective products changes as a result. The literature offers mixed results, which is unsurprising because whether a campaign increases WTP depends on the effectiveness of the particular messaging. However, there does seem to be a general pattern whereby people underestimate the personal harms from pollution, and this misinformation is more pronounced among poorer people.

Barwick et al. (2020) offer particularly compelling evidence on the effects of information. They document how people changed their behavior when the Chinese government began reporting more accurate and regular information about local air quality, which happened in a geographically staggered way beginning in 2013. One effect was that people began avoiding shopping trips (and presumably other outdoor activity) when air quality was particularly bad. In addition, the more persistent component of air quality was capitalized into housing prices. These results focus on how people reduced their exposure to pollution, not how pollution levels changed. Nonetheless, by increasing the demand for clean air, information could spur air quality improvements—for example, if people start to pressure their governments to address pollution. Thus, improvements in knowledge could be an important pathway through which development increases environmental quality.

## 3.2. Access to Capital

Another implication of rising incomes is that people have the capital to make profitable investments that were unavailable to them when they were poorer. In principle, poverty need not be a barrier to investment: People can take out loans and repay them with the investment profits. However, access to credit, which is both a cause and an effect of economic growth, is much more limited in low-income countries (Levine 1997). Whether the source of increased liquidity is one's own income or better developed financial markets, the investments it enables can have environmental implications, both good and bad.

**3.2.1. Productive investments.** Consider someone who has the skills to pursue two productive activities. One generates low profits but requires less capital; the other is more profitable but requires a large upfront investment. A credit-constrained individual will only be able to pursue the first activity, but with increased access to capital, they will switch to the second, more profitable one. Whether that switch is good or bad for the environment depends on which option is more land intensive, energy intensive, and polluting. There is no general theoretical prediction to guide us, and, consistent with this observation, different empirical studies report quite different effects of access to capital on the environment.

For example, Assunção et al. (2020) used a DiD design to study a tightening of access to credit in rural Brazil and reported that the policy change reduced deforestation. Even though the policy was explicitly aimed at protecting the forest, the authors argued that the key mechanism was the reduction in access to credit, which enabled landowners to pursue land-intensive cattle ranching.

Wilebore et al. (2019) similarly found that access to capital had a negative effect on forest protection in Sierra Leone. They used an RCT to study a labeled cash transfer program that targeted households living near the Gola Rainforest National Park. Households did not need to meet any conditions to receive the transfer, but the payments were accompanied by a statement highlighting the environmental goals of the NGO running the program and the importance of preserving the rainforest. The authors estimated that the program led to the loss of 19 hectares of forest per village over 2 years, equivalent to 3.5% of the average area of a village, mostly in areas with regrowth rather than mature forests. The authors argued that the money enabled households to purchase agricultural inputs, hire labor, and buy tools to clear the land. Notably, the estimates might represent an underestimate of the pure effect of the transfer, as the pro-environment messaging likely dissuaded some deforestation.

Other studies have observed the opposite pattern, however. López-Feldman & Chávez (2017) showed that remittances sent from international migrants to families in Mexico caused family members to shift away from environmentally intensive activities. Their research design entailed instrumenting for remittances with the historical transportation costs from the village to the US border. The authors conjectured that the remittances eased credit constraints and allowed the families to transition to new activities that required upfront investment.

Andersen (2016, 2017) found that increases in access to credit among manufacturing firms had positive environmental effects. In this case, pollution rather than land use was the most relevant environmental outcome, but the effect was again theoretically ambiguous. On the one hand, credit might enable firms to expand production; on the other hand, it could facilitate investment in energy-saving technologies. Using differences across 37 countries in when credit bureaus were established, Andersen (2016) found that better-functioning credit markets reduced sulfur dioxide and lead concentrations. Andersen (2017) examined the link between a firm's credit score and its pollution emissions within the US manufacturing sector. Here as well, better access to credit reduced pollution.

**3.2.2. Investments in energy-saving household goods.** Credit constraints can hinder households' ability to purchase energy-efficient products that will save them money in the long run but require upfront spending. For example, someone might forgo weatherizing their home or switching to a more fuel-efficient vehicle because of the high upfront costs. An oft-studied example in developing countries is fuel-efficient cookstoves, which help households reduce their spending on fuel and are better for the environment. Levine et al. (2018) compared different ways of selling cookstoves in Kampala, Uganda. Some study participants were offered the stove in the standard cash-and-carry way: They could purchase the cookstove on the spot by paying the asking price. In another study arm, people were given the option to pay in four weekly installments. Only 4% of households in the cash-and-carry study arm purchased the stove, compared to 26% of those offered the installment plan. Although the study design could not rule out that part of the success of the installment plan was because people could try out the stove before committing to pay the final three installments, the results point to the importance of addressing liquidity constraints.

Berkouwer & Dean (2021) also studied the uptake of energy-efficient cookstoves, and in their RCT in Kenya, they were able to isolate the role of credit. They found that access to credit had a large positive effect on purchases of efficient charcoal stoves. Being offered a stove with a 3-month loan (with a 1.16% monthly interest rate) increased the average WTP from $12 to $25. The study also tracked households' subsequent charcoal use and found that adoption of the stove reduced it by 39%. Within a year, a household would save $120 from reduced charcoal use, which is striking given the average WTP of $12. Consumers' low uptake of high-return investments in energy efficiency—the so-called energy paradox—is a puzzle seen in many contexts (Jaffe & Stavins 1994).

**3.2.3. Other environmentally friendly household investments.** There are other environmentally friendly goods that do not pay for themselves but that households still value, and liquidity constraints can limit the purchase of these goods, too. BenYishay et al. (2017a) studied households' WTP for hygienic latrines, which reduce fecal matter in the environment but require an upfront expense. Using an RCT, they showed that access to microcredit substantially increased WTP and adoption of the latrines.

Upfront costs can also hinder the success of conservation programs. Payments for ecosystem services (PES) programs pay people for undertaking a specific pro-environment behavior. If the payments are back-loaded compared to the costs that are required to comply, then credit constraints can reduce participation. Oliva et al. (2020) conducted an RCT of a program that encouraged Zambian cotton farmers to plant trees on their land. The program was run by an NGO with the goal of promoting carbon sequestration. The PES payments were conditional on tree survival and were therefore back-loaded, and the study found that many more farmers participated when the upfront costs (purchase of seedlings) were subsidized.

## 3.3. Consumption Smoothing

Another way that credit constraints can affect environmental outcomes is if people deplete natural resources because of an emergency need for cash. This phenomenon is particularly relevant in the case of forests, a natural resource that people can cash out by cutting down trees and selling the timber. Ferraro & Simorangkir (2020) studied a multi-year program for poor households in rural Indonesia that provided cash transfers equivalent to 15–20% of the recipients' status-quo consumption. The authors used a DiD design based on the staggered rollout of the program across villages and found that the cash transfers reduced forest cover loss by 30%. This environmental benefit of the cash transfers was concentrated during times when a village experienced a rainfall shortfall, that is, when agricultural output was low. The authors' interpretation is that the cash displaced deforestation as the households' safety net when they suffered an income loss.

