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Session 1: Long Term Trajectories

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Thank you very much. It is a pleasure to be here. There is an underpinning paper to what I'm going to say. Because I'm limited to 20 minutes so it is going to be very fast. Substance is underneath, but it's in the paper.

So these are rates of gain on a global level of our major crops, the three major cereals. Soybean would also fit a similar pattern, I mean all your major crops do. But the siding feature here is the fact that global gain and yields is decidedly linear. And so there's a tyranny there as you know that the relative rate of gain is always decreasing because there's a constant rate of increase on an ever increasing average. And the bottom line is that those rates of gain today are 1.2 percent and decreasing, if they continue as those trajectories indicate, are not enough to produce the food we need under the scenarios Mark showed on existing farmland. That means they must accelerate, otherwise there will be massive expansion of agriculture. Moreover, and if you look on a country basis, there's a large number of countries where the yields have actually stagnated for many crops. And we published that that amount is about 31 percent of total global production today of the major cereals comes from countries where statistically significant decrease in the rate of yield, and in some cases a complete stagnation.

Now, the key here and I want you to think about, and going back here, take a look at the maize line of increase there, the red dots. They had a constant rate over all those years, and the fact is that globally the inflation-adjusted investment in maize breeding has quadrupled, so that it means the rate of gain per unit of investment in breeding has been reduced by 75 percent. Now the outcome of slower growth in, or growth and yields that is less than demand, is that if you're going to feed people is that you expand the area harvested.

*Please see the corresponding paper and/or presentation available at www.kansascityfed.org/publications/research/rscp/rscp-2016 for additional detail and referenced charts.

And this shows global, again, numbers for the harvested area. Now this can include double and triple cropping in some areas, but most of that increase since 2001 or 2002--by the way these were all spline regressions with statistical efficient showing not penned in numbers. Most of the increase in area is due to expansion of crop area, and we're expanding agricultural area at a rate that is faster than at any time in human history. What's more, the more important point is, whereas in the 1980s and 90s, the middle of that graph, we were meeting demand by increasing yields on existing land production base, we are now meeting demand equally by expending area. So there's been a cataclysmic change. When you hear about low food prices, yeah, we can clap our hands we are back down to more moderate prices, but it hasn't been the way it was in the 90s and 80s from increasing yields. It's a lot to do with expanding production. Ninety percent of that expansion is due to five crops shown there on the right— rice, maize, wheat—six crops, I can't count. Soybeans, sugarcane, and oil palm. It tells you what the world is asking for in terms of its grocery basket. Now it seems to me that if were interested in a sustainable future with agriculture, and we would like to constrain agriculture on an existing land base as much as possible without expanding into sensitive bio-diverse, carbon rich habitats like rain forests, wetlands, grasslands, savannas it seems to me that one of the things you'd like to know is what's the yield production capacity for every hectare of existing farmland. It seems to me like that the public good, we should all know it, and as you think strategically about the future, it can kind of help you look at a roadmap for where there are opportunities. At a country level, it's not that we're promoting self-sufficiency. I know I'm amongst economists. We know, we don't do that. But every country does need to think about its food security and where food will come from, and by having this kind of data, you can look at future scenarios, trade trajectories, export opportunities, or import requirements. Furthermore, it's critical to inform policies and investments in research and development.

The last part of my career was spent trying to develop a tool that can do that, and

it's the Yield Gap Atlas. You can publicly access it there. It's a very simple concept, that the good Lord gave every piece of ground a certain potential yield based on things you can't modify by management. And that's the amount of sunlight that falls during a period when crops can grow, the temperature during that period, and the water supply that's either rainfall or rainfall supplemented by irrigation. That's unmodifiable, and that determines the potential yield, and we're actually quite good at being able to simulate that for our major crops. But if you have the data on climate, including solar radiation, etc., your actual yield at the farm level is determined by things that limit that potential— nutrient deficiencies, imbalances, pests, etc. so if you do that, and you go to the Atlas, you'll see that we've got about 25 countries now with some very good bottom up, this is a new way of doing it, hasn't been done before; we use primary data to the extent possible, we developed the very unique upscaling method to be able to do this, very robust.

