White Paper—Conference Proceedings

Systemic Risk in Global Agriculture

Princeton-Columbia Joint Conference

Hosted by:

Agriculture and Food Security Center, The Earth Institute, Columbia University

and

PIIRS Global Systemic Risk Research Community, Princeton University

---

Princeton, New Jersey
October 24-25, 2014

PRINCETON UNIVERSITY

PRINCETON INSTITUTE FOR INTERNATIONAL AND REGIONAL STUDIES

Agriculture and Food Security Center
EARTH INSTITUTE | COLUMBIA UNIVERSITY

Table of Contents

Conference Participants 5

Executive Summary 5

Introduction 6

The Current State of Global Agriculture 7

Systemic Risks in Agriculture 13
- Environmental Risks 13
  - Risks to Agriculture from the Environment 13
  - Risks to The Environment from Agriculture 14
- Nutritional and Health Risks 16
- Conflict and Disease Risks 18
- Demographic Risks 20
- Financial Risks 23
  - Market Risks 23
  - Investment Risks 24
- Technology and Innovation Risks 25
- Efficiency, Profit-Maximization, and Specialization Risks 28
- Complexity, Globalization, and Interconnectivity Risks 30
- Psychological and Behavioral Risks 33

Proposed Solutions 35
- Environmental Risks 35
- Nutrition and Health Risks 38
- Conflict and Disease Risks 39
- Demographic Risks 41
- Financial Risks 42
- Technology and Innovation Risks 44
- Efficiency, Profit-Maximization, and Specialization Risks 46
- Complexity, Globalization, and Interconnectivity Risks 48
- Psychological and Behavioral Risks 51
- Governance Solutions 53

Conclusion 57

Conference Schedule 58

Last Name Index 62

Conference Participants*

Shukri Ahmed, Miguel Centeno, Erik Chavez, Luc Christiaensen, Kaitlin Cordes, Otto Doering, Barbara Ekwall, Shenggen Fan, Jessica Fanzo, Michael Hauser, John Ikerd, Laura Kahn, Robert Kopp, Marc Levy, Ezra Markowitz, Dan Osgood, Stephen Pacala, Cheryl Palm, Michael Puma, Dan Rubenstein, Pedro Sanchez, Wolfram Schlenker, Tim Searchinger, Eldar Shafir, Rob Socolow, Calum Turvey, John Wargo

Executive Summary

The Green Revolution is estimated to have led to our collective ability to feed over one billion additional people largely through scientific advances in crop and soil science. Modern information technology, communication, and transportation have woven interdependent networks that provide greater efficiency of both production and delivery of food, which has led to a systems-driven revolution in agriculture. However, the large scale and advanced technical nature of these complex systems comes at the cost of greater fragility. The critical nature of the agricultural system as the source and sustenance of life elevates the study and remediation of this fragility to a global priority.

The emerging research fields of systemic risk and systems thinking provide insight into understanding and mitigating the current risks and challenges in our global agriculture network. This network is a system-of-systems that begins beneath the ground with our aquifers and soil. Subsequently, it extends through the crops with bidirectional effects between environment and climate, trade and finance, and human health and livelihood. Finally, with its effect on political stability, the network extends into the realm of policy and governance.

This conference and the summary of the proceedings first explore the current challenges to modern agriculture. Next, we seek to contribute to the research field by applying systems thinking in order to explain these critical challenges. Finally, we attempt to understand the implications for prescriptive analysis and governance in pursuit of the goals of greater productivity, mitigating risk, and increasing resilience.

---

* Conference Proceedings and transcript prepared by Michael Byrnes, Peter Callahan, Karla Cook, August Kiles, and Thayer Patterson. Special thanks to Jayne Bialkowski and Nita Mallina at PIIRS and Mary Pasquince at Agriculture and Food Security Center, The Earth Institute, Columbia University. Conference videos and transcript available at risk.princeton.edu. Please send comments or corrections to the PIIRS Global Systemic Risk research community at gsr@princeton.edu.

Introduction

Modernity and increasing prosperity have improved human health and survival through profound advancements in technology and through increasing efficiencies in both the production and the provision of goods and services. Nowhere has this been more critical and apparent than in our global agriculture system. Scientific knowledge and technological innovation have been woven into an increasingly complex and interdependent network of agricultural production and delivery of food. However, these advancements and efficiencies come at the cost of greater systemic fragility and risk, with the increasing potential for catastrophic consequences.

To understand systemic risk, it is necessary to apply an interdisciplinary approach, as the study of risk and the analysis of systems can only be understood by combining insights from academic disciplines as diverse as the natural sciences, engineering, sociology, anthropology, history, philosophy, psychology, public policy, politics, law, economics, finance, operations research, mathematics, and statistics. The goal of this conference was to generate an interdisciplinary conversation among scholars who study agriculture, systems, and risk in order to identify the causes and consequences of agricultural fragility, and to propose solutions for increasing resilience within the agricultural system.

The conference, co-hosted by Pedro Sanchez, Senior Research Scholar and Director of the Agriculture and Food Security Center at the Earth Institute at Columbia University, and Miguel Centeno, Director of the PIIRS Global Systemic Risk Research Community and Professor of Sociology at Princeton University, brought together 27 experts from a variety of fields to discuss topics within the theme of agricultural systemic risk over two days at Princeton University. In each of six panels, individual speakers presented the major risks and potential solutions identified in their research. Subsequently, the panelists engaged in discussion with each other and with the attendees to discover and address common themes and trends among the different disciplines. To encourage interdisciplinary solutions, panels were organized such that group discussions were the focus of the conference, and individual presentations simply served as an outline of key talking points for the structured conversations.

The conference began by presenting a descriptive analysis of the current state of global agriculture, and how it has developed and evolved in recent decades. Critical to the development of modern agriculture are scientific advancements and new methods in agriculture, the proliferation of industrial agriculture, the increasing crop yields through innovation and soil science resulting from the Green Revolution, the increasing interaction effects between agriculture and climate, demographic changes, and effects of health science, diet, and education on agricultural choices. The Green Revolution, launched by Norman Borlaug in the 1940s and 1950s, is credited with producing additional agricultural outputs to save over one billion people from starvation worldwide. When combined with the increasing interconnectedness enabled by high tech communication and transportation, all of these effects together have enabled the development of our modern interdependent global agricultural system.

After developing a systemic view of global agriculture, the conference participants identified

Conference Co-Hosts Pedro Sanchez and Miguel Centeno

Eldar Shafir, John Ikerd, Shenggen Fan, and Tim Searchinger

Participants were optimistic about the potential for a more resilient future in agriculture through continued interdisciplinary collaboration and communication, and through the development and advancement of a systems-based approach to the study of agriculture.

major risks in environmental science, nutrition, epidemiology, finance, psychology, politics, and governance. Many participants noted that these risks are closely interconnected and are therefore challenging to resolve without a unified, interdisciplinary approach.

Finally, conference participants suggested prescriptive methods for addressing these concerns, with the goal of reducing risk and increasing resilience in the global agricultural system. Toward these interrelated goals, participants first discussed the primary driver or systemic risk and fragility—the impact of population growth and demographic changes throughout the world. Participants then advocated innovative solutions for climate change, an increased emphasis on nutrition, and a greater understanding of the effects of political and human conflict on agriculture. Next, scholars stressed the need to address institutional risks through the development of tailored financial instruments for mitigating agricultural risks, deeper understanding of our technologies and their consequences, a shift of focus from efficiency to robustness, and acknowledgment of our cognitive limitations and psychological biases when dealing with complex and nested systems. Finally, at the center of many calls to action were the consistent themes of effective education, cooperation, and governance at local, regional, and international levels.

The Current State of Global Agriculture

During the proceedings, Sanchez, the 2002 World Food Prize laureate, described witnessing many of these advances in agriculture in his experience as a pioneer in the science and application of tropical soil agronomy that has revolutionized agriculture in South America and Africa. Sanchez set the parameters of the discussion by defining agriculture as a "human-dominated ecosystem that produces crops, livestock, forestry, agro-forestry, and fisheries." Humans have been managing productive ecosystems for millennia, but the last half-century has seen dramatic changes in technology, transportation, and management practices that have allowed the agricultural system to grow globally at an unprecedented rate. This growth has typically come in the form of a transition toward "industrial agriculture," where an emphasis on efficiency and economies of scale has created a global system entirely different from that which existed in the early twentieth century.

To better understand the current state of global agriculture, some sought to identify the forces driving modern agricultural transformations. Some of the invited scholars considered advancements in technology and new methods of farming to be the greatest catalysts for change in this field. For example, Tim Searchinger, Research Scholar in Science, Technology, and Environmental Policy at Princeton University, asserted that technology has dictated the path dependency of the evolution of the agricultural system. Searchinger said, "Agriculture responds extraordinarily vibrantly to new technologies, and that has been the overwhelming driver" for recent progress. Other scholars recognized the importance of technology, but focused instead on economic drivers to explain how we arrived at our current agricultural system. John Ikerd, Professor Agricultural and Applied Economics at the University of Missouri–Columbia, said, "All of our agricultural policies since the New Deal, in one way or another, have subsidized the industrialization of agriculture." Ikerd discussed the change in national economic policies in his lifetime, and said, " I saw the shift from supporting the independent family farms to supporting industrial agriculture." While technologies have enabled this new type of agriculture, Ikerd insisted that they are "motivated by economics," and that without current incentive packages, our technologies, and consequently our farmlands, would look significantly different.

While the panelists were split between technology and economic policies as the most important driver, there was uniform agreement that the global agricultural system has indeed transformed, and the panelists then worked to outline the ways in which it has changed. For Shenggen Fan, Director General of the International Food Policy Research Institute (IFPRI), the changes were profound enough for him to juxtapose "old agriculture" and "new agriculture" in stark contrast during the first panel discussion. One of the major differences between the "new" and "old" global systems is the sheer size of farms on which we rely for food production. Fan articulated that in the past, the "small is beautiful" mentality from economics also dominated agricultural thought, and smallholder farms were considered the norm. As mentioned above, Ikerd also touched on this when he illustrated that recent transitions have marked the death of smallholder family farms that once defined global production. Today, these small farms have been replaced by industrial agriculture where massive tracts of land are often managed and controlled by one conglomerate or corporation. For example, John Wargo, Professor of Risk Analysis, Environmental Policy, and Political Science at Yale University, illustrated this with the example of Swiss transnational corporation Nestlé, the largest food company in the world by revenue, with 339,000 employees in 194 countries. According to Wargo, "Nestlé is trying to control their supply chain all the way to the marketplace—to the consumer." He summarized the broader effect of corporate agriculture by saying, "What we are seeing is a concentration of power, capital, and expertise in the

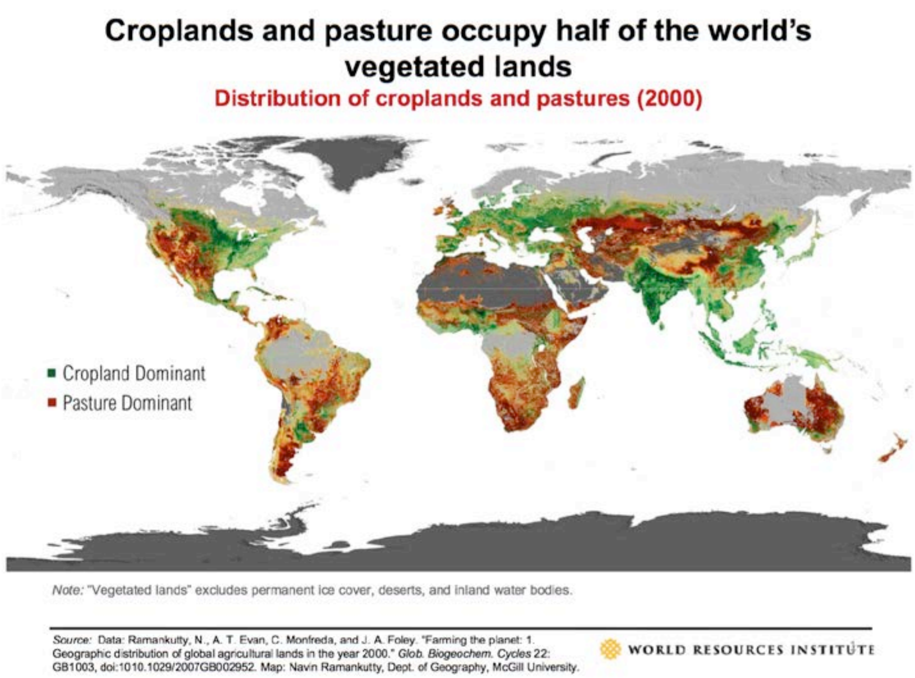


Image from Searchinger's presentation, which shows the massive impact of global agricultural land use

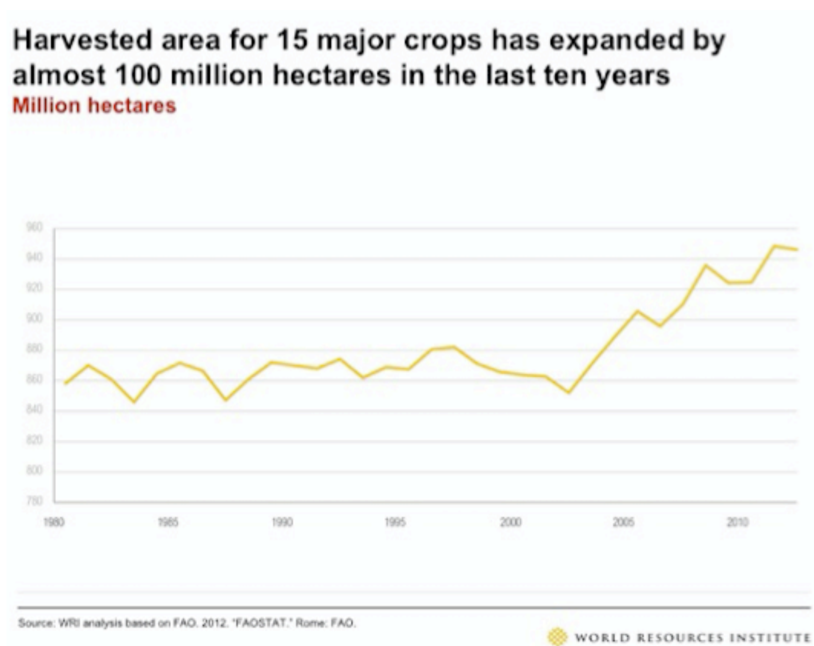
private sector that we haven't seen before."

These new large-scale operations would be impossible without the technology and scientific advancements that enable industrial agriculture today. Some of the greatest technological and methodological changes have taken place at the soil level, where new fertilizers, seeds, pesticides, and management strategies have dramatically impacted crop yields. Soils that were considered low quality or even barren just decades ago are now experiencing tremendous productivity and the countries in these previously infertile areas are able to reap the benefits. When discussing advances in Brazilian soil science and crop yields, Sanchez noted, "They've learned how to manage, and they can compete very well."

Some technologies used in agriculture were adopted from medicine, and have since had tremendous impacts on industrial agriculture. According to Dr. Laura Kahn, Research Scholar in Science and Global Security at Princeton, "There has been a rather parallel evolution between medicine and agriculture in the twentieth century: both have become increasingly specialized, technologically driven, and both are equally dependent on antibiotics." In Kahn's opinion, there is no doubt that today's high-output meat production industry would be difficult to sustain without antibiotics. Also borrowed from medicine, the scientific advancements in genetically modified organisms (GMOs) similarly have played an important role in enabling greater productivity. Though banned in certain parts of the world, GMOs are relied upon heavily for designing plants resistant to insects and pesticides, changing the nutritional output of croplands, and increasing the shelf life of produce. Long associated with the Green Revolution, new technologies and advancements were seen as the answer to Malthusian concerns about the exponential global population growth. As high fertility rates and increased urbanization put tremendous strain on rural communities to produce more food, changing technologies helped build the "new" agricultural system to meet that growing demand we see today.

The panelists spoke about how the agricultural system of today remains inextricably linked to weather and the environment despite these new technologies and innovations. For example, in Europe and the U.S., home to some of the most productive farmland on Earth, only 10% of the cropland is irrigated, while the remaining 90% is rain-fed. Some developments have buffered the environment's impact on productivity, but farmers around the world are starting to see climate change strain their yields, as more extreme weather events have become increasingly unpredictable. "We are still as dependent upon the productivity of the earth, the soil, what comes from that earth—the farmers, the plants, the animals—as we were when we were hunters and gatherers," said Ikerd. "Our dependency is just more complex and less direct and we don't realize it."

In addition to these complex effects of climate change, intensified agriculture also takes a toll on global ecosystems, and the panelists



Graph from Searchinger's presentation showing the scale of crop development in recent years.

Laura Kahn, John Wargo, Shukri Ahmed, Jessica Fanzo, and Marc Levy

acknowledged that the industrialized status quo is environmentally burdensome. Searchinger noted, “We produce an unbelievable amount of food to feed an amazing number of people, and we’ve had gigantic, gigantic yield gains, and it’s just that feeding people is a really tough thing on the planet.” Cheryl Palm, Senior Research Scientist at the Agriculture and Food Security Center at Columbia University, noted that while overuse of pesticides and fertilizers can damage soil, agriculture intensification can similarly render land unproductive by depleting necessary minerals and nutrients. “We’re all familiar with that side of environmental degradation with agriculture,” Palm explained. “Not as many people are aware that when you don’t put things on, you also degrade the environment. And it needs a lot more attention.”

Another notable characteristic of this “new” system has been a gradual shift away from self-sufficiency toward more calculated interdependency. By relying on trade and the global market, many nations have decreased harvest diversity in order to be more efficient, productive, and globally competitive. Focusing on just a few crops, nations with industrial farmland can benefit from the comparative advantage of their massive yields, and then trade to fulfill the country’s needs using proceeds from these “cash crops.” One of the key effects of this transition toward an agriculture system is, Centeno said, “You have specialization of production versus subsistence and self-sufficiency.” Michael Puma, Conference Co-Organizer, Research Scientist and Adjunct Assistant Professor in Climate Systems at Columbia University, also acknowledged this shift using a case study. Puma explained, “Ghana is a country that was self-sufficient in their staple food production. Now they have shifted away to more cash crops and now they rely on imports for the staple foods.”

This industrial production and increased international market efficiency has also transformed the economics of agriculture. Luc Christiaensen, Senior Economist at the World Bank (Africa Region), said of agriculture, “One challenge for the sector is to provide sufficient and cheap food, which could then release labor to do other things.” With developments in farming technologies, this challenge has been met in some ways and Christiaensen said, “From the 70s onwards, food prices [have been] on a downward trend.” Simplifying the equation, Fan stated, “When you produce more food, prices go down.” Kahn provided evidence for how these changing prices have impacted Americans in the past century with data she presented from the U.S. Department of Agriculture, which showed that while Americans previously had to spend approximately 25% of their disposable income on food in the 1930s, that number has dropped to less than 10% today. Kahn added that “our consumer economy depends upon relatively inexpensive food. If people spent most of their income on food, as in many poor, developing countries, then they would not have enough disposable income left to pay for computers and other products.”

While the share of disposable income required for food has gone down globally, this change is most striking in the U.S. and wealthy European nations. This can be explained partly by the massive amount of food that those wealthier countries produce through their advanced industrialized methods. Wolfram Schlenker, Professor of International and Public Affairs at Columbia University, cited Kenneth Cassman, a University of Nebraska-Lincoln professor of agronomy, to explore this point in the U.S. Schlenker said, “Four staple commodities—corn, wheat, rice, and soybeans—constitute 75% of our calories that we consume as humans either directly or indirectly through feedlots. The U.S. produces 23% of those four commodities in terms of calories.” These four crops are hugely important for the global food system, and by producing nearly a quarter of the available stores globally, the U.S. is in a strong market position to keep prices low. At 23%, Schlenker said, “The U.S. market share [of these staple crops] is roughly three-times the share of Saudi Arabia’s in oil.”

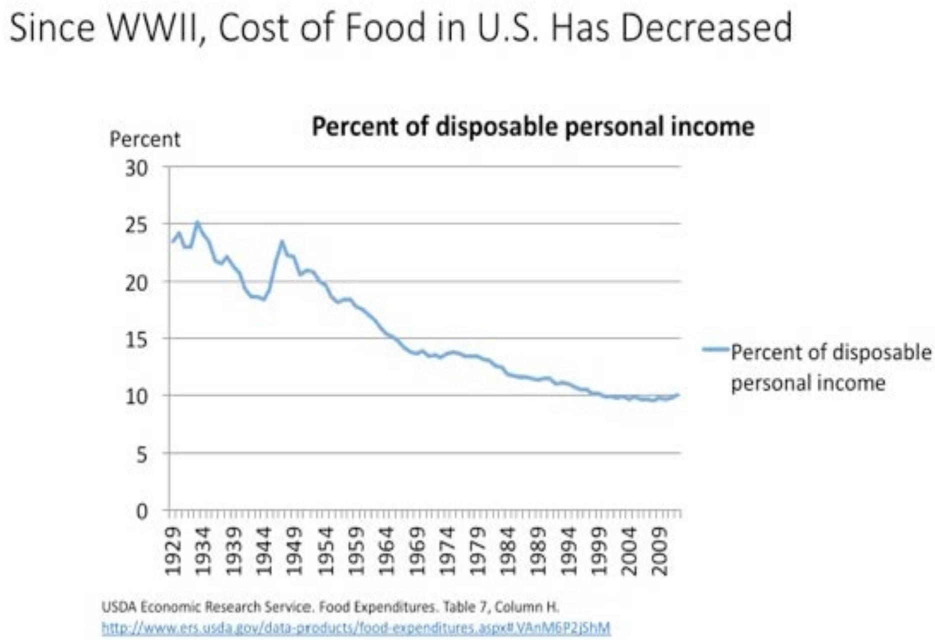


Figure on declining historic food costs from Kahn’s presentation

As food grows cheaper and continues to be imported, exported, and shipped around the world, global tastes and preferences in food have evolved as well. Barbara Ekwall, Senior Liaison Officer at FAO, discussed how changes in supply have led to changes in demand. “Today we have packaging systems, we have refrigeration chains, we have a lot of new technologies that allow us to bring food to market quicker and much more efficiently,” Ekwall said. “Consumers want to have the same products the whole year.” While in the past local demand depended on regional weather-based availability, today, she noted, “You don’t recognize any seasonality of the products that you are buying.” Strawberries, for example, are available year-round, and the increasingly globalized industrial system is giving consumers options they never had before. Nowhere is this more apparent than in meat, fish, and dairy availability. Due to the use of antibiotics, intensified feedlots, and other technologies mentioned above, animal products are more affordable than ever before, and large populations that historically relied on plant-based diets now have the means to consume new proteins. “Meat intake and dairy intake in Asian nations is increasing,” said Wargo. As an effect, in order to meet growing demand by 2050, Searchinger cited estimates: “We need about 80-90% more milk and meat from pasturelands.” Fan illustrated this as well with a personal anecdote from his childhood. “I come from a country where the food consumption has experienced a rapid transformation,” said Fan. “I used to eat three rice meals a day back in China and we only had a half hectare for my whole family. We were able to feed the whole family of five, but in the meantime we sold almost half our food to the urban cities. But today, our consumption is basically meat, fish, not so much rice, wheat, vegetables. So that diet pattern is not sustainable.”

