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PERC REPORTS

FOR FREE MARKET ENVIRONMENTALISM

MARKET ADAPTATION to CLIMATE CHANGE

FROM THE EDITOR

Shawn Regan

No matter what you think about the incoming Trump administration, one thing is certain: The United States is unlikely to pass large-scale carbon mitigation policies anytime soon. What's more, the Clean Power Plan and the 2015 Paris agreement—two of President Obama's prized achievements—now face uncertain futures.

Whether or not those efforts would have succeeded or made any difference is an open question. Even though carbon emissions from U.S. power generation are at a 25-year low, thanks in part to fracking and cheap natural gas, global atmospheric concentrations of carbon dioxide are steadily increasing and show no signs of slowing.

The reality is that climate change is what some have called a "wicked problem"—solving it on a global scale would be economically devastating, politically unattainable, and practically impossible. That leaves us with the theme of this special issue of *PERC Reports*: adaptation.

Until recently, adaptation to climate change was considered taboo. In 1992, Al Gore dismissed it as a "kind of laziness, an arrogant faith in our ability to react in time to save our skins." Focusing on adaptation, many claimed, would only distract us from accepting costly carbon mitigation policies.

That taboo is gone. Like it or not, in today's world, adaptation is the name of the game. And as the articles in this issue explore, free markets and property rights are critical for adapting to climate change. Market prices send signals about local conditions that no central planner or scientific expert could possibly know. Property rights give resource owners the incentives necessary to adjust to changing conditions. If sea levels rise or crop yields decline, property owners have good reason to act—whether to invest in protections or innovations.

These market forces are already at work, although they aren't typically heralded by the media. Wheat is increasingly grown in harsher climates (see page 14). The global coffee sector is adapting to hotter conditions, despite dire predictions from the press (page 22). And financial markets are quietly shielding us from the effects of extreme weather (page 28)—all with little notice or fanfare.

The real challenge is to avoid policies that distort prices, make society poorer, or prevent markets from adapting. Trade barriers, immigration restrictions, federal flood insurance, agricultural subsidies, and zoning regulations each impose obstacles to climate adaptation. This special issue challenges how we think about climate change and highlights the importance of markets and property rights in helping us adapt to our ever-changing world.

PERC

The Property and Environment Research Center is a nonprofit institute dedicated to improving environmental quality through property rights and markets. Learn more at **perc.org**.

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PERC REPORTS
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Giving Credit Where Credit is Due

The environmental case for economic growth.

Here's a surprising fact: At least 70 percent of the reduction in U.S. air emissions since their 1930s peak occurred *before* the Clean Air Act was passed in 1970.

We typically hear that the Clean Air Act was responsible for most, if not all, of the improvements in U.S. air quality over the last century. The truth, however, is that local governments passed ordinances to reduce harmful emissions decades before the federal government acted. Moreover, consumers had already begun demanding "cleaner" goods and services, like natural gas to replace coal for heating and cooking.

Indeed, after Congress passed the Clean Air Act in 1970, the rate of improvement in air quality actually slowed. Why? The low-hanging fruit had been picked. Plus, federally mandated reductions often failed to account for local conditions, creating expensive and often ineffective one-size-fits-none approaches to clearing the air.

This history raises two questions. First, if it wasn't intervention by the Environmental Protection Agency, what motivated those early air quality improvements? And, second, why has the federal government received more than its fair share of the credit?

Three words can answer the first question: Wealthier is healthier. And just one might suffice to answer the second: visibility.

WEALTHIER IS HEALTHIER

As people get wealthier—that is, once they meet their basic human needs of food, water, and shelter—they begin to demand a cleaner and cleaner environment. We observe this phenomenon within countries (by tracking environmental indicators as economic prosperity changes over time) and across borders (by comparing poor and wealthy countries). Although there is often an initial increase in environmental degradation as incomes and levels of consumption rise, at a certain point that degradation slows and eventually reverses as people become wealthier.

One of the first things to improve is water quality because contaminated water often makes people sick immediately. Soon after, air quality improves, first for the visible irritants that have immediate health impacts (particulates and smog) and later for the less conspicuous emissions that cause problems downwind (acid rain precursors).

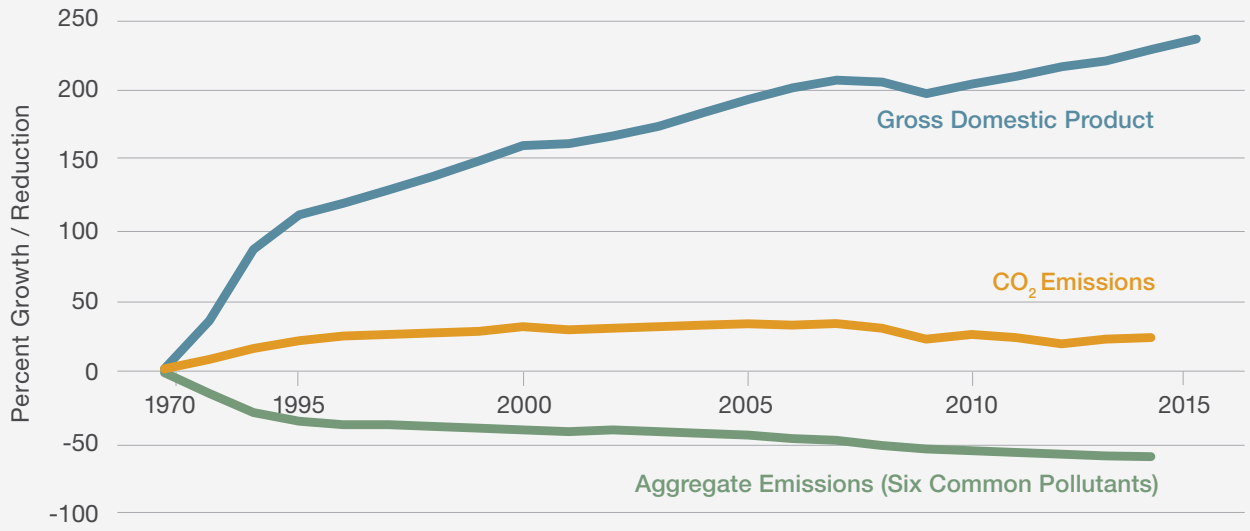
OUTCRY OR OUTCOMES?

If a combination of market forces and local government action had already achieved most of our air quality improvements before passage of the Clean Air Act, then why does this law receive such full and undue credit?

The answer, I believe, is visibility. The Clean Air Act is an enormously expensive law that increases the price of many of

As incomes rise, pollution declines

U.S. economic growth and emissions, 1970-2015



Source: Environmental Protection Agency. Aggregate emissions include ground-level ozone, particulate matter, carbon monoxide, nitrogen oxides, sulfur dioxide, and lead.

the goods and services you consume today. The act regulates everything from the tail pipe of your car to the smokestack of the nearby power plant, costing the United States approximately $60 billion in compliance each year. And the law, itself, was passed amid a flurry of environmental legislation in the 1960s and 1970s, when public outcry over the nation's air, water, and species loss was at a fever pitch.

Meanwhile, the hero of earlier air quality improvements—economic prosperity, guided by an "invisible hand"—was mistaken for the villain. Taking the long view, we now know that economic wealth and environmental health go hand in hand. While public *outcry* might drive environmental legislation, it is ultimately economic growth that drives positive environmental *outcomes*.

APPLICATIONS TO CLIMATE CHANGE

As our growing wealth allows us to address increasingly remote threats to our health, it is easy to understand why there has not been meaningful action to reduce global concentrations of greenhouse gases such as carbon dioxide: The projected harms from climate change are far off in the future and uncertain, while the costs to reduce those concentrations are significant and would be incurred today. Moreover, greenhouse gas emissions, much of which come from developing countries, affect the entire atmosphere and don't necessarily produce direct, local impacts like other emissions.

The question is whether greenhouse gases will create sufficiently acute health threats that action to address them is warranted. Or, alternatively, might global prosperity reach such high levels that adapting to the effects of climate change is relatively cheap?

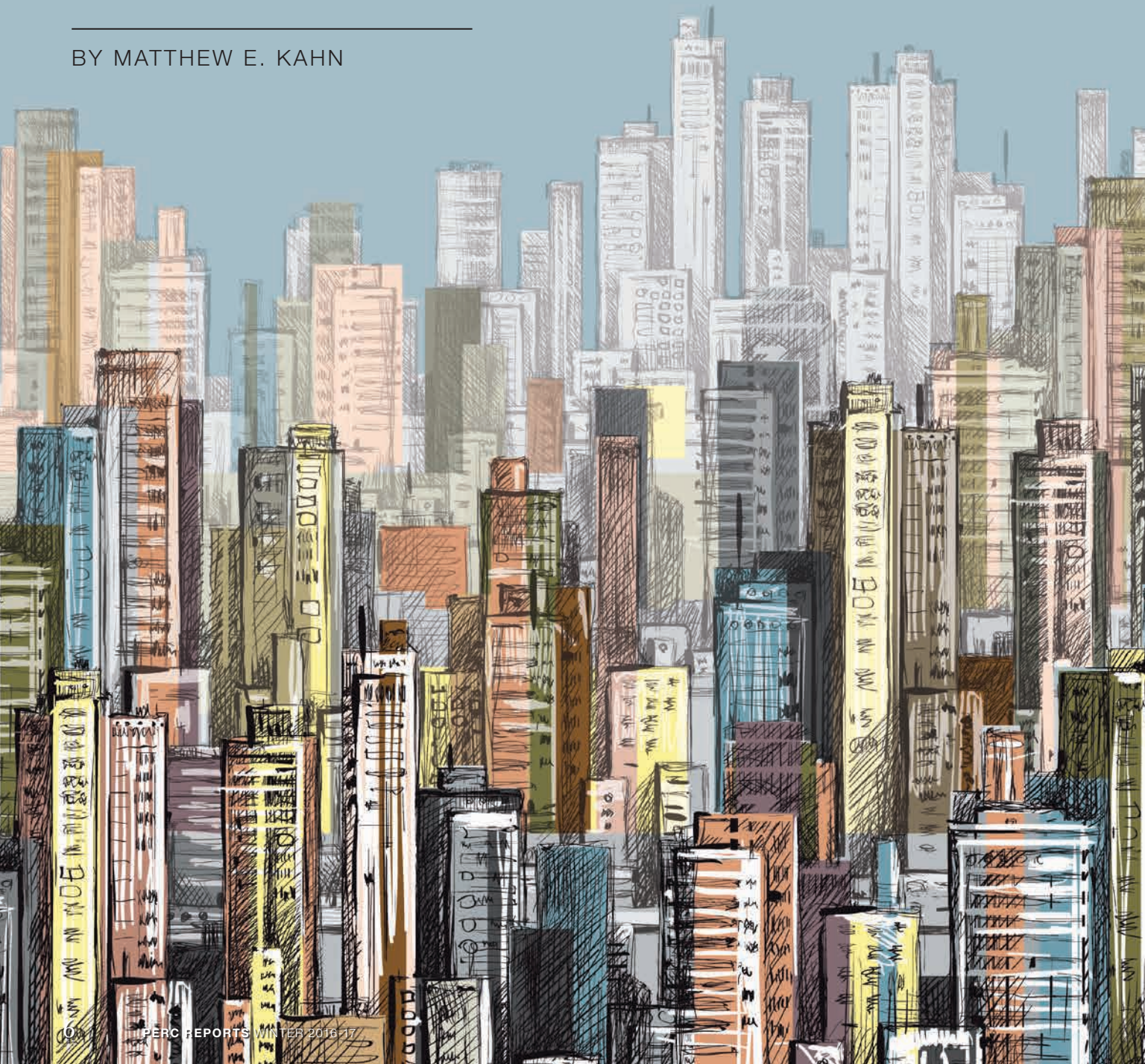
Whichever scenario plays out, we should be wary of any proposed policies that would make the world poorer and therefore limit our ability to adapt. Rather, we should celebrate economic wealth for the environmental health it bestows and do all we can to encourage its future growth.

Reed Watson is the executive director of PERC. In "Frontiers," he describes how PERC is improving environmental quality through property rights and markets.

CLIMATOPOLIS REVISITED

How free markets and urban growth facilitate climate change adaptation.

BY MATTHEW E. KAHN



As the world's population and per capita income have grown, the global concentration of carbon dioxide has increased. For more than half a century, a nearly linear time trend in atmospheric carbon dioxide concentrations has been observed.

Given that the planet's population and per capita incomes will continue to grow, greenhouse gas emissions will keep rising. And in a world with more cars each day and ever-greater demand for electricity, the only way greenhouse gas emissions will decline is if the world shifts to wind, solar, hydro, or nuclear energy and if electric vehicles replace fossil-fuel powered ones. Given current technologies and incentives, however, the transition to the "green economy" will not be quick, and carbon emissions will thus continue to rise.

At the same time that we face engineering and logistical constraints in transitioning to a greener economy, there are also interest groups, such as fossil fuel companies and coal miners, with major stakes in the status-quo energy supply. In both China and West Virginia today, many workers in the steel and coal sectors recognize that they would lose their jobs if their industries were to shrink. The consequence is that these workers use their political clout to lobby their local officials to pursue protective legislation aimed at keeping their sectors alive. Environmentalists who lament increasing emissions have not offered such workers any sort of compensation in exchange for their political support for a transition to the green economy—in other words, they have failed to find ways to compensate those who would lose out in a widespread energy transition. Instead, implicit in regulations such as President Obama's Clean Power Plan is a type of takings such that many low-skill workers will lose their jobs.