Jayachandran (2013) used data from an evaluation of a Ugandan PES program that incentivized forest conservation to study how the inability to smooth consumption influences the effectiveness of PES. Households forgo two types of income when they stop deforesting. First, they clear less land for growing crops and so have a lower flow of income from agriculture. Second, they no longer earn lump-sum income from selling timber. Payment levels that are high enough to offset lost agricultural income and typical revenue from timber may not be adequate when a household has an emergency need for cash. For example, if faced with a hospital bill that is too large to cover with the PES income, a household without liquidity might cut down and sell an unusually large amount of timber. Consistent with this reasoning, the study found that forest owners who sold timber to meet their liquidity needs were less likely to enroll in the PES program. The implication is that PES might be a more effective tool for curbing deforestation if credit markets were better developed, at least in this context.

## 4. TECHNOLOGY AND INFRASTRUCTURE

When technologies and infrastructure improve, boosting total factor productivity, firms can produce goods at a lower cost. This outward shift of the supply curve means expanded production, which generally takes a toll on the environment. However, technological progress or infrastructure might also reduce the amount of natural resources needed to produce a good. New energy-saving machinery or improvements in electricity distribution infrastructure would enable a firm to use fewer natural resources per unit of output. Moreover, technology and infrastructure rarely limit themselves to facilitating the scaling up of production. They might make some production techniques more profitable than others, thus changing how goods are produced and which ones are produced. For example, the advent of publicly available Landsat satellite imagery in the 1970s and 1980s lowered the cost of identifying gold deposits and increased gold mining (Nagaraj 2022). Similarly, a new technology or the building of new infrastructure might prompt a shift away from or toward land-intensive production, with environmental implications.

In addition to their effects on production, both technology and infrastructure can also influence the environment by changing what we consume. For example, advances in electric vehicle design and improved public transportation make gasoline cars less popular and thereby reduce the burning of fossil fuels.[3] Conversely, better roads might encourage people to drive more, causing gasoline consumption to increase among those with a gasoline car.[4] Like infrastructure, new technologies can also change the energy intensity of consumption by expanding the set of products that are available and by changing the relative prices of different products. van Benthem (2015) calculated that today's low-income countries have higher energy use per capita than high-income countries had historically when they were at a similar GDP per capita, despite great advances in energy-saving technologies in the intervening decades. A key reason is that technological progress has led to price declines for energy and for energy-using goods such as cars. People almost always consume more of a good when it is cheaper. As a result, consumption bundles have become more energy intensive over time.

In the remainder of this section, I focus on two of the more active areas of research in this literature: the effects of technology and infrastructure on agricultural productivity and the effects of transportation infrastructure.

### 4.1. Increased Agricultural Productivity

Technological progress and infrastructure that boost agricultural yield (output per unit of land) could increase or decrease land use. The optimistic view is that because more crops can be produced with less land, there will be less pressure to clear more land for agricultural use. This principle is referred to as the Borlaug hypothesis, after Norman Borlaug, who articulated the view in his Nobel Peace Prize acceptance speech in 1970. Borlaug, the "father of the Green Revolution," led efforts in the 1940s to 1960s to develop high-yielding varieties of agricultural crops (HYVs),

[3]A recent contribution on this topic is by Meeks et al. (2019), who studied household biogas systems—a technology that converts human and animal waste into cooking fuel and other products—in Nepal. Adoption of biogas systems reduced deforestation.

[4]Meeks et al. (2021) found that when electricity service quality improved for residential customers in the Kyrgyz Republic after the installation of smart meters, households purchased more appliances and consumed more electricity during peak-demand months.

and he believed that HYVs saved hundreds of millions of hectares of land from being converted into agricultural fields (Borlaug 2007). However, advances that increase agricultural yield also generally lower the cost to produce a given amount of output. This means that the supply curve for agricultural products shifts outward, so the quantity produced in equilibrium will rise. This mechanism increases the amount of land farmers require, all else being equal, and the effect could be strong enough that gains in agricultural yield could lead to a net increase in the demand for land, a phenomenon known as the Jevons paradox (Garcia 2020).[5]

Some studies have confirmed the Borlaug hypothesis, whereas others have found evidence contradicting it. Abman et al. (2020) studied an agricultural program in Uganda run by the NGO BRAC, which provided farmers with HYV seeds and trained them on practices such as manure use, intercropping, and crop rotation. These intensification techniques increase agricultural yield. BRAC ran the program in villages within 6 km of its offices, and the study used this distance cutoff as the basis of an RD design. The core result was that the program reduced annual deforestation between 2008 and 2013 by 13%.[6] This result aligns with a global estimate that HYVs for cereals averted 2 million hectares of deforestation between 1965 and 2004 (Stevenson et al. 2013).

In contrast, Hess et al. (2021) found that a community-driven development (CDD) program in The Gambia led to more deforestation, in part because the demand for agricultural land increased as yields rose. In CDD programs, each community receives a grant and chooses what type of project to spend it on. Some of the communities used the grant to build infrastructure such as roads and bridges, whereas others spent it on agricultural equipment and draft animals. In an RCT among 930 villages, Hess et al. (2021) estimated that the program increased deforestation by 12%, equivalent to a loss of 44 hectares of forest per village. The authors concluded that some of the land clearing was for the infrastructure construction itself, but much of it was to expand agricultural plots. The key mechanism seems to have been that the equipment and draft animals that villages procured increased crop yields.

A CDD program in the Philippines analyzed by Pagel (2020) also led to forest cover loss. The analysis used both an RD design based on the fact that only very poor communities were eligible for the program and an RCT conducted at a later phase of the program. In both analyses, the main result was that the program increased deforestation. The author's interpretation was that the transportation infrastructure that many villages used the funds for increased agricultural and manufacturing productivity, and these sectors expanded, using more land. Also, because the recipient communities enjoyed higher economic productivity, people migrated in; population growth is another likely reason for the ecological degradation.

It is important to note some limitations of the existing literature. First, most studies present short-run effects, but investments and sectoral adjustments take time, so the long-run effects could be quite different. Second, the studies estimate partial equilibrium effects. We would expect the expanded production observed by Hess et al. (2021) and Pagel (2020) to depress output prices, and this force would make the aggregate effect smaller than what the analyses find in partial equilibrium. (The caveat that most of the micro-empirical studies discussed in this review cannot capture general equilibrium effects applies beyond this subsection.)

[5]The question of whether efficiency gains in the use of a natural resource increase or decrease its use is relevant for resources beyond land. Ryan (2018) found that Indian manufacturing firms that were offered consulting on energy efficiency increased their electricity use, an example of the Jevons paradox, or rebound effects.