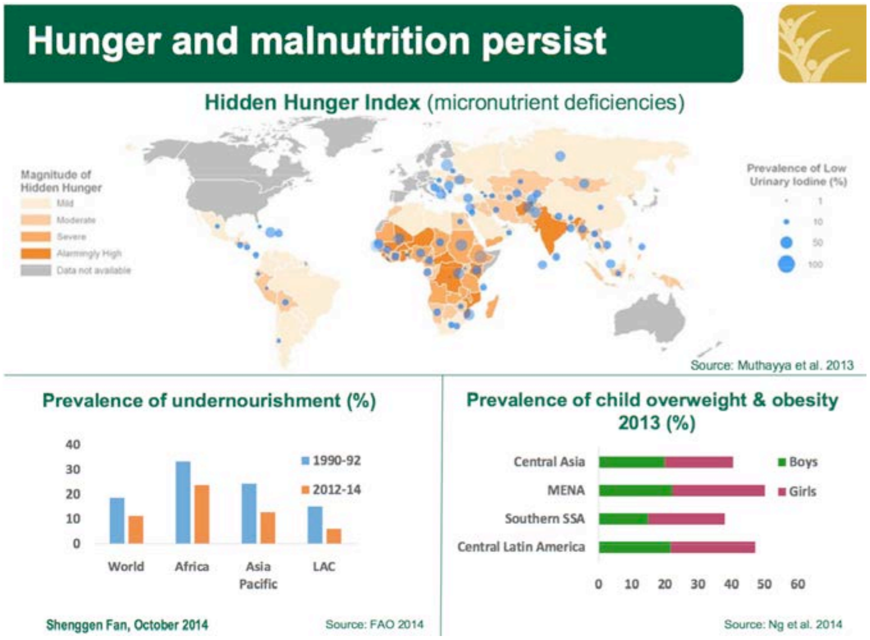


Figure on undernourishment from Fan's presentation

Despite the food availability and increased efficiencies that have developed out of this system, there are still many ways the current state of agriculture is wasteful and ineffective. The main indicator of this is that hunger still persists throughout the world. "We are producing enough food for every man, woman, and child, yet we have approximately 800 million people who go to bed hungry every night." said Kaitlin Cordes, a human rights lawyer and Associate Research Scholar at Columbia University Law School and Columbia's Earth Institute. For Ikerd, this represents "an absolute failure" of industrialized agriculture, which does not succeed at its primary job—feeding the hungry. "The fundamental purpose of agriculture is to provide food for people, not just to increase production," said Ikerd. "It's to provide food security for people, which means providing enough safe, wholesome food so that everyone can live a healthy, active lifestyle. It has failed to do that." Other panelists, like Fan, took a slightly more optimistic approach. Fan justified his hopeful outlook: "In 1990, the hunger rate was about 18-19%. Today, it's about 12%." Fan sees this as a triumph of industrial agriculture, but concedes, "Tremendous progress has been made, but in the meantime, a lot of people are still hungry."

One major problem that panelists identified as contributing to continued hunger in today's global agricultural system was food waste. Losing food to disease, rot, pests, or bad management in the fields, or on the way to market has been a problem throughout agricultural history. But despite scientific advancements in production and transportation, food waste persists globally today. Estimates show that approximately 30% of all food is never consumed. Whether this waste occurs between crop seeds and the market , or "between the refrigerator and our trashcan," as Sanchez put it, waste represents lost nutrition unavailable to help fight global hunger. After presenting compelling statistics, Ekwall concluded, "Food loss and waste shows that the food systems are not working in an optimal manner."

To summarize, today's agricultural system is completely transformed. Technology-driven yet still heavily dependent on environmental factors, agriculture has become increasingly intensified, industrialized, and interdependent. Food has become cheaper than ever, and production is dominated by wealthy nations in the West. Consumers expect food to be available regardless of the season, and animal products are much more widely available thanks to changing economics and technologies. While these increases in production have given more people access to food, malnutrition and hunger are still important concerns. Though the overall efficiency of the global agricultural system has increased dramatically, the system remains imperfect as long as massive food waste continues to be prevalent.

Once the current state of agriculture had been established, the panelists moved on to the main purpose of the conference: identifying and discussing the risks and vulnerabilities of our current global agricultural system.

Systemic Risks in Agriculture

Environmental Risks

Environmental risks were a critical part of the conference discussion, and the panelists divided these risks into two distinct categories. First, the environment presents systemic risks to the agriculture industry. Second, conversely, agriculture itself actually poses risk to the environment.

Risks to Agriculture from the Environment

"Agriculture is an inherently risky business," according to Sanchez. This is primarily because of its dependence on weather and the environment. As climate change makes extreme environmental events and scenarios more common, this "riskiness" continues to grow. Robert Kopp, Professor of Earth and Planetary Sciences at Rutgers University, said, "What was once a one-in-twenty-year climatic shock sort of becomes the new norm." Dan Osgood, Research Scientist in Economic Modeling and Climate at Columbia University, added, "For many farmers, climate change means more bad years."

Schlenker presented one of the most robust examples of how the changing environment poses significant risks to the agricultural system. Through his research, he showed that as temperatures increase globally, crop yields slowly increase as well. This trend continues until a temperature ceiling is reached, after which production falls off dramatically. "In a moderate range," explained Schlenker, "as temperatures get warmer, yields actually increase and then there's this sort of upper limit which is around 29° C [84° F] for corn, and 30° C [86° F] for soybeans, after which further temperature increases become harmful." According to his research, the benefits of increased production as the thermostat rises do not offset the negative impacts of crossing the upper threshold. "The slope of the decline [in yields] is about an order of magnitude larger than the slope of the incline," said Schlenker. "If you make things hotter with climate change, then basically you have a beneficial effect of making the cooler temperatures medium, but you have a real detrimental effect of shifting the moderate [temperatures] to the extreme heat. And given that the slope [of the decline] is ten times as big, it just dominates everything."

Other panelists backed up Schlenker's findings on the risks of temperature on yields. Otto Doering, Professor of Agricultural Economics at Purdue University, expressed that even increased irrigation and different farming techniques will not help plants once temperatures rise above a certain threshold. "The ability of the plant to transpire is limited," added Doering. "It literally cannot keep the leaves cool, no matter how much water you apply." Kopp also showed models that corroborated these findings, while Sanchez added that plants are incredibly vulnerable to high temperatures, especially when temperatures remain high overnight. Erik Chavez, Research Associate in Environmental Policy at Imperial College in London, also contributed to this discussion by identifying a possible gap in the literature. While the negative impacts of extreme heat are undisputed everywhere in the world where it has been tested, Chavez argued that a better

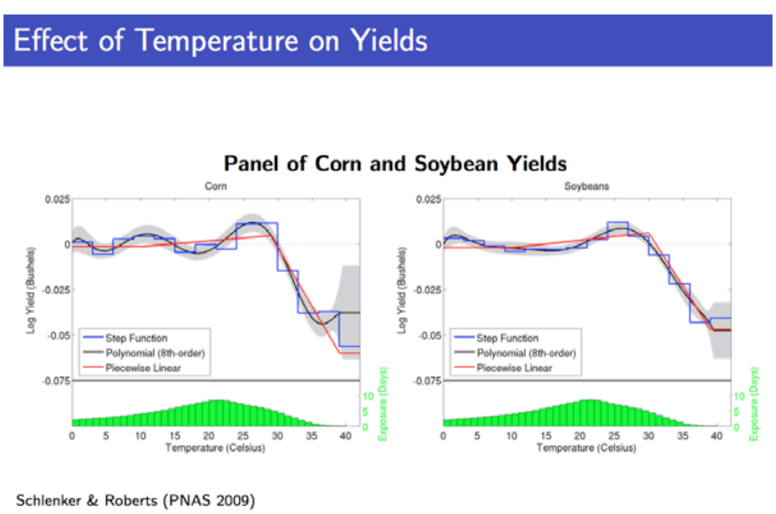


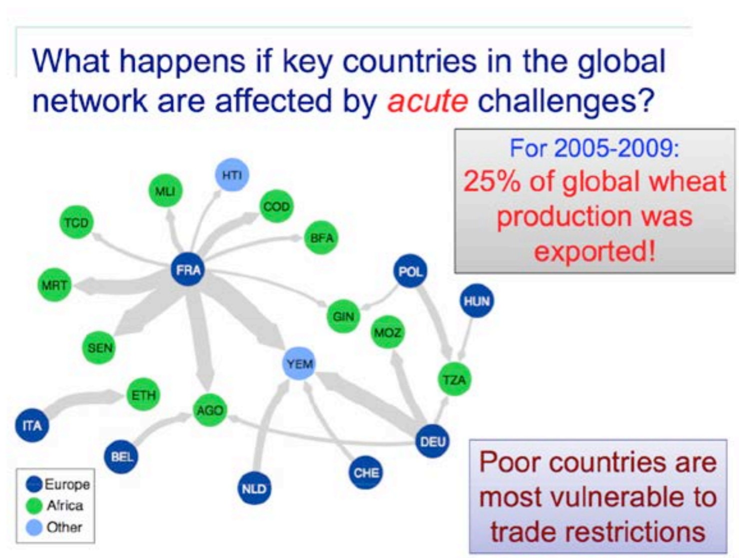
Chart from Schlenker's presentation showing the relationship between temperature and yields

Dan Rubenstein, Pedro Sanchez, Michael Puma, and Barbara Ekwall

understanding of crops in tropical and generally poorer regions would make these finding even more robust.

Moving on from the topic of temperature, panelists discussed other environmental factors that pose threats to the agricultural system. As mentioned above, the majority of our croplands depend on rainfall for their productivity, making them particularly susceptible to water-related environmental risks. Doering expressed concerns that climate change is leading to heavier rainfall at less frequent intervals. "What that means," said Doering, "is soil ability to hold water becomes increasingly important and it also changes the whole ballgame in terms of erosion." Looking at water risks as they relate to sea level change, both Puma and Sanchez were concerned about how rising salt water will impact global output. Desalination remains too expensive for large-scale agricultural use and crops are incredibly sensitive to even small amounts of brine used in watering.

In his presentation on water and agriculture, Puma applied medical terminology and metaphors to water challenges, referring to long-term problems as "chronic symptoms" and short-term problems as "acute." Depleting groundwater aquifers and other issues that develop over time fall under the category of chronic symptoms, while shocks to yields or extreme weather events can be considered acute. Puma spoke about how both types of symptoms are very closely linked to the agricultural system, and how the increasing globalization of agricultural markets can make local water symptoms a worldwide risk. To illustrate this point, Puma looked at how small regions can be responsible for a large portion of staple crop consumption in the developing world. He noted that 25% of the world's wheat is exported and one such exporter, France, is a critical producer of the wheat consumed in Africa and other developing nations. If France or another staple producer were hit by a drought or another water-related problem, the impacts would be felt globally. The risks from water and the environment, therefore, become far greater when put in the context of our current interconnected agricultural system.



Slide from Puma's presentation, which shows how "acute" water challenges could be devastating for food supply in vulnerable regions of the world

Risks to The Environment from Agriculture

The panelists then explored ways the global agriculture system puts the environment at risk. One of the most important effects that agriculture has on environmental risks is its contribution to climate change through greenhouse gas emissions. Searchinger provided data behind this concern that land-use change and the production process have had a significant impact, and said, "Agriculture now produces about one quarter of all the world's greenhouse gas emissions." Referencing the literature and his own predictive models, Searchinger explained that between 2006-2050, farms will have to produce 70% more crops and 80-90% more milk and animal protein globally to meet rising demands. Searchinger stressed how difficult it will be to increase the food supply this much in a sustainable and environmentally responsible way, and acknowledged, "Climate change is going to make yield gains harder." "Most analyses of how you might hold climate change to 2°C say we have to have total human emissions of [at most] 21-22 gigatons of greenhouse gasses… by 2050," Searchinger said. He added, "According to projections I've put out, agriculture should produce about 15 gigatons of greenhouse gasses... by [2050]. So that means, that agriculture alone would be responsible for about 70% of the allowable [21-22 gigaton] budget." He further discussed how this would be unacceptable and presented potential solutions.

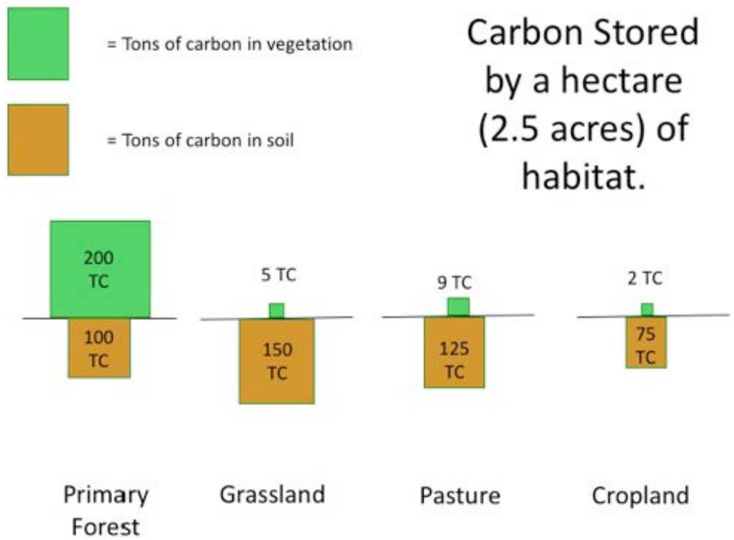


Figure from Pacala's presentation showing how carbon is stored in different land-use categories

As mentioned above, land-use change remains a major contributor to agricultural greenhouse gas emissions. According to Stephen Pacala, Professor of Ecology and Evolutionary Biology at Princeton University, "Roughly one-third of historic global warming was created by land-use change… If we take [one hectare of] a primary forest and convert it into a cropland, that represents, after all of the dynamics take place, a one-time transfer of 200-2=198 tonnes of carbon [from vegetation] to the atmosphere, and 100-75=25 tonnes of soil carbon to the atmosphere." These statistics were supported with a compelling visual graphic demonstrating this fact that primary forest holds 100-times the amount of carbon in vegetation and one-third more carbon in the soil than cropland. Agreeing with Searchinger, Pacala insisted this massive one-time transfer is critical and said, "Expansion of agriculture has the potential to actually be a major disruption in the carbon cycle."

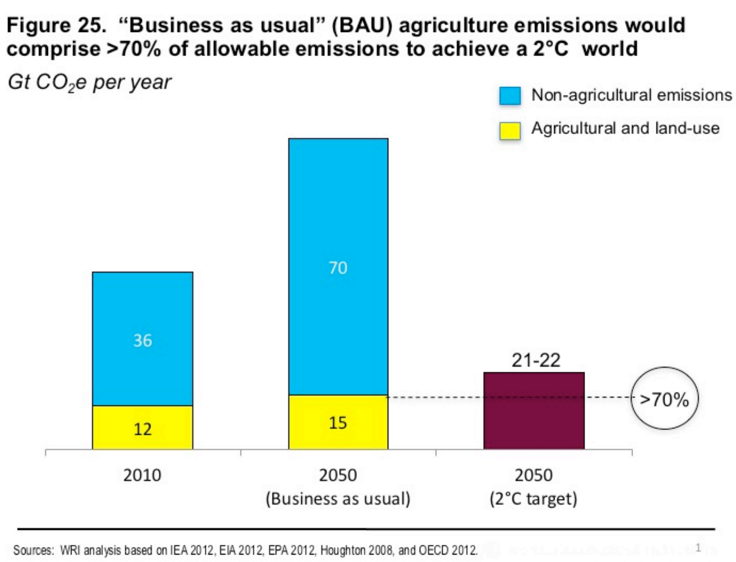


Figure from Searchinger presentation showing how business as usual agricultural development will make 2050 carbon targets difficult to achieve.

One potential mitigator to increased emissions is known as "CO_2 fertilization." Pacala explained the effect of this process whereby plants reabsorb previously emitted carbon, and said, "When you add CO_2 to the atmosphere, plants gain weight." The hope is that the increased biomass from this CO_2

fertilization could begin to offset the massive amount of carbon released through agriculture, but the panelists agree that this idea is too risky to depend upon heavily for emissions reduction. There are significant doubts about the impacts CO_2 enrichment might have even if it worked to its full potential. In addition, if assumptions about CO_2 fertilization are wrong and plant growth becomes limited by nitrogen or another element, Pacala illustrated how this would be "a catastrophe," where atmospheric carbon reaches astronomical highs.

In addition to the risks that agriculture poses to the environment through carbon emissions, panelists also demonstrated concern about chemicals used in intensified agriculture and their potential damage in global ecosystems. "There are more than 1,000 active pesticide ingredients that are used in agriculture," said Wargo, along with "hundreds of different pharmaceuticals." Combined with the liberal application of fertilizers, this abundance of chemicals can easily leach out of industrial fields to impact water, ecosystem services, and endangered species in the surrounding area. For example, Wargo added, "Neonicotinoids have been implicated in the decline of bee populations," and surface water eutrophication is often spurred on by nutrient runoff from farmland.

Further contributing to the systemic risks of chemical use to the environment is the loss of biodiversity that intensified agriculture promotes. Biodiverse primary forests are cleared and many farmers who previously rotated plant types now seek to enhance efficiency by specializing with large monocrops. New technologies have enabled this transition away from biodiversity and some panelists expressed concerns about this impact over time. GMOs, for example, have been very effective at optimizing yields, but also encourage the use of a single seed type in farmlands across the globe. As a genetically modified seed is customized in the laboratory to be resistant to certain herbicides and insecticides, the increased use of this GMO crop is often accompanied by greater use of these pesticides. "It may not be the issue that the GMOs themselves are the problem," said Wargo, "but especially when the companies are producing specific strains that can take over such a large portion of the landscape, it promotes a reduction in biological diversity of our food supply, and it also concentrates a very specialized set of technologies [pesticides] on very large tracts of our ecosystem." Reducing biodiversity for the sake of agriculture is an environmental risk in itself, but that risk is compounded by the fact that it encourages greater concentrations of chemicals as well.

Stephen Pacala

Finally, the panelists also discussed the idea of "sustainable diets," and many concluded that global preferences are becoming increasingly risky from an environmental impact perspective. Jessica Fanzo, Professor of Nutrition at Columbia University, challenged the other speakers to ask, "How can we—the planet—consume a healthy diet that treads lightly on the earth?" Consumers tend to ignore the environmental consequences of the food they buy. Similarly, government agencies are prone to disregard the environment when giving advice to the general public. To illustrate this, Fanzo claimed, "If everyone in the United States followed the guidelines [from USDA & HHS for fish and seafood consumption] we would deplete the marine natural resources in about 50 years."

Nutritional and Health Risks

Nutrition and health have always been closely tied to agriculture and food. Some health and nutritional risks from the "old" agricultural system are still with us today and modern agriculture has given rise to various new systemic health and nutrition challenges.

As mentioned previously, the modern agricultural system still perpetuates systemic hunger and malnutrition despite enjoying massive increases in yields since the early twentieth century. Providing a framework through which to think about hunger, Fan outlined the FAO's "triple burden of malnutrition," which identifies three distinct challenges in this arena. First, there is "undernourishment," which relates to the 800 million people globally who lack adequate daily caloric intake. The next dimension of malnutrition is "hidden hunger." People in this category might not seem hungry or appear to be underfed, but their diets lack essential micronutrients and vitamins, which can damage their physical and mental health. Finally, the third burden of malnutrition is "overnutrition" or obesity. Unhealthy for individuals and burdensome for the environment, overnutrition is a growing challenge in the modern agricultural system as affluence increases globally.

The risks of malnutrition go further than just hunger or obesity and the panelists discussed the deeper impacts that improper food availability can have on human populations. Building on the idea of hidden hunger, Fan illustrated that malnutrition especially can be damaging to children who without the proper nutrients in early stages of development can suffer from lifelong disabilities. "Lots of young children become blind because of lack of vitamin A," added Fan. "Also hidden hunger can affect the IQ by a big margin." Fanzo added, "Undernutrition—*in utero*, in the womb, as well as in early childhood—can lead to overweight and obesity into adulthood." Once overweight and obese, these individuals are also at risk of many non-communicable diseases such as diabetes, hypertension, coronary artery disease, and several types of cancer. Chronic malnutrition can also lead to stunting, which can have real impacts on learning and future earnings. "Poor cognitive development," added Fanzo, "is highly associated with being 'stunted.'" and the effects of undernutrition on large populations can last generations. Fanzo put compelling numbers to these categories: "2.1 billion people are overweight or obese, 51 million children are 'wasted' or acutely malnourished [putting them at a] high risk of mortality, and another 161 million children are 'stunted' or chronically undernourished."

Cordes furthered the discussion on the risks of hunger and reiterated the idea that malnutrition persists even though the food supply is more than adequate to feed the entire global population. "I think that perhaps the greatest risk from a right to food perspective is the focus on simply supply-side solutions to address hunger needs, said Cordes. "This is because hunger is a question not only of food production, but also of poverty, of inability to access food, of political crises as well as conflict. And so if we only focus on increasing food production, we're not going to get where we need to be to address the main needs that the agricultural system is supposed to serve, which is feeding those who need food." Fan backed up Cordes's assessment, and said, "[In the past] we were struggling with food supply—there was a supply problem. But today accessibility is more important or equally important than availability."

Building on these ideas, Fanzo presented the "three pillars of food security," which she believes are crucial to providing adequate nutrition around the world: food production, food access, and food utilization. Food production covers the supply-side issues, but food access and food utilization are equally important. Even if plenty of food is produced, it is only nutritionally helpful if it is (1) accessible (i.e., affordable, geographically attainable, etc.), and (2) usable (i.e., the food is good quality and those consuming it have the internal ability to properly digest, extract, and absorb its important nutrients). Fanzo asserted that only when these three pillars are met can people begin to move out of malnutrition and into a healthier environment.

Conflict and Disease Risks

Conflict and disease pose risks to the agricultural system, to the workers who rely on the industry for their economic livelihood, and to the consumers who depend on crops for their sustenance.

When asked to discuss the "worst-case scenario," or "the biggest risk in the food system," Sanchez was quick to say, "War," and the panelists agreed that conflict posed the greatest threat. "If you think large-scale conflict," said Fanzo, "to me [that] would be the biggest risk." Fanzo related conflict back to nutrition, and said, "If you look at the top ten countries with the highest burden of undernutrition, almost all of them are conflict countries, or post-conflict countries immediately in the last decade." Using Timor-Leste (East Timor) as an example, where 60% of children are stunted, Fanzo demonstrated how conflict-ridden regions simply cannot maintain a strong agricultural system.

Marc Levy, Professor of International and Public Affairs at Columbia University's Earth Institute, also cited conflict as the biggest risk, but tied it closely to environmental changes. Supported by his research showing how climate and conflict are closely linked, Levy said, "There is statistically a very powerful connection between unusual climatic events and violent conflict events. [If] you elevate the climatic anomalies, you elevate the incidents of violent conflict." As environmental systems become more unpredictable with climate change, the foundations of human security are compromised, allowing conflict to begin to threaten our agricultural system at any moment.