A carbon mitigation optimist would point to the recent ratification of the 2015 Paris climate accord as an example of nations around the world working together to tackle the global "tragedy of the commons" problem of climate change. While I wish this claim were true, I reject it. Each nation has only weak incentives to enforce its Paris promises. Many countries such as India set only carbon intensity targets (emissions per unit of output) rather than hard caps on emissions. And the treaty lacks an explicit punishment or incentive mechanism to reward "good behavior." In the absence of such incentives, greenhouse gas emissions will continue to rise, with the developing world producing an ever-larger share. On top of that, climate mitigation policy appears even less likely now that Republicans control both Congress and the White House, making adaptation even more important.

THE ADAPTATION CHALLENGE

The New York Times and other media outlets regularly highlight the emerging consequences of climate change. In one extreme example, *Rolling Stone* magazine published a high-profile, front-page story titled "Goodbye Miami" predicting the submersion of South Beach by the middle of this century. Such "doom and gloom" stories help galvanize progressive support for introducing costly legislation such as a carbon tax, which would raise the price of gasoline and electricity.

Much of the media appears to believe that Americans are complacent and ignorant about the risks that we have collectively unleashed, and they evidently are trying to use climate shocks to "wake up" American voters and encourage them to take costly action against climate change. In past work, I have documented how this strategy might succeed, by demonstrating how disasters can be risk-regulation catalysts.

Much of the media appears to believe that Americans are complacent and ignorant about climate risks. Against this backdrop of pessimism, I offer a counter-narrative: Free market capitalism will help us adapt to the new challenges we have unleashed.

Against this backdrop of pessimism, however, I offer a counter-narrative: As a University of Chicago trained economist and a firm adherent to Julian Simon's optimism about human ingenuity, I have argued that free market capitalism will help us to adapt to the new challenges we have unleashed. Starting with my 2010 book, *Climatopolis: How Our Cities Will Thrive in the Hotter Future*, I have explored how urbanites and their cities will cope with climate change. Our urbanized economies have the right mix of competition, incentives for innovation, and freedom of choice to help us both individually and collectively adapt to new conditions. And as I will explain below, climate change adaptation offers the ultimate test of the predictions made by the nascent field of behavioral economics, which often models humans as irrational or shortsighted.

Imagine a nation that has hundreds of cities spread across a large geographic area. This spatial variation creates a type of portfolio problem. Cities differ with respect to their natural beauty, climate conditions, and risks they face, including natural disasters, extreme heat, and sea-level rise. But suppose that people can costlessly move among these cities. Economic theory suggests that real estate prices and wages will adjust across cities such that places that are less productive will feature low wages and low rents while those that are beautiful will feature low wages and high rents. Note that some people will choose to live in certain cities because their rents will be quite low, which will increase their purchasing power and allow them to afford more leisure or market goods.

Now suppose that a coastal city such as Miami faces rising sea levels due to climate change. As the city's quality of life declines, basic supply and demand logic predicts that both local housing demand and local labor supply will decline as people move elsewhere. As Miami's real estate prices decline and local wages rise, homeowners will lose out as their assets become less valuable, and local firms will see their profits decline because their labor bills have increased. These economic factors represent interest groups with strong incentives to seek sensible climate adaptation solutions because they will suffer large income losses if the harm to Miami's quality of life is not remediated.

Many environmentalists view people as passive victims in the face of climate change, but I reject this view. Forward-looking, risk-averse economic actors have strong incentives to take protective actions to reduce their losses in the face of climate shocks. The only decision makers who will not take protective actions against changing circumstances are those who "do not know that they do not know." But when it comes to "known unknowns," as Donald Rumsfeld famously described them, economic actors *who know that they do not know what climate change will do* to assets such as coastal real estate have strong incentives to take defensive actions. In this age of smartphones and easy access to information, who can claim that they are ignorant of emerging climatic risks? If such "climate skeptics" truly do reject the stream of news, then a new market for trusted information providers will emerge.

Insurance companies and for-profit firms also have strong incentives to be the "adult in the room" in the debate over climate change. Real estate will become much less valuable if insurance rates rise or if there are no local jobs for people. If objective local risks to real estate rise, then insurance companies will

Property owners, such as those in Miami, have strong incentives to seek sensible climate adaptation solutions if they would otherwise suffer large income losses due to climate change.

raise premiums and only offer discounts to those who take preventative actions, such as investing in stilts for homes near coastlines. This would encourage all policy owners to take actions regardless of their personal beliefs. For-profit publicly held firms must face their shareholders, so they will take prudent actions of avoiding increasingly risky areas. If such areas start to lose employment, then all local real estate owners will take note because the value of their properties will decline.

For those who choose to live in risky areas, such as coastal Miami, they will have increased adaptation options. In my recent work, I have discussed the "economics of Legos" as one example of an adaptation strategy. Recall that the children's building blocks can be assembled and disassembled with ease. If we have a modular real estate capital stock that—at a cost—can be moved, then we would not lose our entire capital if sea-level rise reclaims coastal land. Each generation of young people choose to invest their time in building up human capital in specific skills. If our cities now face new risks, then some of them will choose to become architects with expertise in building more resilient structures.

Today, coastal cities feature large quantities of stuck capital. If we build a new capital stock in the future that incorporates planned obsolescence as a feature (perhaps built for 20 years, not 80 years) and includes flexible options for retrofits with stilts or anti-flooding infrastructure, then we will be better protected against the challenges presented by rising oceans.

If Miami does suffer sea-level rise and its real estate investors are unable to defend against it, then its population will move elsewhere. Other areas will gain as we surrender some land to the ocean. But most environmentalists ignore such decentralized and uncoordinated economy-wide responses. In fact, environmentalists' well-meaning land use policies actually inhibit such migration. An emerging literature in urban economics, for instance, has argued that zoning regulation causes high home prices. To adapt to climate change, we need to identify higher ground and then allow for high-rise buildings to be built there. To provide one extreme example, if half of Montana was built up to Hong Kong's density, then 1.5 billion people could live there.

Cities compete against each other for jobs and people. And as demonstrated by Detroit in the 20th century, a city that booms can later decline. San Francisco has boomed over the last few decades. In this footloose age, cities with great quality of life attract and retain skilled workers, and cities with more human capital are more likely to grow. In this sense, competition for

Climate change will shake up the rankings of U.S. cities. As new risks emerge, people have strong incentives to make wise choices about where to live. Even within a single city, such as New Orleans (shown above), people choose where to locate. Residents could move to higher ground—either literally or figuratively, as with areas protected behind levees. Critics who say that people couldn't afford to move must first confront government-created housing supply limits, including zoning regulations, that inhibit new construction and raise prices for poorer renters. *Image by Robert Simmon, based on data by the Landsat 7 Science Team; Photo credit: NASA/GSFC/Landsat*

skilled workers provides cities and their landowners with strong incentives to address the climate change challenge. Demand for solutions will encourage entrepreneurs to dream up new products ranging from more energy-efficient air conditioners to more flood-proof real estate designs that can protect urban residents at risk. The next generation of entrepreneurs will be focusing on such climate change adaptation products, and in a world where billions of people face these challenges, there is a huge market—and enormous payoff—for those who succeed.

WHAT MY CRITICS MISS

My work has been criticized for several reasons (just type "Joe Romm" and "Climatopolis" into Google to see this), but the major reason I have faced pushback is due to the "lulling hypothesis." If distracted suburbanites and everyday working families believe that we can adapt to the challenge of climate change, then this reduces their willingness to accept costly carbon mitigation policies today. Progressive intellectuals worry that climate mitigation will not be a focal issue if people believe that we can adapt.

Within the environmental economics community, my friendly critics have also argued that many people face significant migration costs because they have built up their social networks in large coastal cities like New York and Los Angeles. These scholars are implicitly arguing that most people are less mobile than the migration model I described above. This group of scholars often also embraces the elitist behavioral economics vision that most Americans continue to be blissfully ignorant of the risks they face. Many reject the rational expectations vision of individuals as forecasters who use all available information today and are aware of the "known unknowns" associated with climate change. If these scholars are correct that individuals are

both ignorant and immobile, then many top-down, paternalistic policies such as using federal funds to finance local sea walls become potentially rational investments.

Adaptation pessimists also argue that we have placed our most productive centers of excellence in harm's way—think Manhattan's Wall Street—and thus there will be huge productivity losses associated with climate change. These critics, however, fail to appreciate a key concept in economics: opportunity costs.

The concept of opportunity costs essentially asks the following question: If you weren't reading this article now, what would be the next-best use of your time? In a similar fashion, for those who choose to live in the below-sea-level part of New Orleans, what would be their second-favorite affordable location if they had to leave? How much would they suffer from moving? More economic research is needed on these topics.

The United States has a rich menu of cities to choose from, and even within cities such as New Orleans there are many neighborhoods to choose from. If older residents could move to "higher ground" within the city—either literally or figuratively, as with areas protected behind levees—then they could be safe and retain their social networks. And a critic who says that they can't afford the new neighborhood must first address the government-created housing supply limits, including zoning regulations that inhibit new construction and raise real estate prices for poor renters.

Furthermore, while the elderly do face high migration costs, there is always a new generation of young people who haven't planted roots yet. As new risks emerge, they have strong incentives to make wise choices of where to live. They will look to places that appear to be more robust in the face of climate change's shocks. In this sense, climate change will shake up the rankings of U.S. cities, and people will choose the best match for them.

I reject the notion that the New York metropolitan area would become unproductive if Wall Street was submerged. As sea levels rise, major firms such as Goldman Sachs would move to Connecticut or Westchester. Other firms would follow suit, and a new "Wall Street" would emerge. This would be a zero-sum game for the region, as capital assets would be lost. But these buildings do not last forever, and the new construction would create construction jobs elsewhere.

As I discussed in *Climatopolis*, federal and local policies are currently impeding climate change adaptation. To take one example, subsidies from the Federal Emergency Management Agency for living in flood zones creates spatial moral hazard as more economic activity moves to such areas. Policies that do not allow insurance, electricity, or water prices to reflect scarcity inhibit conservation and innovation. If prices actually reflected scarcity, then entrepreneurs would face the proper signals about where to devote their innovation efforts.

> The next generation of entrepreneurs will be focusing on climate change adaptation products, and in a world where billions of people face these challenges, there is a huge market—and enormous payoff—for those who succeed.

My *Climatopolis* work mainly focused on the United States, but the future of urbanization is in the developing world. The challenge of climate change adaptation will be more difficult for nations with less land area because international migration is becoming increasingly restricted. PERC's work on property rights will be especially valuable here. Economists such as Ted Miguel of UC Berkeley have argued that drought and heat waves brought about by climate change will increase the risk of civil war in the developing world. But there's an alternative view: The risk of this threat will increase investments in property rights and rule of law because of heightened awareness that violence could break out. If there is a fixed cost to establishing rule of law, then this cost will only be incurred if the benefits of rule of law exceed their cost. If climate change raises the benefits of rule of law, then it follows that societies will push to have stronger institutions that permit freedom of trade and commerce.

Matthew E. Kahn is a professor of economics at the University of Southern California and a 2016 PERC Julian Simon Fellow. He is the author of *Climatopolis: How Our Cities will Thrive in the Hotter Future* (Basic Books, 2010) and co-author of *Blue Skies over Beijing: Economic Growth and the Environment in China* (Princeton University Press, 2016).

by Esteban Rossi-Hansberg and Klaus Desmet

A Climate Without Borders

How free trade and free migration can help us adapt to climate change.

What if some of the most effective climate adaptation policies weren't climate policies at all? Esteban Rossi-Hansberg and Klaus Desmet visited us this summer as PERC Lone Mountain Fellows to explore two seemingly unrelated—and often unrecognized—methods of climate adaptation: free trade and migration. We asked Rossi-Hansberg, an economist at Princeton University, and Desmet, an economist at Southern Methodist University, about their research and its potential influence on current policy debates over climate change.

Q: We don't often think of climate adaptation this way, but you argue that free trade and migration can be important tools to allow us to adapt to climate change. First, why is free trade so important for climate adaptation?

A: If you are a wine grower, climate change will affect you more in southern Spain, where temperatures are already quite extreme, than on the Oregon coast, where the climate is much milder. So as global temperatures rise, we expect trade patterns to shift. As some places become too warm to produce wine, other locations will become more suitable for grape production. In a world with trade, where we don't all need to grow our own vegetables in our backyard, there is no reason why people cannot prosper in the middle of the desert. Between 2000 and 2010, one of the fastest-growing cities in the United States was Las Vegas. Such growth would have been unthinkable if all of the city's food had to be sourced locally.

Q: What about free migration? Why is it so important for climate adaptation?

A: Migration would not be much help if the entire world loses from climate change. However, the Intergovernmental Panel on Climate Change predicts that by 2100 temperatures will increase by about 2 degrees Celsius at the Equator and by about 6 degrees at the North Pole. While this could spell disaster for some tropical regions, it will bring advantages to places farther north, such as Canada and Siberia. These areas have the additional advantage of being thinly populated, so in principle free migration should be able to solve many of the problems derived from rising temperatures.

Q: What would we expect the effects of future climate change to be in a world with free trade and free migration, compared to a world in which there is less trade and migration?

A: In our research we have developed an economic model of the world that allows us to analyze both the local and the global effects of climate change. We find that rising temperatures would essentially have no effect on economic welfare in a world with free migration and free trade. In contrast, in a world where no one is allowed to move, the cost would rise to about 5 percent of world GDP, with some regions of the world suffering huge losses of more than 20 percent.

Q: What are some of the dynamics between the human economy and physical climate that you are accounting for in your work?