[6]Brainerd & Menon (2014) documented a different environmental consequence of the Green Revolution. The increased use of chemical fertilizers seems to have worsened health outcomes among infants whose mothers were exposed to the chemical runoff during pregnancy.

Land use intensity is just one component of a production technique's environmental footprint. New techniques can be more or less environmentally harmful than the techniques they displace in other ways, too. For example, over the past two decades, stubble burning, or the burning of stalk or stubble left in the ground after crop harvesting, has become a severe environmental and public health problem in India. The practice harms soil fertility, and it is also a major contributor to air pollution. The main reason stubble burning has become rampant is that mechanical harvesters are now more widely used, and mechanized harvesting leaves stubble in the ground. Behrer (2019) used India's employment guarantee program to study this phenomenon. With a DiD design, he presented evidence on the following causal chain. The social safety net program, by offering poor people an alternative source of income, decreased the supply of agricultural workers. This prompted farmers to adopt a labor-saving technology, that is, to mechanize. Mechanization is not harmful to the environment per se, but in this case it was: The end result was more stubble burning and air pollution.

Sekhri (2011) studied a different topic at the nexus of infrastructure, agricultural productivity, and the environment. She examined the effect of public water infrastructure on agricultural water use. An important part of the story is that public infrastructure crowded out private infrastructure. In rural India, farmers can pay to build a private tube well and tap groundwater at no charge. When they instead use public sources of water, they must pay a unit price, but they avoid the fixed cost to build their own well. Sekhri (2011) examined what occurred when, between 1988 and 1993, hundreds of public tube wells were built or rehabilitated in the state of Uttar Pradesh through the Indo-Dutch Tube Well Program. She found that in villages where installing private infrastructure was expensive (because the groundwater level was so low that a more expensive pump was required), new public infrastructure reduced groundwater use. This might seem surprising, because the public water source enabled some farmers to begin irrigating their fields. However, their increase in water use was more than offset by reduced water use among farmers who were deterred from building their own well and had to pay for water from the public well based on how much they used.[7]

To summarize, when infrastructure and technology increase agricultural production, they also change the factor intensity of land in agriculture and cause reallocation of factors of production from other sectors that have ecological footprints themselves. In addition, higher economic productivity influences migration and local purchasing power, which, in turn, affect the environment. Technology can also have incidental effects on the environment, as with mechanical harvesters and stubble burning. For these reasons, technology and infrastructure are arguably the topics covered in this review whose effects on the environment we can make the fewest generalizations about.

### 4.2. Transportation Infrastructure

Roads and other transportation infrastructure that connect a location to other markets decrease production costs by lowering the costs of acquiring inputs and of transporting finished goods. On the consumption side, they make certain goods and services cheaper. Transportation networks also differ from most infrastructure in that they integrate markets, which enables areas to specialize in certain types of production. Through all of these channels, transportation infrastructure affects where and how much ecological damage takes place.

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[7]Two other studies that highlight the inefficiency of low marginal prices for natural resources are by Ito & Zhang (2020a), on the decline in heating use when flat-rate residential customers were switched to usage-based pricing in China, and Ryan & Sudarshan (2020), on the misallocation of water use across farmers in India due to low marginal prices combined with quantity rationing.

Asher et al. (2020) studied the environmental impacts of two different types of new road access in India. First, some villages became newly connected to a main road through a rural road-building program, which the researchers analyzed using RD and DiD designs. Second, some communities gained highway access because they were incidentally along the route of new highways connecting the country's four largest cities. The small roads were found to have zero effect on deforestation. In contrast, places along the highway corridors experienced increased deforestation. The forest loss along the highways seems to have been due to industrial demand for timber, consistent with prior evidence of growth in manufacturing activity along highway routes (Ghani et al. 2016).

Garg et al. (2020) examined the same rural road-building program in India and found that when a community acquired a new road, agricultural fires and particulate matter levels rose. Roads facilitated a transition out of agriculture for workers, so the cost of hiring workers to clear fields increased, causing farmers to turn to stubble burning.

A quite different type of transportation infrastructure is public transport, which can reduce air pollution and energy use if it crowds out travel in private vehicles. Li et al. (2019) studied the expansion of Beijing's subway system between 2008 and 2016, during which time 14 new subways lines and 252 stations were opened. Subway expansion can have dispersed effects across the network, but the authors assumed that the effects would diminish with greater distance from the expansions. Using this identification assumption, they estimated that the opening of new subway lines reduced air pollution in the nearby area by 8%. Note that this is an underestimate if there were also improvements in air quality further away from the expansions. Gendron-Carrier et al. (2022) examined subway expansions worldwide between 2000 and 2017 and found that, on average, subway station openings have no detectable effect on air pollution, though there were improvements in locations where the pollution level was initially very high.

## 5. INSTITUTIONS

Limited state capacity and weak government institutions are major challenges in developing countries (Acemoglu et al. 2005, Besley & Persson 2009). It has long been recognized that these weaknesses can undermine environmental protection (Dasgupta & Mäler 1995, Dasgupta 1996). In this section, I discuss some ways in which institutions typically evolve with economic development—property rights become more secure, regulatory capacity improves, the economy becomes more open to trade, and product markets become more competitive—and their implications for the environment.

### 5.1. Property Rights

Secure and well-defined property rights, which are less common in developing countries, could increase long-term investment in land for several reasons (Besley 1995, Besley & Ghatak 2010). First, the expected return to investing in one's land is higher if the risk of land expropriation is lower; expropriation risk shortens a person's effective time horizon. Second, formally owning property allows one to use it as collateral, which helps lower the cost of borrowing. Third, if the property can be sold to someone who can use it more productively, investments that might not be profitable for the current owner become attractive. The longer time horizon, in particular, is conjectured to be beneficial for the environment: Someone who expects to use their land for a sustained period will pursue sustainable agricultural practices. A forest owner with a short time horizon might cut down trees and sell them, or a farmer might overfarm their land. With more secure property rights, this deforestation and overfarming might be avoided. For these reasons, among others, providing land titles and strengthening property rights in developing countries have been high on international aid agencies' agendas for the past several decades.

Ali et al. (2014) tested whether stronger property rights lead to the adoption of environmentally friendly practices. They analyzed a land titling program in Rwanda using a spatial RD design based on where the program was implemented. They found that receiving formal land rights caused farmers to invest more in soil conservation. For example, farmers built terraces and embankments, which reduce soil erosion. Under the informal system of property rights, women's claims on their land were more tenuous. For this reason, titling led to especially large increases in land investment among women. This pattern echoes a finding of Goldstein & Udry (2008), who studied property rights and fallowing in Ghana, and it suggests that granting uniformly strong property rights to everyone can narrow gender gaps in the returns to conservation and in economic productivity.