While agriculture relies on the environment for rain and resources, Levy argued that there is an even stronger interdependence. If the environment changed to put stress on a population, widespread conflict could break out, and agriculture in that region would never recover. "Imagine going through 10-15 years of rapid expansion of agriculture in Africa in response to the global needs that have been articulated, which leads to rapid reorganization of social life across the African countryside—lots of incipient new social patterns responding to all of that," postulated Levy. "Then you get a recurrence of something like the Sahelian drought of the 70s and 80s over the course of 5-10 years. So you have new social patterns, new vulnerabilities, new transmission develops in the global system... that would be a very easy cauldron in which you could have a virtual continental-wide war break out. It might start as a series of local events, but then generalize really badly, really fast."

Like conflict, disease outbreaks can devastate agricultural development, and leave populations sick, starving, and without the means to prepare for the next harvest. An excellent example of this is the 2014 Ebola epidemic. According to Shukri Ahmed, Early Warning Team Leader at the FAO, the outbreak was a risk not only to public health, but to agriculture as well. Ahmed discussed how the outbreak in Western Africa had a devastating impact on food production, supply, and access in the region. Spreading rapidly during a crucial period of the crop cycle, Ebola not only took people out of the workforce due to illness and potential for transmission, but also kept healthy populations from cooperating

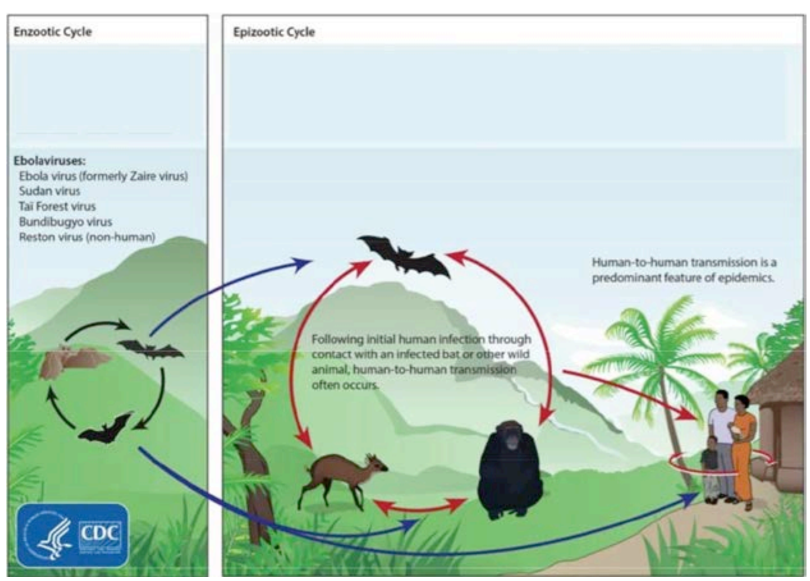
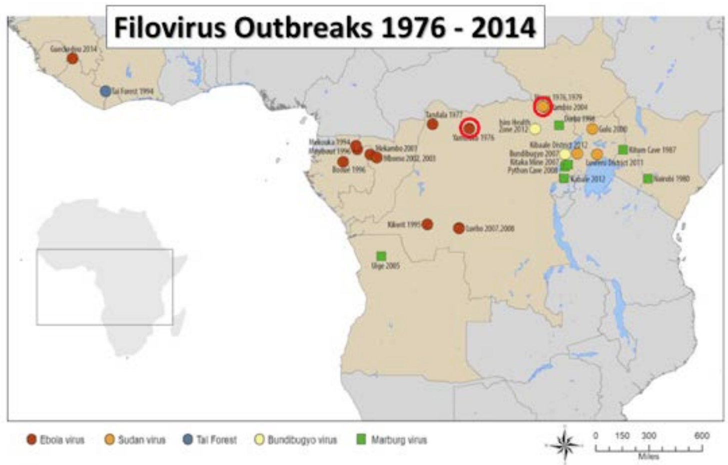


Image showing the ecology of the Ebola virus from Ahmed's presentation

in the fields for fear of infection. Many farms were left unworked and the production of food as well as cash crops like rubber, cocoa, and coffee plummeted, having a devastating impact on local nutrition and local economies in the process. These problems were exacerbated in communities that relied heavily upon imports, as many shipping companies refused to dock near affected regions.



Map from Ahmed's presentation showing filovirus outbreaks in Africa over the last several decades

While disease can clearly pose a risk to agriculture, the panelists also showed ways in which agriculture contributes to disease risk around the world. Wargo began this discussion, and said, "Among the preventable killers in the world, food plays an important role with respect to diabetes, stroke, cancer, and heart disease." Wargo went on to explain as people's diets change, the diseases they are likely to suffer from change as well. "Epidemiology is demonstrating," said Wargo, "that people who consume a Mediterranean diet, or a typical Asian diet, that used to be high in rice and vegetables, but low in animal-based saturated fat, had a different health profile than people who grew up in the United States or in some of the nations in Europe that had a high dietary intake of animal products and dairy products. So when people from Asia moved to the U.S. and adopted U.S. dietary patterns, their disease profile began to match the profile of people who had lived in the United States for their lives."

Focusing on livestock, Kahn also explored the disease risks associated with intensive agriculture. "When you go back to the earliest times, when people started living closer to animals, they started getting [animal] diseases," said Kahn. Wargo added by saying, "The density of the living environment is the perfect medium [for disease transmission]—it's like a daycare center for one- and two-year-olds." Kahn went on to provide examples of agricultural diseases that began harming human populations. "Measles," she said, "is in the same family as rinderpest, which is a deadly disease from livestock that almost certainly jumped into the human population." She added that influenza can be traced back to wild waterfowl, Q fever came from goat and sheep farms, and Nipah virus grew out of deforestation efforts for pig husbandry. Citing one of the most panic-inducing incurable diseases, she said, "Bovine spongiform encephalopathy, also known as 'mad cow disease,' came from feeding cattle ground-up offal from other animals." In addition to this, she connected the

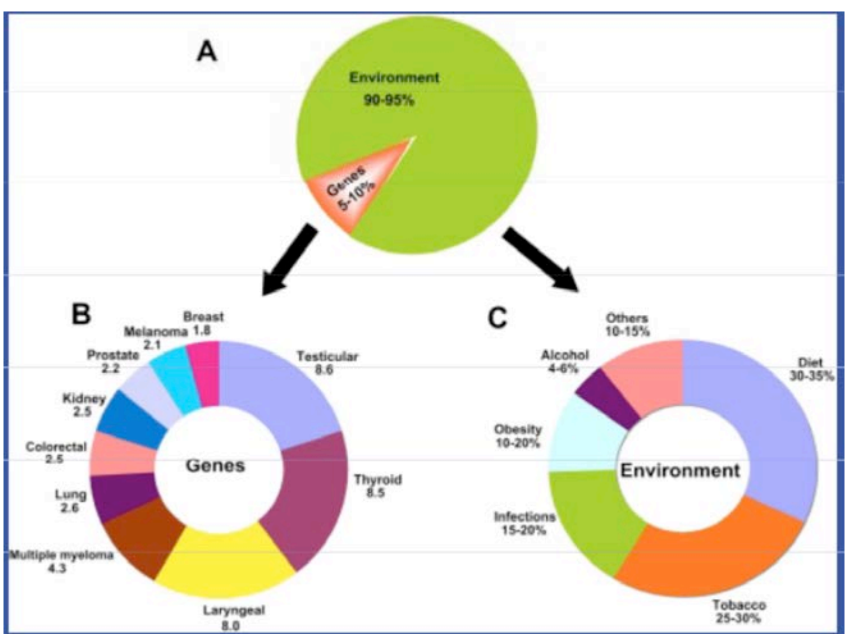


Image from Wargo's presentation, which illustrates different factors that contribute to disease in the human population

Campylobacter genus of bacteria to poultry and *E. coli* to manure-contaminated meat. Acknowledging the "inherent risks with eating meat," Kahn emphasized that for many residents of tropical regions, consuming animal protein from industrial agriculture is still safer than eating the alternative: bushmeat. Diseases from wild bushmeat can be much more devastating, and Kahn cites HIV/AIDS, SARS, and Ebola as just a few examples. "The Ebola virus," she explained, "certainly came from somebody who was butchering and/or eating wildlife." "So choose your poison," she concluded. "Would you rather eat the known disease from livestock or the unknown, potentially deadly disease from bushmeat?"


Michael Hauser and Miguel Centeno

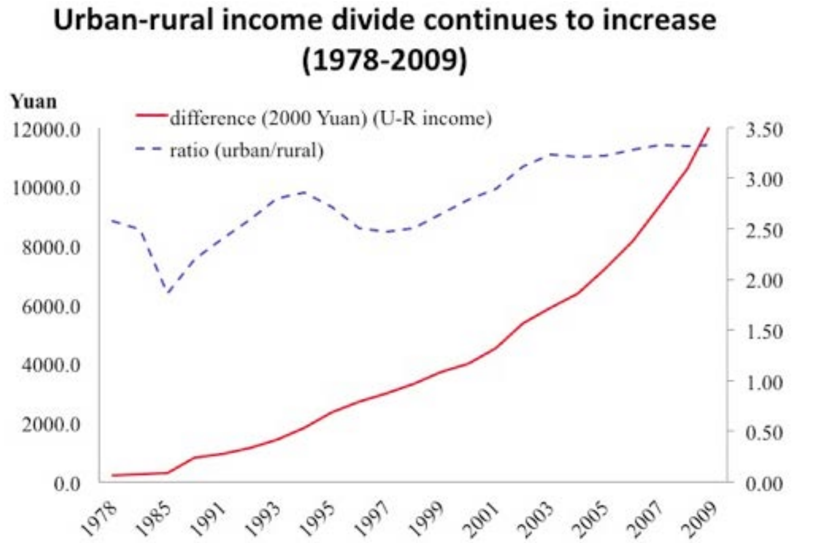
Fan summarized these risk factors to our global agricultural system succinctly, saying, "Agriculture-related diseases (Ebola is only the latest edition, even influenza), food contamination, food safety, conflict/displacement—all these short-term risks could easily dislocate our food systems and collapse our food systems."

Demographic Risks

Global demographics trends and changes create risks for the agricultural system. The demographic change that historically has put the most strain on the agricultural system is population increase. The total number of people on Earth has nearly tripled since 1950 and these new mouths to feed have forced the agricultural system to ramp up production to meet rising demand. As mentioned above, hunger rates have fallen but increased supply has not benefitted everyone evenly as many populations still face pressing risks. Exploring these demographic risks, the panelists sought to identify the vulnerable populations and explore their specific challenges.

The panelists began by looking at rural inhabitants of sub-Saharan Africa and showed that they are a vulnerable demographic group. Dan Rubenstein, Professor of Zoology, Ecology and Evolutionary Biology at Princeton University, said, "Over 650 million inhabit Sub-Saharan Africa, and two-thirds live in rural areas and survive directly off the land." Rubenstein discussed areas in Africa where he performs field research and said, "The populations continue to grow at incredibly high rates—in Kenya and Tanzania, the birth rate hovers around 3%," which compounds the existing levels of hunger in that region. Though his figures differed slightly, Searchinger expressed similar concerns about the growth of that already vulnerable group. "We have more or less solved population challenges in terms of bringing down fertility rates virtually everywhere in the world, except for in Sub-Saharan Africa [where the fertility rate] is still about five," asserted Searchinger. "That means the population is expected to grow from 900 million to 2.1 billion [by 2050], and then maybe four billion by 2100." "This is already," he continued, "the hungriest place and yields are lowest."

While many populations have moved closer to urban centers, Palm discussed how especially in Africa, rural populations are at risk of being left further and further behind when it comes to new agricultural technologies. Due to a lack of modern communication in rural areas, a large



Graph from Christiaensen's presentation reflecting Chinese income inequality in urban vs. rural demographics

portion of the African farmer demographic does not have access to these technologies. "How do people get that information in an area where there are broken extension services?" asked Palm. "There can be one extension officer for 100,000 people in some of these places." Even as people try to connect to urban centers, she said, "These are the risks that they won't get the information." When it comes to increasing agricultural yields by implementing new technology, Palm concluded, "There are demographic issues and all sorts of other constraints to this potential adoption." Even when communication is possible and extension services are intact, Fanzo highlighted the point that physical access for rural populations can pose a significant challenge as well. "Geography and roads," said Fanzo, "play a huge role in [food and technology] access." Without proper connectivity to the outside world, remote communities are not able to interact with larger markets and subsequently risk low yields, poor nutritional diversity, and lower incomes.

Even with adequate connectivity, the rural demographic that relies on the land for their livelihoods and nutrition is still more at risk than other populations. "The majority of people who are hungry are actually those who are producing food—the smallholder farmers, family farmers, especially in the developing countries," according to Ekwall. "There are 570 million farms in the world. About 90% of them are [run by] family farmers. Most of them—in the developing countries at least—represent the population that is vulnerable and poor and food-insecure."

Furthering the discussion on vulnerable populations, Cordes spoke about how large investors take advantage of many poor farmers in developing nations. As such investors look for productive land, she explained, they can often displace locals and take over their rangelands. "Most of the investments so far through acquisitions have arisen either in places where cropland is already in production and where people are relying on that land, or in forests. This has clear risks... for the people who rely on the land, who might not have very secure tenure rights." "These risks," she continued, "can range from forced evictions to loss of productive resources to—in the most extreme situations—loss of life."

Calum Turvey, Professor of Agricultural Finance at Cornell University, also mentioned these disenfranchised groups from developing nations, and spoke about how rural populations are largely illiterate and therefore cannot take advantage of many resources available to them. From financial lending opportunities to insurance coverage to securing the tenure rights highlighted by Cordes, these illiterate groups have many disadvantages.

Another demographic described as particularly at risk for a number of challenges was women. Fanzo said, "[Women are] generally the ignored group. They don't have access to education. They don't have access to goods and technology. There's inequity across the board." And while population growth puts a strain on a community's food supply, Fanzo argued that women in particular face a challenge from the birth rate: "The fertility rates in some countries are incredibly burdensome for women." Children are also at risk and while the threats specific to children will be addressed more in a following section, Wargo noted that different age demographics are vulnerable in varying ways.

Finally, the poor in general were discussed as an at-risk demographic in agriculture. Even when food is available, they might not be able to afford it. While panelists mentioned how food prices were decreasing in wealthy nations, Kahn noted that regretfully these benefits still elude the impoverished. "For much of the world's poor, that is not the case, and many of them spend virtually most of their income on food," Kahn said. Even if the poor can pay everyday food prices, Christiaensen noted that when prices spike or increase, poorer populations rarely have the savings or means to absorb those shocks.

In addition to being unable to pay for food produced by others, poor family farmers face unique challenges in growing their own crops, preserving their food, and getting it to market. While wealthier producers have access to advanced pesticides, fertilizers, and storage technologies, Sanchez and Ekwall spoke about how many poorer communities struggle without them. Sanchez mentioned how poor farmers who cannot afford crop treatments are particularly at risk for bad insect infestations. Even if plants survive and grow to maturity, Ekwall explained how storage and transportation can be a major problem post-harvest, and said, "In poor countries, in rural areas... the harvest is not stored properly, there are difficulties with the transportation, and so on." She added, "It gets humid...sometimes bags of crops are just stored in their own homes. They are transported on bicycles or donkeys. They get wet. They get destroyed." To make their situation more difficult, poor farmers are also rarely able to afford insurance to cover their losses from failed crops. While the wealthy have the money cushion, or "slack" as Eldar Shafir, Professor of Psychology and Public Affairs at Princeton University, referred to it, to buy expensive insurance plans, the poor who really need it cannot front the costs.

Some governments try to help poor farming populations with agricultural subsidies and peg food prices above market values to increase incomes for producers. Christiaensen explored some of these governmental aid packages and was disappointed to say that the subsidies rarely work and usually only help the wealthiest farmers in a region. "If the price is higher," he said, "those who produce more benefit more. If I have more acres, I produce more, so I get a higher share with a higher price band. So I get more of the benefits." Sometimes fertilizer or pesticide subsidies will succeed in increasing crop productivity in a poor region, but more food rarely translates to more income, as starving subsistence farmers often need the extra calories in their own homes. "You can increase food security without making a dent on poverty, unfortunately," said Sanchez.

Panelists also showed that in addition to having a hard time buying food, growing crops, storing grains, transporting goods, and taking advantage of subsidies, poor populations have cognitive disadvantages due to scarcity that put them at risk of making bad long-term decisions. This will be discussed more fully in the Psychological and Behavioral Risks section of this report.

Looking past populations that are at risk, the panelists also examined ways in which demographic changes themselves create risks to the agricultural system as a whole. Demographic shifts, in other words, are at the heart of many threats the panelists discussed in other areas. Relating back to the idea of unsustainable diets, for example, demographic changes are what made many of the demand shifts possible. "The world is experiencing what I think of as dietary convergence," said Wargo, and this is widely driven by increasing affluence in historically underprivileged regions. "The rising middle class and changing diets," said Ekwall, "will require more protein to be produced, which in turn requires more land," and will contribute to the environmental risks we have explored. This income effect on consumption was described by Rob Socolow, Professor of Mechanical and Aerospace Engineering at Princeton University,

Luc Christiaensen, Dan Osgood, Calum Turvey, and Cheryl Palm

as a "problems of prosperity" where things "get worse as we get wealthy." Growing affluence for some demographics therefore can increase the overall risks in the system, and the populations who remain poor are often left behind to deal with the brunt of the costs. "We are all dependent on the system," said Centeno, "but the consequences, depending on your class, depending on where you live, are going to be very, very different." For Shafir, this represents a "deeply painful paradox" because, he said, "Those who are suffering the most [from riskiness in the agricultural system] are not the ones who are going to be able to solve it" And he concluded, "Those who are responsible for solving it are not suffering and are not that interested."

Financial Risks

Market Risks

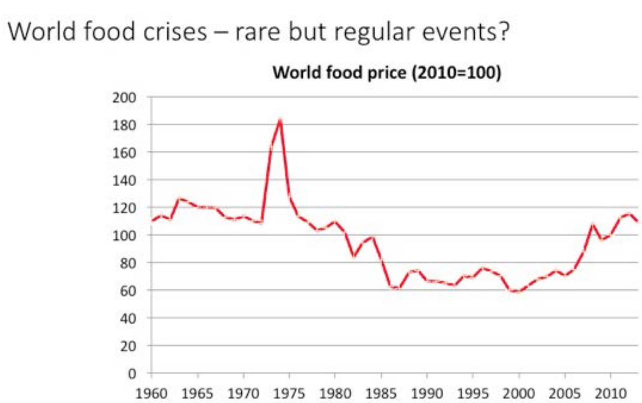
Christiaensen opened the discussion on financial risks by arguing that market forces are failing to mediate the food system appropriately. Christiaensen said, "The idea [of a market-mediated food system] is simple, based on core economic principles... [where] food production should happen in the countries which have a comparative advantage... where it can happen most efficiently. Then you trade [and] in trading you can also reduce some of the risks. If there is an open trading system, if harvests fail in your country, they may actually be abundant in another country, and so… you use the whole world to diversify." If this principle works, added Christiaensen, "The global prices… are supposed to signal scarcity and thus introduce investment. If prices go up, you start to invest. If prices go down, that's a sign there should be enough." In practice, however, Christiaensen argues that today this system is failing and that instead of reducing risks, market forces actually increase riskiness in agriculture and promote price volatility. According to Christiaensen, this failure is caused by two factors: poor global coordination and price signals failing to incentivize investment at the right time.

To illustrate the first problem of poor international coordination, Christiaensen cites the 2007-08 spikes in global rice prices. He explained how the crisis began when India had a bad year in wheat production. Fearing that they would have to import the expensive grains, the Indian government saw domestic rice production as a good substitute for feeding the population and subsequently issued an export ban on all rice

Graph from Christiaensen's report showing how political responses, not supply and demand, created price spikes in the global 2007-08 rice market

produced within its borders. Unsure if India had unique information about the global market, Vietnam quickly followed suit and issued an export ban on their rice as well. This panicked rice importers like the Philippines and Indonesia, who believed there was a global shortage coming and rushed to buy rice, thereby driving the price up significantly. For Christiaensen, this is an example of an information and coordination failure in the market, which made the food system experience an unnecessary crisis. “This all happened,” said Christiaensen, “while in effect there was sufficient rice in the market. There was no rice production shock at the time.” Instead, he said, “This is the idea that a coordination failure in that market system led to this high price volatility.” And this increased volatility translates into more riskiness in the agricultural marketplace. Citing the inability to recognize and avert information failures and coordination failures, Christiaensen concluded, “A lot of that could have been prevented.”

The second problem threatening the agriculture system’s ability to regulate itself through the investment market has to do with price signals. The traditional model suggests that, according to Christiaensen, “Investment happens in response to food prices.” Thus costs will remain low as any slight upswings are quickly met with competitive investment and increased production, which together stabilize the market and drive prices back down. The problem is, however, according to Christiaensen, “It takes time for the system to produce results,” and there is a delay between when the investment is made and when prices respond. Christiaensen argued



Graph from Christiaensen illustrating food price spikes

that this leads to a cycle of price spikes and troughs every 30 years, where investment stagnates when prices are low and then rushes to catch up as increasing demand and the diversification of diets consistently drive prices up again. While it may seem like the market-mediated food system would decrease price volatility and risk, Christiaensen showed that because of the failures in global coordination and investment response time, the international marketplace is still vulnerable to shocks.

Investment Risks

As Sanchez was earlier quoted, “Agriculture is an inherently risky business.” Turvey emphasized this point and addressed the significant volatility of output based on weather: “These systemic risks [from rainfall] come over time and time again, in a repeated fashion, but in a random way.” Turvey emphasized the effect of risk on investment and said, “These kinds of risks make lending to agriculture almost impossible by any commercial lender.” Putting himself in the minds of these bankers, Turvey imagines the loan officers asking: “Why on Earth would we lend to a small expensive, high-risk producer, when we can lend to a lawyer in town who is very safe?” Investments that Christiaensen spoke about usually take place at the industrial level, where large-scale government subsidies can help protect financiers from some of the riskiness in agriculture. In the developing world, however, where many such protections do not exist, investing in agriculture rarely pays off and the risks outweigh the rewards.

Obtaining loans to finance farming improvements can also be extremely difficult for rural farmers who rarely have assets that lenders would accept as collateral or payment if the case of default. Turvey mentioned this as a big challenge, especially for pastoralist communities. “There are many banks,” said Turvey, “which will not look upon livestock, which could die in a drought, as being good collateral, when in fact the main risk that [the borrowers] are going to face is the loss of those animals in a drought situation. So animals are not going to be a good collateral on that." Even if banks accepted animals as collateral, Turvey spoke about how the deal could still break down from the other side of the transaction. Turvey said, "Farmers themselves, when they look at that livestock as being their livelihood, [would not be] willing to give up that animal as a piece of collateral." In addition to this obstacle, many rural groups simply do not have access to financing opportunities, regardless of their ability to provide collateral. This is a function of the fact that banks and other lending agents rarely establish themselves in pastoral areas away from metropolitan centers. When these banks are accessible, they sometimes effectively engage in credit rationing by "redlining" these farm populations. Turvey described the dynamic: "Banks set up in a rural area, accept all the savings, but never lend in the area—they just transfer that savings out elsewhere." By not investing back into the community, these institutions do not actually provide the key financial services that farmers need to improve their productivity. Instead, this capital produced by the agriculture industry is transferred to alternative investment uses in other geographic areas.