A: Economic activity generates emissions, which in turn leads to rising temperatures. Global warming affects economic production, but its impacts differ across sectors and space. Growing crops is more sensitive to temperature than assembling cars, and an increase in temperatures may lower crop yields in the Congo but increase them in Canada. As a result, climate change will affect not just specialization and trade patterns but also the spatial distribution of people and economic activity. That, in turn, will have a profound impact on the geography of innovation, as well as on local and global economic growth. In our work, we model and quantify these links.

Q: There are major obstacles to free migration today. So how likely is it to be an effective strategy?

A: We live in a world with political borders, visa requirements, and migration restrictions. At first sight this appears to be a major obstacle. But we should remember that climate change is a slow-moving process. Yes, over the next 200 years the distribution of population across the globe will look quite different if we are to adapt to climate change. However, because the process is so gradual, we are unlikely to see massive movements of people over short periods of time.

This makes migration as a way of adapting to climate change more politically feasible than we might think. After all, if instead of looking 200 years into the future, we go 200 years backward, the distribution of population across the globe looked quite different than it does today. In 1800, only 3 percent of the world's population lived in the Americas, compared to 14 percent today, whereas Europe's share declined from 21 percent to 12 percent. Of course, the past need not predict the future. One obvious difference is that the world's population has increased six-fold in the last two centuries. Although that might make it harder to move people, it is worth remembering that 70 percent of the world's population lives on only 10 percent of the land. So there continues to be plenty of unpopulated land available in northern latitudes that could be put to productive use.

Q: How do you see recent issues relating to global migration—from European countries' mixed response to refugees coming into the European Union, to a newly elected U.S. president pledging to build a border wall, to a Brexit vote fueled partly by anti-immigration sentiments—affecting our ability to adapt to climate change?

A: The political debate on immigration is understandably dominated by short-sighted concerns. In the short run, immigration may bring a certain degree of economic, social, and cultural turmoil. Workers in the United States worry their jobs will go to newcomers, Brexiteers are concerned about the strain migrants from the rest of the European Union put on the social welfare state, and Europe debates about the loss of its cultural identity. In the long run, however, countries that accept more immigrants expand the size of their local markets, which ends up being a powerful driver of innovation. Our research shows that freer migration has enormous long-run benefits for economic growth in the United States and Europe. It would be foolish to shut our borders. Doing so would not only limit our ability to adapt to climate change, it would also sow the seeds of our long-run economic decline.

Q: You've argued that the world has seen climate change before and people have taken measures to adapt to these changes. When and how did these adaptations happen?

A: During the Medieval Warm Period from the 9th to the 14th century, world temperatures increased about 1 degree Celsius. This had a profound impact on both trade patterns and population movements. During that period there were vineyards as far north as southern Norway, and there is evidence of long-distance trade across the Arctic. Scandinavia's population grew, and the Vikings ventured to new lands, colonizing Iceland, Greenland, and the coast of Newfoundland.

In more recent times, the Dust Bowl drove 2.5 million Americans from the Great Plains to California. These examples illustrate how movement has historically been a powerful way to adapt to changing climatic conditions.

Q: What implications do these past examples have for the way we will respond to changing climatic conditions this century?

A: As anthropologist Brian Fagan says, in old times "the only protection against [climate] disasters was movement." While this may not have been exactly true—by the 16th century the Dutch were experts at reclaiming land from the sea—in today's world our menu of choices is much broader. In addition to moving, we can mitigate global warming by developing new technologies, we can adapt to rising sea levels by building sophisticated seawalls, and we can turn on the air conditioning whenever it becomes too hot.

This suggests that the world will likely pursue a wide variety of strategies to respond to climate change. However, the current policy debate over global warming often ignores free migration and free trade. We believe that should change.

READ MORE

Klaus Desmet and Esteban Rossi-Hansberg, "On the Spatial Economic Impact of Global Warming," *Journal of Urban Economics* 88 (2015) pp. 16-37.

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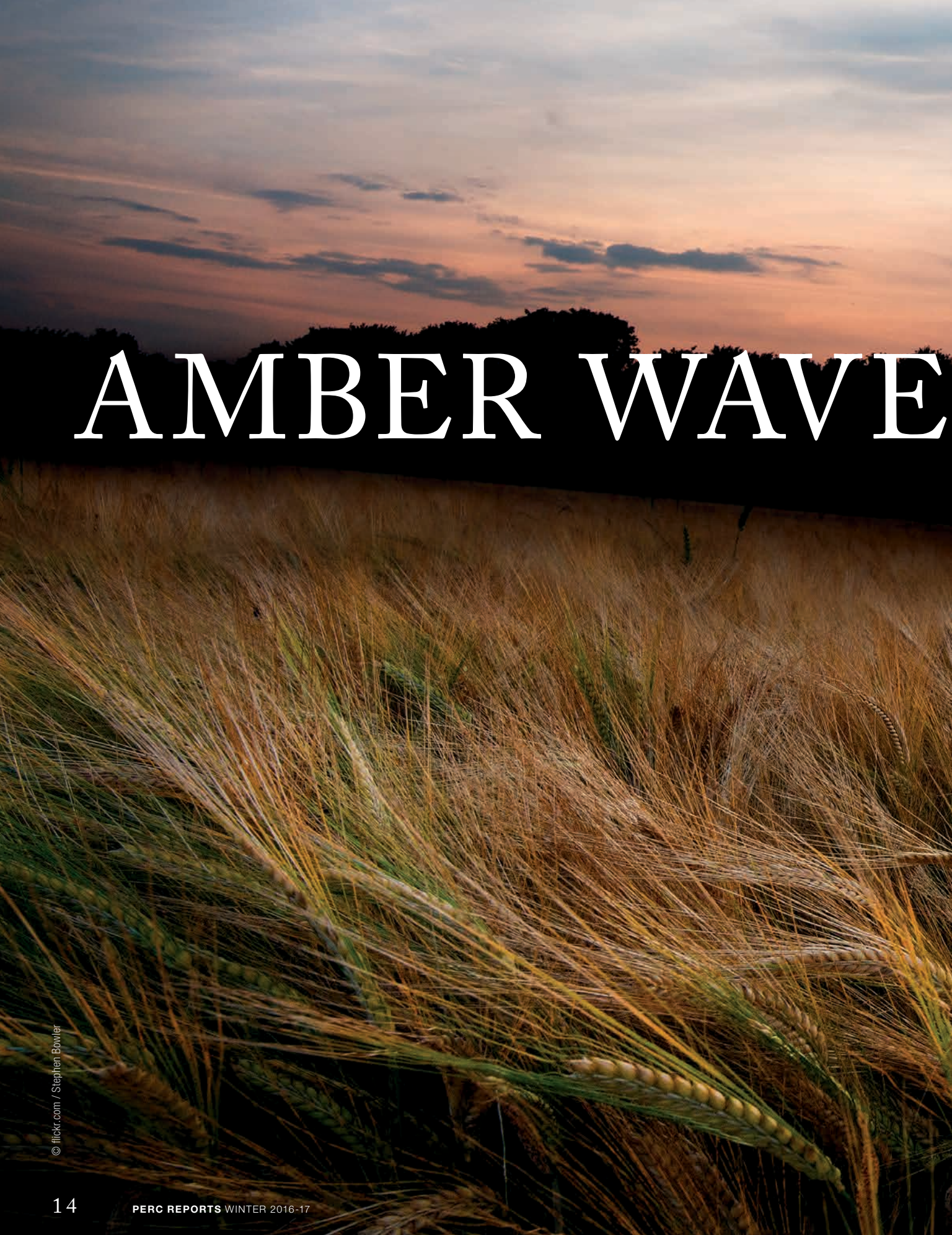
AMBER WAVE



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S OF CHANGE

BY ALAN L. OLMSTEAD AND PAUL W. RHODE

The historical record offers considerable insight into the adaptability of agriculture to climatic challenges. During the late-19th and early-20th centuries, farmers on the frontiers of North America, Australia, and other regions pushed wheat production into environments previously considered too harsh and variable to cultivate. Their experiences inform the agricultural challenges and potential adaptations we face today.

Wheat is taking a wallop. In recent years, weather shocks in many of the world's major wheat-growing regions have sapped yields and output. In Australia, for example, severe drought has plagued much of the country since 2003, with only limited spells of relief, and its grain crops have suffered. During the Great Russian Heat Wave of 2010, summer temperatures exceeded any observed in 130 years of recordkeeping, ravaging wheat crops and leading to a ban on grain exports. In the winter of 2010-11, a drought across the North China Plains—purportedly the worst in two centuries—endangered China's winter wheat crop. And in a globalized economy, local crises such as these—or even prospective crises—can have immediate effects worldwide. Adverse shocks to grain supplies raise global prices, threatening the food security of developing countries and potentially fueling political unrest.

The recent succession of weather-related harvest shocks has heightened concerns that global climate change is making it harder to feed the world, a recurrent theme in the mainstream press and leading academic journals. In a 2011 article in *Science*, Stanford scientist David B. Lobell and co-authors reported that between 1980 and 2008, global warming reduced wheat yields in major producing countries by 5.5 percent compared to what would have been the case without the warming trends. A spate of more recent studies suggests a 6 percent fall in wheat yields for every 1 degree Celsius (C) increase in temperature, all else equal. One prominent study by researchers at the International Maize and Wheat Improvement Center anticipates that North American wheat farmers will have to cease production at the southern end of the grain belt by the year 2050.

These recent travails are new in that agriculturalists have never faced such a rapid widespread increase in temperature and the expected accompanying increases in weather variability; however, a more general form of the problem—overcoming environmental challenges—is nothing new. Wheat is no stranger to threatening environmental conditions, and farmers have a centuries-long track record of overcoming harsh growing conditions and climate challenges. Between 1839 and 2008, wheat output in the United States increased 26-fold, and in Canada it increased 270-fold. These increases in output depended in part on pushing wheat production into new environments. The historical record of this migration in production helps inform how agricultural producers adapt to climatic changes—and it just may shed light on the challenges farmers will face to grow enough grain to feed future populations.

To help understand the prospects for adapting to predicted climate change, it's useful to examine how farmers who settled the North American continent adapted wheat production to new areas, particularly locations with significantly harsher and more variable environments. These changes, for the most part, occurred before the advent of modern plant genetics. This historical adjustment process indicates the malleability of the agricultural enterprise: something that many past experts failed to appreciate when they made doomsday predictions about the future.

'AN UNPRODUCTIVE DESERT'

In the mid-19th century, John Klippart was arguably the most-informed person in North America on wheat. As a member of the Ohio State Board of Agriculture, Klippart published a 700-page tome in 1858 that detailed much of what was then known about wheat farming around the world. In Klippart's view, agro-climatic conditions limited the permanent commercial wheat belt to the area between the 33rd and 43rd latitudes, which encompasses Ohio, the southern parts of Michigan and New York, Pennsylvania, Maryland, Delaware, and Virginia. The soils in the latter three states had been largely exhausted, and without considerable investment in fertilizer, he predicted that production would soon decline.

Although there had been a large increase in wheat output west of Ohio, Klippart maintained that the soils and climates of Illinois, Iowa, and Wisconsin would ultimately doom those states to haphazard production of low-quality and low-yielding spring wheat. Farther west, the area that would later become North America's great wheat belt was mostly "an unproductive desert." And in the South, rust infestations (a class of fungal infections that can devastate wheat crops) were expected to forever limit production. Unless the country husbanded its resources, Klippart surmised, it would soon become an importer of wheat. In addition, he argued that "Canada may be left out of the wheat region" due to declining productivity.

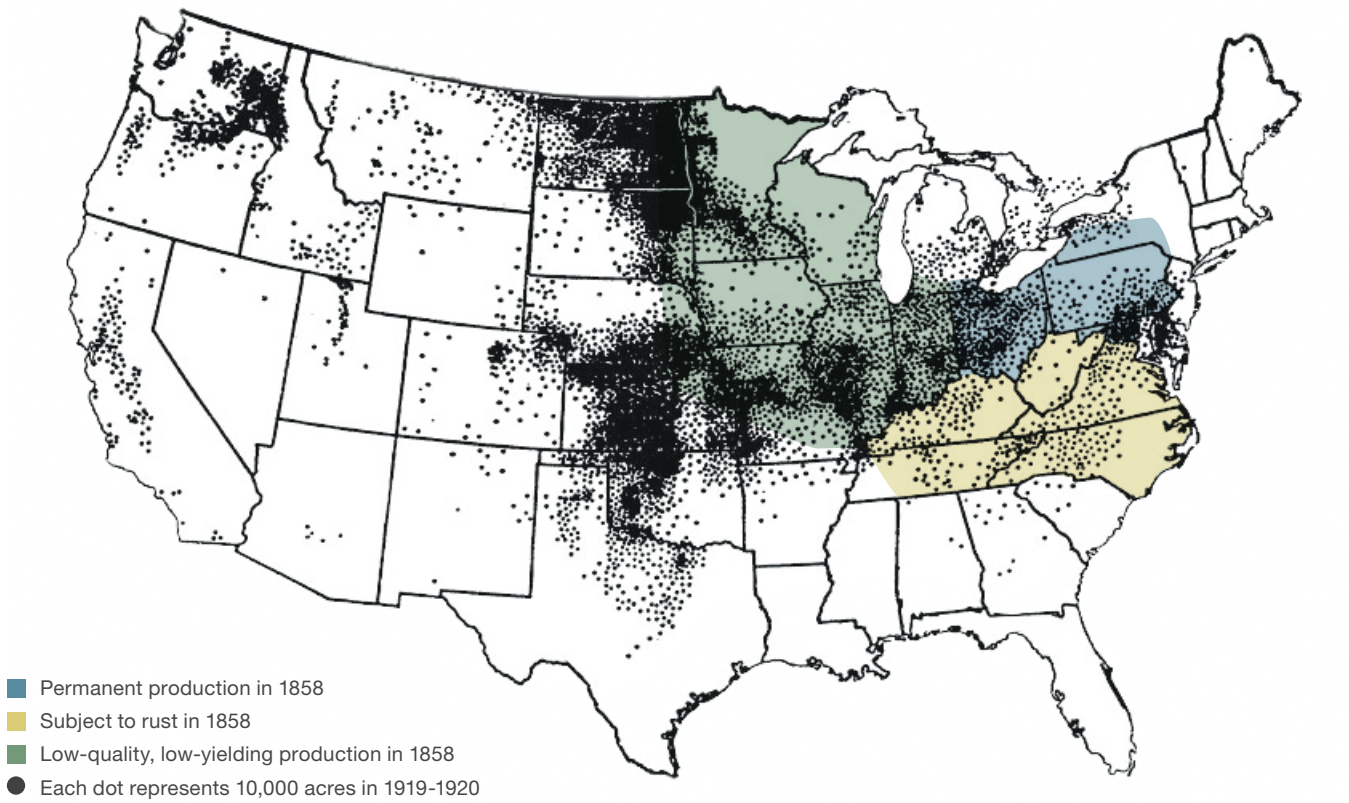
Reality swamped Klippart's calamitous predictions (see Figure 1). By 1919-20, wheat production covered an area much vaster than Klippart could ever have imagined. His estimates proved so far off the mark because he failed to anticipate the biological innovations that would transform North American wheat production. And as impressive as the geographic spread of wheat production was, the accompanying shifts in the ranges of growing conditions were even more amazing. According to Mark Alfred Carleton, a prominent agronomist with the U.S. Department of Agriculture, the regions of North America producing wheat in the early-20th century were as "different from each other as though they lay in different continents."