Other studies have assessed how property rights affect deforestation. In 2009, the government of Benin rolled out a multi-pronged intervention, called Plans Fonciers Ruraux, under which the community demarcated customary land parcels and communal areas and the government provided land certificates and established local institutions to facilitate conflict resolution. Wren-Lewis et al. (2020) conducted an RCT of the program, comparing forest cover in 300 treatment villages to 275 control villages during the post-intervention period from 2009 to 2017. The intervention reduced tree cover loss by about 20%. Based on survey data, the study suggested that the key mechanism was improved tenure security, as farmers believed they would have enough land for future agricultural production and had less of an incentive to clear more land. Another potential mechanism, distinct from secure individual property rights, was that the newly established local institutions improved the management of communally owned land. Another study on the Beninese program found evidence of increased investment in the land, in the form of tree planting and cultivation of perennial crops, but no increase in fallowing (Goldstein et al. 2018).

The RCTs on land titling so far have been concentrated in sub-Saharan Africa, but several nonexperimental studies have analyzed land titling in other regions. For example, Blackman et al. (2017) used a DiD design to study a titling program targeting indigenous communities in the Peruvian Amazon and found that it led to a significant reduction in deforestation, whereas Probst et al. (2020) reported the opposite effect (at least among some landholders) of a recent titling program in Brazil. In their synthesis of 117 studies of interventions that strengthened land tenure security, Tseng et al. (2021) found that the majority reported positive impacts on environmental outcomes.[8] Note that most of these studies examined programs that strengthened individuals' property rights over land that de facto was already held privately. An exception is provided by BenYishay et al. (2017b), who studied a large program in Brazil to formalize indigenous communities' land rights and concluded that it had no impact on deforestation. Whether land and other natural resources should be owned privately or communally and how best to manage communal resources are also important questions, which have been discussed by Ostrom (1990), among others.

## 5.2. Regulatory Capacity

Regulation is a powerful means of protecting the environment. For example, the steep decline in manufacturing pollution in the United States between 1990 and 2008 appears to have been almost entirely due to the 1990 Clean Air Act amendments (Shapiro & Walker 2018).

Unfortunately, regulation is often less effective in limiting environmental degradation in developing countries. Regulations tend to be less stringent or less strictly enforced due both to the

[8]A systematic review of the effects of tenure formalization on economic, as opposed to environmental, outcomes concluded that there is stronger evidence that such interventions improve agricultural productivity and consumption in Latin America and Asia than in Africa, perhaps because customary land rights are quite strong to begin with in much of Africa (Lawry et al. 2017).

insufficient resources available for monitoring and enforcement activities and to the prevalence of corruption.[9] Improving governments' capacity to regulate is one of the few surefire ways to protect the environment.

**5.2.1. Resources for regulatory enforcement.** A recent success story for environmental regulation is Brazil's stronger protection of the Amazon that began in the mid-2000s. Brazil increased penalties for illegal deforestation and dedicated more resources to enforcement. Burgess et al. (2019) examined forest cover near Brazil's border, comparing it with its neighbors to the north and west. Brazil initially had a deforestation rate that was 37% higher than its neighbors, but within a year or so of stepping up its regulatory efforts, it was able to bridge the gap. Assunção et al. (2019) showed that Brazil's success in protecting the Amazon was made possible by the use of satellite imagery by regulators to detect deforestation almost in real time. The study used variation in whether cloud cover obscured officials' ability to monitor deforestation in an area and showed that when clear satellite images were available, that area experienced less deforestation. Unfortunately, Burgess et al. (2019) also showed that Brazil's progress reversed when the political and economic climate changed in 2014.

The importance of allocating enough resources to monitor compliance with environmental regulations was also demonstrated in an experiment in Gujarat, India, in which some industrial plants were randomly assigned to receive more inspections (Duflo et al. 2018). The increased frequency of inspections seems to have decreased the likelihood that a plant's emissions would be noncompliant with regulations.

When a government has insufficient resources for monitoring, it is easier for people to pollute while evading detection. For example, because governments can only measure river pollution near monitoring stations—and specifically, only the pollution generated upstream of them—people can strategically locate downstream of them. He et al. (2020) compared chemical oxygen demand emissions just upstream and downstream of monitoring stations. With this RD design, they estimated that the pollution level was half as high upstream, presumably because local officials had the information and incentive to crack down on polluting activity in this area.

Another challenge is that pollution in one jurisdiction can spread to other jurisdictions, which weakens the incentive of governments to robustly regulate pollution. For example, local officials might be laxer about curtailing river pollution just upstream of their border because it will soon leave their jurisdiction. Lipscomb & Mobarak (2016) showed evidence of such behavior in Brazil. Greater oversight of local regulators by a central government—which has an incentive to internalize cross-jurisdiction externalities—could help solve this problem. Kahn et al. (2015) studied the Chinese government's efforts to do just that. In 2006, the government announced that provincial officials who did not attain specific targets by 2010 would be punished. The government was aware that many provinces concentrate pollution near borders to "export" it, so it designed province-specific targets with this behavior in mind. Based on a DiD design, the study found that the policy was effective in lowering pollution levels that had been concentrated just upstream of borders.

**5.2.2. Corruption.** Even if a government nominally has strong regulations in place and allocates enough resources to enforce them, corruption can undermine their effectiveness. For example, Mexico City introduced compulsory semiannual smog checks for vehicles in 1990 in an effort to reduce air pollution. To prevent misreporting, they created an electronic system through which tests results were automatically uploaded to the environment ministry. Nonetheless, Oliva (2015)

[9]Limited regulation is also due to societal preferences. As discussed earlier, people's willingness to sacrifice some of their income to protect the environment increases as their income grows.

detected widespread corruption in smog check certification. If a customer's car was noncompliant and they were willing to pay a bribe, a smog check center would use another customer's car in lieu of the bribe payer's car. The statistical signature of this form of cheating is that two consecutive pollution readings will be excessively similar; that is, there will be serial correlation in the pollution readings. When Oliva (2015) implemented this statistical test, she rejected the null hypothesis of no cheating in over three-fourths of smog check centers.

In many settings, third-party auditors, such as operators of smog check centers, certify compliance with government regulations. If people are permitted to choose their own auditors, this makes it easier for them to seek out known corrupt auditors. Even without outright bribes, auditors have an incentive to provide results that please their customers to get repeat business and word-of-mouth referrals. The RCT among industrial plants in Gujarat, India, described above also randomly varied whether the plants could choose their own pollution inspectors (the status quo) or were assigned a randomly chosen auditor (the treatment group) (Duflo et al. 2013). As part of the treatment, the government put in place a system to audit the auditors: The inspectors were aware that 20% of their readings would be verified and that their pay would be tied to the accuracy of their readings. Under the status quo, about 56% of plants were compliant with pollution regulations, but in an additional 29% of cases, the third-party auditor falsely reported that the plant was compliant. The intervention reduced this rate of false reporting by 80%.