Even if rural farmers do eventually get access to financial services, loans can potentially devastate a community if farms begin to struggle. Osgood said, "If you have that one drought year, say out of five… you could lose everything. You can't repay your loan, or the bank faces massive defaults. You may lose the farm; you may lose your animals. Because of that threat, you can't take the chance that you need to… in order to adapt." With access to fertilizers and technology through financing, farmers could potentially increase yields by three to six-times their current production. Instead they settle for current output levels and hope to get by with their existing farming strategies. The chronic lack of access to capital is in itself a systemic risk in rural agriculture as it prevents both productivity from increasing and resilience from developing in the region.

Ikerd spoke about economic risks facing agriculture from a different perspective. For Ikerd, the biggest threats arise from focusing too much on economics and financial gain when trying to make agricultural policies. "As a consequence of [focusing on economic value], it makes no economic sense to do anything solely for the benefit of society as a whole, and it certainly makes no economic sense to invest in anything for the sole benefit of those people of future generations. The more we focus on economics, the further we move from sustainability," Ikerd said. The short-sighted focus on current profits and the prioritization of financial concerns can thus create long-term systemic risk and lack of sustainability.

Technology and Innovation Risks

While technology and innovation are extremely important for increasing yields, they too can pose certain risks to the agricultural system. For Wargo, pesticides and fertilizers are among the most risky technologies in agriculture today and he argued that since they continue to play a larger role in the system, we must study them to gain a better understanding of their impacts. As mentioned above, these chemicals can pose threats to the environment, but Wargo also stressed the health risks of using heavy pesticides and fertilizers when they might contaminate the foods they help grow. "Food is a vehicle for conveying nutrients to your body," Wargo said, "but it's also a vehicle for conveying a variety of these contaminants." He elaborated, "Many of the pesticides are neurologically active, many are endocrine disruptors, and many are carcinogens."

The physiological effects on the body constitute a significant risk. Wargo explained, "Our body recognizes these chemicals as if they are hormones, either estrogen or androgen or others, so that they can send biochemical signals throughout the body that produce effects in animal studies and we do not know what the eventual outcome will be for human health." When the cost is in the form of a yet-unknown risk, a cost-benefit analysis will favor chemical use. "We introduce new technologies where we see the benefits," continued Wargo, "but we don't really test what the adverse effects might be either environmentally or on human health. When we realize the risks, we tend to replace those technologies in a way that carries new threats that often are not known at the time that they are introduced." Even if a compound proves to be dangerous, Wargo said, "Bans of chemicals are very rare events in human history. So we tend instead to set maximum concentration limits." These limits are often not monitored or enforced.

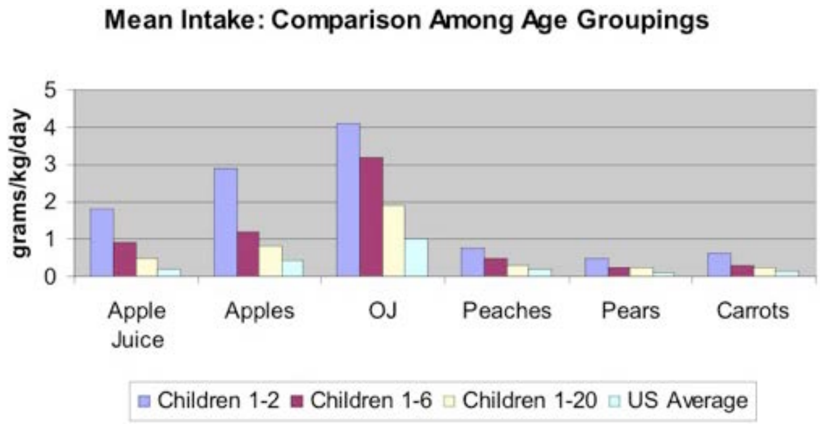


Chart from Wargo's presentation showing how different age groups are exposed to drastically different dosages of various foods

Though these concentration limits could potentially mitigate chemical risks in the field, Wargo spoke about uncertainties in knowing how some of these concentrations might impact or bioaccumulate in certain consumers. One example he gave was apple juice. Wargo said, "Children between the ages of one and two consume roughly 20-times the amount of apple juice, [and] about five-times the amount of orange juice [that adults consume]. This means that if you were really going to regulate these chemicals in the international food supply, you would want to take into account variable patterns in human exposure driven by dietary intake."

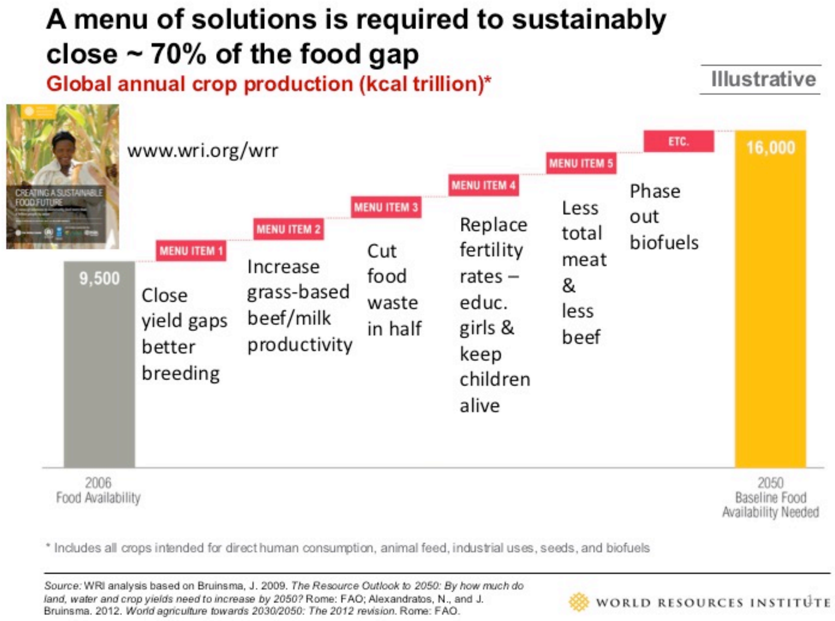
While the consumption of some chemical residues might be deemed safe, certain populations are exposed to much higher dosages, putting them at risk. This example of apple juice also relates to age-related risks, and Wargo also emphasized the dangers of "variable susceptibility" at different ages. He noted, "Different organ systems mature at very different rates," which enables him to identify a few "windows of vulnerability" where exposure to certain chemicals at certain stages of development can have an unprecedented impact on health. Recent studies have also shown that some contaminants are able to cross the placental barrier in pregnant women and impact a growing fetus. Wargo suggests that new risk and exposure assessments need to incorporate these findings into their experimental models, emphasizing that we do not fully understand all the chemical risks facing people of all ages who depend on the food system.

Antibiotics were another risky technology that the panelists identified. Kahn emphasized this risk and said that the increasing use of antibiotics in livestock is putting pressure on what she called the "global resistome." "All use of antibiotics," she said, "leads to resistance... The more antibiotics we put into the system… the more resistance we encounter in the clinical setting." Wargo added to this discussion, and said, "Pharmaceutical use is enormous in the world on animals, and 80% of the pharmaceuticals in the United States are used on animals, not prescribed to humans, and some 70% of those are used prophylactically on animals. They're not used therapeutically to treat a specific illness. So that these low-level background exposures are producing a pattern of resistance that is working its way back into our food supply—contaminated water as well—in a way that it is reducing the effectiveness of the same pharmaceuticals that are prescribed for humans. The overlap between the drugs used on animals and those used on humans is not identical," noted Wargo, "but it is very close." A significant consequence of this extensive use of antibiotics and overlap is, according to Wargo, "The rise of penicillin resistance, tetracycline resistance, cephalosporin resistance." The risk implications here are huge as these drugs are "at the core of our medical defense system," and we rely heavily on their effectiveness in the clinical environment.

Despite these concerns, both Wargo and Kahn clearly acknowledge the usefulness of these technologies and certainly do not advocate for their complete removal from the system. "If we didn't use pesticides in the world," said Wargo, "we would probably lose between 30 to 50% of the food that is currently sold. So they're enormously important." Similarly, Kahn said, "Intensive agriculture relies on antibiotics... And so far, no substitute has been found for meat production." While moving away from these technologies may not be possible, both Wargo and Kahn emphasized the need for more rigorous research and better management to guard against technology risks.

Even if health and environmental dangers of certain technologies are appropriately accounted for and mitigated, some panelists warned against the risks of relying too heavily on these technologies to solve everything. While scholars might expect GMOs and other technologies to reduce some risks across the board, heat is one example where technology has so far been ineffective. Schlenker noted, "There has been a lot of innovation in getting crops' average yields up, but the sensitivity to extreme heat is just as bad now as it was in 1950." Raising a similar concern, Sanchez pointed to crop salinity tolerances, discussing how many programs have been devoted to the cause, but no real progress has been made, and farmland close to sea level continues to be at risk. Palm also built on these concerns, and said that even when risk-reducing technologies exist and work in some areas, they can be ineffective when adopted in other parts of the world. While most scholars see Sub-Saharan Africa as an area where tremendous gains in productivity can be achieved with the use of appropriate technologies, Palm warns against too much optimism there, saying that refined farming methods are not always as efficient in these regions. "Even when you use some of these technologies," said Palm, "there is not a very large increase in yields." Some African farmland resists fertilizers and chemicals that work well in other parts of the world and these lands have been designated "unresponsive soils." In addition to this potential unresponsiveness, adopting new technologies can be difficult and expensive. Palm's research shows that it remains challenging to convince populations to fully commit to new practices. "Adoption is in fact low," said Palm, "and where there is adoption, it's on very small pieces of land." Palm's point is that even when technology does help, it often goes unused. With these risks in mind, Palm has doubts over how much we can rely on new technologies to secure our agricultural system in an increasingly risky future.

Rounding out the discussion on the riskiness of focusing too heavily on scientific solutions, Searchinger spoke about how it is unrealistic to depend on technology alone to meet future demands. According to calculations he put together with the World Resources Institute and the World Bank, 70% more crops will need to be grown between 2006 and 2050. Recognizing a conflict between climate goals and food production goals, he noted, "Most strategies for solving climate change assume that we very rapidly eliminate deforestation." Searchinger tried to explore where this increased production could come from, concluding that technological advancements alone would not be sufficient. "If we wanted to produce 70% more of the world's crops without expanding agricultural land area and… [maintaining the current level at] only 2.5% of the world's transportation fuels from bioenergy from biofuels," said Searchinger, "we would need to increase yields going forwards at a 30% more rapid rate than we increased them in the previous 50 years. And in the previous 50 years, we brought commercial fertilizer to most of the world, we doubled irrigation, we brought scientifically bred seeds." This rapid increase in the rate of gains seems unlikely and Searchinger concluded, "We can't do it through inputs anymore, because we basically use a lot of inputs already. So that means smarts. It's all got to be done basically by farming smarter and more efficiently…. And we're not doing it."



A slide from Searchinger's presentation showing that technological advancements need to be accompanied by other developments to meet future agricultural needs

Another technological risk was identified when the panelists looked at who performs the majority of research and development for agricultural enhancements. Large food companies are often both vertically and horizontally integrated within the food system, giving them access to huge amounts of capital. When these corporations put their capital behind the development of new technologies, they also invest tremendous resources into protecting their interests and are often far ahead of government agencies that then face the challenge of trying to catch up and regulate corporate activities. Working with considerably fewer resources, these regulatory bodies are constantly trying to catch up to the private sector and are often unable to ensure new developments are safe for public and environmental health. "If you compare the wealth or the expertise of the Environmental Protection Agency or the Food and Drug Administration to Eli Lilly, Pfizer, Syngenta, Novartis, there's no comparison," said Wargo. "This differential in expertise gives [them] a terrific advantage in litigation, in avoiding liability, and also in getting their products licensed." Wargo added, "What we are seeing is a concentration of power, capital, and expertise in the private sector that we haven't seen before, meaning that their global influence is increasingly difficult to regulate at the national level." In addition to this, many companies protect the secrecy of their technology as confidential business information. While the chemicals and additives in use must be released to government agencies for regulation, the law protects these companies in ways that prevent this information from being released to the public. "To protect their enormous financial investments in new technologies," said Wargo, corporations have no obligation to communicate with consumers and labels rarely show what was used in the growing process. With government regulators behind the curve and with the public in the dark about the science behind new chemicals and technologies, corporations are incentivized to introduce unknown risks into the system.

There is no doubt that different technologies will continue to play an important role in agriculture in the coming years, but there are clearly risks associated with their use and it is important to have realistic expectations for the types of impacts they are likely to have. It is also critical to acknowledge the private sector's dominance in the technological arena and to see the risks associated with this trend.

Efficiency, Profit-Maximization, and Specialization Risks

The transition from family farms to industrial agriculture in the last century has meant that efficiency and specialization have been increasingly emphasized. To maximize profit in the global market, actors in the food system have sought to eliminate redundancy and surplus in favor of smaller reserves and more precise relationships between supply and demand. While these are usually considered best practices from an economic and business perspective, the panelists identified the fragility resulting from this shift as a critical systemic risk in agriculture today.

Ikerd was one of the first to direct the discussion toward the risks of efficiency. “Whenever you focus… on making [a system] increasingly efficient,” said Ikerd, “it becomes increasingly fragile. Systems that are tremendously efficient are inherently lacking in terms of resilience.” When efficiency is the goal, Ikerd added, “What you want to do is remove the redundancy, because redundancy has costs. You want to remove the flexibility and adaptability, because when… you have to do more than one thing, you lose the gains of specialization.” Christiaensen added to this discussion, and said there is always a “tradeoff between efficiency and risk.” You can either maximize efficiency at the cost of more risk or accept losses in profit to increase resilience and robustness.

One good example of this tradeoff can be found when looking at food reserves, or “buffer stocks.” The idea behind food reserves is that during years of good crop production, some of the harvest is set aside and stored for the future in anticipation that a bad year may follow. These reserve stocks then serve as buffers to shortages and price shocks, thereby making the food system more predictable, stable, and resilient from year to year. Doering spoke about how after World War II, government policy had been affected by wartime shortages. “The American government [was] holding tremendous stocks…, [which were] the world buffer for many years,” Doering explained. A few decades later, however, excessive storage costs and changes in the commodity programs inspired the elimination of the government accumulation of storage. While some farmers would hold inventory from year to year, the increasingly industrialized private sector was much less willing to bear the costs of storing reserves. Drawing on his business background, Centeno articulated that most competitive companies today follow the “just-in-time inventory” model,

Pedro Sanchez

in which keeping excess product in the warehouse is considered wasteful and thus supply is closely matched to demand. Risks arise due to the fact that, according to Centeno, “We’re forcing the system to ever be more efficient, to always depend on the continuance of the flow, and any disruption of that flow can’t be backed up by some kind of reserve.” If the product is a consumer good such as a cell phone, a disturbance in flow might mean loss of profit and frustrated customers. But when it comes to supplying grains and other staple crops, the stakes are much higher. In this way, traditionally coveted efficiency from the business world is seen as a significant risk in agriculture.

Speaking to the same point, Socolow used the term “over-engineering” to explore this theme of increasing efficiency in agriculture. While over-engineering might sound like a negative term, for Socolow it is a reminder of a more robust and resilient past where products were designed to last longer and tolerate more stress than they might ever have to endure. Infrastructure that was over-engineered still stands strong today, while bridges, pipelines, or holding tanks designed more efficiently to meet minimum requirements often crumble and fail once unexpected stressors act upon them. Reserves and buffers are examples of over-engineering in the agricultural system, where a less efficient route is taken to increase robustness. “We are doing less over-engineering than we did, say, 50 years ago," said Socolow. He questioned the effects of this trend on systemic risk, and said, "It's another way of getting at this question of whether we are making our systems more taut and more fragile."

The pursuit of efficiency is not only risky from a food supply and price stability perspective, but also from an environmental and health perspective. Specifically, livestock feedlots and similarly designed fish farms are incredibly efficient at producing animal protein quickly at low cost. Searchinger also showed that feedlots produce fewer CO_2 emissions per pound of meat than traditional grazing, but panelists discussed how these concentrated and more efficient ways of agricultural production give rise to significant risks. Sanchez highlighted the health risks, and said, "By feeding [cattle] corn and soybeans and God knows what else just so we can put much more fat in our meat, more cholesterol in the parts of red meat, [we get] delicious steaks full of fat, we get more cholesterol in our veins and heart attacks." Wargo added that the dense animal living environments translate to more disease transmission, which results in using more antibiotics, which leads to higher levels of contamination and human exposure to pharmaceuticals. For fish farms, the aquatic equivalent to feedlots, the negative environmental impacts have been widely researched and it is clear that the concentration of organic waste in the surrounding waters is changing ecosystems globally. Sanchez blames the pursuit of efficiency for the proliferation of these risky farming techniques, and says that they only exist because, "It happens to be very profitable." Socolow agreed and added, "Things that make sense economically have a hard time not happening unless you're very vigilant."

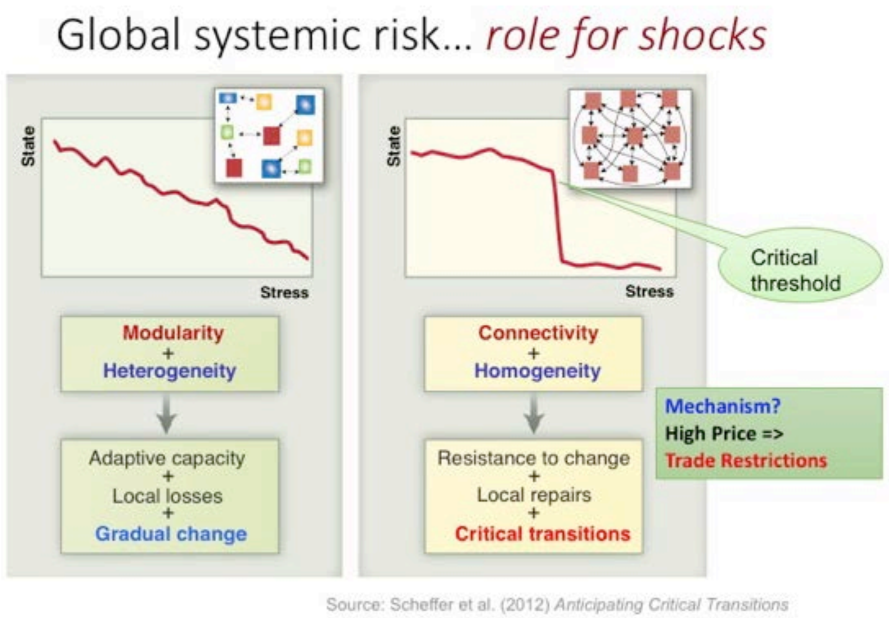
Efficiency and specialization can make sense from a business perspective where profit maximization is a primary goal. Kahn added, "The price of food has dramatically decreased because of the increased efficiencies" in the agricultural system. This decrease in the cost of staple or inelastic goods leads to a change in the consumption profile for large portions of the population, who now have the ability to consume more food while freeing up income to purchase other consumer goods and services, thereby improving the standard of living. With the benefit of both the income and substitution effect, there clearly are positives to these newer "under-engineered" solutions. However, these profits and cheaper outputs come at the cost of added risk, and the panelists debated these tradeoffs. "We are essentially paying for our wealth with fragility," said Centeno, and the hope in the end is to find a balance between a lean system and one that still maintains resilience.

If a system is predictable, the pursuit of efficiency over resilience is rational, since the actors in that system always know the precise relationships between the inputs and outputs. As the next section will show, however, the complex system of global agriculture is far from predictable and this increasing volatility and complexity makes it extremely risky.

Complexity, Globalization, and Interconnectivity Risks

The panelists agreed that global agriculture has become a complex adaptive system. According to Centeno, these systems are defined as networks that (1) arise organically and endogenously out of the interactions of components, and (2) have collective behaviors that cannot be reduced to those of their individual parts. Each component in this network can connect with countless other components—or nodes—across many domains, creating a web of interactions that is self-organizing, not centrally controlled, and susceptible to nonlinear responses to change. As the agricultural system becomes increasingly globalized, the number of components involved in the system grows exponentially and creates what Centeno called "a network of networks that lends itself to greater and greater fragility." This increased complexity, globalization, and interconnectivity leads to risk and fragility as it makes the agriculture system even more unpredictable, harder to "fix," and more vulnerable to shocks that would otherwise be contained locally.

As mentioned in previous sections, agriculture has always been somewhat unpredictable because of weather, but developments in complexity have made it even more so. As countless actors are connected through technology, communications, the environment, politics and conflict, global markets, and other domains, they lose their ability to understand how their individual actions will impact the larger system. At the conference, Centeno likened the global agricultural system to the "world's plumbing," where an incredibly intricate network of pipes binds all of the actors into a messy and convoluted web. The problem from Centeno's perspective is, he said, "We are essentially relying on a system of pipes that we don't necessarily have a map for." This missing map inherently represents a complete lack of predictability in the agricultural system and makes it very difficult to understand causes and effects when changes are happening. Christiaensen's case study about the coordination failure in the South Asian rice market is a good example of this. Who could have known for instance that a bad year of wheat production in India would lead to rice shortages in the Philippines nearly 3,000 miles away?



Graphic from Puma's presentation showing the impact of shocks on global networks

Related to this unpredictability, complexity in the system also makes the system very difficult to "fix" if things go bad. Centeno offered a compelling analogy for this when he asked the panelists to choose between a Lamborghini or 1966 Volkswagen Beetle. While the obvious answer might be the Lamborghini, Centeno argues that depending on your goals the Beetle might actually be the prudent choice. "If you want to go 200 miles per hour on an Autobahn," said Centeno, "the Lamborghini is much better. If you're crossing the desert and all you have to fix the engine is a bunch of duct tape and a stick, I'll take the 1966 Beetle anytime." Applying this metaphor to the agricultural system's growing complexity, Centeno said, "We are increasingly driving a Lamborghini and it works beautifully, but one small thing and the maintenance costs of that Lamborghini are massive." The system, similar to a performance automobile, is fragile and failure is expensive. Michael Hauser, Professor of Development at the University of Natural Resources and Life Sciences in Vienna, offered a similar aircraft metaphor when he spoke of Airbus A380 double-deck wide-body jet airliners that work perfectly 99.9% of the time, but cannot be fixed if the 0.1% event takes place. Seizing on this comparison, Sanchez later referred to this illustration as the "A380 Paradox" and explained that with millions of lives at stake, he would rather have a simpler agricultural system that could be more easily manipulated.