The massive increase in U.S. and Canadian wheat output over the past 170 years was fueled by the gradual expansion of the crop's production westward and northward. In 1839, the geographic center of North American wheat production, based

Figure 1

The wheat frontier shifted west and north as farmers adapted to new conditions

U.S. wheat production in 1858 and 1919-1920



Sources: Compiled from John H. Klippart, *The Wheat Plant: Its Origin, Culture, Growth, Development, Composition, Varieties, Diseases, Etc., Etc.* New York: A.O. Moore & Company, (1860), pp. 296-327; Oliver E. Baker, "Agricultural Regions of North America. Part VI—The Spring Wheat Region," *Economic Geography*, 4:4 (Oct., 1928), pp. 399-433.

on average output, was located in eastern Ohio. Today, the center of wheat production is in west-central South Dakota, 1,800 kilometers farther west and beyond the extreme western boundary of wheat production in 1839.

These shifts reflect dramatic changes in the distribution of production across climatic conditions. In 1839, the year data became available, a typical wheat farm had nearly 100 cm of annual precipitation. In 2007, the typical wheat farm received less than 50 cm of precipitation per year—a drier environment than virtually any place that had grown wheat in the United States or Canada in 1839. As the growing gap between the 5 and 95 percent lines in Figure 2 indicates, the range of precipitation conditions widened significantly. The driest 5 percent of wheat production received about 80 cm of precipitation in 1839 but only about 35 cm in 1907. And because of the overall increase in production, more wheat was grown with 35 cm of precipitation in 2008 than was grown in all of North America in 1839.

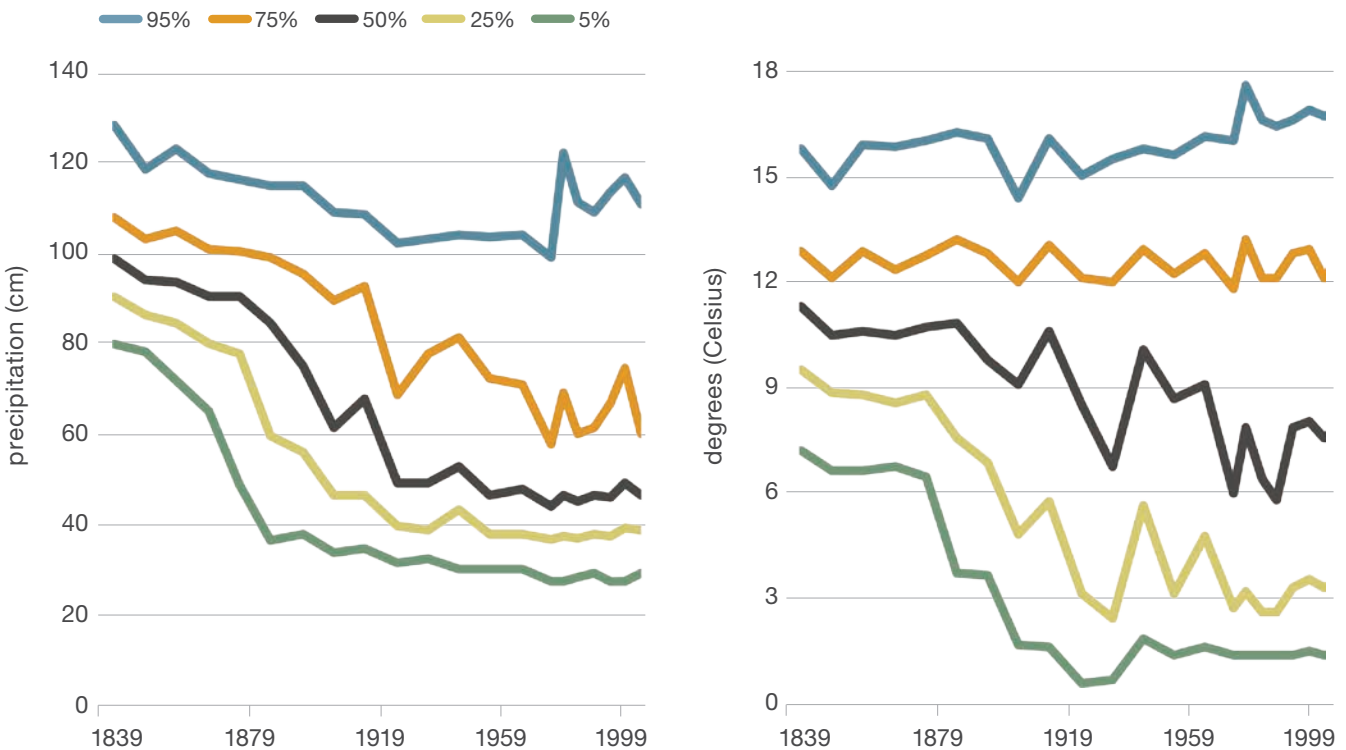
The range of temperature conditions also widened greatly. The most pronounced movement of wheat production was into colder domains. Between 1839 and 2007, the area of cultivation shifted so much that median annual temperature norms for wheat-producing areas fell by 3.7 degrees C. Furthermore, the coldest 10 percent of production as measured by January temperature occurred where the norm was -5.1 degrees C in 1839 but -17.7 degrees C in 1929, a fall of 12.6 degrees.

Wheat's expansion was not limited to places with colder climates—the crop spread to hotter areas as well. In 1839, 5 million bushels of wheat were produced in areas with a July temperature norm of 26 degrees C or hotter. By 1929, more than 192 million bushels were produced under such conditions.

Figure 2

Wheat production expands into harsher climates

The changing distribution of North American wheat production, 1839-2007



Source: Compiled from Alan L. Olmstead and Paul W. Rhode, "Adapting North American Wheat Production to Climatic Challenges, 1839–2009," *Proceedings of the National Academy of Sciences*, 108:2 (Jan. 11, 2011), pp. 480-85.

HOW WHEAT FARMERS ADAPTED

Agricultural production is location specific, at the mercy of conditions that differ across regions and even across neighboring farms. Settlement was intrinsically a biological process that required wheat farmers to harmonize their production practices with specific local soil and climatic conditions. New lands often required new varieties and agricultural techniques for wheat growing to thrive. It was common for the initial settlers of a region to fail, because it often took years or even decades to discover varieties and production techniques appropriate to the strange environments. Success often involved selecting an area that had an environment similar to that "back home."

The Mennonites, who moved from the Russian steppes to the Great Plains of North America in the late-19th century, offer an example. Among their cargo was Turkey wheat, a hard red winter wheat that became a mainstay in the southern U.S. wheat belt. Success for those farmers already in place often involved searching for suitable seed from around the world. Sometimes this occurred through happenstance, as in the case of the 1842 discovery by David and Jane Fife of a hardy red spring wheat amongst a packet of winter wheat seed sent from Scotland. This wheat, eventually named after Fife, made possible the expansion of grain cultivation across the northern plains and Canadian prairies.

Increasingly, the search for suitable seeds took on a systematic global nature. At the turn of the 20th century, USDA wheat specialist Mark Alfred Carleton scoured the Russian Empire seeking wheats that thrived in harsh environments. He introduced scores of new varieties, including durum wheats, to the Great Plains.

Many varietal innovations were the result of government investments in breeding. In 1886, the Canadian Parliament created a federal experiment station system. Its most acclaimed breeder, William Saunders, started a systematic program of breeding hybrids that crossed high-quality cultivars with early-maturing wheats introduced from around the world. In 1903,

his son, Charles Saunders, took over the work at the Dominion Experimental Farm near Ottawa. The most valuable result of their combined research efforts was Marquis, a cross between Red Fife and Red Calcutta, a very early ripening wheat from India. Released in 1909, Marquis was an immediate success and accounted for the vast majority of wheat acreage in Canada and the northern United States by 1920.

In Australia, government researchers made innovations that were more akin to those needed to confront global warming—the most important of which was William Farrer's breeding of the Federation variety of wheat, which helped extend the crop into hot and arid regions previously too hostile for cultivation. There are similar stories of government-supported researchers helping expand wheat's geographical domain in South America, Africa, Europe, and Asia.

THE PERILS OF CROP PREDICTIONS

Since the time of Malthus, there have been dire predictions about the future of the world's food supplies. The repeated failures of such projections have led many observers to dismiss the entire "pessimistic" enterprise out-of-hand. But it is important to recall the example of Sir William Crookes, whose prophecies of mass starvation in his presidential address to the British Association for the Advancement of Science received wide currency in the closing years of the 19th century. Crookes worried that the settlement and globalization process discussed above was coming to an end, that the world was running out of new wheat lands, and that the food supply would soon fail to keep pace with population.

Crookes' predictions, though ultimately proved wrong, had consequences. He argued there was a way out: Learn to fix atmospheric nitrogen to create fertilizers and raise yields on existing soils. Crookes' powerful statement of the problem and his proposed solution helped prompt the chemist Fritz Haber to initiate a search for such a new technology. Haber began experimenting with ammonia in 1904, and after a hit-and-miss start, he gained the support of the German chemical giant Badische Anilin- & Sodafabrik (BASF) in 1908.

In 1909, Haber sent a letter to the BASF directors describing his recent breakthrough in synthesizing ammonia. Led by Carl Bosch, who headed BASF's nitrogen fixation research, the company overcame numerous technical obstacles to translate Haber's experimental procedures into a large-scale commercial operation. BASF's first ammonia fertilizer plant went on line in 1913. Subsequent improvements in the production process dramatically increased the supply of nitrogen while lowering its price. Scientist and author Vaclav Smil has elevated Fritz Haber and Carl Bosch's nitrogen synthesis processes to high prominence, claiming that "without this synthesis about 2/5 of the world's population would not be around." With Bosch's aid, Haber rendered Crookes' prophecies wrong not by adopting a dismissively optimistic attitude, but rather by taking Crookes' challenges seriously and searching for a creative response.

Current concerns about the impact of global climate change on wheat production and agriculture more generally are real. Adaptation will be one important key to addressing the problem, just as it has been for centuries.

Current concerns about the impact of global climate change on wheat production and agriculture more generally are real; if the now widely accepted predictions on climate trends are correct, we are amidst rapid changes unprecedented in the human era. The progressive actions of farmers, researchers, government agencies, and private industry proved able to surmount many previous climate challenges because agriculturalists were able to adapt in unforeseen ways not only to maintain the supply of wheat but also to vastly increase it. The alarms of the past stimulated research—including farmer experimentation—that proved up to most challenges. There is no doubt that as the effects of climate change continue to manifest themselves, adaptation will be one important key to addressing the problem, just as it has been for centuries.

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A Shot of CLIMATE CHANGE *with Your* MORNING COFFEE

What Haiti reveals about the adaptation challenges facing the global coffee sector.

BY TATE WATKINS

My grandparents probably couldn't have fathomed paying $5 for a cup of coffee. For that price you can buy an entire vacuum-sealed tin can of the Maxwell House or Folgers beans that lined the pantries of their generation. But while many Americans still see coffee as little more than a source of caffeine to start the day, the way many of us consume the beverage has transformed in recent years. High-end cafes across the country now offer single-serve, made-to-order coffees prepared for customers with exacting detail—and sometimes for prices that rival those of a glass of house wine.

Today, the retail coffee market in the United States is estimated to be worth nearly $50 billion. And the high-quality, so-called "specialty" segment of it—the filet mignon to the sirloin that is tin-can coffee—has been booming, growing at an estimated 10 percent annually for about a decade. Europe, the largest coffee market in the world, has also awakened to good coffee, and demand there is ratcheting up, as it is in coffee-crazed Japan. The boom even extends to traditionally tea-drinking China, where Starbucks plans to expand its operations by 70 percent over the next three years, opening 1,400 new cafes—an average of more than one new store a day.