Burgess et al. (2012) presented evidence consistent with the proposition that bribery is one of the key factors that enable illegal logging in Indonesia. The study tested the hypothesis that, if bribery is occurring, then political competition across jurisdictions will lead to more illegal logging. In essence, the supply of officials willing to sell a logger the right to illegally harvest timber will be larger. An increase in competition is similar to an outward shift in a supply curve in that the market-clearing price—or bribe level, in this case—falls, and more transactions take place. The study tested and confirmed this hypothesis by using a wave of decentralization in the 2000s, which created smaller and more numerous jurisdictions, as the source of variation in competition.

There is also evidence of the environmental costs of corruption beyond the realm of regulatory enforcement. Mahadevan (2020) used an RD design based on close elections of local legislators in West Bengal, India, to show that when the winner's party was in power at the state level, the legislator used their additional political power to provide subsidized electricity to their constituents, which, in turn, caused their constituents to use more electricity.

### 5.3. Trade Openness

As explained by Grossman & Krueger (1991), there are three ways by which international trade could influence environmental quality. The first is a scale effect: When there is more production, it harms the environment. The second is a composition effect: The mix of goods changes, in ways that could be more or less damaging to the environment. Third, international trade can lead to the adoption of cleaner technologies, which is referred to as the technique effect. The technique effect occurs because trade encourages technology transfer; it can entail new, stricter regulatory standards; and it can increase the demand for environmental protection if people become better-off financially. Recent reviews by Cherniwchan et al. (2017) and Copeland et al. (2021) have discussed international trade and the environment in detail. Here I will limit my discussion to a few recent studies that used causal research designs to disentangle the different forces.

The simplest way that trade openness can hurt the environment is if it increases the scale of production in existing resource-depleting or high-pollution industries. Eisenbarth (2022) provides evidence of such an effect for fisheries. She used the collapse of fisheries in Japan in the 1980s and 1990s as an instrument for the export demand enjoyed by fisheries in other countries. (Collapse refers to a very large reduction in the stock of fish.) She found that increases in overseas demand for fish caused fisheries to expand production, which increased the likelihood of collapse.

Besides increasing market size, trade also allows different countries or subnational regions to specialize in industries in which they have a comparative advantage. How they specialize depends partly on their factor endowments. Richer countries might concentrate on industries that use more high-skill labor (or, more precisely, highly educated labor), such as those in the service sector. Meanwhile, poorer countries might specialize in heavy manufacturing and primary industries that generate more pollution. A different reason poorer countries might specialize in dirty industries is that their environmental rules are laxer.

Tanaka et al. (2021) studied this "pollution haven" hypothesis by examining the relocation of lead-acid battery recycling to Mexico in response to the imposition of more stringent air quality standards in the US. They first showed that the upward trend in US exports of used lead-acid batteries to Mexico became steeper in 2009, when the policy change occurred. They then conducted a DiD analysis that compared mothers living near and far from battery-recycling plants in Mexico before and after the US regulatory change. Because they could not directly study lead pollution due to a lack of data, they used poor birth outcomes—a known consequence of exposure to lead pollution—as a proxy (and important outcome per se). The authors found a 39% increase in low birthweight incidence among mothers living near battery-recycling plants.

Davis & Kahn (2010) also studied the pollution haven hypothesis in the context of US–Mexico trade but focused on consumption rather than production. The authors leveraged the deregulation of US–Mexico trade in used cars and trucks following NAFTA. As part of NAFTA, in 2005 Mexico began allowing the import of 10–15-year-old vehicles from the United States and Canada. Using data on vehicles that were tested under California's smog check program, the authors showed that vehicles that were exported to Mexico were more likely than average to have failed emissions testing. They then looked at the effects of the increased trade on the vehicles in circulation in the United States and Mexico. The number of vehicles in the United States did not change significantly after 2005, suggesting that most of the vehicles exported to Mexico would have been scrapped otherwise. Within Mexico, the additional cars did not replace existing ones but instead increased the total number of cars, shifting the composition toward an older fleet. The study estimated that, due to trade, annual $CO_2$ emissions increased by 5.6 million tons annually.

Another type of study on international trade and the environment estimates the effects of foreign demand shocks on firms' pollution levels. Often, a shift-share instrument is used to generate variation in foreign demand.[10] Barrows & Ollivier (2021) used this approach to study the link between foreign demand and $CO_2$ emissions among Indian manufacturing firms between 1995 and 2011. They constructed product-specific demand shocks for each firm by combining importing country–specific changes in demand for the product and the initial destination mix for the firm's exports of the product. They found that positive shocks to demand lowered pollution intensity ($CO_2$ emissions relative to output) but increased overall $CO_2$ emissions. The first result is consistent with a salutary technique effect, whereas the second result implies that the technique effect is dominated by the opposite-signed scale effect. (Because this exercise held the product fixed, the composition effect was shut down.)

Bombardini & Li (2020) considered another mechanism through which demand shocks affect pollution, one related to local purchasing power. A positive shock to foreign demand will raise wages and profits, and this increase in local purchasing power could lead to higher

[10]With a shift-share instrument, the demand shock experienced by a firm is constructed by combining changes in the aggregate quantity purchased by different buyers (the shift) and the proportion of the firm's sales to each of those buyers at the outset of the study period (the share).

consumption and different forms of consumption that harm the environment. The authors disentangled this consumer-side effect from producer-side effects by constructing two shift-share instruments, one that took into consideration the pollution intensity of the industry experiencing the demand shock and one that was general. They implemented their strategy using data from Chinese firms and found that the increased pollution that resulted from higher foreign demand could be fully explained by producer-side effects. The increase in people's incomes had, if anything, a dampening effect on pollution in this context.

## 5.4. Market Competition

Market competition often increases with development, both because trade openness creates import competition and because of other policy reforms. Increases in competition can have environmental consequences. A profit-minded manufacturer might upgrade to more energy-efficient machinery to cut its energy costs, and this behavior will create environmental benefits. Whereas all firms have an incentive to take advantage of these cost-saving opportunities, firms that do not face much competition are often not run as efficiently. Competition puts pressure on inefficient firms to cut costs to match competitors' lower prices, which can help improve the environment if it leads to energy conservation. Gutiérrez & Teshima (2018) tested this idea using tariff reductions that occurred in Mexico between 2000 and 2003. Due to the lower tariffs, Mexican firms selling to the domestic market faced more import competition. The authors used industry-specific tariff changes to calculate the tariff change applicable to each manufacturing plant in their sample. They found that lower tariffs—that is, increased competition—increased energy efficiency, measured as the firm's fuel and electricity expenditures divided by its total revenue. The study also presented some suggestive evidence that lower tariffs led to a reduction in air pollution in the vicinity of the plant.