While this complexity makes it difficult to "fix" and "repair" a fragile network that experiences systemic failure, it can also make it difficult to achieve improvements. Less hunger, conflict, and waste are just a few examples of where scholars hope to instigate change. "Complex dynamical systems are difficult to steer," said

Hauser. "The system would bounce back because of its self-organizing nature, but what we can do, is to nudge it, to coach it, to accompany a change that is in the best interest of system actors." However, the law of unintended consequences dictates that meddling with such complexity often leads to negative outcomes and Mark Levy spoke to this risk when he said, "Our solutions are often more powerful at generating problems than relief." "In a highly complex system," added Ikerd, "you don't really know where all those interconnections are. You don't know when you're going to run into something where your dependency and your lack of flexibility is going to cause a major problem." In other words, because of the system's complexity, one cannot always identify the most important drivers of change. Levy gave two examples of how this has played out in the real world. First, Levy mentioned that while biofuel subsidies seemed like a good solution to reduce fossil fuel dependence, they have potentially decreased food security around the globe. His second example looked at conflict and illustrated that some irrigation projects that aimed to increase productivity and water security inadvertently boosted violence by providing valuable assets that stakeholders could fight over. Complex systems are, said Levy, "Rife with potential for unintended consequences that can create big headaches for human security," and this makes effective problem-solving within them incredibly difficult.

Another factor that adds to the complexity of global agriculture and makes problem-solving even more difficult in today's system is the extended timescale on which this global industry grew and developed. Instead of having a nicely designed web that materialized quickly, the global agricultural system is built upon centuries of outdated practices and policies that still impact the structure we see today. Kopp called these practices and policies "lock-in effects," where decisions in the past outlive their usefulness but still linger as barriers to change. Centeno related this to theories of "path dependence" and made it clear that the legacies from the past add more layers of obscurity to an already complex network.

Robert Kopp

A final way in which increased complexity, globalization, and interconnectivity leads to risk in agriculture is through shocks that easily propagate through the entire system. Fifty years ago, when food was sourced more locally and there was less global interdependence, changes in the geopolitical landscape would rarely impact food security across the world. Today, however, supply chains are growing increasingly long and complex and any disturbance to a link could rapidly ripple through the entire system. Centeno used shipping to illustrate this point, and said, "Something like 80% of the world's goods are transported in container ships. About 85% of those have to go through six or seven chokeholds—the Malacca Straits, the Straits of Hormuz, the Panama Canal, etc. One break in one of those, one disruption in something like the Malacca Straits, for example, can contage, can cascade throughout the system much faster than before." In this way, shocks that might have only been felt locally in a less interconnected and less globalized system now run the risk of grinding the world economy to a halt.

Centeno argued that just as the 2010 volcanic eruption in Iceland disrupted air travel all the way to Australia, so too could a similar anomaly rapidly derail the network that drives the agricultural system. What worried Centeno most, however, is that unlike the airline business, the agricultural system might not be able to recover from a severe shock. He spoke of the 2007-08 Global Financial Crisis as an analogue and said, "Let's simply be aware that that connection does come at some kind of price. The obvious model for this is 2007-08. It's this assumption that this system will clear, that the market will clear, that you will be able to have this resolution of these various crises through the mechanisms at hand. I'm not so certain about that. I think there's enough friction in the system where you might not be able to do that." "Should we go back to a world without trade, without this connectedness?" he asked in closing. "No. But let's simply be aware that that connection does come at some kind of price."

Psychological and Behavioral Risks

The final category of risks that the panelists discussed was associated with the cognitive constraints of the actors within the system. Though the human mind is incredibly powerful, it has weaknesses in the form of heuristics, biases, fallacies, and limited cognition, and when looked at through the lens of agriculture, clearly these weaknesses add risks to the system.

Perhaps one of the most obvious behavioral risks to the agricultural system comes as people work toward their own perceived self-interests. Focused on issues of grazing, Rubenstein mentioned the tragedy of the commons, which dictates that given the option, rational farmers will allow their livestock to take full advantage of the area for themselves and overgraze shared lands. Applied more broadly, this concept illustrates how resources that are not privately owned by an individual or corporation can be depleted quickly. This human tendency to abuse shared assets is risky in agriculture as factors like the environment, ecosystem services, water quality, and other common goods that are essential to agricultural production suffer. Other panelists mentioned the possibility of fish and seafood depletion in the ocean commons, and fertilizer and pesticide runoff into the common supply of lakes and rivers to feed crops. Michael Puma provided a trenchant example of the tragedy of the commons in his discussion of the danger of depletion of aquifers that supply agriculture for entire regions of some continents. Laying out the world map, Puma said, "There is major groundwater depletion—Peninsular India, Northeastern China, Central Valley of California, and the Ogallala Aquifer [beneath the Great Plains in the U.S.]. This is a chronic problem. It's a slowly accumulating problem."

Christiaensen's explanation of the 2008 food crisis in South Asian rice provided another example of how perceived self-interest could negatively affect the overall system. When there were whispers of a possible grain shortage, some Asian nations banned rice exports with the hope of protecting their own population. "There was a perception of a big rice shortage," explained Christiaensen, "which led to a lot of hoarding, which added to the price spike. but in reality there wasn't a real shortage," and this selfish hoarding behavior sent the whole system into turmoil. "Exporters want markets to be open, but they don't want to take on the obligation that they will export also when things are getting dark," Christiaensen said, referring to the danger of supply shocks. While this may seem like a rare situation, Christiaensen believes that this self-interested behavior has the potential to create shocks in the agricultural system several times a decade with potential for significant costs. Also commenting on this ad hoc autarky, Centeno said, "You've got selfish behavior to withdraw from networks in times of risk." Centeno added, "So when you get times of risks, when you get times of crisis, you don't come together. Actually, everybody starts trying to get their own lifeboat. This leads to very, very quick contagion and dispersal of danger."

Moving past selfish behavior, some argued that even with the best intentions actors in the system will inevitably make costly mistakes. Shafir expressed this view when he said, "People are inherently terribly fallible in ways that policymakers choose not to acknowledge." The greatest risk comes when both these system actors and the policymakers fail to admit their shortcomings, believing that they have a full grasp of the system's dynamics. Related to the aforementioned risks of complexity, panelists argued that all the interconnections in the system are unknowable and that bounded rationality will always limit actors' decision-making capabilities. "The system has become much more complex than our ability to understand it," said Centeno. "Even with all our great data management and data hunting," he added, "there is a bounded amount of information that we can absorb." It is hubristic to believe that we can understand these intricate systems in full detail. Yet even if we had that intellectual capacity and if we were given access to the full map of "pipes," individuals are fallible—human stupidity and malfeasance will always add unknowable risks to the equation.

Building on this idea of human error and poor decision-making, panelists looked at the issue of risk from a clinical psychology perspective and Shafir discussed circumstances that can instigate reckless and dangerous behavior. Shafir's research has looked at the psychology of scarcity and his findings show that people who feel like they lack some critical resource experience stress and actually lose significant mental competence by trying to cope with those limited assets. "When you juggle not having enough," he said, "when you're focusing a lot of your cognitive capacity on managing this thing you don't have enough of, you have very much less mind for the periphery, for everything else in life." Referring to this cognitive-limiting impact of scarcity as "tunneling," Shafir showed that it could actually reduce a stressed individual's IQ by 13 points and make it very difficult to process information from anything outside the immediate focus of one's tunnel. If for example you are hungry or do not have enough money, those concerns will dominate your intellectual bandwidth and will distort and crowd out other issues. This phenomenon has risk implications in the agricultural system and shows that communities under stress will be more likely to become disoriented and make bad long-term decisions. One such group in many parts of the world is subsistence farmers, who often struggle to make ends meet. Applying Shafir's concept of tunneling to past efforts of conservation, Doering said, "Unless farmers are making a decent living, they are not going to practice conservation." Human cognition is limited and rational investments in things like better farming techniques, education, or more sustainable eating practices will become sidelined until more urgent and immediate issues of scarcity have been dealt with.

Ezra Markowitz, Professor of Environmental Conservation at the University of Massachusetts–Amherst, also looked at factors that could impact decision-making, and concluded that for many in the world today, agricultural concerns associated with climate change are not "top of mind" issues. In other words, if these issues are not prioritized and therefore never find their way into anyone's "tunnel," the dangers will continue to grow. "We want people to take these risks seriously," he urged, and he then used a marketing and communications perspective to suggest several ways of presenting these risks to the public. Nonetheless, even if the public began to see the importance of these issues, Hauser is concerned about another cognitive limit—the speed at which a culture can adopt a new viewpoint. "Societal learning and also intergovernmental learning take a long time," he said. "This itself is a risky behavior, because in some areas we don't have that time."

Two major reasons why people do not see long-term risks like agricultural sustainability and climate change as a priority are the time scales on which they face such issues and the discount rates they subsequently apply. The panelists

Ezra Markowitz

agree that current gains are dramatically overvalued in relation to future potential and that actors will almost always sacrifice tomorrow for today. Scarcity and tunneling will increase this effect, but even when basic needs are met, the discount ratios for the future are still grossly misrepresented. Centeno addressed this and said, "Individuals and organizations don't understand time scales. The discount ratios are completely off." Doering spoke about how economists, government agencies, and businessmen demand high yearly returns on investments, which stifles long-term visions and distorts any inter-generation valuation. As noted previously, Ikerd drew a link between sustainability and today's discount rates, and said, "It makes no economic sense to invest in anything for the sole benefit of those people of future generations." Misjudging the importance of the present in relation to what is yet to come encourages unsustainable behavior and puts the future of the agricultural system at risk.

Proposed Solutions

Identifying risks was the key first step toward addressing them and once the main threats were thought to be well understood, the panelists worked to propose potential solutions. The format of this section will mirror that from above and each of the aforementioned risks will be addressed individually. Proposed solutions to the various risks are discussed together here as many of the methods are parallel and complementary.

Environmental Risks

With unanimity that managing environmental risks is critical to the future of agriculture, the panelists suggested approaches to increase sustainable productivity, protect the resources we have, and better predict how some solutions will impact the status quo.

Addressing sustainable increases in production, Rubenstein presented his research on grazing strategies that are designed, he said, "to sustain and improve livestock herding without harming wildlife." Traditionally, wildlife is strictly separated from livestock for fear that the two groups will compete for resources and lead to a thinning of the farmer's herd. Rubenstein's work in East Africa showed, however, that not only can livestock live among wildlife in the prairies, but can actually thrive when allowed to comingle. By putting cattle and donkeys (used as surrogates to mimic zebras as they have similar digestive systems and grazing patterns) together, Rubenstein tested this principle. He found that instead of competing, the two groups actually complemented and facilitated each other's grazing and made them grow fatter in equally sized pastures. In effect, comingling established a form of symbiosis or "mutualism" between the two species. The equids (donkeys and zebras), which are hind-gut fermenters, prefer to eat the harsher taller stems that the cattle, which are ruminants, cannot digest. In addition, with these stems out of the way cattle can feed more effectively because the taller shoots do not poke them in the face and eyes as they reach down to the ground to feed on the short grass. Helping the equids in return, the cattle remove many parasites from the pasture, which cannot survive inside a ruminant digestive tract, allowing the unburdened zebras and donkeys to thrive. In addition to these benefits, when the animals are combined, findings show that they walk less in pursuit of food, thereby spending less energy. "That is a huge benefit," said Rubenstein, "because you need less land if you manage this way to get the same benefits without causing expenditures. It gets to the theme of waste. By managing your animals [in this way], they're spending their energy more wisely, and therefore are more efficient in their offtake."

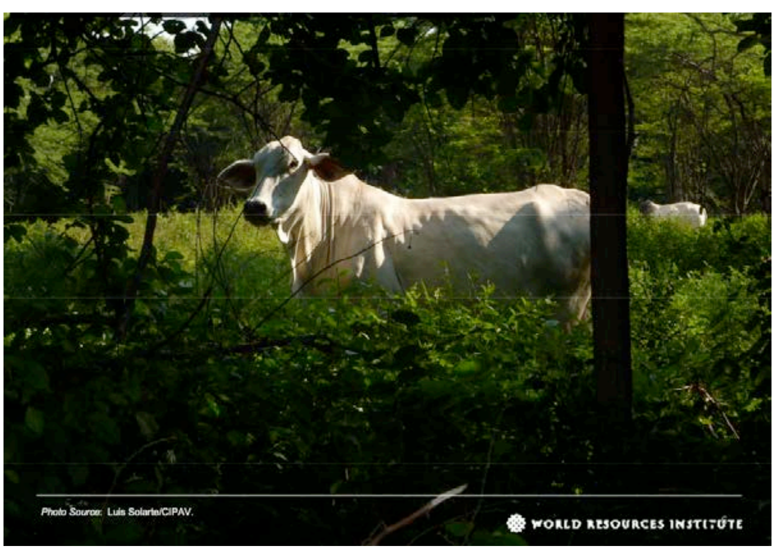

Cheryl Palm

"Bunching" from Rubenstein's presentation

The benefits of "bunching" different species together in pastures go beyond just the livestock and equids. Citing his research, Rubenstein noted, "If you have a diversity, a portfolio of grazers and browsers, they will change and increase the diversity of vegetation on your landscape." Combined with planned grazing, which rotates mixed herds to new areas before grasses are completely depleted, this method "can improve rangeland and sustain wildlife of many species, many lifestyles and many types." In addition to zebras, other big-bodied species such as warthogs and Cape buffalos grow more efficiently as well. As a positive externality on the vegetation, once herds move one, grass actually recovers more quickly from the diversified grazing. This means that the entire grasslands ecosystem benefits, and demonstrates that appropriate grazing strategies can transform the landscape, sustainably produce healthier livestock, and reduce the risks that pastoralist communities face daily. "New techniques of planned grazing can improve rangeland, buffer cattle during periods of drought, and can enhance production and milk yield of small stock [sheep and goats]." This is an example of a simple solution or change in methods that can lead to huge gains in resilience and environmental stability.

Searchinger also suggested an alternative to business-as-usual cattle grazing to begin mitigating some environmental risks. Instead of clearing forested lands to allow cattle to feed, Searchinger spoke about "silvopastoral" techniques, which allow livestock to roam and graze through wooded areas without being intensely managed. Pastures account for two-thirds of the world's agricultural lands and Searchinger argues that there would be many carbon, ecosystem, and overall environmental benefits if they could be left naturally vegetated. Acknowledging that silvopastoral agriculture is "institutionally very hard," Searchinger touts it as being "phenomenally productive," and a real opportunity to begin mitigating environmental risks associated with intensive herding on clearcut lands.

Looking at the environmental risks associated with weather, Chavez proposed new ways of managing these risks for large corporations. Bad weather is responsible for massive losses in supply chain efficiency. Chavez presented his work on models designed to minimize these losses through forecasting. Using machine learning technologies to look at variables from meteorology in order to predict weather patterns, Chavez hopes to advise companies on how to prepare their distribution and supply networks for upcoming weather events. By taking some of the uncertainty out of the equation, Chavez said of his work, "Where this model is being applied, is to try to propose to these [corporations] that



Silvopastoral agriculture from Searchinger's presentation

have a global supply chain a way to balance mitigation and transfer risk in order to create competitive advantage by differentiating the cost of sourcing key raw materials." Predicting an El Niño year well in advance for example could give a company enough warning to invest in different strains of maize, take extra measures to hedge price uncertainty, or shift their supply away from parts of the world that will be most impacted.

Kopp also spoke about ways to use technology to assess, mitigate, and advocate for adaptation in the agricultural sector around climate change and weather. Through his work on the "Risky Business Project" and integrated assessment models, Kopp sees significant potential in the power of climate models to instigate change and minimize future environmental threats. While he realized that the models are missing some key variables, he is confident in how they show the evolution of risk and the potential impact of different mitigation strategies. For example, one model is designed to show how a carbon tax would impact land-use change over time, which could have significant policy implications. By having a clearer understanding of how specific risks develop over time, Kopp hopes to encourage innovation through biotechnology, irrigation, and selective crop use.

The most threatening risks from the environment have to do with climate change and Socolow's proposed solution to these issues was an aggressive carbon tax held at $100 per tonne of CO_2. Ideally reached within the next 15 years, Socolow described the tax and said, "$100 a tonne of carbon dioxide translates into $400 a tonne of carbon [a CO_2 molecule weighs 3.7-times each carbon atom—CO_2 molar mass 44g vs. carbon molar mass 12g], which turns into $200 per tonne of biomass." He continued, "$100 a tonne of CO_2 is the kind of price for emissions that would begin to have a chance to affect the investment patterns away from fossil energy." Such a price would be "enormously dislocating for the competition between coal and natural gas, for example," Socolow added. "It would shut down coal plants and develop natural gas." While a tax like this would meet staunch opposition from lobbyists and interest groups, the panelists were in agreement that it would have a tremendous impact on the state of global agriculture and incentivize more sustainable practices.

Pacala also discussed carbon emissions reduction as a way to mitigate environmental risks in agriculture, and said, "Just by changing cultivation practice a little bit, you can store an extra half-tonne of carbon per hectare at no extra cost, and you might actually receive a substantial payment from that in a carbon-constrained world where there was a price on the carbon." With small adjustments, "restoration of cropland and pasture soils could cancel a landowner's personal fossil emissions relatively easily." While it would be good to begin minimizing the amount of carbon that agriculture releases back into the atmosphere, Pacala acknowledges that emissions here are "an order of magnitude down from the primary culprit," the energy sector. "Restoration of cropland and pasture soils would remove a total of 50 gigatons of carbon emissions, a one-time transfer," Pacala said. "That's roughly five years of current fossil emissions, [and] would represent 25 parts per million in the atmosphere. Whereas fossil fuels are going to be responsible for the addition, if we don't do something about them, of hundreds of parts per million added to the atmosphere." [2013 CO_2 level was 400ppm with 1ppm ~ 2.13 gigatons] Therefore, it is clear that reducing deforestation and incentivizing better farming methods are part of the solution and would begin to limit the risks that agriculture poses to the environment. That being said, reducing the risks of climate change as a whole will take an effort across multiple sectors.

Continuing the discussion on mitigating environmental risks through the reduction of carbon emissions, a lively debate took place among panelists over the role that biofuels should play in the future of agriculture. Socolow outlined the ways in which the International Panel on Climate Change (IPCC) sees its atmospheric carbon scrubbing strategy—Bio-Energy with Carbon Capture and Storage

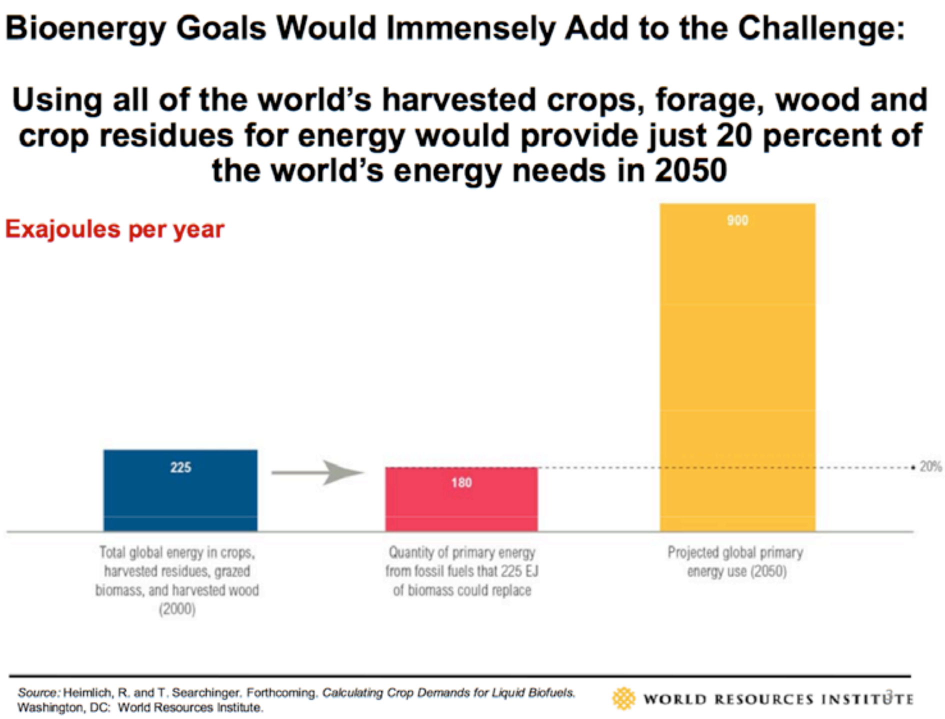


Chart from Searchinger's presentation illustrating why he believes relying on biofuels would be impractical to meet world energy needs

(BECCS)—as "the workhorse of achieving low carbon targets" in the future. Searchinger did not share the IPCC vision on the role of biofuels in the future, claiming bluntly, "Any, even modest amount of bioenergy [going forward] blows up the planet." Backing up this claim, Searchinger showed that reaching the goals that many nations have of supplying at least 10% of their transportation fuels (2% of total energy supply) through bioenergy by 2020 would come with extreme costs for the environment and for agriculture in general. "10% of the world's transportation fuel would require about 30% of all the energy in all the world's crops," said Searchinger. Going further, he spoke about how some nations have more ambitious targets where, he said, "bioenergy would supply 20% of the world's energy supply by 2050." To demonstrate how unrealistic he found this goal to be, Searchinger calculated, "That's equal to the energy in all of the world's harvested crops, all of the world's harvested forage [grass or hay as fodder for horses and cows], all of the world's harvested timber, and all of the world's harvested crop residues." Puma also chimed into the discussion, "I really don't see a role for biofuels," adding that in his opinion, biofuels just take away from our food supply instead of doing meaningful work to mitigate carbon emissions.

Nutrition and Health Risks

To address some of the risks of malnutrition and bad health, Fanzo pushed for a shift toward a new thinking that mindfully includes nutrition as a goal in food security efforts. She argued that the conversation should change away from just trying to "feed the world," and instead to aim higher and work to "feed the world *well.*" "When we talk about 'feeding the world,'" Fanzo explained, "a lot of nutritionists equate that to: 'How do you keep people alive?'" "Well," she continued, "we want to keep them alive, and we want them to thrive." While she was impressed with the diversity of scholars represented at the conference, Fanzo lamented that nutritionists are often left out of key conversations on global health. By advocating for more interdisciplinary cooperation, increasing the participation and influence of nutritionists in policy, and addressing issues surrounding equity in nutrition, Fanzo argued that global efforts to improve health would be drastically advanced.

Cordes looked at the issue of nutrition and food security from a legal human rights perspective and argued that international governance needs to have better ways of holding nations accountable for their failures to provide basic nutrition. "The right to food is already codified in international human rights law," she explained, "which means that it's in treaties that are binding on governments." Under these treaties, she said, "Governments have certain obligations to protect that right, to respect that right, and to fulfill that right." The problem, however, is that if governments fail to meet the criteria set by the UN, they face few or no consequences. "It's very hard to enforce it in practice at the international level," Cordes said. "There are different processes at the UN where you can complain about 'right to food' violations, but it takes a very long time. It doesn't have the teeth that a lot of other international legal processes have." Cordes suggested that improving the enforcement power of these international organizations could have a stronger impact on encouraging governments to prioritize their human rights obligations related to food.

Ekwall also looked at how nutrition is handled at the international governance level and argued, "The guidelines are there, the practical tools are there, and what we need to do is to implement." Citing the Voluntary Guidelines on the Progressive Realization of the Right to Adequate Food in the Context of National Food Security, which was adopted by member countries of the FAO in 2004, she showed that many states have made the commitment, at least on paper, to begin addressing issues of malnutrition within their borders. With regards to enforcement, Ekwall gave examples where nations have linked the "right to food" to the "right to life," which gives it significantly more legal power. She explained, "'Right to life' is [a] civil and political right—immediately applicable. [By contrast] economic, social and culture rights are progressively applicable, depending on resources that the country has. But when the 'right to food' becomes the 'right to life,' it becomes mandatory." While this link has so far only been made in a few countries such as India and Switzerland, it is an example of how nutrition legislation could get more bite. But where individual nations chose not to make a commitment, however, the challenges of international enforcement still remain.