This growth is presenting new opportunities for the people who are increasingly featured in the marketing of these coffees: the tropical farmers who produce them. By selling to a quality-minded buyer, a coffee grower might be paid twice what he or she would make if selling into a less-discriminating commodity market. Amidst this boom, however, there's an overarching challenge staring down coffee farmers all over the tropics: climate change.

HIGH-END COFFEE

The beans that go into making your morning coffee actually come from the fruit of a small tropical tree. Ripe red coffee cherries contain the seeds, or beans, that are harvested, processed, shipped, roasted, and eventually brewed into the hot liquid that kickstarts so many Americans' days.

But coffee is a finicky plant—especially arabica coffee, the species known for its excellent cup quality that comprises the majority of specialty coffee. Coffee trees grow only in specific microclimates limited to wet, mountainous areas of the globe's tropical belt. As temperatures are predicted to rise in coming

Coffee seedlings germinate in a nursery (top) and eventually grow amongst banana and other fruit trees on a Haitian farm (middle photos). Coffee beans are later harvested and dried at a farmer's small processing facility (bottom).

For many of the same reasons that Haiti is vulnerable to natural disasters, a changing climate stands to exacerbate many of its coffee sector's existing challenges—if not decimate it entirely.

decades, the area viable for coffee cultivation is expected to retreat toward cooler climes found higher up mountaintops. The latest research from both the International Center for Tropical Agriculture and World Coffee Research suggests that by 2050, the global area suitable for coffee production could shrink by half. The upshot is that farmers who currently rely on coffee for their livelihoods could be devastated—if they don't find ways to adapt to their changing environments.

Because most coffee is harvested selectively by hand, and coffee cherries ripen sporadically over the course of a months-long season, there are relatively few economies of scale in harvesting it. Partly for this reason, coffee is one of the most profitable crops for small-scale farmers. Collectively, an estimated 25 million smallholder farmers produce about 80 percent of the world's coffee. And because they'll never compete on volume with the large farms that have the highest yields in the world, the more lucrative specialty market is a natural fit for them. Even a meager harvest can be a worthwhile proposition if sold at the right price.

The high-end coffee boom has brought about more product differentiation. Trendy roasters today often market a bag of coffee similarly to how you'd expect to be sold a bottle of wine—the label might feature information about the variety of the coffee plant, the altitude it grew at, and how the beans were processed, all of which can influence its taste. And as with wine, roasters are also likely to emphasize the coffee's origin down to the growing country, region, or even farm.

With these shifts, many coffee companies have adopted some version of "direct trade"—a concept without an official definition but that essentially boils down to two things: transparency and traceability. The idea is that instead of having a third-party stamp your bag with a label like "fair trade" to signal that it was produced responsibly, a company tries to directly show and tell its clientele how its product was produced, doing its own due diligence throughout the supply chain. Many direct-trade roasters visit coffee growers regularly to emphasize the importance of quality and confirm that the relatively high prices they pay to exporters truly trickle down to farmers.

As one result, these growers have become the focal points of specialty coffee marketing. Consequently, awareness has shifted toward the challenges at this end of the supply chain—including climate change, and how it might shift the outlook of the global industry over coming generations. And if there's one coffee-growing country that may be a canary in the coal mine when it comes to the global industry, it's Haiti.

HAITI AS A HARBINGER

"It's better to grow something you can sell on the international market," says Dieujuste Joseph, a farmer in the mountains of southeastern Haiti. As we walk around his farm, Joseph explains that he can make more money selling his high-quality arabica coffee into an export market than by selling to local buyers. But diversifying his crop production is also important to him, he adds. Avocado, mango, banana, and grapefruit trees also grow among his coffee plantings.

Coffee, in theory, is a great option for a rural farmer in tropical mountains. But many of Joseph's fellow Haitian farmers have either neglected their coffee or abandoned it entirely because they're "in misery," he says, struggling to feed their families. Their need for subsistence crops to feed a family today wins out over investing in a longer-term cash crop.

Haiti's coffee sector has been on a steady decline for a half-century. Since the 1980s, production has fallen by half, and official exports have plummeted by 95 percent. There are many underlying causes—some of them not related to coffee at all.

Since Haiti gained its independence through a successful slave revolution in 1804, it has been plagued by political instability and weak institutions. In just the past 30 years, there have been 18 separate terms served by heads of state—rather than the six you would expect since the term limit for a Haitian president is five years. Over those years, political instability has wracked the nation—from the vacuum left after the 1986 ouster of the Duvalier dictatorship, to the international sanctions and embargo of the early 1990s aimed at removing a military junta, to the insecurity and violence of the mid 2000s. Regardless of who's dwelled in the presidential palace, the state has too often been more focused on private, short-term gain than on building a proper education system, functioning roads, secure property rights, a fair judiciary, or any other system that would help ordinary citizens flourish.

The uncertainty that still undergirds much of daily life threatens long-term planning and investment of all sorts. When it comes to coffee, it can take up to four years for a new seedling to give its first full harvest. Food crops like beans or vegetables, on the other hand, have multiple growing cycles each year, and they can help feed a farmer's family in addition to earning income on local markets.

On top of that, land tenure in Haiti is notoriously a mess. Less than 5 percent of land is officially recorded in the national cadastre. The informality and uncertainty of the system can limit economic activity, investment, and dynamism—not an ideal situation for coffee farmers who require long-term investment in their trees, let alone those who may have to move to higher altitudes if they want to stick with the crop in the face of a changing climate.

Beyond the economic challenges, coffee plants are vulnerable to more than 1,000 diseases and pests, including two of the most damaging—a fungus called coffee leaf rust and a beetle that bores into cherries and ruins the beans. Other hazards, such as drought, are nothing new to farmers, but that makes them no less difficult to cope with.

When it comes to weathering natural hazards like hurricanes, drought, and earthquakes, Haiti is famously one of the least-resilient nations in the world. While some of the vulnerability can be chalked up to unfortunate geography—the country lies along a hurricane alley and sits on a tectonic boundary—most experts agree that the crux of it is poverty, along with the consequent deforestation and soil erosion after centuries of pressure on the land. For many of the same reasons that Haiti is vulnerable to these disasters, a changing climate stands to exacerbate many of the coffee sector's existing challenges—if not decimate it entirely.

COPING WITH CHANGE

Making projections decades into the future may be more akin to using a sundial than an atomic clock, but most experts agree that climate change is expected to weaken coffee-growing prospects in much of Haiti. A 2014 report by the International Center for Tropical Agriculture (CIAT) notes that by 2050 "coffee will become considerably less suitable for production at lower elevations." Less rainfall and higher temperatures could cause both coffee yields and quality to fall, especially at altitudes below 1,200 meters.

The effects of a changing climate will be mixed, even across a country that's only about the size of Massachusetts. But one ubiquitous threat is that the high-altitude forests that coffee depends on could be converted to cropland as growing ranges creep upward—an unfortunate consequence for a country that's already severely deforested after decades of farmland replacing forests and firewood and charcoal being the primary fuel sources.

The CIAT models predict that while arabica coffee production will become less viable in low-altitude areas, it will become more suitable in higher areas, including the southeastern mountains where Joseph lives and farms.

Like Joseph with his assortment of fruit trees, most Haitian farmers practice diversified agriculture. But farmers at low elevations will likely have to diversify into other crops even more in the face of climate change, if not completely replace their coffee production. Cacao, the raw ingredient for chocolate, may be one viable alternative—CIAT notes that it's "highly suitable for production in Haiti and is likely to remain so, despite long-term changes in the climate." Like coffee, cacao also grows in tropical mountains, just at lower altitudes. The models also suggest that mango—already Haiti's current leading agricultural export—may in fact become more viable due to higher temperatures. Sorghum, yam, and peanuts could also become promising candidates for diversification or substitution.

Impending climate challenges will require various solutions depending on context and local factors, but the CIAT report makes one recommendation clear: farmers should adapt.

THE WAYS FORWARD

Researchers from CIAT and elsewhere have modeled climate predictions across much of the coffee-growing world, particularly the effects on arabica production. As in Haiti, the effects are not expected to be uniform.

A report commissioned by the Consultative Group for International Agricultural Research suggests that Brazil may find its area suitable for arabica coffee reduced by 25 percent by 2050.

A Haitian cooperative dries coffee beans on a concrete patio.

East African producers, on the other hand, could see increased rainfall and shorter dry seasons. The report predicts there will be "little change in suitability of the areas in Ethiopia, Kenya, Rwanda, and Burundi" that currently grow arabica coffee. Indonesia, the fourth-largest coffee producer in the world, and much of the rest of the Asia-Pacific would likely see relatively minor changes in rainfall but lose arabica production area overall.

What's the mechanism for climate threatening coffee cultivation? The variations in climate can be particularly damaging. Too much moisture can promote leaf rust, whose orangish spores attack leaves and prevent plants from photosynthesizing, which can destroy an entire farm in a single season. In 2012, a rust epidemic caused an estimated $1 billion in crop losses across Central America. Too little rain, on the other hand, will stress plants' ability to produce full crops. Drier conditions can also be favorable to certain types of the borer beetles that attack coffee.

Potential adaptations to manage these effects include irrigation systems, improved coffee varieties resistant to drought or disease, and better shade management to cope with higher temperatures. Haitian growers may be well-suited to improve shade conditions. Virtually all their coffee is already grown under some shade, largely due to the diversified agriculture practiced throughout the country. A major question for Haiti, however, will be how small-scale farmers accomplish these sorts of adaptations in a country with a per capita GDP of just $830 and feeble political and legal institutions that are antithetical to long-term investment.

It may simply turn out that it will no longer make sense for many Haitian coffee farmers to remain coffee farmers. Mangoes, cacao, and other crops, if not other lines of work entirely, may become better options given the trade-offs. But if adaptation will be particularly difficult for Haiti, other countries should be better suited to adapt to a new coffee world.

Cenicafé, Colombia's National Coffee Research Center, for instance, has for decades invested in developing coffee varieties that are resistant to leaf rust. The Center has helped Colombian farmers replace more than 3 billion coffee trees with improved varieties, translating into "higher productivity and regional adaptation." Thanks to a Cenicafé web platform, Colombian growers can also check regional climate conditions online and compare them to historical trends.

Similarly, Brazil has funded research into coffee adaptation strategies focusing on heat-resistant varieties suitable for the relatively low altitudes and high temperatures of the country's coffee areas. Certain growers in Guatemala have also begun to adapt their farms by using improved shade management, homemade

sprays that help prevent leaf rust, and mixes of both traditional and disease-resistant or high-yielding varieties. Some have even started to diversify their coffee production with cardamom and honey.

Most coffee-agronomy research is conducted by public institutions or national governments. As the coffee sector's vulnerability to climate has become more apparent in recent years, however, the private sector has started to focus on the great needs at the production end of the chain—and on what will have to happen to make sure the sector will be able to adapt and continue to thrive.

World Coffee Research (WCR), a non-profit organization housed at Texas A&M University and largely funded by donations from coffee importers, roasters, and other actors in the sector, is pushing the limits of coffee research—"ensuring the future of coffee," as its website reads. In summer of 2016, WCR released a comprehensive "variety catalog" packed with information concerning yields, disease resistance, botanical data, and cup quality for coffee varieties grown across Central America and the Caribbean. The organization estimates that just by using the resource to help make decisions about which varieties to plant, farmers can increase both coffee quality and quantity by up to 15 percent.

WCR also researches coffee genetics and breeding, factors that affect quality, and adaptation strategies to cope with climate change effects. It notes that the "best hope for sustaining the supply of high quality coffee in the 21st century is to focus on making the coffee plant more resilient. The creation of new, highly adaptable varieties, supported by a vibrant new seed sector, will result in major global productivity and quality gains in the next 10-20 years."