Another effect of competition is that it can drive less productive firms out of the market. This phenomenon could have environmental implications if these firms are especially low- or high-polluting. To analyze this phenomenon, Qi et al. (2021) studied firms in heavily polluting industries in China. A relevant fact about the context is that larger firms tend to be more productive. One of their findings was that larger firms have, on average, lower intensity of water pollution, that is, pollution relative to output. This pattern is consistent with another finding: Larger firms are more likely to use an advanced abatement technology that reduces pollution but has high installation costs. Their study focused not on competition but on misallocation, or how policy distortions and factor market imperfections affect which firms exist and how large they are (Hsieh & Klenow 2009). Like competition, misallocation can enable inefficient firms to survive. Qi et al. (2021) found that fewer large, low-polluting firms exist in China than would exist in the absence of misallocation, and if this problem were eliminated, pollution intensity would decline by over one-third. Moreover, even though the scale of production would increase in this scenario, the gains from reallocation across firms would more than offset the scale effect, so aggregate pollution would decrease as well.

# 6. CONCLUSION

Over the past two decades, economists have increasingly used randomized experiments, regression discontinuity designs, and other quasi-experimental methods to study causal questions. Research at the intersection of development economics and environmental economics is no exception. In tandem, new and better data sources to measure environmental outcomes (for example, from satellite imagery and pollution monitors) have become available. These trends, combined with greater awareness about climate change and other environmental crises, have led to a flourishing of research that examines how different aspects of economic development influence the environment. This article synthesizes recent work in this area.

While we should not expect a tidy, universal answer to the question of whether economic progress helps or hurts the environment, this article identifies a few key patterns. One conclusion I draw is that better regulation is a reliable path through which economic development will bring about stronger environmental protection. Most behaviors that harm the environment impose a negative externality on others, so we should not expect individual unregulated behavior to lead to a socially desirable level of environmental protection. Hence, environmental regulation is crucial. Economic development increases both the supply of and demand for regulation. In the first mechanism, the government's capacity to create and enforce regulation improves. In the second, as citizens become richer, they are more likely to prioritize a healthy environment. Another predictable pattern is that economic advances that expand consumption and production generally harm the environment, as the increased scale of activity depletes resources and creates pollution. However, we cannot use this assumption to generalize the total effect of pushing out the production possibilities frontier, which is more complex than the scaling up of current activity. The specifics of the new possibilities and how they compare to the status quo matter. This is true whether new economic possibilities are opened up by financial market development, technology, trade, or infrastructure.

The synthesis also reveals several areas where more work would be valuable. I will list four. The first concerns what policies, technologies, and institutional reforms will enable governments to regulate more effectively. A second avenue for research is to better understand the mechanisms by which development causes people to value environmental protection more. We know little about the relative importance of pure gains in purchasing power versus having a citizenry more informed about environmental harms, for example. A third open question relates to how a community's degree of market integration influences the effect of economic productivity on the environment. Most of the existing evidence focuses on local environmental outcomes, but a critical unanswered question is how aggregate outcomes change when trade enables the geographic separation of production and consumption. A fourth and very broad question is how public policy can direct economic growth to be more pro-environment. Although we sometimes get lucky and an economic improvement helps the environment, often it does not. However, public policy can intervene to try to direct economic growth in a greener direction. One tool is industrial policy. For example, Garg & Shenoy (2021) studied a government policy in India that used tax breaks to attract new, environmentally friendly industries. The policy spurred economic growth without measurable ecological damage. Another policy approach would be to incentive pro-environment technological innovations, such as cleaner production techniques or mechanical harvesters that do not leave behind stubble.

It would be naive to expect that industrial policy or new innovations will fully eliminate the trade-off between economic development and environmental protection. The world faces a climate crisis and other pressing environmental problems, and, at the same time, more than 60% of the global population has a purchasing power of less than $10 a day (Roser 2021). Understanding the tensions involved in simultaneously solving both problems and the ways in which their solutions are aligned is of vital importance and will hopefully remain a vibrant area of research in economics.

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## LITERATURE CITED

Abman R, Garg T, Pan Y, Singhal S. 2020. *Agriculture and deforestation*. Work. Pap., San Diego State Univ., San Diego, CA

Acemoglu D, Johnson S, Robinson JA. 2005. Institutions as a fundamental cause of long-run growth. In *Handbook of Economic Growth*, Vol. 1, ed. P Aghion, S Durlauf, pp. 385–472. Amsterdam: Elsevier

Ali DA, Deininger K, Goldstein M. 2014. Environmental and gender impacts of land tenure regularization in Africa: pilot evidence from Rwanda. *J. Dev. Econ.* 110:262–75

Alix-Garcia J, McIntosh C, Sims KR, Welch JR. 2013. The ecological footprint of poverty alleviation: evidence from Mexico's Oportunidades program. *Rev. Econ. Stat.* 95(2):417–35

Andersen DC. 2016. Credit constraints, technology upgrading, and the environment. *J. Assoc. Environ. Resour. Econ.* 3(2):283–319

Andersen DC. 2017. Do credit constraints favor dirty production? Theory and plant-level evidence. *J. Environ. Econ. Manag.* 84:189–208

Asher S, Garg T, Novosad P. 2020. The ecological impact of transportation infrastructure. *Econ. J.* 130(629):1173–99

Ashraf N, Berry J, Shapiro JM. 2010. Can higher prices stimulate product use? Evidence from a field experiment in Zambia. *Am. Econ. Rev.* 100(5):2383–413

Assunção J, Gandoura C, Rocha R. 2019. *DETERring deforestation in the Brazilian Amazon: environmental monitoring and law enforcement.* Work. Pap., Pontif. Cathol. Univ. Rio de Janeiro, Rio de Janeiro, Brazil

Assunção J, Gandour C, Rocha R, Rocha R. 2020. The effect of rural credit on deforestation: evidence from the Brazilian Amazon. *Econ. J.* 130(626):290–330

Banerjee A, Duflo E, Goldberg N, Karlan D, Osei R, et al. 2015. A multifaceted program causes lasting progress for the very poor: evidence from six countries. *Science* 348(6236):1260799

Barrows G, Ollivier H. 2021. Foreign demand, developing country exports, and CO2 emissions: firm-level evidence from India. *J. Dev. Econ.* 149:102587

Barwick PJ, Li S, Lin L, Zou E. 2020. *From fog to smog: the value of pollution information*. NBER Work. Pap. 26541

Baylis P, Greenstone M, Lee K, Sahai H. 2021. *Pollution masks and the demand for clean air: experimental evidence from Delhi*. Work. Pap., Univ. Chicago, Chicago

Behrer AP. 2019. *Earth, wind and fire: the impact of anti-poverty efforts on Indian agriculture and air pollution*. Work. Pap., Stanford Univ., Stanford, CA

BenYishay A, Fraker A, Guiteras R, Palloni G, Shah NB, et al. 2017a. Microcredit and willingness to pay for environmental quality: evidence from a randomized-controlled trial of finance for sanitation in rural Cambodia. *J. Environ. Econ. Manag.* 86:121–40

BenYishay A, Heuser S, Runfola D, Trichler R. 2017b. Indigenous land rights and deforestation: evidence from the Brazilian Amazon. *J. Environ. Econ. Manag.* 86:29–47