The target for a population of farmers isn't the potential yield ceiling, that's not an economically viable proposition due to diminishing return to added inputs and so forth. So a reasonable target that we have found that's quite robust also is about 80 percent of the yield potential ceiling. So if you can simulate that potential, we can estimate where the national production potential is by 80 percent of that value, and that value is on the right here for national production. It's 80 percent of the potential yield. This is Argentina with very good quality data. What you find there for Argentina is that on existing land, because when they expand by the way, there expanding into the Chocon, it's not a rain forest, it's a semi-tropical forest that's considered one of the bio-diverse, carbon-rich habitats that probably we should think about conserving a bit. But anyway, if you were to try to do it on existing farmland, we could reach national production capacity on the right column there, and it turns out that value now is 9 percent, 4 percent, and 9 percent of current global maize exports, respectively. So that's how much Argentina can contribute to global supplies if they brought production up to this 80 percent level. We've started doing it in some countries in sub-Saharan Africa;

these are the results. These are screenshots from the Atlas. The key about our approach is we not only we get mean yield, we get the coefficient a variation in yield. See you get some idea of yield stability. Again, very robust, simulated over years of weather data.

What you find for West Africa is though it has large amounts of rainfall in maize areas, and actually Africa as a whole, much more on average than the corn belt, soil depth and the higher temperature and higher evapotranspiration makes it highly uncertain. I'm going to go here. So this is a plot from the counties in Iowa and Nebraska that produce maize. It's the average yields over a 10-year period, 2001 to 2009; it plots the coefficient of variation versus the average yield for about 100 counties. And you see that the blue set of points is irrigated agriculture in Nebraska. Very high average yields, coefficient of variation typically less than 10 percent. Even in the drought year of 2012, average irrigated maze yields in Nebraska were slightly above average. The red points are Iowa, which is the most favorable rain fed area you can think of. And then Nebraska starts to the west, starts getting into the rain shadow of the Rockies, and it ranges all the way from fairly favorable to very unfavorable where you have low average yields and high variation. It turns out that by our analysis, the first is able to do this, a majority of sub-Saharan Africa falls in what we would call harsh rain fed, which means, for instance in Nebraska, we would never have the robust agriculture we have without irrigated agriculture to stabilize that highly uncertain production environment.

So I want to conclude here, the first set of conclusions, that yeah, irrigated agriculture is sustainable where water withdrawals don't exceed recharge capacity over the medium to long-term, the water quality is maintained. Of course, it requires good governance, and I offer to any of you that aren't familiar with it the Nebraska Natural Resource District's Model of Governance. Can current irrigated agriculture be maintained or expanded? Well, we know, and Mark, we don't have to repeat accepted, my bottom line is that overall best guess, global irrigated agriculture can be maintained, but not likely to be increased significantly.

So what's the scope for improving water use efficiency per se? We're all adults here, we all know that if you increase water efficiency at the crop or field level, it doesn't mean you save water, you know in a watershed, we all know that. However, if you have a set amount of sustainable, rechargeable water, and you want to allocate it as efficiently as possible across as much land as possible, water efficiency becomes very important.

I want to talk a little bit about improved crop management, better irrigation, and crop genetic improvement. This is a model we've used, the water productivity model, used very heavily in Australia as well, but essentially says you have a water supply that is the amount of water in the soil when you plant your crop, the amount of rainfall during the crop that doesn't run off, and any irrigation you apply. So that's your water supply. You can plot grain yield versus that, and when we do we get, look the red line is, a lot of the tales in the paper are about this if you want the guts. But the red line is the target. That's what a great grower at the frontier of technology should be able to do. So any specific yield can be looked at, and you can consider ways to increase yields at the same water use level that would be things like improved agronomy, better genetics, or you can cut back on your water use and apply water more efficiently and lower yields, but do so at less water supply, and of course a combination of both. That's the model. It's robust if you look at real data. These are data from Nebraska. I won't go into details, except for the bottom line. Based on these data, you can reduce water use by 33 percent in this particular natural resource district if you adopted pivot irrigation, improved irrigation, timing based on real-time weather and soil water status, and that can inform policies and decisions made by this NRD when they need to come into compliance because of falling water tables.