BULLISH ON THE BEAN

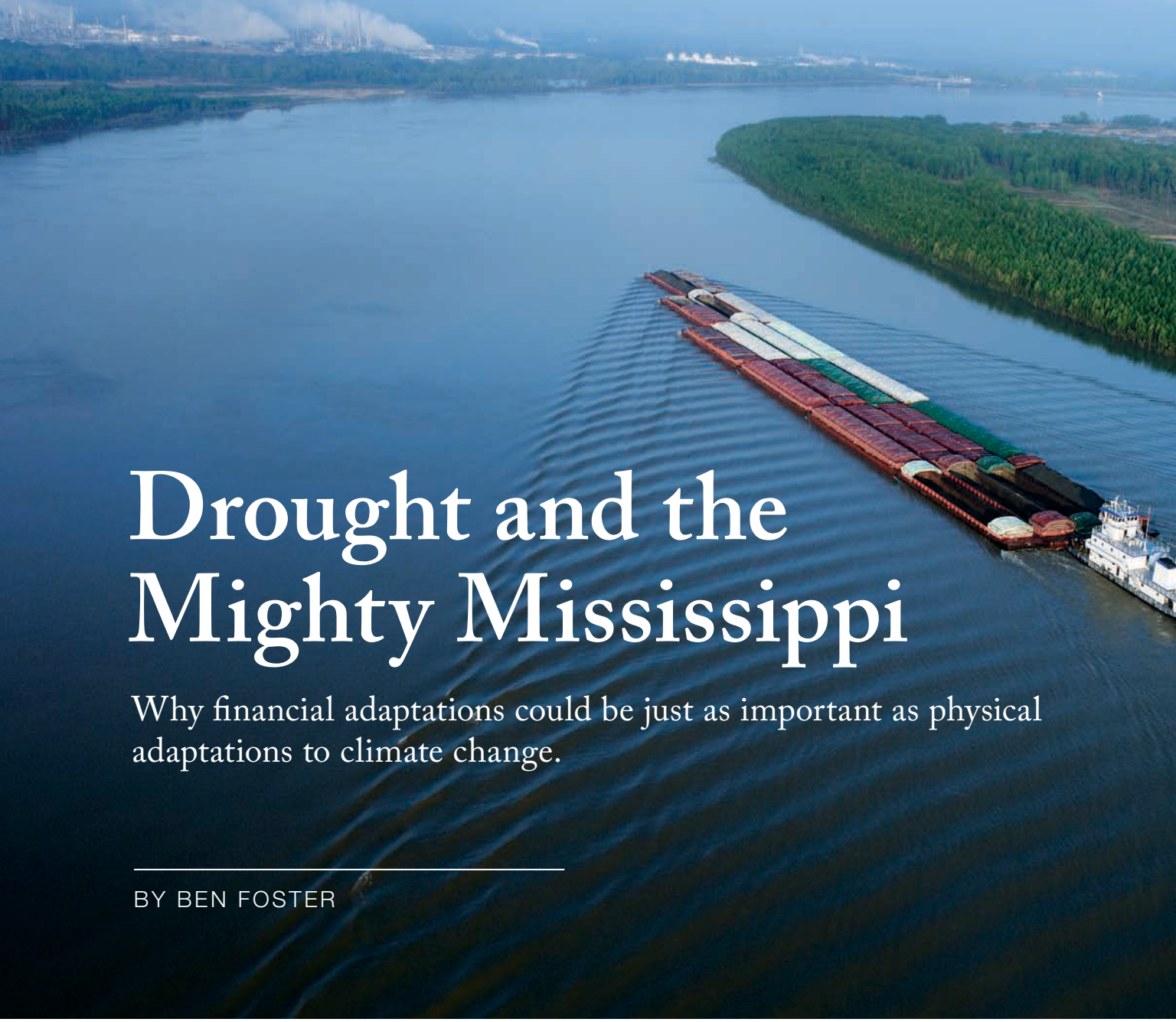
Decades from now, some of today's coffee-farming families will surely find that cacao, mangoes, or another line of work entirely are better options than coffee production. But one advantage for whoever becomes the next generation of coffee farmers is that the craze for pour-overs, espressos, and other high-priced coffee drinks shows no sign of slowing any time soon. Overall, it's a good bet that this demand will continue to drive innovation and adaptation, ensuring that coffee drinkers around the globe can still get their fix. But a long way from the trendy cafes, there will be significant changes in land use and production techniques across the tropics.

Small-scale farmers might have a leg up with certain adaptation challenges. If Brazil loses a significant portion of its coffee-growing area, the world market would lose a huge chunk of its volume. Producers like Vietnam—which hardly grew coffee 30 years ago but now ranks second in the world by growing the species of the plant that's used in cheap, instant coffee—could fill in that volume at the low end of the market. That might leave smallholders high up in the mountains, whether in East Africa, the Andes, or Papua New Guinea, better suited to supply specialty markets.

The demand for coffee will continue to drive innovation and adaptation. But a long way from the trendy cafes, there will be significant changes in land use and production techniques.

"The solution for coffee and climate change will not be one big, blunt hammer," writes Hanna Neuschwander of WCR, "it will be thousands of tiny hammers, designed to hit very specific nails." Adaptations and solutions to changing climates will likely look very different from Brazil to Ethiopia to Haiti. Despite a spate of doomsday media headlines about "coffee's coming extinction" due to climate change, global demand will continue to drive innovations from the coffee farmers, agronomists, and researchers who make the sector their lives and livelihoods—and ensure pour overs and espressos remain. But from farmers' perspectives, the world of coffee production may look very different in the next 50 years—and it's possible many will not call themselves coffee growers anymore.

Tate Watkins is a research fellow and managing editor of *PERC Reports*. He previously worked with small-scale farmers in the Haitian coffee sector.



Drought and the Mighty Mississippi

Why financial adaptations could be just as important as physical adaptations to climate change.

BY BEN FOSTER

When most people think about climate adaptation, they think of sea walls, levees, dams, and other massive infrastructure projects that reduce our exposure to extreme weather. While these projects can be effective in some cases, uncertainty about future conditions—both climatic and economic—often poses significant and costly design challenges. By focusing on large infrastructure projects, we often overlook another means by which we can adapt to a changing climate: financial markets.

Financial instruments have long been used to manage uncertainty in economic conditions. Futures markets and options contracts, for instance, are commonly used to reduce risk and hedge against uncertain outcomes. So why not look to financial markets to manage risks related to a changing climate? The answer is that, to some extent, we already are.

Recent financial innovations are creating new tools specifically designed to mitigate the impacts of extreme environmental conditions. But more could be done. If the long-run goal is to minimize the cost of a changing climate, a greater reliance on these financial strategies could be less expensive and more flexible than depending on traditional concrete-and-rebar physical adaptations, particularly when the events of concern are low probability and high impact.

THE DROUGHT OF 2012

Financial contracts can serve two beneficial functions when it comes to adaptation to climate change: First, they provide a hedge against financial losses related to environmental shocks, and second, they provide important price signals that help coordinate the mitigation of other risks.

To illustrate the value of these two functions, consider the U.S. drought of 2012-13, which dramatically reduced crop yields across the Midwest and nearly brought barge traffic on the Mississippi River to a standstill due to receding water levels. This event offers insight into how financial markets can limit the impacts of extreme weather and demonstrates the potential value of using these strategies to adapt to changing climate conditions.

Financial strategies could be less expensive and more flexible than traditional concrete-and-rebar physical adaptations.

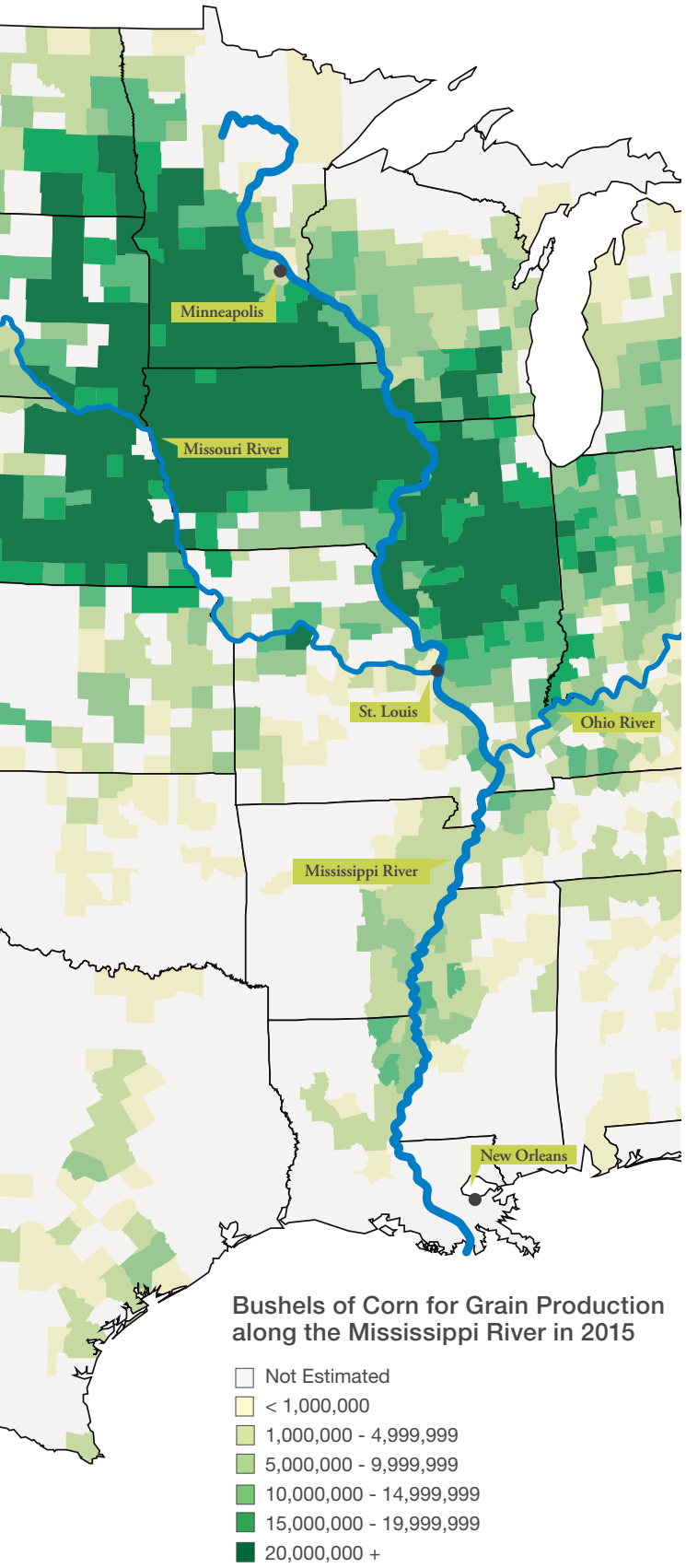
In June 2012, water levels on the lower stretches of the Mississippi River had fallen so low that fully loaded barges were at risk of running aground. In response, the U.S. Coast Guard restricted barge drafts (the distance from the water surface to the bottom of the hull) to just 10.5 feet, a foot-and-a-half less than normal. The result was that the average barge's cargo capacity fell by about 300 tons—a loss of more than 7,000 tons per 24-barge tow.

Shippers and carriers panicked, eventually leading to a flurry of emergency dredging by the U.S. Army Corps of Engineers. But transportation on the river was far from the only consequence of the drought. Agricultural yields were also affected. The corn crop was hardest hit, with the harvest ending up 26 percent below the U.S. Department of Agriculture's pre-drought prediction. By the time rain arrived in early 2013, the drought had cost the United States approximately $32 billion in total, almost $5 billion of which was a reduction in net farm income.

WHAT PRICES REVEAL

The 2012 drought was a complicated event with consequences that reverberated throughout the economy. Prices, though, give us a window into how various market actors adapted their strategies—both logistic and financial—to manage the impacts of the drought.

In the case of corn, market prices convey information about not only current conditions but also expectations about the future, allowing people to make the best decisions about where and when they should buy, sell, or transport the commodity. For example, if prices in downriver markets are high relative to upriver markets, corn sellers will be more inclined to pay the costs of transporting their product to the downriver markets. Or if navigation disruptions are expected to halt barge traffic in the near future, as happened during the 2012 drought, then corn marketers may be more likely to either hold corn in storage or sell it into upriver domestic markets.



Source: U.S. Department of Agriculture, National Agricultural Statistics Service

Buyers and sellers harness the information embedded in market prices to avoid crippling financial losses. This can take the form of purchasing hedging contracts, such as forwards or futures, or altering marketing strategies, such as holding corn in storage, using a different form of transportation, or selling it into a different market altogether. To the extent these strategies are used effectively by relevant parties in response to market prices, financial risk will be spread out, and the worst financial outcomes—such as bankruptcies, defaults on debt, or extreme price swings—will be largely avoided. Third-party insurance or hedging products such as environmentally indexed insurance or catastrophe bonds can also further spread these types of risk.

In 2012, spot prices revealed one important logistical reaction to the drought. Rather than sending corn to export ports near New Orleans at high cost (either on the river or via more expensive overland modes), many marketers instead sold corn into upriver domestic markets for use in animal feed or ethanol. U.S. corn exports fell 52 percent from the year before, making it one of the few years that the United States was not the world's leading corn exporter. By contrast, American producers used only 6 percent and 5 percent less corn for feed and ethanol respectively, a small reduction considering the poor harvest.

While spot prices give insights into the logistical tradeoffs of bringing corn to market, *forward prices* tell us how valuable logistical flexibility can be for adapting to future drought expectations. In the case of corn, there are robust forward markets at multiple locations along the Mississippi River. Forward prices are agreed upon today for corn delivery at some point in the future (for example, "the first business day of December," or "30 days from now"). These contracts act as an important risk management tool by providing a hedge against sudden corn price changes, including those related to increases in transportation costs due to disruptions in river navigation. As opposed to futures contracts—which are similar in function but traded on a centralized exchange—forward contracts are location specific. This allows them to provide a better hedge against environmental shocks that affect financial outcomes on local levels. During the 2012 drought, forward contracts were important for corn markets because navigation disruptions affected different sections of the Mississippi River at different times.

Forward prices can also reveal a great deal of information about expected future environmental and economic conditions. In fact, prices help organize market-wide responses to shifts in environmental conditions *prior to* their onset. This allows interested parties to glean information about future conditions just by looking at prices, rather than having to make their own

predictions about the future. Empowered with this information, producers and consumers can make decisions today that may help mitigate losses in the future. And because prices can adjust quickly to new information, these adaptations can be incredibly powerful if the probability or magnitude of extreme events changes in the future. In stark contrast, dams and sea walls cannot easily be disassembled, altered, or rebuilt elsewhere when new information becomes available.

WHEN PAPER BEATS ROCK

Extreme droughts like the one in 2012 are nothing new. In fact, a similar drought occurred on the Mississippi River in 1988. But the parameters of drought could be changing. Scientists predict that climate change could make droughts longer and more frequent in some places but shorter and less frequent in others. Either way, this much is clear: We face a future of increased uncertainty, where historic probabilities and magnitudes of extreme droughts may no longer be representative of future risk.

Often, the first instinct when confronted with this uncertainty is to think immediately of physical adaptations. In fact, this was the exact response by many parties during and after the 2012 drought. Industry groups and shippers immediately began lobbying the Army Corps to implement emergency dredging operations to alleviate navigation restrictions. As conditions worsened, there were requests for additional interventions, such as altering the operating rules of upstream Missouri River dams to provide increased flows on the Mississippi. Some called for increased investment in physical infrastructure to guard against future emergencies.