Berkouwer SB, Dean JT. 2021. *Credit, attention, and externalities in the adoption of energy efficient technologies by low-income households*. Work. Pap., Univ. Pa., Philadelphia

Berry J, Fischer G, Guiteras R. 2020. Eliciting and utilizing willingness to pay: evidence from field trials in Northern Ghana. *J. Political Econ.* 128(4):1436–73

Besley T. 1995. Property rights and investment incentives: theory and evidence from Ghana. *J. Political Econ.* 103(5):903–37

Besley T, Ghatak M. 2010. Property rights and economic development. In *Handbook of Development Economics*, Vol. 5, ed. D Rodrik, M Rosenzweig, pp. 4525–95. Amsterdam: Elsevier

Besley T, Persson T. 2009. The origins of state capacity: property rights, taxation, and politics. *Am. Econ. Rev.* 99(4):1218–44

Blackman A, Corral L, Lima ES, Asner GP. 2017. Titling indigenous communities protects forests in the Peruvian Amazon. *PNAS* 114(16):4123–28

Bombardini M, Li B. 2020. Trade, pollution and mortality in China. *J. Int. Econ.* 125:103321

Borlaug N. 2007. Feeding a hungry world. *Science* 318(5849):359

Brainerd E, Menon N. 2014. Seasonal effects of water quality: the hidden costs of the Green Revolution to infant and child health in India. *J. Dev. Econ.* 107:49–64

Burgess R, Costa F, Olken BA. 2019. *The Brazilian Amazon's double reversal of fortune*. Work. Pap., Mass. Inst. Technol., Cambridge

Burgess R, Hansen M, Olken BA, Potapov P, Sieber S. 2012. The political economy of deforestation in the tropics. *Q. J. Econ.* 127(4):1707–54

Cherniwchan J, Copeland BR, Taylor MS. 2017. Trade and the environment: new methods, measurements, and results. *Annu. Rev. Econ.* 9:59–85

Copeland BR, Shapiro JS, Taylor MS. 2021. *Globalization and the environment*. NBER Work. Pap. 28797

Dasgupta P. 1996. The economics of the environment. *Environ. Dev. Econ.* 1(4):387–428

Dasgupta P, Mäler KG. 1995. Poverty, institutions, and the environmental resource-base. In *Handbook of Development Economics*, Vol. 3A, ed. J Behrman, TN Srinivasan, pp. 2371–463. Amsterdam: North-Holland

Davis LW, Kahn ME. 2010. International trade in used vehicles: the environmental consequences of NAFTA. *Am. Econ. J. Econ. Policy* 2(4):58–82

Duflo E, Greenstone M, Pande R, Ryan N. 2013. Truth-telling by third-party auditors and the response of polluting firms: experimental evidence from India. *Q. J. Econ.* 128(4):1499–545

Duflo E, Greenstone M, Pande R, Ryan N. 2018. The value of regulatory discretion: estimates from environmental inspections in India. *Econometrica* 86(6):2123–60

Eisenbarth S. 2022. Do exports of renewable resources lead to resource depletion? Evidence from fisheries. *J. Environ. Econ. Manag.* 112:102603

Feng W, Cai B, Zhang B. 2020. A bite of China: food consumption and carbon emission from 1992 to 2007. *China Econ. Rev.* 59:100949

Ferraro PJ, Simorangkir R. 2020. Conditional cash transfers to alleviate poverty also reduced deforestation in Indonesia. *Sci. Adv.* 6(24):eaaz1298

Franzen A, Vogl D. 2013. Two decades of measuring environmental attitudes: a comparative analysis of 33 countries. *Global Environ. Change* 23(5):1001–8

Garcia A. 2020. *The environmental impacts of agricultural intensification*. Tech. Rep. 9, CGIAR Standing Panel Impact Assess., CGIAR, Rome, Italy

Garg T, Jagnani M, Pullabhotla HK. 2020. *Agricultural labor exits increase crop fires*. Work. Pap., Univ. Calif., San Diego

Garg T, Shenoy A. 2021. The ecological impact of place-based economic policies. *Am. J. Agric. Econ.* 103(4):1239–50

Gendron-Carrier N, Gonzalez-Navarro M, Polloni S, Turner MA. 2022. Subways and urban air pollution. *Am. Econ. J. Appl. Econ.* 14(1):164–96

Gertler PJ, Shelef O, Wolfram CD, Fuchs A. 2016. The demand for energy-using assets among the world's rising middle classes. *Am. Econ. Rev.* 106(6):1366–401

Ghani E, Goswami AG, Kerr WR. 2016. Highway to success: the impact of the Golden Quadrilateral Project for the location and performance of Indian manufacturing. *Econ. J.* 126(591):317–57

Goldstein M, Houngbedji K, Kondylis F, O'Sullivan M, Selod H. 2018. Formalization without certification? Experimental evidence on property rights and investment. *J. Dev. Econ.* 132:57–74

Goldstein M, Udry C. 2008. The profits of power: land rights and agricultural investment in Ghana. *J. Political Econ.* 116(6):981–1022

Greenstone M, Jack BK. 2015. Envirodevonomics: a research agenda for an emerging field. *J. Econ. Lit.* 53(1):5–42

Grossman GM, Krueger AB. 1991. *Environmental impacts of a North American Free Trade Agreement*. NBER Work. Pap. 3914

Grossman GM, Krueger AB. 1995. Economic growth and the environment. *Q. J. Econ.* 110(2):353–77

Gutiérrez E, Teshima K. 2018. Abatement expenditures, technology choice, and environmental performance: evidence from firm responses to import competition in Mexico. *J. Dev. Econ.* 133:264–74

Hanna R, Oliva P. 2015. Moving up the energy ladder: the effect of an increase in economic well-being on the fuel consumption choices of the poor in India. *Am. Econ. Rev.* 105(5):242–46

Haushofer J, Shapiro J. 2016. The short-term impact of unconditional cash transfers to the poor: experimental evidence from Kenya. *Q. J. Econ.* 131(4):1973–2042

He G, Wang S, Zhang B. 2020. Watering down environmental regulation in China. *Q. J. Econ.* 135(4):2135–85

He P, Baiocchi G, Feng K, Hubacek K, Yu Y. 2019. Environmental impacts of dietary quality improvement in China. *J. Environ. Manag.* 240:518–26

Health Eff. Inst. 2020. *Average seasonal population-weighted ozone*. State of Global Air 2020. **https://www.stateofglobalair.org/data/#/air/table**

Hess S, Jaimovich D, Schündeln M. 2021. Environmental effects of development programs: experimental evidence from West African dryland forests. *J. Dev. Econ.* 153:102737

Hsieh CT, Klenow PJ. 2009. Misallocation and manufacturing TFP in China and India. *Q. J. Econ.* 124(4):1403–48

Ito K, Zhang S. 2020a. *Reforming inefficient energy pricing: evidence from China*. NBER Work. Pap. 26853