Moving past international enforcement and human rights, some panelists spoke about nutrition in the fields, and advocated for the use of crops with higher nutritional intensity. Offering an example, Kahn mentioned Golden Rice, which has been genetically engineered for nutritional gains. This rice, according to Kahn, "provides vitamin A to the world's starving children who [would otherwise] develop blindness because of vitamin A deficiency." Fan also spoke on the issue of improving available nutrition through crops and insisted that it could be done with traditional plant breeding instead of GMO processes. He advocates the use of "biofortification to add nutrition into crops through breeding" and spoke about how vitamin A, iron, zinc, and many micronutrients can be efficiently added to existing plant strains. These are concrete examples of how practical changes on the ground can be helpful in mitigating nutrition and health risks in agriculture.

Conflict and Disease Risks

Ahmed made it clear that an epidemic like the Ebola virus in West Africa can impact all aspects of the agricultural system. From the production of food in the fields to its access in the markets, a serious disease can grind the networks and flows of global agriculture to a halt. However, Ahmed suggested that with the help of early monitoring systems within the FAO, some of the negative

Kaitlin Cordes, Otto Doering, Erik Chavez, Wolfram Schlenker, Marc Levy

disease impacts could be avoided. By understanding ways in which illness disrupts food security, we can hope to dampen some of the potential impacts of an outbreak and secure important hubs to keep the system afloat.

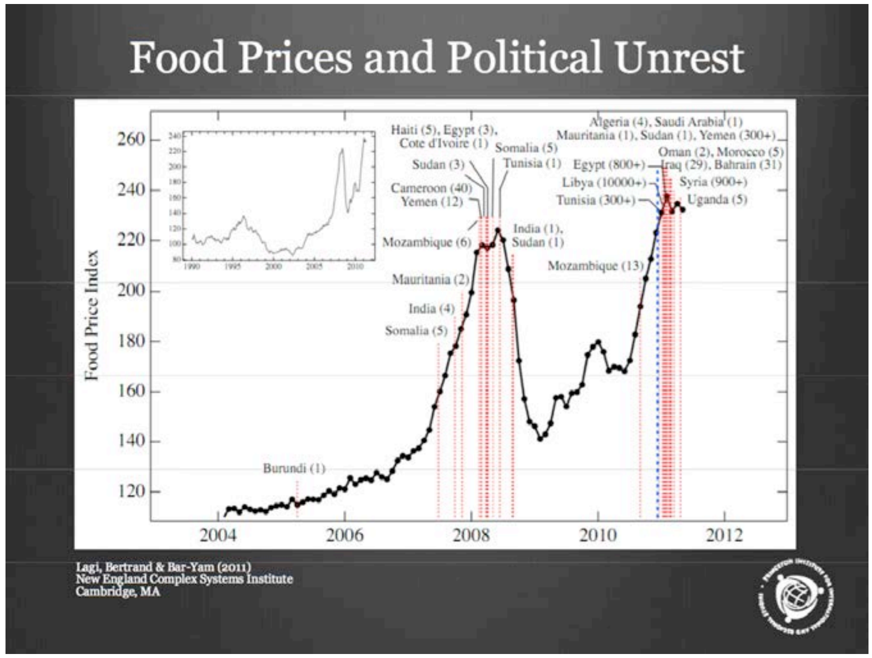


Figure from Centeno's presentation, which shows food riots (vertical red lines) and death tolls (in parentheses) as they relate to food prices. Source: Lagi, Bertrand, and Bar-Yam, "The Food Crises and Political Instability in North Africa and the Middle East," New England Complex Systems Institute, 2011.

In addition to human illness, Ahmed discussed the importance of monitoring plant and animal diseases, highlighting the FAO's Emergency Prevention System for Transboundary Animal and Plant Pests and Diseases (EMPRES). This system specializes in following specific viruses that could potentially impact the food system from the bottom up. Ahmed explained that by increasing our knowledge and our early warning systems, we can increase preparedness and mobilize quickly when the food system is at risk. In addition to early monitoring and warning systems, Wargo suggested that biodiversity in our harvested crops would be another way to increase the resilience of agriculture to plant pests and disease. By avoiding monocrops and diversifying, the agricultural system is defended better against single strains or contagions that would otherwise decimate an entire harvest.

Looking at agriculture-related conflict, Levy stressed the importance of fixing the instabilities within the system that contribute most to violence and unrest. For Levy, the most important factors are climate volatility and food security, and while these cannot be stabilized completely, some improvements could go a long way toward mitigating violence. For addressing the connections between climate and conflict, Levy argued that environmental scientists and security professionals should begin coordinating the time scales in their research so that it can be mutually beneficial and applicable in the field. He said of his research, "What I have found is that the climate security issue is a useful bridge between people who have been fixated on the very long term, which is true of much of the climate change community, and the people who are focusing on the extremely extremely short term—the next month or the next six months—which is true of a lot of the security community." To achieve this, Levy saw "the decadal time scale as a useful common ground" between the climate science and security communities, and one that allows these disciplines to communicate effectively. As with any multidisciplinary effort, it is crucial that the parties at work can "speak the same language" to learn from each other and construct a common processes of decision analysis. Beginning to work with the same time scales is a critical first step to developing a shared model.

Levy also emphasized that parties working on agricultural conflict should be careful to take a systems approach when hoping to stabilize a region. Emphasizing the risks of unintended consequences, he urged policymakers to "think about systems, not just events" when analyzing the connections between food and conflict, and he warned that misjudgments in this area could have severe and deadly consequences.

Demographic Risks

To address the demographic risks associated with population growth, Searchinger stressed that efforts should be directed at Sub-Saharan Africa, where fertility rates are highest but crop yields are low—a dangerous combination for food security. Lowering the birthrate would start to ease the strains on this region. Searchinger championed what he called a "marvelously simple mechanism" to accomplish this. "Everywhere in the world where you educate girls and you keep babies alive," he said, "people decide to have fewer babies." Searchinger was confident that this formula would work well in Sub-Saharan Africa as well, and saw it as a helpful solution to food-related demographic risks in the region.

Even if population risks are controlled, however, poor and disadvantaged populations are still threatened by food insecurity. Other panelists looked at ways to mitigate these other risks. Cordes offered suggestions to protect poor demographic groups who are actively taken advantage of through unfair land grabs. "In the example of large-scale land acquisitions," said Cordes, "governments need to ensure that they are not leasing away the land on which people rely for their livelihoods or for their own food production, and they need to stop third parties from coming in and taking away that food. If they are going to allow that, then they do need to take certain steps to ensure proper compensation [so] that people's livelihoods are not negatively affected." Cordes argued that indigenous land ownership needs to be respected and that displaced peoples should be managed fairly.

To address the disadvantages of the abject poor, Socolow suggests that they simply be given access to some new carbon emitting technologies. "The World Bank," he said, "is suffering under the instructions that they must not use fossil energy to deal with the poorest people of the world." While Socolow stressed the importance of reducing carbon emissions, he spoke about the three billion people globally who each produce less than one tonne of CO_2 per year, and could greatly benefit from slightly more carbon-intensive technologies. Simple things, Socolow suggested, like "a diesel engine, a bus, [or] modern cooking fuel," could bring this massive portion of the global population out of abject poverty and into a social bracket where children are immunized, girls can go to school, and the cycle of poverty is disrupted. Socolow puts the world's bottom three billion emitters in stark contrast to the top one billion (most Americans, 20% of the Chinese, half of the Europeans, and many others in the developed world), who produce more than ten tonnes of CO_2 per capita per year. By giving the abject poor the opportunity to produce even 10% of the CO_2 that the wealthiest emit, Socolow said, you only contribute "three billion additional tonnes in a system that's [already] emitting 35 [2013 global CO_2 emissions ≈ 35 gigatons or 35 billion tonnes]." He argued that this slight increase is worthwhile when you look at the potential benefits for this at-risk demographic, for whom many of the UN Millennium Development Goals were established.

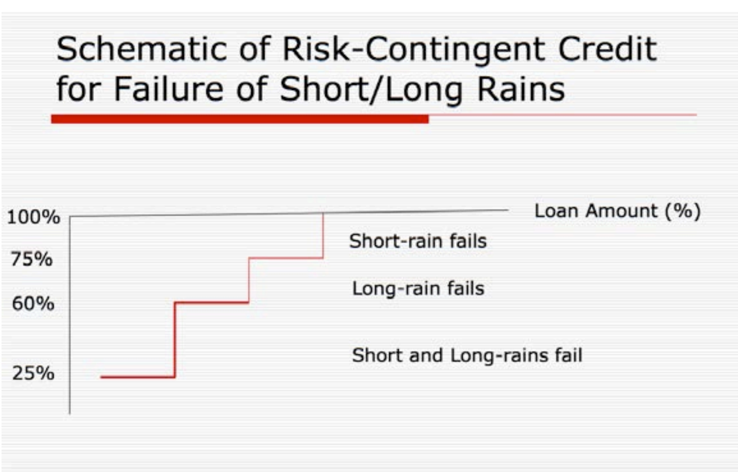
As global demographics change, wealthier populations have developed less sustainable tastes that pose risks to the agricultural system. Acknowledging the importance of supply-side adaptations as well, some panelists suggested that these risks should be mitigated by changing the global demand. Touting the power of the shopper, Ekwall said, "Consumer behavior can make a much bigger difference than [before]… If enough consumers, enough citizens demand something, automatically, you will have the market responding." Searchinger also spoke to the importance of consumer preferences. In response to wealthier demographics straining the agricultural system for more animal protein, he said that we probably "have to bring that demand for milk and meat from pastureland down." Through education and awareness, the panelists hope that consumers around the world will begin to change the way they shop to limit the negative impacts of demographic changes and to promote more sustainable diets.

Financial Risks

Examining financial challenges in this system, the panelists discussed new lending and insurance structures that could help address the risks associated with investing in an inherently volatile market like agriculture.

Farmers, especially in rural and developing nations, have a difficult time gaining access to credit to expand their business and increase productivity. "Commercial lenders," said Turvey, "were not eager to lend to farmers." Without robust financial structures that exist in the developed world specifically for the agricultural sector, these lenders are smart to avoid the risky proposition of investing in farmers. Even where credit is available, farmers are hesitant to take out loans for fear of defaulting during an unlucky year. With these challenges in mind, Turvey suggests an alternative structure for rural agricultural lending called "risk-contingent credit," designed to add a type of weather insurance to the lending instrument. Under Turvey's system, the borrower—a farmer in this case—repays the loan at different rates every year, depending on the farming or livestock-related weather conditions during the agricultural season. In Kenya, for example, Turvey explained how successful farming depends on the frequency of "long rains" and "short rains." If short rains fail crop production suffers slightly but is not devastated. If long rains fail, the impacts are more severe, and if both fail in the same year yields are dramatically reduced. Turvey's plan is designed to take these different scenarios into account and protect the farmer from having to pay fully when productivity wanes. "If all goes well," explained Turvey, "short and long rains come, 100% of the loans [are repaid]. If the short rains fail, maybe 75% of the loan is repaid. If the long rains fail, then maybe 60%. If both fail, maybe only 25% is repaid." Turvey explained that farmers would pay higher interest rates for this embedded weather protection, and he is confident that this structure would stimulate an increase of credit in agricultural farming, increase productivity, and mitigate some of the risks associated with borrowing and lending.

Osgood also proposed a solution for financial risks associated with weather volatility in agriculture. Echoing Turvey's point about borrowing, he offered a typical situation in which one in about every five years would be difficult for farmers because of drought or other weather complications. Osgood argued that because of this risk of a bad year, farmers are rarely willing to take on the gamble of investing additional capital into their land. "The key to adaptation for many of these farmers," said Osgood, "is to reduce the risk of the threat from that bad year so [they] can take chances to unlock the productivity options" that investment allows. Capital investments like fertilizer or irrigation improvements have huge potential for increasing yields, but if a farmer puts up the capital during that unlucky year, they are at risk of losing everything. "If you have that one drought year, say out of five…," explained Osgood, "[and] you can't repay your loan, or the bank faces massive defaults, you may lose the farm, you may lose your animals." The tool that Osgood discussed to help address this problem is "index insurance," which acts like crop insurance to protect farmers during bad years. What distinguishes index insurance from crop insurance is that it relies on weather data such as satellite rainfall estimates to determine the insurance payouts farmers should receive. If you



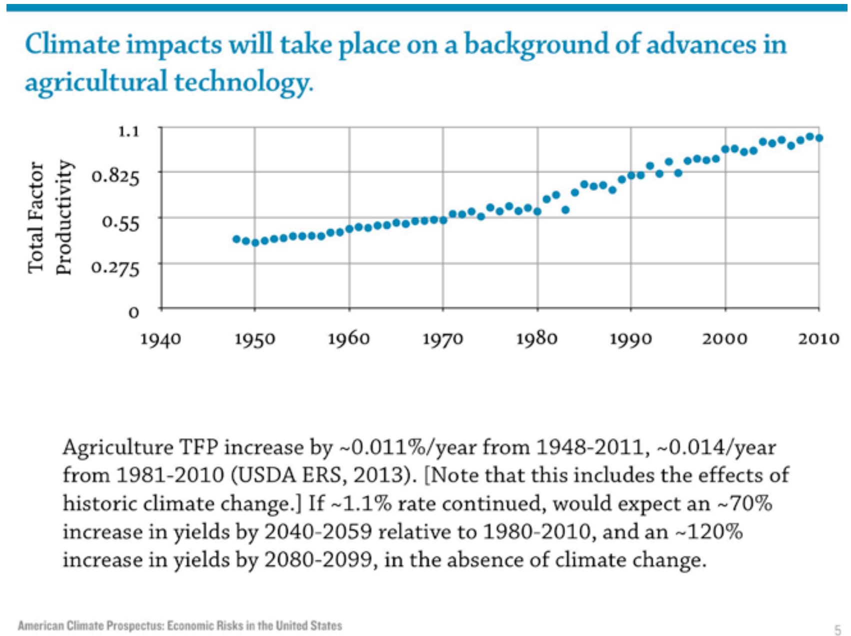
Weather-contingent loan repayment structure from Turvey's presentation

have one farmer with 1,000 acres, traditional insurance models can be effective, where an insurance agent or adjustor physically visits the fields to determine if crops have grown and if a payout is warranted. If, however, there are 1,000-2,000 farmers on those 1,000 acres or as the land is increasingly rural, Osgood explained that the traditional insurance model has not worked. With index insurance, however, the providers can access an untapped market of some of the smallest farms in the world. He noted that the goal is to find "things you can measure that allow payouts that target that one year out of five, so farmers can take strategies—or banks can take strategies—to increase productivity." By opting into this insurance model, farmers can use the gains from the four good years to pay a yearly premium that covers them on the fifth, thereby reducing volatility, smoothing their revenue stream, and incentivizing capital investment in their own land. By allowing famers in even the most remote areas to have access to weather insurance, Osgood argued that increases in productivity could be enabled where they are needed most.

While this insurance strategy based on satellite metrics and indices shows promise, Osgood cautioned that there are challenges associated with "communicating between NASA and some of the smallest farms in the world, places where some people don't necessarily even know how to write numbers." For example, miscalculating the perceived impacts of certain measured conditions could result in "unfair" payouts, which could cause farmers to lose faith in the project. In addition, as anyone who has ever had an insurance policy knows, it is difficult to ensure that stakeholders fully understand their coverage. If farmers in rural communities misinterpret their protection, the consequences can be devastating. Farmers are placing bets on an index or macro measurement, while each individual farm is subject to idiosyncratic or specific micro risk. Thus, Osgood cautioned, "This is not something you buy and suddenly you're safe. This is something where you're buying and it sometimes helps you but not always.… If we get it wrong, and people think they're safe, then take a chance, and then there's a big problem." While he acknowledged the challenges, Osgood believes making weather insurance available remains a critical aspect of mitigating the financial risks inherent within agriculture.

Making these financial instruments available is important, but farmers will not sign up for them unless they understand the potential benefits. To address this issue, Turvey recommended that education programs be put in place in conjunction with these new insurance projects so that they can be appropriately used and understood. "Finance education," he said, "is also a pretty big deal when you're talking about a largely illiterate population in many areas as well."

In addition to insurance and credit, subsidies were also discussed as a way to overcome financial risks in agriculture. While Ikerd, Fan, and Searchinger argued that agricultural subsidies in the developed world are too high, are mismanaged, and often lead to unintended consequences, many panelists did see value in well-structured subsidies programs, especially in the developing world. Sanchez suggested, "I think subsidies are needed to pull people up by the bootstraps who have nothing else to get them started." He argued that for addressing inequality in agriculture and mitigating financial risks for the poor, "subsidies have been a great weapon." Rubenstein concurred and noted, "Subsidies are necessary." But he emphasized that different situations call for different subsidy structures. When capital is added into a complex system like agriculture, it is important to understand which parties benefit and how those benefits will ripple through the system as a whole. Differently designed subsidy programs can shape system dynamics in unique ways, and it is crucial to anticipate those impacts beforehand. As described in the Financial Risks section above, for example, the wealthiest farmers can be the beneficiaries who absorb most of the payouts of these programs. To combat this tendency, Rubenstein argued, "What types of subsidies can be effective needs to be analyzed first, before money is just thrown at a project." The panelists discussed subsidies for fertilizer, water, electricity, and even crop insurance, emphasizing that subsidies can be powerful financial instruments, but need to be implemented with caution to be effective.



This graph from Kopp's presentation shows how technology has increased total factor productivity in agriculture

Fan and Puma spoke to the usefulness of subsidies as a financial instrument in the developed world. "Just a comment on subsidies in wealthier countries," Puma began. "If we view as a goal for the global system to maintain redundancy of food availability and production," he said, "then it makes sense to maintain the high levels of agricultural productivity in wealthier countries so that we have a large supply of food." While he acknowledged that there might be more efficient ways to motivate this productive behavior, Puma believes that by limiting financial risks for farmers, subsidies contribute to the stability of the overall food system. Though subsidies may have a place in ensuring global food security, Fan was frustrated with the amount of funding that current structures require. "In the U.S.," he said, "the subsidies on agriculture could be up to $30 billion [annually]. In the European Union, agriculture subsidies could be €40 billion every year. In the meantime, in 2009, G8 countries came together to commit [only] $23 billion for three years to tackle hunger and malnutrition issues." He concluded, "So, this is not right," and he argued for a more thoughtful allocation of funds that could make a profound difference in the global agricultural system.

Technology and Innovation Risks

Many of the key technological risks discussed above revolve around the use of chemicals in the agricultural food system. Kahn spoke to the negative health and disease impacts of the use of antibiotics in industrial meat production, but she argued that this is merely accepting one risk instead of another more serious risk. "So you have many problems with large-scale agriculture," Kahn said, "but on the other hand, if you don't have agriculture, you run the risk of the diseases from eating bushmeat, and that includes HIV/AIDS, SARS, the Ebola virus that we've heard a bit about that's spiraling out of control in West Africa." Seen as the lesser of two evils if animal proteins are to remain part of the human diet, Kahn argued, "Some form of intensive agriculture will be needed to feed the 9-10 or more billion people by 2050," and under this system, antibiotics are here to stay. Keeping this in mind, Kahn insisted that ensuring that antibiotics remain effective for humans in the clinical setting and protecting the "global resistome" are top priorities. She said, "We need to be more judicious in our use of antibiotics both in humans and in livestock." And since resistance to major antibiotics will have impacts worldwide, she concluded, "It has to be a global effort." International coordination and regulation is difficult, but Kahn sees this as an important strategy to manage these technology-related health risks.

Wargo also discussed the health risks that some technological advancements can foster, and argued that protecting main water sources from contamination was one of the most significant means of diminishing these threats. "Water is the most consumed 'food' in the world," said Wargo, and if it is contaminated with pesticides, herbicides, fertilizer, antibiotics, or other chemicals through drainage or runoff, the consequences for human health can be catastrophic. With these serious consequences in mind, Wargo urged the international agriculture community to keep water safety on the agenda as an important way to mitigate the risks associated with technology.

Different chemicals interact with each other and affect the human body in different ways, and Searchinger argued that there are critical information gaps that need to be filled before the risks associated with these chemicals can be appropriately managed. Wargo suggested that with these information gaps in mind, we should consider "how to reduce toxicity and exposure in a very strategic way," and he put forth a simple framework to help work through the unknowns in the complex system. "There is a really quick strategy that might be applied," said Wargo, "and that would be to try to reduce risk by type of toxicity. So, among the class of substances that are neurotoxic, reduce the use of the most risky. Among the carcinogens, reduce the most risky." This approach of "multi-criteria decision-making" would allow us, Wargo said, "To achieve an efficient reduction in each of these adverse endpoints," and begin to methodically reduce toxicity across the system. While he acknowledged that this strategy might be challenging, especially when "your less risky approach may be the most costly," Wargo believes this would be an effective way to reduce the risks of toxicity in agriculture.

Toxicity from chemicals in agriculture is especially risky for children, and Wargo insisted that regulators and governing bodies should take this into account when working to approve the use of different chemicals in the food system. There are currently almost 10,000 food additives that are not required to be tested or labeled. Wargo hopes that reforming the management and monitoring practices for these chemicals will contribute to understanding the impacts they

John Wargo

have on the body. He suggested that ingredients and warnings should be more explicitly labeled and hopes that the public can be educated about different chemical risks. In addition, Wargo urged the use of precautionary policy in the face of uncertainty, encouraging regulatory action to err on the safe side when the impacts of chemical technologies are not fully understood.

Finally, addressing the risks presented by private sector dominance of technology and innovation in agriculture, the panelists agreed that more funding should be allocated to public universities and regulatory agencies to enable monitoring, risk assessment, and oversight to keep up with private sector developments. Wargo suggested another strategy that would empower non-governmental third-party certification agencies, which perform auditing and testing and do not have the same conflicts of interest private corporations have when it comes to regulating their own technologies. Such third-party groups—analogous to Underwriters Laboratories (UL), which monitors and enforces safety standards with electrical devices—could provide a similar process to monitor and certify chemicals and additives used in agricultural production. Some companies are self-regulating effectively, however, and Sanchez and Wargo support acknowledging corporations that are encouraging best practices. "The NGO community of environmentalists and health advocates have used environmental law as their primary tool for many years," said Wargo, "and they've often simply thought of the private sector as being the enemy. But it's a new world. There are values of sustainability that are being internalized by some corporations—not all corporations. But the larger ones are finding that their long-term profitability is likely to be tied to adopting these values, bringing in the expertise, and figuring out how to adjust their processes, their ingredients, and their product lines." Much can be learned from these forward-thinking companies and panelists suggested that their expertise can be valuable to public entities as well. To this end, Ekwall advocated for better communication between the private and the public sector when it comes to research goals, and Chavez spoke to the potential of "inventing new regulatory frameworks that will allow for innovative public-private partnerships to build a more resilient food system."