Because infrastructure is usually unchangeable, or at least very expensive to alter, and its lifetime can span many decades, infrastructure projects can be troublesome if weather conditions deviate from the projections used at the time they were built. Over- or under-design could lead to over- or under-investment in such projects—a serious issue for both public and private investors, especially when most of these projects are financed with debt.

Financial adaptations avoid these problems. They don't require long-term investment and can be modified in the face of changing conditions. While financial markets can't entirely prevent losses, they spread them out and allow exposed parties to pursue strategies that can avoid some of the most devastating financial outcomes. And in most cases, the best adaptation strategies will likely involve a combination of the two. Identifying the trade-offs between the array of financial and physical options available is an ongoing and innovative area of study.

The 2012 drought was a complicated event with consequences that reverberated throughout the economy. Prices give us a window into how various market actors adapted their strategies—both logistic and financial—to manage the impacts of the drought.

THE FUTURE OF ADAPTATION

As a commodity, corn has obvious advantages that make it especially adaptable in financial markets: It can be stored. It can be moved by barge or rail. It can be sold in a variety of markets. It has well-developed forward and futures markets. An important question is whether financial adaptations could have the same potential for other important resources affected by a changing climate.

Even if this is not yet the case in other markets, innovations in financial contracts that target specific environmental risks could become useful in a variety of settings. Weather derivatives have long been used in energy markets, and more environmentally indexed derivative or insurance contracts are being used to manage environmental risk in other settings. Catastrophe bonds have also become popular for managing high-cost, low-probability risks.

Developing a better understanding of how markets react to environmental shocks could change the way we think about climate adaptation. In particular, it could alter how we evaluate traditional infrastructure adaptations. It might also highlight opportunities for entrepreneurs to create new financial products to address environmental risks, which would help all of us adapt to the uncertainties of a changing world.

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The Hole in the EPA's Ozone Regulations

The agency's past efforts to limit ozone emissions backfired. Will its new regulations work this time?

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In October 2015 the Environmental Protection Agency (EPA) announced new rules to cut ozone in the ambient air to 70 parts per billion (ppb) from the currently mandated 75 ppb. Despite an attempt by the House of Representatives to block the rules, and in the face of several ongoing legal challenges, the EPA is now writing the regulations that will implement the new standards.

According to the EPA's most recent analysis, the new rules would cost $1.4 billion per year to implement but yield annual benefits of $2.9 billion to $5.4 billion, including the avoidance of 320 to 660 premature deaths each year. Yet earlier EPA analysis of the proposed rules yielded much higher cost estimates, and even today, 19 major metropolitan areas have not managed to meet the existing 75 ppb standard issued in 2008.

The EPA would have us believe that cutting allowable ozone to 70 ppb will reduce illness and save lives. But careful analyses of past EPA ozone rules suggest that the new standards are unlikely to live up to the agency's promises.

A study by Vernon Henderson (1996) documents one such analysis. During the early decades of EPA's ozone rules, the agency focused on peak levels of ozone—measured by one-hour concentrations. The regulations did reduce the number of areas with high peak concentrations by about 15 percent—a success, it would seem. Yet there were also fewer areas with very low peak readings;

instead of cutting ozone across the board, the rules led to peak readings that tended to cluster just below the federal standard. The distribution of peak and average ozone concentrations thus became more compact: fewer highs, but also fewer lows.

What is more striking is that the rules did *not* reduce average—and thus total—concentrations of ozone across the country. Indeed, Henderson found that overall ozone exposure *rose* by about 10 percent. Cuts in peak emissions in some areas were more than offset by higher off-peak emissions in those areas and by rising overall emissions throughout the nation.

How could this happen? There were two mechanisms, neither of which the EPA seemed to contemplate beforehand. First, the timing of economic activity over the day changed. To comply with the rules, businesses shifted their activities from peak ozone times to off-peak times. Moreover, some businesses shifted operations from high ozone areas to locales with lower initial levels, areas where there was still room to increase pollutants without hitting the EPA's peak standard. These two responses—presumably unintended consequences of the EPA standard—reduced peak exposure but on balance raised total ozone exposure. Eventually, the EPA decided that one-hour peak exposures were not the correct target for its rules, so in 1997 it began regulating the pollutant based on average eight-hour exposures.

Cuts in peak emissions in some areas were more than offset by higher off-peak emissions in those areas and by rising overall emissions throughout the nation.

More recent ozone rules have also failed to deliver their intended results. The gasoline we burn in our cars is a major source of volatile organic compounds (VOCs), which are an important contributor to ozone. Thus, a key part of the EPA's post-1997 ozone strategy has focused on this fuel. Specifically, the agency began requiring oil companies to reformulate gasoline so that it would generate fewer VOCs. A recent study by Maximilian Auffhammer and Ryan Kellogg (2011), however, finds no evidence that this effort has resulted in meaningful ozone reductions.

The reformulation process has added about 1.5 cents per gallon to the cost of refining gasoline. At 140 billion gallons per year, this translates into higher total costs of about $2 billion per year. Because the EPA has different formulation rules for different locales across the country, gasoline that may lawfully be sold in one area is unlawful in others—some perhaps immediately adjacent. The resulting segmentation of gasoline markets prevents sellers from moving gasoline from low-price areas to high-price areas. The consequence is prices at the pump that are much higher than even the added refining costs, plus periodic gasoline shortages in areas subject to the tougher rules.

Sadly, these costs and disruptions have come without the benefits promised by the EPA. The agency's rules limit the total evaporation of VOCs from gasoline—but without regard to which particular VOCs are most important in the creation of ozone. Under the rules, refiners are free to choose which VOCs to remove from their gasoline. It turns out that it is cheapest to reduce a type of VOC that is only weakly related to ozone formation, so this is the one that refiners cut. As Auffhammer and Kellogg demonstrate, the result is that the EPA's rules have essentially no effect in reducing the ozone that we breathe.

Many people complain that government agencies let us down because bureaucratic inertia results in inaction. In the case of the EPA, however, the ozone rules suggest a greater problem: the inability of the agency to deliver action that makes our lives better.

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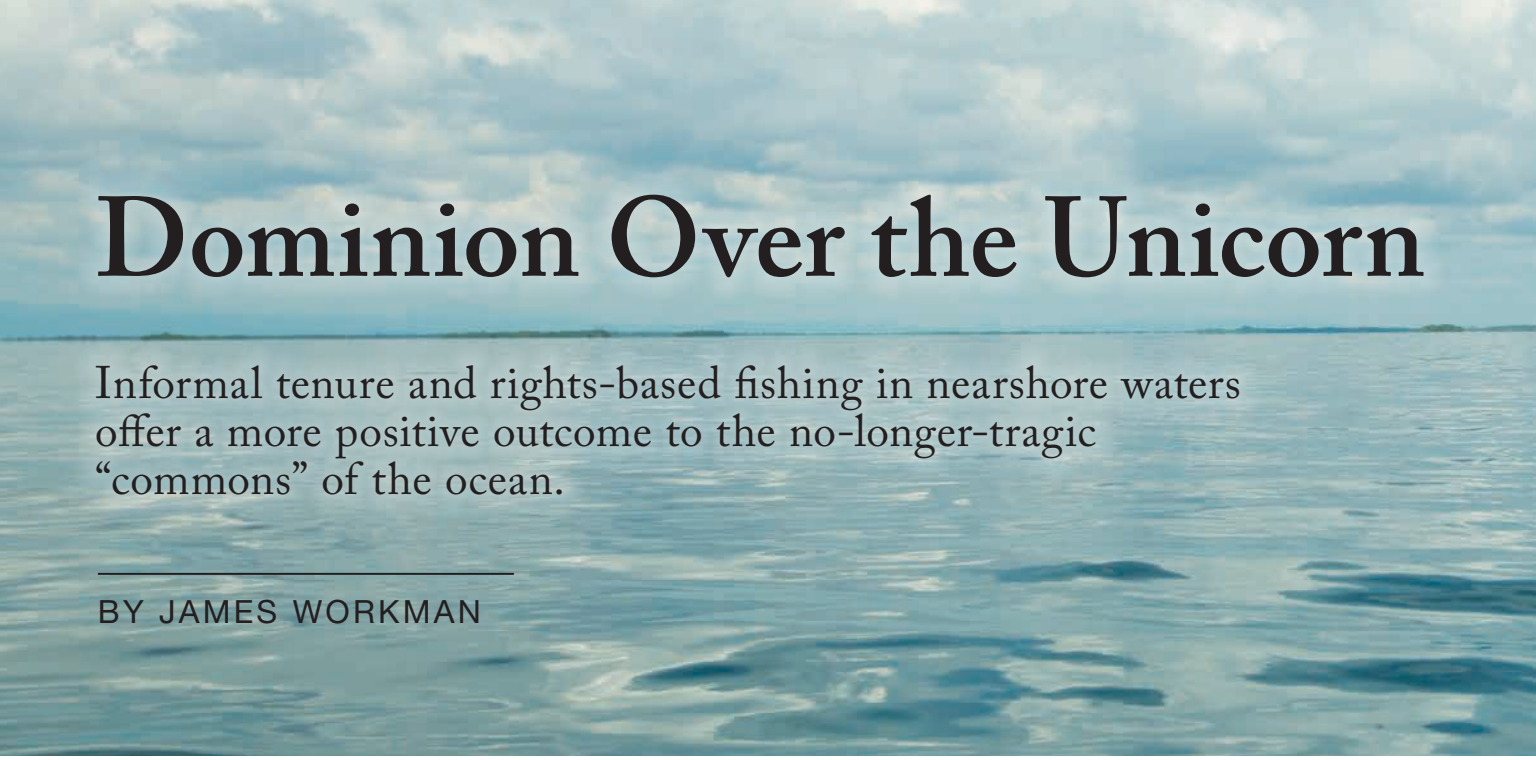

Dominion Over the Unicorn

Informal tenure and rights-based fishing in nearshore waters offer a more positive outcome to the no-longer-tragic "commons" of the ocean.

BY JAMES WORKMAN

The addiction began when I was 12, overpowered by the pull of psychedelic colors. The fix was immersion with snorkel and mask in the warm waters of that fringing coral reef in Kaua'i. There, countless Moorish idols, masked triggerfish, wrasse, and polka-dotted boxfish swam about their business. A lionfish glowered; a spotted ray glided past. Amidst Darth Vader breaths I heard the background crackle of feeding shrimp, punctuated by the crunch of parrotfish teeth on coral. Above all, near shore swam the strange big fish I came to know in an almost proprietary way: a resident school of *kala*. The tang species can grow two feet long, with olive-yellow skin, astonished eyes, cobalt tail spots, and a thin horn protruding from the head which gives its name: *Naso unicornis*, or bluespine unicornfish.

The rush couldn't last. Back on the beach, I shook saltwater from my ears as six heavy-set locals, or *kane*, came trudging across the sand past me. The men surveyed the sea like surfers watching wave breaks. But the water was calm. They hadn't come to play.

They wore cutoff jeans, neoprene booties, sideburns, and moustaches. A few carried dive masks with broken straps and a fine-mesh gillnet. The group eased in chest deep and took positions. Deep breaths, a nod from the leader, and the work began.

They formed an arc. Those in masks ducked underwater. Others maneuvered backward or sideways, fast as crabs, quietly gesturing with hands, heads, or feet. The group rotated, pulled the net taut, and burst into violent splashing. Their half-circle spiraled inward, then out, as men yanked the net down, pinned it to the sand with a foot, then leaned back as a tight-knit system. Soon their net quivered with life until they dragged it up onto the shore in a tangled heap.

As the men picked out their catch I counted a dozen of the gasping animals. Their glimmering scales faded to a dull sheen, blotted with wet sand. My unicornfish. Unable to get close while snorkeling, I reached out now to touch the rough skin as the gills stopped moving.

This impromptu Hawai'ian fish harvest, or *hukilau*, lasted all of 15 minutes. Then the fishermen vanished into the trees. While shaking out beach mats, my parents marveled at "an art" more authentic than the "canned shtick at Fern Grotto." It felt like I'd been mugged, and I resented the menacing strangers at our pristine reef who killed my fish and left behind a hole.

THAT DAY INTRODUCED me to the so-called tragedy of the nearshore commons, a zone shared globally by millions of coastal communities. With families to support, men like these depend on the ocean for food. On average such families may eat half a pound of seafood per week, which can provide remarkably nutritious protein for an increasingly crowded, hungry world.

Ostensibly, the sea is free. It belongs to anyone and everyone, outsider or local,

Empowered through locally designed Territorial Use Rights for Fishing (TURF) programs, millions of small-scale fishermen are gaining secure, long-term incentives to be stewards of nearshore waters. *Photo credit: John Rae*

tourist or harvester. My liberty to snorkel meant their liberty to find the shortest distance from the reef to hand to mouth. But it was clear even then that open access to all could lead to collapse if there was nothing to sort out my visual hunger or their real hunger. That's when my addiction got complicated.

I was still sulking that evening at an informal cafe where my family ordered fresh poi, made of pounded local taro root, and "mahi-mahi," or dolphinfish, whose thin but firm, moist filets vanished from our plates. On my way to the bathroom, I made a wrong turn. In the garbage outside the kitchen I saw the heads and bony remains of the dinner I'd just devoured. My stomach clenched as I noticed the protruding horn of a unicornfish.

At the kitchen door, I looked up at the cook and dishwasher. They were the same men from the beach, who had been holding the net. That's when I made the link between supply and demand, producer and consumer, complicit in nudging *Naso unicornis* closer to local extinction. I met the guilty, menacing stranger who poaches fish and leaves a hole in the sea, and it was me.