What about genetic improvement? And here I'm more sanguine than Mark, because we already have some real data on this. We already know that between our major seed companies, there's been over $1 billion of investment in drought tolerance. Today, in terms of modifying single genes, whether it's by old biotechnology or CRISPR, there hasn't been

any advance that has been tested and published in peer-reviewed journals. We do know that one company has been successful in using what I call in the paper a turbocharged, brute force breeding approach, but that success is no more than you'd expect from a conventional breeding program well applied. It turns out that there published improvement is about 6.7 percent over best available commercial germplasm, and that took an investment of many hundreds of millions of dollars over 10 to 12 years. That's what you'd expect from a robust conventional breeding. My point is there is no silver bullet here. It's going to be a slog, and you've got to talk about improving agronomy as much as improving genetics, and if you don't get that right, then our investments will fall short heavily. And you can see that in looking at what it's taken to maintain a linear increase in maize yields in the United States over the past 45 years.

So I want to call your attention here to the kinds of technologies that have supported this linear rate of gain. Think about back in the 60s when the average rate of nitrogen application to maize corn in the US was 40 pounds per acre. The average today as 160 pounds. Think of the productivity enhancing ability of that increase in nitrogen. Now there's problems with nitrogen, okay. But in terms of enhancing yields, tremendous impact. Think of expansion of irrigated area. Back in the 60s, there was hardly any irrigated area. Today, 15 percent of US maize comes from irrigation on land that was producing the lowest yields in the corn belt. We have integrated pest management, you have transgenic insect resistance, multilocation hybrid testing, this brute force breeding, improved balance of N-P-K. So once you start applying nitrogen, lo and behold, you have other nutrients, there are 17 other essential nutrients that came in soil testing, plant tissue testing, to make sure that growers were applying the right amount in balance of all essential nutrients. I think the most important technologies of the past 15 years, because remember transgenic crops were released in the mid-90s, and since then there's been no significant transgenic crop other than those that were originally released. There's been other cassettes, there's

been other types of BT, there is been other types of herbicide resistance, but no other new technology through biotechnology. What's really been significant in the past 15 years have been precision planters and electronic auto-steer which increase farm productivity, avoid overlapping resources, doubling up on seed and fertilizers are missing altogether, and I think we underestimate the productivity enhancement of these kinds of technologies. The point is that these are earthquake type technologies, and we've been fortunate to have them punctuate this period of time, and all we've done is support a linear rate of gain. What I'm telling you is that we need to accelerate that rate of gain to contain agriculture on existing farmland.

I want to conclude. While there is tremendous potential to close current yield gaps, doing so will not likely reduce expansion of production area without also well-coordinated land-use planning and land-use rules. Likewise, there is enormous potential to improve the water efficiency of agriculture, particularly in irrigated agriculture. But again, it won't help us with declining aquifers unless there is also good governance. Future improvements can be expected from current innovations in both agronomy and genetics, but I will tell you the current business model for seed companies is clearly not tenable. Witness the need to merge, to maintain profits. And though there's tremendous profit in big data, this idea of big data, we haven't seen a business model that can successfully harness it yet. But having said that, I'm a firm believer biotechnology has a huge role to play; it's just not a panacea. Having said that about big data, I am a huge supporter. The only way were going to be able to accelerate yields is by using both tools rigorously coupled with other agronomic and agricultural equipment innovations as well.

I would say, the last point is not just investing in the right mix between genetics and agronomy. This point is larger than that. This point gets to the fact that you've got to accelerate the rate of gain in yields. That is, the linear rate is not good enough. You've got to accelerate it. But you must do so while protecting the environment. I didn't have time

to talk to you about the nitrogen problems, about biodiversity, climate change, greenhouse gas emissions, and so forth. But while we were very good at increasing yields in the past 45 years, we weren't as good at protecting the environment. Going forward that's not tenable. We've got to do both together. And here's what I mean by the priorities.

If it was true that we could agree in this room today that we've got to accelerate yield growth rates and reduce environmental impact of agriculture, then when you prioritize research, you've got to focus on that. What's happened is, and by the way, I can think of thousand ways to increase yields if I don't have to carry the burden of improving the environment. By the way, I can figure out thousand ways to reduce the environmental impact of agriculture if I don't have to increase yields. Unfortunately, we fund research into scientific community separately. You'll never get there. You've got to ask every research you fund to be able to explain how you can contribute to the goal of both accelerating rates of gain and yield and decreasing the environmental footprint of agriculture, together. The problem is that the scientific community that wants to work on reducing the environmental impact, doesn't really like agriculture. They're not interested in productivity. The community that wants to increase yields doesn't really, isn't the community that's going to help on the environment. So that's what's meant by the last point, we have to bring those two together. I'm eminently confident that both goals can be achieved if we do. Thank you very much.