Ito K, Zhang S. 2020b. Willingness to pay for clean air: evidence from air purifier markets in China. *J. Political Econ.* 128(5):1627–72

Jaffe AB, Stavins RN. 1994. The energy paradox and the diffusion of conservation technology. *Resour. Energy Econ.* 16(2):91–122

Jayachandran S. 2013. Liquidity constraints and deforestation: the limitations of payments for ecosystem services. *Am. Econ. Rev.* 103(3):309–13

Kahn ME, Li P, Zhao D. 2015. Water pollution progress at borders: the role of changes in China's political promotion incentives. *Am. Econ. J. Econ. Policy* 7(4):223–42

Lawlor K, Handa S, Davis B, Seidenfeld D, et al. 2020. Poverty-environment relationships under market heterogeneity: cash transfers and rural livelihoods in Zambia. *Environ. Dev. Econ.* 25(3):291–314

Lawry S, Samii C, Hall R, Leopold A, Hornby D, Mtero F. 2017. The impact of land property rights interventions on investment and agricultural productivity in developing countries: a systematic review. *J. Dev. Eff.* 9(1):61–81

Levine DI, Beltramo T, Blalock G, Cotterman C, Simons AM. 2018. What impedes efficient adoption of products? Evidence from randomized sales offers for fuel-efficient cookstoves in Uganda. *J. Eur. Econ. Assoc.* 16(6):1850–80

Levine R. 1997. Financial development and economic growth: views and agenda. *J. Econ. Lit.* 35(2):688–726

Li S, Liu Y, Purevjav AO, Yang L. 2019. Does subway expansion improve air quality? *J. Environ. Econ. Manag.* 96:213–35

Lipscomb M, Mobarak AM. 2016. Decentralization and pollution spillovers: evidence from the re-drawing of county borders in Brazil. *Rev. Econ. Stud.* 84(1):464–502

López-Feldman A, Chávez E. 2017. Remittances and natural resource extraction: evidence from Mexico. *Ecol. Econ.* 132:69–79

Mahadevan M. 2020. *The price of power: costs of political corruption in Indian electricity*. Work. Pap., Univ. Calif., Irvine

Malerba D. 2020. Poverty alleviation and local environmental degradation: an empirical analysis in Colombia. *World Dev.* 127:104776

Meeks R, Isaev R, Omuraliev A, Wang Z. 2021. *Smart meters and the benefits from electricity quality improvements*. Work. Pap., Duke Univ., Durham, NC

Meeks R, Sims KR, Thompson H. 2019. Waste not: Can household biogas deliver sustainable development? *Environ. Resour. Econ.* 72(3):763–94

Nagaraj A. 2022. The private impact of public data: Landsat satellite maps increased gold discoveries and encouraged entry. *Manag. Sci.* 68(1):564–82

NationMaster. 2014. *Motor vehicles per 1000 people*. NationMaster. **https://www.nationmaster.com/country-info/stats/Transport/Road/Motor-vehicles-per-1000-people**

Nriagu JO. 1990. The rise and fall of leaded gasoline. *Sci. Total Environ.* 92:13–28

Oliva P. 2015. Environmental regulations and corruption: automobile emissions in Mexico City. *J. Political Econ.* 123(3):686–724

Oliva P, Jack BK, Bell S, Mettetal E, Severen C. 2020. Technology adoption under uncertainty: take-up and subsequent investment in Zambia. *Rev. Econ. Stat.* 102(3):617–32

Ostrom E. 1990. *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge, UK: Cambridge Univ. Press

Pagel J. 2020. *Aid against trees? Evidence from a community-driven development program in the Philippines*. Work. Pap., Univ. Barcelona, Barcelona, Spain

Probst B, BenYishay A, Kontoleon A, dos Reis TN. 2020. Impacts of a large-scale titling initiative on deforestation in the Brazilian Amazon. *Nat. Sustain.* 3(12):1019–26

Qi J, Tang X, Xi X. 2021. The size distribution of firms and industrial water pollution: a quantitative analysis of China. *Am. Econ. J. Macroecon.* 13(1):151–83

Roser M. 2021. Global poverty in an unequal world: Who is considered poor in a rich country? And what does this mean for our understanding of global poverty? *Our World in Data*, March 5. **https://ourworldindata.org/higher-poverty-global-line**

Ryan N. 2018. *Energy productivity and energy demand: experimental evidence from Indian manufacturing plants*. NBER Work. Pap. 24619

Ryan N, Sudarshan A. 2020. *Rationing the commons*. Work. Pap., Yale Univ., New Haven, CT

Sekhri S. 2011. Public provision and protection of natural resources: groundwater irrigation in rural India. *Am. Econ. J. Appl. Econ.* 3(4):29–55

Shapiro JS, Walker R. 2018. Why is pollution from US manufacturing declining? The roles of environmental regulation, productivity, and trade. *Am. Econ. Rev.* 108(12):3814–54

Stern DI. 2017. The environmental Kuznets curve after 25 years. *J. Bioecon.* 19(1):7–28

Stevenson JR, Villoria N, Byerlee D, Kelley T, Maredia M. 2013. Green Revolution research saved an estimated 18 to 27 million hectares from being brought into agricultural production. *PNAS* 110(21):8363–68

Tanaka S, Teshima K, Verhoogen E. 2021. North-South displacement effects of environmental regulation: the case of battery recycling. *Am. Econ. Rev. Insights*. In press

Tseng TWJ, Robinson BE, Bellemare MF, BenYishay A, Blackman A, et al. 2021. Influence of land tenure interventions on human well-being and environmental outcomes. *Nat. Sustain.* 4(3):242–51

van Benthem AA. 2015. Energy leapfrogging. *J. Assoc. Environ. Resour. Econ.* 2(1):93–132

WHO (World Health Organ.). 2016. *SDG Indicator 11.6.2. Concentrations of fine particulate matter (PM2.5)*. The Global Health Observatory. **https://www.who.int/data/gho/data/indicators/indicator-details/GHO/concentrations-of-fine-particulate-matter-(pm2-5**)

Wilebore B, Voors M, Bulte EH, Coomes D, Kontoleon A. 2019. Unconditional transfers and tropical forest conservation: evidence from a randomized control trial in Sierra Leone. *Am. J. Agric. Econ.* 101(3):894–918

Worku IH, Dereje M, Minten B, Hirvonen K. 2017. Diet transformation in Africa: the case of Ethiopia. *Agric. Econ.* 48(S1):73–86

World Bank. 2018. *Co2 emissions (metric tons per capita)*. The World Bank. **https://data.worldbank.org/indicator/EN.ATM.CO2E.PC**

World Bank. 2020. *Gdp per capita, ppp (current international $)*. The World Bank. **https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD**

Wren-Lewis L, Becerra-Valbuena L, Houngbedji K. 2020. Formalizing land rights can reduce forest loss: experimental evidence from Benin. *Sci. Adv.* 6(26):eabb6914