Worse, I was far from alone. My middle-class family was then, in 1980, part of a rising human tide encroaching on the earth's shores. Over the previous two decades, annual tourism to these remote islands had mushroomed from 100,000 overnight visitors to 3.5 million. Within a decade it would double. Haena reef was a sleepy patch on a secluded coast of the farthest northwestern island in the last colonized archipelago in the most distant patch of the largest ocean. Human impacts on the sea here meant that on more densely populated shores the pressure would be crushing. Soon there'd be nothing left to see, or to harvest. As the men looked at me, I felt I should say something to stop us all from crossing a point of no return. But as our eyes connected, we remained silent.

FOR SOME THERE is nothing we *can* say to reconcile diverse life with human hunger. The nearshore commons falls into

Bluespine Unicornfish

the abyss between private property and public state. Even if those island kane had held back that day, nothing prevented others from killing the unicornfish the next. Only rigid enforcement of ironclad laws by sovereign powers might restrain such basic instincts—and even that might not be enough to prevent the tragedy of the commons.

Garrett Hardin crystalized this fatalistic mindset in a parable that went beyond wild fish to put at stake the existence of all life. By 1968, Hardin had grown so troubled by overpopulation and the biological imperative to breed (a concern that emerged only after he became a father of four), that he constructed a metaphor about the dangers of free will. In an open-access public "commons," every producer is aware that natural resources—from a grassy pasture to a shore filled with unicornfish—are finite, but each is compelled to harvest past the point of irreversible systemic collapse. "Ruin is the destination toward which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons," Hardin wrote. "Freedom in a commons brings ruin to all."

This "tragedy" fueled authoritarian impulses among liberals and conservatives alike. Left and Right agreed coercion was the only solution, and only differed over where and against whom to apply force. To prevent this chaos of human appetites, the sovereign state faced two mutually exclusive options in the nearshore ocean commons: Either police could guard public natural resources from private theft via strict regulation (i.e. marine reserves). Or police could guard private property from public theft through strict privatization (i.e. fish farms).

But what if there was more to it than this public-private dichotomy? What if there was a force to reverse the vicious cycle and turn the tide in favor of a resilient and productive reef?

It turns out there was, and, with trust, can be once more. The late Nobel laureate Elinor Ostrom showed how traditional communities around the world evolved informal systems for self-regulating their access to and use of natural resources. From ridge out to reef, Hawai'ians had clearly defined rules, or *pono*, that judiciously guided equitable harvests, trade, and natural resource stewardship, or *malama*. Their system, known as *ahupua'a*, was an ancient form of what we now call "territorial user rights to fishing," or TURFs, that have evolved along tropical coastlines throughout the Pacific, from Fiji and Vanuatu to the Cook Islands and Palau to Northern Australia. In industrial nations, while big, regulated commercial fisheries like cod, whiting, snapper, or pollock get all the attention, it is these small-scale, nearshore

In Belize, Fidel Audinette helped pioneer a demonstration fishing rights or "managed access" program, which is being formally expanded under national policy. *Photo credit: John Rae*

fisheries that hold real potential for secure fishing rights as ocean governance shifts responsibility toward local hands.

I COULDN'T SEE IT at the time, but what I was witnessing that morning was part of an informal but effective and long-standing system, which revealed that the nearshore commons need not be tragic. Building on the work of Elinor Ostrom, researchers have now examined hundreds of fisheries globally and found that a key to recovery is to empower fishermen with secure, long-term rights to the resource; in exchange, they adhere to responsible limits on what they catch. This unlocks a profound stewardship incentive: Fishermen (along with restaurants and tourists) benefit financially as fish populations rebound.

Traditional and formal fishing rights have been taking shape around the world for years. After decades of decline in the United States, many of the biggest commercial fisheries have now adopted "catch shares." Under these systems, fish populations are rebounding, while the number of fishing jobs has increased 23 percent, and fishing revenues are up 30 percent. They boost resilience. Even reef fisheries in the Gulf of Mexico, hard hit by the 2010 Deepwater Horizon oil spill, are doing better. Red snapper catches have more than doubled, revenues have increased by 108 percent, and today there are three times more red snapper in the ocean. Last year, with two-thirds of federally managed fisheries under catch shares, the U.S. government announced that overfishing was at an all-time low.

For another example, consider Belize, which in recent decades suffered sharp declines in reef fish and conch; spiny lobster harvests shrank from 200 per day to 20 for many fishermen. Then two groups of fishermen tried a new approach called "managed access"—essentially a TURF—granting them secure rights to their historical fishing areas, and everything changed. Early adopters saw a dramatic decline in illegal fishing, fish populations started to stabilize and rebound, and fishing businesses grew. Fishermen became champions of nearby marine protected areas. Word spread up the coast until nearly all 3,000 fishermen wanted the same opportunities. Recently, Belize voted to scale its TURFs nationwide.

In the Philippines, where 85 percent of fishermen are small scale and more than half of the animal protein in the country's diet comes from fishing, the nearshore commons was in trouble until recently. Overfishing meant the catch of the average hook-and-line fisherman had dropped from 72 pounds per trip in the 1970s to just 7 pounds today. But there, too, coastal communities are forming TURFs, linking exclusive access rights and responsibilities.

In a race against time, can the rights-based renaissance of nearshore fisheries take root fast enough? In remote places, there are signs that the old unwritten rules may still be intact, offering a cornerstone on which to build trust.

I RETURNED TO HAENA three decades after I first visited, an overweight father of two daughters, aged four and seven, who'd been nurtured in chlorinated pools. In the rental car they slept in the back seat, dreaming, perhaps of the fictional realities of *Finding Nemo*, *The Little Mermaid* or *Spongebob Squarepants*. At road's end, I lugged a beach bag down to the water's edge. Then I took my eldest by the hand and waded with her into the wild and buoyant warm salt water. Fitted with a small mask, she learned to breathe through a snorkel, and she noticed the small pipefish and wrasse. Gripping hands, we drifted out deeper. After 15 minutes kicking and paddling with her free arm, her hand tightened. She stopped, lifted her head and shoved the snorkel from her mouth. Her eyes were ecstatic.

I couldn't see it at the time, but I was witnessing part of an informal but effective system, which revealed that the nearshore commons need not be tragic.

"Daddy," she sputtered. "Did you see them? The funny-looking ones?"

She described several large round fish with blue spots near their tails. The big ones, she said, appeared to have horns growing out of their foreheads.

She wanted to know their name.

James Workman works for Environmental Defense Fund's Oceans program, where with Amanda Leland he is co-authoring "Sea Change: The Quiet Revolution in Fisheries That Is Transforming Life Offshore—and On." He is an alum of PERC's Enviropreneur Institute.

The Power of Prices

An innovative contract pays farmers to conserve water.

Thanks to a mixture of "no-till" pasture management and regenerative grazing practices on the Double Check Ranch in southeastern Arizona, more water is left in the San Pedro River.

We like to nod sagely at the abstract "value" of water, yet few of us know its actual price. For reference, the average cost of the bottled water you toss back at a family barbeque is about a buck-and-half per gallon. On my 215 arable acres along the San Pedro River of southeastern Arizona, the price is considerably less. In fact, the only "price" I've ever tracked is the electric utility's rate to operate a commercial irrigation pump—around $120 per month, or 0.003 cents per gallon.

Until recently, I couldn't have even told you how much water I was using. That is, until my family agreed to an irrigation-reduction contract with the Arizona Land and Water Trust. This market transaction has spurred us to conserve water and represents the first instance of water payments in one of the Southwest's most ecologically significant riparian areas. It also demonstrates how information can be discovered through the application of site-specific knowledge. Friedrich Hayek is no doubt nodding in his grave.

Here's how it happened: My family supplies beef to farmers' markets and restaurants in Tucson and Phoenix, and we finish our cattle on irrigated land along the San Pedro River. We recently adopted a "no-till" model of pasture management, hoping to establish a base crop of native perennial grasses that would provide year-round forage for our cattle. We also hoped

the change would reduce our water consumption by increasing the soil's capacity for retaining our limited rainfall. The experiment has paid off—and in some unforeseen ways.

After spending a couple of seasons fiddling with seed-drills and 14-way native seed mixes, we discovered that reestablishing native grasses was actually quite simple. By ending the annual tillage and using regenerative grazing practices, we were able to develop a thick sward of native grass that is both beautiful and productive. Nevertheless, even though we were interested in conserving water, we still had no absolute sense of our water consumption or any incentive to economize, since the resource went "un-priced" in any meaningful sense.

Then, a few years ago, the Arizona Land and Water Trust approached us about their privately funded irrigation-offset program. The Trust heard about our work with native grasses and, knowing that we refuse public subsidies, invited us to apply to their Desert Rivers Initiative, which seeks willing farmers to fallow their fields seasonally so that water can be left in-stream to improve riparian conditions. In exchange, the program pays landowners the equivalent commodity value of the crop they would forego.

We agreed to participate, but with a caveat: Rather than a full fallowing, we proposed an arrangement in which we reduced, rather than ceased, our pumping. A recent picture in National Geographic, which showed the extent of perennial grass root structure (with root mats 13 feet deep), convinced us of the net positive hydrological gains of well-managed perennial pasture. We wanted our pastures to remain a "sponge" for the riparian zone, rather than become an un-irrigated hardpan that would simply flush water into the river basin.

After experimenting with fallowing the pastures for a full year—which took quite a toll on the native grass—the Trust agreed to alter the contract and extend the payment period over two years of water reduction instead of a full one-year cessation. We now work within a water budget of 135 acre-feet per year, which enables us to sparingly use irrigation to maintain perennial pastures while leaving a significant amount of water in the stream.

This deal represents an important lesson in how on-the-ground market transactions can flexibly adjust to site-specific conditions, allowing environmental sanity to prevail. We now have a deep root base that holds our pastures in a stable matrix, slowly releasing rainfall and irrigation water back into the riparian zone. And if our experiment in "lightly irrigated" perennial pastures turns out to be wrong, then we have created a dynamic market relationship that can adjust accordingly.

The deal represents an important lesson in how on-the-ground market transactions can flexibly adjust to site-specific conditions, allowing environmental sanity to prevail.

What is striking about our project is its relative simplicity. Although we are managing unimaginably complex ecological systems, our ranch and the Trust were able to spontaneously create a water market, albeit a small one, that strips away much of the underlying complexity. The prices we've created are tentative and subject to change—as all prices are—but they represent one of the first voluntary comparisons of relative water values between agricultural producers and environmentally motivated consumers in our region. Moreover, we are hoping to demonstrate that well-managed landscapes can be a net positive for ecological stability and the provision of environmental goods. With creativity, land management decisions can generate win-win returns.

Price is a noun, not a verb. The challenge, therefore, is not to simply "price" something but to discover what its price is. Rather than imposing prices based on the ordained judgments of central planners—as is often done with environmental resources—markets provide the rough-and-tumble process of price discovery that helps solve Hayek's "knowledge problem." The free-market contracting that we're experimenting with in the arid Southwest may prove to be the most efficient and the most just way to save the West's most "priceless" resource.

Paul Schwennesen is a rancher and owner of Double Check Ranch in Tucson, Arizona, and a frequent contributor to PERC. He is also an alum of PERC's Enviropreneur Institute.

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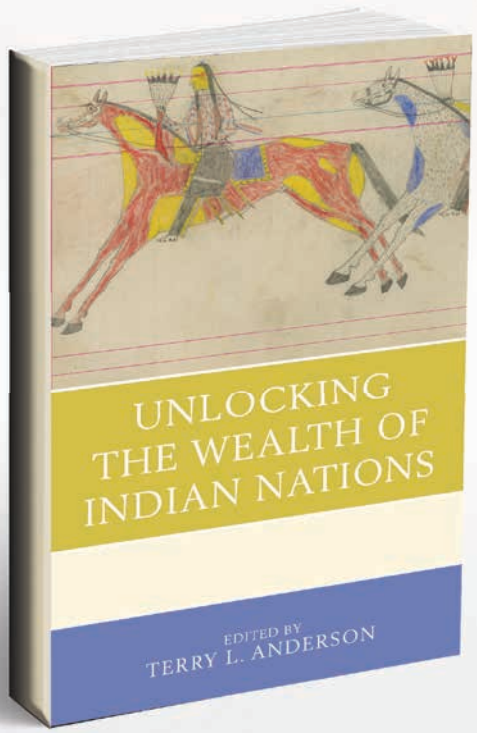

Unlocking the Wealth of Indian Nations

Edited by Terry L. Anderson

"The comparative development of the American Indian Nations provides an unrivaled natural experiment with enormous relevance to social scientists. This volume isn't therefore just a practical agenda to help some of the most marginalized people in the US, it's also an important intellectual milestone."
—*James Robinson, University of Chicago*

"In *Unlocking the Wealth of Indian Nations*, Terry Anderson has assembled an excellent collection of essays confirming the failure of more than a century of top-down, federal paternalism and the promise of bottom-up institutional development by autonomous Indian nations and their citizenry. Through many examples drawn from a wide sampling of native populations, the authors provide convincing proof that, as in the past, property rights and trade are the keys to unlocking the future wealth of Indian nations."
—*James Huffman, Lewis & Clark Law School*

Most American Indian reservations are islands of poverty in a sea of wealth, but they do not have to remain that way. To extract themselves from poverty, Native Americans will have to build on their rich cultural history, including familiarity with markets, and integrate themselves into modern economies by creating institutions that reward productivity and entrepreneurship and that establish tribal governments that are capable of providing a stable rule of law. The chapters in this volume document the involvement of indigenous people in market economies long before European contact, provide evidence of how the wealth of Indian Nations has been held hostage to bureaucratic red tape, and explain how their wealth can be unlocked through self-determination and sovereignty.

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