Developing new technologies is a critical part of building an effective and efficient food system, but it is clear that the adverse effects of these technologies must be assessed and examined fully before they are widely adopted. Through greater global cooperation, robust regulation, precise labeling, education, age-specific research, precautionary policies, targeted risk-related strategies of mitigation, and public-private partnerships, the panelists hope to begin reigning in the threats that technology can pose to the overall agricultural system.

Efficiency, Profit-Maximization, and Specialization Risks

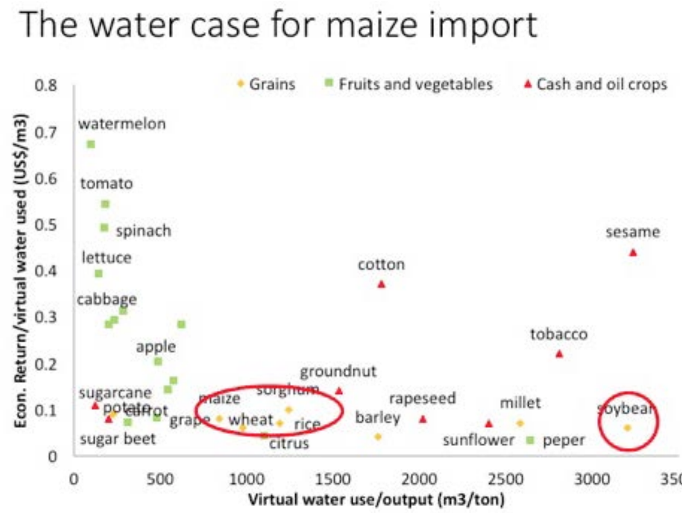
While efficiency, profit-maximization, and specialization are primary goals for any business hoping to make quarterly gains, this strategy and short-sighted planning can be dangerous in a complex system like agriculture. Thin reserves, just-in-time inventory management, and streamlined processes lead to losses in resilience, and the panelists advocated for methods of combating this trend. "We need to move towards the systems," urged Ikerd, "that are diverse, dispersed, and decentralized, rather than specialized, standardized, with consolidation of control." While most panelists agreed with Ikerd, some heavy debate followed his pronouncement that industrial agriculture as a whole should be abandoned and that traditional family-style farming should be restored. "Industrial agriculture," said Ikerd, "has been a failure," and he argued that it is time to move away from this industrial system and instead work to increase the productivity of smallholder developments. He emphasized, "We're not talking about going back" to primitive technologies and methods. Instead, Ikerd refers to the goal of fostering local small-scale agricultural growth, which will counter the threats to resilience of efficiency, profit maximization and specialization that industrial agriculture have brought about. "Contrary to what we might believe in this country," Ikerd concluded, "the whole world doesn't have industrialized agriculture, and contrary to what we might believe, they don't want it." By encouraging redundancy and moving away from industrialized practices, Ikerd believes that resilience can be incorporated back into the food system.

This ambition to abandon industrial agriculture was not shared by the other panelists. Searchinger, for example, dissented. "I am in sharp disagreement with John [Ikerd]…. Industrial agriculture," he continued, "creates a certain set of challenges… but it also has fantastic productivity and reduced land use demands compared to produc[ing] the same food [through traditional methods]." Comparing Ikerd's suggested smallholder model to the traditional agriculture that happens in Africa, Searchinger argued that they suffer from "unbelievably low yields, unbelievably low labor productivity, [and] massive expansion [into] forest right now."

Kahn was also skeptical of the plan to push agricultural development toward returning to family farms. "When you look at the history of farming, particularly in this country," said Kahn, "from 1910-20, a lot of the farmers went out of business. The family farms couldn't compete." In addition to this, Kahn pointed to increasing global urbanization and argued that Ikerd would be hard-pressed to find city dwellers who would prefer to move out to rural farmland. "You earn a much better income in the city, at a job that's a lot easier than trying to grow crops or raise livestock," said Kahn. Instead of abandoning the current system, Kahn suggested that we make changes and adjustments to mitigate risks and increase resilience. "Industrial agriculture," she said, "is really going to be what we're going to have to address and live with to sustainably feed the world's growing population: it's not going to be through the family farmer."

Puma proposed an adjustment to industrial agriculture, arguing that large-scale food reserves would be an effective way to add redundancy and combat risks of over-efficiency. While buffer stocks are expensive to store and maintain, the cost could be worth the resilience they add to the system. Puma looked at the Irish Famine as an example where food reserves and storage infrastructure could have saved many lives. The famine, caused by the "potato blight" crop disease, came on very suddenly. "The crop was destroyed over a three-week period," said Puma. With this in mind, he continued, "You have this short window with which to respond to any disturbance. To the point of food reserves, they need to be at least at the national level or clusters of countries in close proximity." Without buffer stocks or the infrastructure needed to store incoming aid, the Irish population suffered dramatically. While many things have changed since that era, Puma argued that reserves would still be an effective way to reduce our vulnerability to similar shocks.

Fan agreed with the view that buffer stocks reduce the risks of an overly-efficient system and reasserted the importance of a quick response time during a crisis. To this end, he urged policymakers not only to maintain reserves, but to decentralize them as well, so the food can be disseminated effectively where it is needed most. "For example," said Fan, "Maybe in the Horn of Africa… we [should] have a couple million tonnes of wheat and some other grains over



Economic return vs. water use. The is graph from Christiaensen's presentation shows how food imports can represent large amounts of virtual water being shipped around the globe

there, and another couple million tonnes [for] somewhere in west Africa, so when the crisis comes, you're missing three months [of food production], we can go move the food around." Fan explained how this is especially crucial for countries like Singapore that import over 90% of their food and depend entirely on the precise flows of the global trade system. An interruption of as little as five days could precipitate disaster. "If there is some sort of failure somewhere…," he added, "they won't have enough food to feed their population."

Schlenker also spoke to the importance of food reserves, but believes that they will happen organically, without government funding or organization. "Farmers have an incentive to store if they think prices will go up," said Schlenker. "If there's a predicted increase in variability," he continued, "a lot of that actually gets taken care of by profit-maximizing farmers and storers who basically smooth that production out over time." Schlenker thought market forces would obviate the need for policy mandates, and concluded, "I think those profit-maximizing storers are pretty savvy people, so I think you don't necessarily need much government intervention." Whether or not governance is needed to incentivize or require the storage of buffer stocks, the overall consensus from the panelists was that such reserves would be a key strategy to reduce risk.

Turvey presented an alternative to a constant baseline of stored food when describing his work on early warning systems for famine conditions. While food shortages precipitate quickly, Turvey's research indicates that signs in rainfall and other weather indices can predict when famine will occur up to six months in advance. If there is a significant shock in regional rainfall, for example, an early warning for catastrophe management will be "triggered," and global markets will have plenty of time to send aid and react. "When the failure [in rainfall] happens and there's a higher probability of future famine," Turvey said, "that [alarm] gets triggered, so that the aid can then be bought at that time, shipped at that time, and stored at that time in preparation for something coming six months down the line." While this early warning system could be a preventative tool, some panelists raised concerns about false alarms and bad predictions that could have severe consequences. In addition, overconfidence in this system could result in even riskier efficiency, where actors expect to know exact predictions and trim away at their ability to react and adapt to unexpected changes, with the unintended consequence of actually increasing danger to the system.

Food waste represents a serious inefficiency within the agricultural system. Paradoxically, addressing this inefficiency could be a solution to the concerns about over-efficiency in the system as a whole. Ekwall led the discussion on food waste at the conference, and said, "Food loss and waste should be part of the food security dialogue… because of the impact it has on hunger, on the environment, and on economic development." If the food we produce can be used more effectively, with more calories and nutrients going to feed people instead of being lost as waste, the overall system will be more robust as food supplies increase. "In a world of limited resources," said Ekwall, "we need not only to look at increasing the production, but also to produce better—more efficiently, more sustainably—and consume in a more intelligent manner." This goes against the motives of supply side revenue growth and profit-maximization as consumers will need to buy less if they throw away less, and less demand means lower prices. On the positive side, farmers will have less pressure to scramble to increase productivity with unsustainable options at an impossible rate. And by reducing demand, slack will be added to the supply side of agriculture, giving consumers greater flexibility, choice, and availability at lower cost.

Complexity, Globalization, and Interconnectivity Risks

The increasing interdependence in the globalized food market creates an increasing number of opportunities for failure, and the panelists began the discussion of complexity and globalization by discussing various means of mitigating those risks. In a global and interconnected world, Puma acknowledged that trade is essential, but he wondered if too much reliance on imports for food security is wise. "Ghana is a country that was self-sufficient in their staple food production," said Puma. "Now," he continued, "they have shifted away to more cash crops and now they rely on imports for their staple foods. Is that a good way forward for a country like that?" While food self-sufficiency is not practical and is even impossible for many nations today, Ikerd proposed the concept of "food sovereignty," which he believes can dramatically increase a nation's resilience when it comes to depending on others for food resources. Self-sufficiency stipulates that nations remove

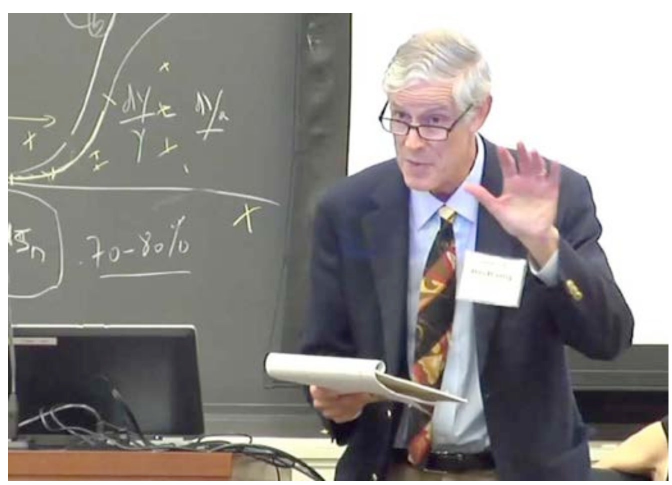
John Ikerd

themselves from trade—autarky in the food sector—but for Ikerd, "food sovereignty" ensures that participating states have power within those trade agreements. Trade is not eliminated but is instead made more fair, and independent nations are empowered to choose the markets in which to take part. Borrowing biological imagery, Ikerd suggests that the borders of even the weakest countries could behave like selective "semi-permeable membranes," which have tight control over what food they allow in and out. Fan agreed with this concept of empowerment in the marketplace and acknowledged that while trade can improve life in some circumstances, he said, "We must make sure that trade is fair and is open."

Looking beyond changes to the global agricultural marketplace, panelists repeatedly emphasized the need for new frameworks and ways of thinking when trying to address risks of complexity and globalization. First, Levy affirmed the importance of developing new tools to analyze complexity in these interconnected and complex systems. Levy argued that traditional problem-solving methods simply do not apply here and are ineffective when trying to manage intricate network dynamics. "If the main problem that we are wrestling with," said Levy, "is these risks that cascade across systems in complex ways, I think we have to recognize that managing these things is going to take the invention of new tools, because this is a clear illustration of not being able to make use of the tools that we normally use to manage these kinds of things. We can't use the market to send the right signals to direct investments in the appropriate way—the market's not doing that. We can't even use our scientific methods because they're getting disparate answers and we're not agreeing on what the implications are…. [If we] want to help the world manage these five or six big global systems that are interacting… then we're talking about inventing new forms of discussions, dialogue, and governance." Levy recognized that developing these new tools of systems thinking would not be easy, but assured the other panelists that it will be worth the effort, saying that these advancements would be "perhaps as transformative as the invention of the modern science establishment of the 1800s."

Doering agreed with Levy and introduced the concept of "wicked problems," as a useful lens through which to look at complex systems. Doering said, "Putting a man on the moon is a tame problem," which can be worked out with the scientific method, while in contrast, "health care [and] feeding the world are wicked problems." These issues are unique in that "there is no agreement on the problem, there is no agreement on the goals, [and] there is no end point." With this in mind, Doering insisted that we have been trying to manage wicked problems with tame solutions and like Levy, Doering made it clear that new mechanisms and systems of thought need to be established and deployed.

While the panelists did not establish what the specifics of these new mechanisms would look like, they agreed that solving wicked problems depends on interdisciplinary communication and cooperation. Kahn expressed this sentiment succinctly, saying, "I think approaching some of these wicked problems really requires a very multidisciplinary approach: scientifically, economically, legally. Everything that people brought to the table needs to be looked at in this holistic way, and not just one discipline." Centeno pressed that "we can learn a great deal from each other," and Levy added that we need an "epistemic community that unites experts from different disciplines toward a common



Otto Doering

purpose, not divided disciplines the way normal academic work is organized, but around a common purpose." Acknowledging that this conference was a great start to this type of interdisciplinary communication, Levy insisted that more is needed, and pointed to how Europe successfully began mitigating air pollution as an example of how this can be done correctly through interdisciplinary solutions. "They integrated scientific communities, managers, creative monitoring networks, [and] communication strategies. They were very flexible, they were coordinated, and they operated in the spirit of learning and systemic transformation." Levy concluded, "In North America, we don't approach air pollution like that at all," and he argued that we must, if we hope to understand and mitigate the risks of complexity in agriculture.

While interdisciplinary communication will be imperative, it has its difficulties and the panelists highlighted issues that must be acknowledged when academics from different fields come together. First, Kahn and Fanzo spoke about the "language" barriers that often exist between disciplines. "Usually," said Kahn, "we are in our little silos, talking with people in our own fields [who] speak the same language." These problems require cooperation across those dialectal lines, and Fanzo concluded her talk by asking the critical question, "How do we start to develop a common language around solutions."

Next, Doering and Sanchez both warned against the dangers of "reductionist science," which refers to the temptation to simply cut away some of the complexity in a problem to make it more manageable, thereby reducing the complex interactions within networks to the sum of the constituent nodes or parts. While some reductions, simplifications, and assumptions must be made when attempting to work on such massively complicated networks, the panelists advise interdisciplinary groups to exercise extreme caution when "trimming the fat." While including micro-level systems granularity makes the analysis process more difficult, acknowledging as much complexity as possible helps us to understand and manage multiple risks at once and thereby avoid unintended consequences in our proposed solutions.

Centeno offered another strategy for dealing with the risks of complexity and interconnected systems. When searching for where the risks lie, Centeno suggests that scholars ask, "What is a terrorist's dream? What is the node you can knock out that will bring everything down or will disrupt the most?" By engaging this thought experiment, Centeno believes we can start to unravel the dense networks that manage our food system and see what points actually contribute most to our security and stability. After these points are identified, actions can be taken to strengthen connections, solidify surrounding nodes, and increase redundancy to mitigate future risks. Hauser agreed with Centeno's strategy, and called the risky nodes "leverage points." "We should identify those leverage points from a terrorist's perspective," Hauser said, "and ask ourselves, 'What's the worst case that could happen?' simply to get prepared."

Socolow suggested the concept of "fuses" as a way of dealing with shocks and failures in these complex systems. He argued that by strategically engineering breaking points into a network, cascading disasters can be avoided and risks can be isolated. "When systems break," said Socolow, "they can break badly or they can break intelligently." Just as fuses act as a failsafe to keep electric shocks and surges from damaging an entire circuit, mechanisms like insurance or quarantine can keep drought or contagion from permeating the entire agriculture system. Socolow urged the panelists to consider fuses and believes they are a useful tool for mitigating the risks of complexity and globalization. Of course, fuses come with costs and not only is a fuse box more expensive than running the wires directly through a home, but as Centeno recognized, "If you are going to have a fuse system, you have to be willing to not have your lights on for the 15 seconds that it takes for you to go downstairs and replace the fuse. That's a political choice." While this may seem like a small inconvenience, at the scale of a global system these periods of engineered failure could have significant consequences and they illustrate another example of the tradeoffs that exist between resilience and efficiency.

Panelists also discussed the potential for "adaptive management" to mitigate risks in the complex system of agriculture. Originating with natural resource management in the field of ecology, techniques of adaptive management are designed to facilitate decision-making in uncertain environments. Through an iterative feedback and learning process, leaders are expected to constantly monitor and review the impacts of their policies and nimbly adjust their approaches when needed. This method acknowledges the uncertainties within complex network interactions and gives decision-makers an opportunity to anticipate and uproot unintended consequences before they take hold. Doering was a strong proponent of this process, insisting that we focus on "having adaptive management built into the system." Ikerd also endorsed this method and said that when "managing sustainable agriculture systems, we're talking about complex systems, so we [need to] leave a degree of redundancy, adaptive management, [and] flexibility."

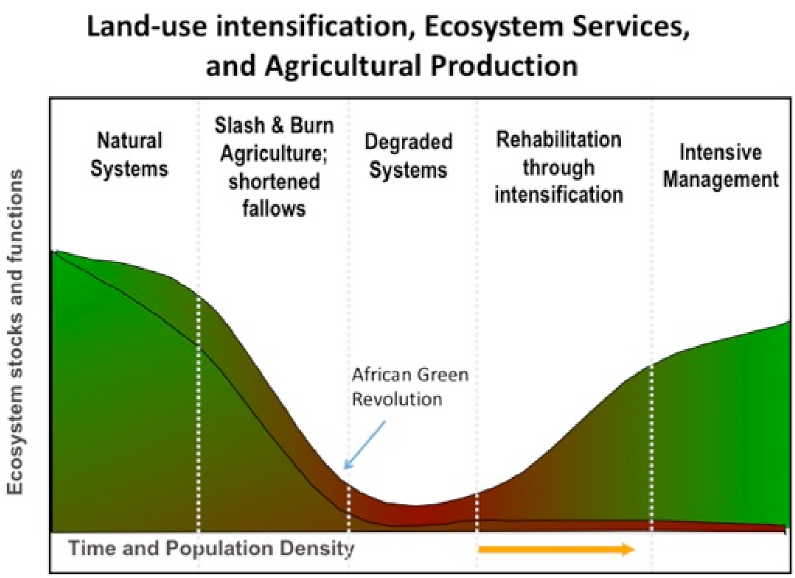


Figure from Palm's presentation showing the impact of effective management on increasing agricultural productivity and ecosystem quality

Psychological and Behavioral Risks

Selfish behavior in its worst forms generates risk as a negative externality, and when done on a global scale it can be devastating. From the perspective of the tragedy of the commons, where shared agricultural resources are at risk of unsustainable exploitation, Rubenstein suggested that local-level intervention is the key to effective preservation and management. From his experiences with pastoral communities in Africa, Rubenstein has learned that if local actors are enabled to participate in conservation efforts themselves, their priorities often shift away from pure self-interest, and they begin to act with the whole community in mind. "What is changing people's behavior," said Rubenstein, "is their engagement with the process… They become champions of the wildlife and of the mutualism. They then start to put pressure on their elected leaders."

Levy and Doering also looked at the problems of selfish behavior, pointing to morality as a potential tool for progress. Both panelists referenced cases in which ethical arguments based on faith were the only strategies that worked in promoting change. For Levy, the example was based on how U2 lead singer and activist Bono used the Bible to convince Senator Jesse Helms in 2000 to support policies that favor the poor. Doering showed how the Agricultural Adjustment Act of 1938 was sold "on the basis of the Bible and the story of Joseph and the storing of grain between good years and bad." The ethics and principles of decision-makers, policymakers, and individual actors is critical to their behavior and in a self-interested world, Levy argued, "We have to be prepared to inject a kind of moral sphere when we're aiming for high-level transformation of complex systems."

Moving past issues of selfish behavior, the panelists also looked at the risks associated with bad decision-making and human error. First, to address concerns of bounded rationality and cognitive biases, Kopp advocated the use of more robust modeling to ease the burden on human actors. If computer models can encompass more factors, decision-makers do not have to juggle as many variables. While models certainly have their flaws and can create errors on their own, they can also help in dealing with human limitations and cognitive restraints. As mentioned earlier, Shafir spoke about how "people are inherently terribly fallible in ways that policymakers choose not to acknowledge," but the paradox is that these very policymakers are fallible as well. Centeno called this "the hubris and confidence of knowledge and education," and stressed the importance of self-awareness in realizing our shortcomings. The complex system of agriculture is impossible to fully understand and human actors must realize that the systemic risks are intrinsically difficult to identify and avoid. Through honest discussion about and recognition of our limitations, the risks associated with unwarranted confidence can be avoided, allowing policymakers and the public to begin improving agriculture more effectively.

Shafir also addressed issues of bad decision-making, discussing his research that has focused on the impacts of scarcity. As previously mentioned, one important consequence of scarcity is "tunneling," wherein the poor and those who have inadequate resources rarely have the capacity to think ahead and plan for the risks of the future. To combat this tendency to fixate on short-term needs, Shafir suggests that individuals should be forced to "pre-commit" to important long-term goals. Automatic retirement funds are one example of this pre-commitment, where saving for the future is "happening on its own and it's outside of your control." Once you opt in to a pre-commitment, future willpower and decision-making is largely taken out of the equation, and if scarcity or poverty become a factor, you are still compelled to do the right thing. While some pre-commitments can be optional, Shafir argued that others should be mandatory and suggested that policymakers "have to be paternalistic about it." Home insurance is one example where Shafir advocates for a more forceful form of pre-commitment. "You have to basically get people to buy insurance when they're paying the property tax," said Shafir. "You can even allow them to opt out by sending for 16 forms. Nobody is going to do it, and then you have a situation where people are insured. Paternalism isn't popular here. It's much more popular in Northern Europe and a lot of things look better as a result." With this type of intervention, Shafir believes that the risks of psychological tunneling can be mitigated and many bad decisions can be avoided.

Eldar Shafir

The fact that agricultural risk is not a "top of mind" issue for most citizens and policymakers was another problem the panelists hoped to address. "Especially… when it comes to consumers and people who are involved in using this system," said Markowitz, "the risks are not 'top of mind.' This is not a salient issue in the media, this is not something that we think a lot about, especially at the systemic level." While Markowitz acknowledged that people do notice and worry about immediate food security threats, the more nuanced and long-term risks are rarely considered. This lack of awareness is in itself a systemic risk and Markowitz suggested that making the public more mindful of different concerns within the system could help initiate important and sustainable changes. To increase this mindfulness, Markowitz began learning from other risk communication domains that have faced similar problems. By looking at the strategies employed by advocates in climate change and the public health sectors, for example, who have expertise with communicating intangible risks to wider audiences, Markowitz found strategies that work to encourage public engagement and interest.

First, he found that we should make clear connections between distant risks in agriculture and things that people already care about. By linking future food supplies to the safety of people's children and grandchildren, for example, Markowitz believes we can attract the attention of those who would otherwise dismiss these more abstract risks. Second, Markowitz saw that to gain interest from the public, we have to make these concerns more "concrete." Levy agreed with this strategy and suggested that the use of more robust quantitative indicators—including specific numbers and metrics—could help focus the conversation, redirect attention, and transform behavior. Through specific numbers, Levy argued that a concrete "headline goal" could be established that could "mobilize support and keep attention." Third, Markowitz said, "Different things are going to resonate about this risk with different communities, and we need to figure out what resonates with the people that we actually want to engage." Next, he spoke about how "figuring out who [the] right messengers are for the different sectors that we're interested in is going to be really important for actually moving forward in terms of engagement." "I'm not the right person," Markowitz said, "to go talk to a farmer in Iowa to try to change the practices so that they have a more stable and resilient system, but an extension officer from the University of Iowa might be." Finally, Markowitz noted that while we should not be so overconfident as to ignore complexity, we should also not be intimidated to the point of inaction. "We really need to acknowledge the uncertainties that we have about what these risks are," said Markowitz, "[but] uncertainty doesn't have to inhibit behavior…talking about uncertainties very openly can actually promote people being engaged with these sorts of issues." By using these strategies, Markowitz is optimistic that we can begin making agricultural risks a "top of mind" issue and engage the public more effectively in the mitigation process.

Governance Solutions

An underlying theme throughout many of these strategies needed to address the various agricultural risks was governance. The panelists made it clear that appropriate government structures need to be established for any solutions to take hold or make a significant difference. Because the agricultural system is so vast with countless cross-scale connections between diverse sectors like technology, the environment, medicine, energy, transportation, healthcare, and trade, it is difficult to know what types of governance would be effective. In addition, decisions must be made about the levels—local, state, federal, international, private sector, third-party, NGO—at which these governance structures should be implemented.

A major theme of governance was the assertion that cooperation across governing bodies is crucial to solve these complex global issues. For example, Ahmed said, "Now, due to the interdependence of the world… you cannot simply contain [disease outbreak] in a local area," and this realization worldwide is, "creating the fertile ground for engagement of the international community in a big way." Cooperation of governments at the global level is critical, especially for issues of the commons like water quality, biodiversity, and climate change, which cannot be contained within national borders. Pacala took this argument even further and insisted that the multitude of food, water, biodiversity, and climate challenges that will likely impact the world of agriculture by 2050 will "be impossible to solve without some sort of global design with lots of interconnectedness." For Pacala, this global design takes shape through aggressive international cooperation, where global players work to solve an optimization problem, which dictates that "every hectare in the world is going to have to have a planned and managed use."

While this cooperation at an international scale is important, it can be exceedingly difficult to establish due to the different interests and power dynamics among stakeholders. For example, Puma described how even if only two nations share a river, their ability to work together for mutual gain can be challenging. With the Indus River basin as a case study, Puma showed how upstream-downstream relations between India and Pakistan remain tense, even after intervention from the international community. There are complex power dynamics within river systems around the globe and Puma described how these can have significant impacts on whether or not nations decide to work together to protect their shared resources. "If the more powerful country is upstream," Puma explained, "then they don't want to be involved in basin-level negotiations, whereas when you have the downstream country more powerful, they then want some basin-level cooperation." Nations do sometimes choose to work together and form bilateral water agreements, but Puma explained that because of efforts by countries to protect their own national sovereignty, "there's no global international body that can promote good behavior in water use and allocation." This example from water can be applied across the board when looking at shared agricultural resources, offering the critical lesson that multilateral agreements and cooperation are very difficult to create, let alone enforce, at the global level.

Levy also spoke about the role of higher-level governance for instigating sustainable change and argued that governing bodies have to be willing to make difficult choices to promote the changes that are necessary. Acknowledging that lobbyists and others will fight for their special interests, Levy insisted that policymakers must be forward-thinking and strong enough to stand up to those groups and push for what needs to be done. "Any deliberative transformation of systems, I would argue," said Levy, "entails a transfer of rights—creation of new rights [and]

Kaitlin Cordes

degradation of old rights." He argued that the sooner governments can stop acceding to the interests and rights of groups that contribute to risk in global agriculture, the sooner sustainable changes can be achieved. It may not be diplomatic or easy at first, but Levy is sure that changing rights through governance will lead to much more effective and lasting change toward a more stable equilibrium. From a human rights perspective, Cordes acknowledged the validity of Levy's argument, but insisted, "There are ways of thinking about how you can respect rights in certain ways while also doing what you need to do to develop certain sectors or improve them…. There are ways of thinking about how you can perhaps take actions that do harm certain people in certain situations when it's absolutely necessary but then to do it in a way that respects their human rights to the extent possible as well." While there is a precedent for governments to infringe on rights under some circumstances—such as land acquisitions and forced evictions—she argued that it should be a last resort.

What is best for some government organizations, however, might not be best for others, and the panelists discussed the issue of tradeoffs that exist within resilience strategies at various levels. "Global system resilience and local system resilience: it's a tradeoff," said Fan. "The problem is when a country begins to build up their resilience, then the global system actually suffers," he continued. Kopp looked to flood prevention for an example of these types of tradeoffs, or "competition between different levels of resilience," and noted that when levies are built up in one region, surrounding areas are more susceptible to floods as a result.

Higher-level global coordination is important but the panelists also stressed that more local involvement is crucial for these changes to stick. Hauser was one of the first to open this debate. Citing literature on technological transition theory, he argued that intervention in a complex and interconnected system must be supported at multiple levels of governance. With small and large-scale government structures working in concert, Hauser is confident that sustainable transitions can be fostered and adopted. Instead of waiting for shocks to transform the system in unpredictable ways, Hauser advocates a more gradual approach that bypasses regime forces with the creation of a "niche." These niches are insulated and isolated sectors that comprise the micro-level, or "niche level," in a multi-level perspective of socio-technical systems. The niche level is more autonomous than the meso-level, or regime level, which forms an interlinking web of actors following systemic rules. Above the regime level is the macro-level, or landscape level, which involves meta trends, abstract themes, and values. Change is able to occur most rapidly at the niche level, slower at the regime level, and slowest at the landscape level.

Dr. Laura Kahn

Hauser described how through a niche, an alternative or transition can be nurtured and groomed locally, before it is gradually transitioned into the mainstream at higher levels as well. If sustainable changes are to be adopted for the long term, Hauser insisted that top levels of governance must create an environment to help nurture that transition and local actors must be involved to push that change into the mainstream once it is developed. "If you leave a good idea at that high level," said Hauser, "the regime will change it immediately and it will not survive. I believe local-level action is key, but there is room for intergovernmental forces as well because they would have to set the framework for those niches to emerge and to survive." He concluded that an incremental organic approach is thus more likely to succeed than trying to change the blueprints or the rules of the system, and said, "We have to be careful—rather we should go to the niche level and nurture those things that we can overlook [have oversight over] and couple those and create good examples for an alternative rather than trying to change the DNA or the grammar without knowing what the likely outcome may be."

Osgood also agreed that local smallholder involvement is critical to successful governance structures. For Osgood, good governance should empower people at the local level with the tools they need to make good decisions on their own and then facilitate the process of scaling those decisions more globally. "It's not [about] deciding in Geneva or New York what the rest of the world should do," said Osgood, "but having a governance system… that spans…from the villages—people are making good decisions, they have the tools to make those decisions and… to do things that make sense—all the way to the global processes."

Effective governance at multiple levels requires resources and the panelists agreed that a village, city, nation, or group of nations would never agree to spend those resources without a strong political will to do so. Doering emphasized the importance of this factor, saying, “Political will and institutional support [are] absolutely necessary.” During his main presentation, Sanchez introduced his “1-3-6-10” framework for contextualizing the potential progression of global food production. The framework has four categories, defined by the numbers, which represent tonnes of cereals produced per hectare in 2005 under various levels of agricultural development. He explained that much of Sub-Saharan Africa is in the first—and least efficient—category, producing approximately one tonne of cereals per hectare. In the second category over three tonnes per hectare was the yield for India and Latin America, while the third category marked the six tonne yield in China. Nations like the U.S., Japan, many European countries, and other highly industrialized countries comprise the fourth category: producing ten or more tonnes of cereal per hectare of cultivated land. Moving from one category of productivity to the next presents unique challenges at each level and Sanchez argued that political will in governance is the limiting factor for these efficiency transitions. “[Productivity] increases have taken place in countries where the leaders had strong political will to increase food,” said Sanchez. “And yes there is technology behind it, yes you need to use fertilizers and improved seeds. But in the countries where you don’t have a committed political will at the very top, it’s not happening.”

To illustrate the transformative power of political will at the higher levels of governance, Sanchez spoke to the example of Malawi, which until 2005 depended on foreign food aid for 45% of its consumption. Sanchez described how in 2005 the nation’s president made a conscious decision to change the status quo and begin directing public funds to increase productivity in the fields. Better farming technologies had been available for decades, but were unable to make a difference until appropriate government structures were put in place. “Yields have doubled or tripled nationally in the last eight years,” said Sanchez. “It’s that political will, that political courage that is happening in about a dozen countries right now in Africa, including the biggest ones, that is making the difference.” Without it, agricultural subsidies lose funding, agricultural education programs are shut down, and productivity does not improve until leaders make food security a priority.

The panelists then worked to identify new ways to cultivate political will. In some cases, political will occurs naturally when a forward-thinking leader is elected to office, as was the case in Malawi. Sanchez recounted his meetings with the president of Malawi in 2005, who solicited and implemented suggestions that led to a tripling of agricultural yields in the eight years following those conversations. Ekwall argued that political will can be fostered more reliably from the bottom up. By empowering stakeholders through education, she claimed that citizens would demand more food-conscious governance structures from their political leaders. An educated populace can impose political will on elected officials and Ekwall is confident that politicians will respond if there is enough consumer demand. “One way of creating this political environment where there is more accountability, more transparency, and more participation by those who are hungry,” said Ekwall, “is to give voice to the hungry.” Once that empowered voice is established, she is confident that a nation will have no choice but to prioritize food productivity and security within its borders.

Governance at the local, regional, and global scales will play a critical role in managing the systemic risks in agriculture. While many challenges arise when different interests come into play, there is no question that smallholder empowerment, cooperation within and across different levels, and the cultivation of political will will be necessary to comprehensively address these risks.

Conclusion

The multidisciplinary diversity of the 27 panelists proved essential for understanding the scope and intricate nature of the systemic risks at hand, and demonstrated the importance of continuing such a dialogue in this field.

In the preliminary discussion of the current state of agriculture, the panelists identified ways in which the system has grown more complex and fragile in recent decades, and worked to unravel the wide variety of risks to be addressed. Key among these risks were human pandemic, crop disease, water shortage and drought, finance and insurance market failures, toxicity of chemical additives (pesticide, herbicide, fertilizer), new technologies such as GMOs, demand imbalances from food waste, emergent complexity within networks, psychological factors in decision-making, biofuels and energy, sustainability, biodiversity, war and political conflict, weather risk and famine, and demographic changes and population growth.

Participants drew connections between various fields: finance and psychology, technology and the environment, nutrition and conflict. Throughout the weekend, speakers and audience members alike remarked on the degree to which these different domains overlapped and it became clear that viable solutions could not be insular. Rather, they must acknowledge the interconnected nature of risk using a systems approach.

Most panelists saw effective multi-level governance as a prerequisite for beginning to mitigate interconnected risks. With governance as a foundation, participants proposed solutions that would have positive effects across multiple areas of concern. For example, by addressing environmental risk with sustainable technologies, governments can address nutrition, conflict, and disease. Simultaneously, incentivizing new financial products can increase robustness to mitigate risks of complexity and efficiency. Ultimately, reducing scarcity and uncertainty using these methods will have a positive psychological impact on at-risk populations, facilitating healthy decision-making at the individual level. By introducing and promoting an ethos of systems thinking among both the individual actors within networks and the policymakers charged with governance, systemic risks can be better understood, anticipated, and prevented.

We see this conference as a springboard for action, modeling the necessary interdisciplinary coordination to mitigate the widespread risks facing the agricultural system. By initiating this conversation, we hope to provide others with a resource for future discussion and research. The actions of leaders in government and academia across the world will be essential in ensuring the structural resilience and reliable productivity of our global agricultural system in the future.

Systemic Risk in Global Agriculture
Princeton-Columbia Joint Conference

Friday & Saturday, October 24-25, 2014
219 Burr Hall, Princeton University

Conference Schedule

FRIDAY, OCTOBER 24TH
8:00am–9:00am Coffee and breakfast

9:00am **Welcome & Introductory Remarks**

- **Pedro Sanchez, Columbia University, Conference Co-Director and Co-Host**
  Senior Research Scholar, Director, Agriculture and Food Security Center, The Earth Institute, Columbia University
- **Miguel Centeno, Princeton University, Conference Co-Director and Co-Host**
  Musgrave Professor of Sociology; Professor of Sociology and International Affairs; Chair, Department of Sociology; Director, PIIRS Global Systemic Risk Research Community, Princeton University

9:15am **PANEL 1: What is the state of global agriculture and how did we get here?**

- Ecology, agronomy, economics, greenhouse gases and food needs
  - **Tim Searchinger**
    Research Scholar, Woodrow Wilson School, Science, Technology, and Environmental Policy Program (STEP), Princeton University
- Hunger, food security
  - **Shenggen Fan**
    Director General, International Food Policy Research Institute
- Factors behind environmental decision-making
  - **Ezra Markowitz**
    Assistant Professor, Department of Environmental Conservation at the University of Massachusetts Amherst
- Sustainability, economics, agriculture and associated human costs
  - **John Ikerd**
    Professor Emeritus of Agricultural & Applied Economics, College of Agriculture, Food and Natural Resources, University of Missouri Columbia
- Psychology of decision-making, policy-making in times of perceived scarcity
  - **MODERATOR: Eldar Shafir**
    William Stewart Tod Professor of Psychology and Public Affairs, Princeton University

10:45am Coffee

11:00am **PANEL 2: What are the risks in the demand chain?**

- Ebola, labor, food security and cascading failure
  - **Shukri Ahmed**
    Senior Economist, Global Information and Early Warning System (GIEWS), Team Leader for Early Warning and Vulnerability assessment and Analysis group within the Trade and Markets Division, FAO.
- Food security and water scarcity as national security issue
  - **Marc Levy**
    Deputy Director, Center for International Earth Science Information Network (CIESIN); Adjunct Professor of International and Public Affairs, Center for International Earth Science Information Network; Earth Institute, Columbia University
- Pollution and human health

  - **John Wargo**
    Tweedy Ordway Professor of Environmental Health and Politics, School of Forestry & Environmental Studies, Yale University
- Human nutrition and hunger
  - **Jessica Fanzo**
    Assistant Professor of Nutrition, Director of Nutrition Policy, Center on Globalization and Sustainable Development; Institute of Human Nutrition and Department of Pediatrics, Columbia University
- Epidemics, health crises and chain of accountability
  - **MODERATOR: Laura Kahn, MD**
    Research Scholar, Program on Science and Global Security; Princeton University

12:30pm–1:30pm Buffet Lunch

1:30pm **PANEL 3: What are the risks to the environment?**
- Soil degradation and food security
  - **Pedro Sanchez, Columbia University, Conference Co-Director/Co-Host**
    Senior Research Scholar, Director, Agriculture and Food Security Center, The Earth Institute, Columbia University
- Food waste
  - **Barbara Ekwall**
    Senior Liaison Officer, Liaison Office for North America, Food and Agriculture Organization of the United Nations
- Food system, food security, water, food, climate
  - **Michael Puma (Conference Co-Organizer – Columbia)**
    Associate Research Scientist; Adjunct Assistant Professor, Center for Climate Systems Research; NASA Goddard Institute for Space Studies, Columbia University
- Global commons management, animal behavior
  - **MODERATOR: Dan Rubenstein**
    Class of 1877 Professor of Zoology; Professor of Ecology and Evolutionary Biology; Director, Program in African Studies, Department of Ecology and Evolutionary Biology, Princeton University

3:00pm Coffee break

3:15pm **PANEL 4: What are financial aspects of systemic risk in agriculture?**
- Poverty, food security, rural urban migration, sustainable development
  - **Luc Christiaensen**
    Senior Economist, Development Research Group, World Bank
- Rural credit and weather insurance
  - **Calum Turvey**
    W.I. Myers Professor of Agricultural Finance, Director of Graduate Studies, Charles H. Dyson School of Applied Economics and Management, Cornell University
- Climate and insurance
  - **Dan Osgood**
    Lead Scientist, Financial Instruments Sector Team; Associate Research Scientist in Economic Modeling and Climate, International Research Institute for Climate and Society, Columbia University
- Conditionality, climate, energy, public policy
  - **MODERATOR: Rob Socolow**
    Professor of Mechanical and Aerospace Engineering. Co-Director, The Carbon Mitigation Initiative; Director, Climate and Energy Challenge, Princeton Environmental Institute, Princeton University

- Rural livelihoods, land use, degradation and rehabilitation, ecosystem processes, agricultural intensification
  - **Cheryl Palm**
    Senior Research Scientist; Associate Director, Center for Globalization and Sustainable Development; Director, Millennium Villages Project, Agriculture and Food Security Center, Lamont Doherty Earth Observatory, The Earth Institute, Columbia University

4:45pm Free Time
FRIDAY EVENING

6:30pm–7:15pm Reception & Welcome, Mathey College Common Room

7:15pm–9:00pm Buffet Dinner, Mathey College Common Room

SATURDAY, OCTOBER 25TH

8:00am Coffee and breakfast

9:00am–10:30am **PANEL 5: What are other risks in the supply chain?**
- Sustainable development, infectious disease, risk reduction in ecology & economic development
  - **Marc Levy**
    Deputy Director, Center for International Earth Science Information Network (CIESIN); Adjunct Professor of International and Public Affairs, Center for International Earth Science Information Network; Earth Institute, Columbia University
- Conservation, farm bill, water
  - **Otto Doering**
    Professor of Agricultural Economics, Department of Agricultural Economics, Purdue University
- Climate and economy; linking global agriculture, retail and finance to smallholder farmers in Africa
  - **Erik Chavez**
    Research Associate, Business School, Finance Department and Civil and Environmental Engineering Department, Imperial College, London
- Sustainable investment, human rights, right to food
  - **MODERATOR: Kaitlin Cordes**
    Associate Research Scholar, Columbia Center on Sustainable Investment, Columbia University Law School & The Earth Institute
- Changing climate, changing yields, biofuels
  - **Wolfram Schlenker**
    Associate Professor of International and Public Affairs, School of International and Public Affairs, Columbia University

10:30am Coffee

10:45am **PANEL 6: How can we repair damage, or prepare for uncertainties?**
- Complex systems and risk, social order, interdependent rules and institutions that allow interaction
  - **Miguel Centeno, Princeton University, Conference Co-Director/Co-Host**
    Musgrave Professor of Sociology; Professor of Sociology and International Affairs; Chair, Department of Sociology; Director, PIIRS Global Systemic Risk Research Community, Princeton University
- Ecological structure and function, carbon cycle, greenhouse gases
  - **Stephen Pacala**
    Frederick D. Petrie Professor in Ecology and Evolutionary Biology, Director, Carbon Mitigation Initiative, Princeton University
- Complexity, resilience, and transformation of agriculture and food systems

  - **Michael Hauser**
    Assistant Professor, Director, Centre for Development Research, University of Natural Resources and Life Sciences (Vienna)
- Assessing potential of climate mitigation, adaptation in agriculture, “American Climate Prospectus”
  - **MODERATOR: Robert Kopp**
    Associate Professor, Department of Earth & Planetary Sciences, and Associate Director, Rutgers Energy Institute, Rutgers University

12:15pm PANEL 7: Closing Remarks
- Recapitulation of goals from this conference
  - **Pedro Sanchez, Columbia University, Conference Co-Director and Co-Host**
  - **Miguel Centeno, Princeton University, Conference Co-Director and Co-Host**

12:30pm Buffet lunch

Last Name Index

Ahmed, Shukri	Senior Economist, Global Information and Early Warning System (GIEWS), Team leader for Early Warning and Vulnerability assessment and Analysis group within the Trade and Markets Division, FAO
Centeno, Miguel	Conference Co-Director and Co-Host, Musgrave Professor of Sociology; Professor of Sociology and International Affairs; Chair, Department of Sociology; Director, PIIRS Global Systemic Risk Research Community, Princeton University
Chavez, Erik	Research Associate, Business School, Finance Department and Civil and Environmental Engineering Department, Imperial College, London
Christiaensen, Luc	Senior Economist, Development Research Group, World Bank
Cordes, Kaitlin	Associate Research Scholar, Columbia Center on Sustainable Investment, Columbia University Law School & The Earth Institute
Doering, Otto	Professor of Agricultural Economics, Department of Agricultural Economics, Purdue University
Ekwall, Barbara	Senior Liaison Officer, Liaison Office for North America, Food and Agriculture Organization of the United Nations
Fan, Shenggen	Director General, International Food Policy Research Institute
Fanzo, Jessica	Assistant Professor of Nutrition, Director of Nutrition Policy, Center on Globalization and Sustainable Development; Institute of Human Nutrition and Department of Pediatrics, Columbia University
Hauser, Michael	Assistant Professor, Director, Centre for Development Research, University of Natural Resources and Life Sciences
Ikerd, John	Professor Emeritus of Agricultural & Applied Economics, College of Agriculture, Food and Natural Resources, University of Missouri Columbia
Kahn, MD, Laura	Research Scholar, Program on Science and Global Security; Princeton University
Kopp, Robert	Associate Professor, Department of Earth & Planetary Sciences, and Associate Director, Rutgers Energy Institute, Rutgers University
Levy, Marc	Deputy Director, Center for International Earth Science Information Network (CIESIN); Adjunct Professor of International and Public Affairs, Center for International Earth Science Information Network; Earth Institute, Columbia University
Markowitz, Ezra	Assistant Professor, Department of Environmental Conservation at the University of Massachusetts Amherst
Osgood, Dan	Lead Scientist, Financial Instruments Sector Team; Associate Research Scientist in Economic Modeling and Climate, International Research Institute for Climate and Society, Columbia University

Pacala, Stephen	Frederick D. Petrie Professor in Ecology and Evolutionary Biology, Director, Carbon Mitigation Initiative, Princeton University
Palm, Cheryl	Senior Research Scientist; Associate Director, Center for Globalization and Sustainable Development; Director, Millennium Villages Project, Agriculture and Food Security Center, Lamont Doherty Earth Observatory, The Earth Institute, Columbia University
Puma, Michael	Conference Co-Organizer, Associate Research Scientist; Adjunct Assistant Professor, Center for Climate Systems Research; NASA Goddard Institute for Space Studies, Columbia University
Rubenstein, Dan	Class of 1877 Professor of Zoology; Professor of Ecology and Evolutionary Biology; Director, Program in African Studies, Department of Ecology and Evolutionary Biology, Princeton University
Sanchez, Pedro	Columbia University, Conference Co-Director and Co-Host, Senior Research Scholar, Director, Agriculture and Food Security Center, The Earth Institute, Columbia University
Schlenker, Wolfram	Associate Professor of International and Public Affairs, School of International and Public Affairs, Columbia University
Searchinger, Tim	Research Scholar, Woodrow Wilson School, Science, Technology, and Environmental Policy Program (STEP), Princeton University
Shafir, Eldar	William Stewart Tod Professor of Psychology and Public Affairs, Princeton University
Socolow, Rob	Professor of Mechanical and Aerospace Engineering, Co-Director, The Carbon Mitigation Initiative; Director, Climate and Energy Challenge, Princeton Environmental Institute, Princeton University
Turvey, Calum	W.I. Myers Professor of Agricultural Finance, Director of Graduate Studies, Charles H. Dyson School of Applied Economics and Management, Cornell University
Wargo, John	Tweedy Ordway Professor of Environmental Health and Politics, School of Forestry & Environmental Studies, Yale University