Discussant: Patrick Westhoff
Professor and Director, Food and Agricultural Policy Research Institute
University of Missouri

I'm going to start off by summarizing some of Dr. Cassman's remarks with just translating some of them for those of us who aren't so experienced in agronomy. One of the first things he's pointing out is that linear growth in yields across the world, the global yields for corn, for wheat, for rice, have been pretty much increasing at a constant absolute year-over-year amount each year for the last number of years. So in the case of corn, for example, that translates to roughly one bushel per year as a global average increase. The global average unit for corn is roughly half the U.S. level, increasing about a bushel per year. The area devoted to major crops has increased by 10 million hectares per year, or 25 million acres per year, for the last 10 to 15 years. How much is that? Well how much is our corn acreage? We're talking about in four years time, adding the equivalent of the total U.S. corn acreage to the global total. I'm using global, but probably we can't keep outpacing that growth going forward.

While there is some reasons for the yield growth to be slowing down and percentage terms year-over-year and local disruption, as you've pointed out, being an issue in the Soviet Union when it broke up lots of other parts of the world where you have those sorts of challenges, climate change can be an important future issue, investments in research that don't have the same level of return per dollar of investment that we've seen in the past, and very importantly, something that I tend not to think much about in doing 10 year projections that we do for FAPRI, are biophysical limits and how close we may be or not be to those in particular places on all the real particular crops.

In 2008, he had on his paper that FAO estimated that irrigation accounted for 40 percent of global food supply, and less than 20 percent of land. So the future of irrigation

matters tremendously, obviously. We are unlikely to see bigger increases in irrigated area, perhaps some in sub-Saharan Africa, or perhaps losses elsewhere. We can take steps to increase water productivity as he pointed out by better managing both irrigation and crop reduction. And again, pointing out at the end that, so far at least, supporting conventional plant breeding appears to be generating as much or more benefits in terms of addressing some of those issues as has our more recent focus on genetic engineering. He recommends the importance of appropriate policies, linear improve both genetics and practices, and research to increase crop yields while reducing environmental impacts. So that was by way of summary.

So, I'll talk about one important premise of that discussion. I won't pretend to be able to comment on the agronomics. I'm going to talk about an important premise though. The degree of the challenge depends on just how much we expect future food demand to increase. There's a lot of disagreement about that. I will be the first to tell you I do not know what food demand will be in 2050. That said we find that hard enough to deal with the next 10 years, rather than looking far beyond that. But let me just bring up some important things here. In this paper, you cited a possibility of having an increase in global food production by between 50 percent and 100 percent. The 100 percent figure comes from a paper by Tillman and Company that is comparing the need for food in 2005 to that in 2050. So first, to be clear, that's 2005, not today, and that makes a difference right there. That's the Tillman paper. Then you also said that's based on a statistical model and it looks at calorie protein consumption by country group, income levels, assumed rates of population, a lot of the things that we think are very appropriate to consider. And the growth would be even more than that paper suggests if we have other countries reaching the kind of levels of per capita consumption we have in this part of the world. FAO on the other hand, in 2012, projected food production growth of 60 percent between an average of 2005 and 2007 and 2050. So 60 percent between 2005 to 2007, and the year 2050, a 45 year period of time.

That's a number that is more commonly quoted out there in the press. That report is based on expert opinion, not a formal statistical model. It takes into account both supply and demand constraints, and uses the same population figures as the Tillman paper as far as I can tell. So the difference is entirely in terms of per capita consumption levels going forward. But obviously, a huge difference between 60 percent and 100 percent, as you're looking forward over that 45 year period of time. FAO furthermore projected an increase in cereal production over that period of time a 50 percent for mostly 2 billion tons in 2005 to roughly 3 billion tons in 2050.

Now it's very important to note that since 2005 to 2007, since that three-year average 10 years ago, global production of cereals has increased by 400 million tons, 20 percent. We've already had a 20 percent increase since the point of comparison of that study. So if we still thought that study was exactly the right thing for the future, which implies that the future growth of the world cereal demand between now and 2050 is only 600 million tons, about 25 percent. That's a big difference when we talk about doubling world food production by 2050 and only increasing world cereal production by 25 percent from today's level. Again, I'll tell you why in a second, but I think that's probably lowball figure, but that is actually what the FAO numbers suggest if you take them literally. So it's hard to know who's right obviously, as opposed to what's most likely. The FAO numbers were intended to be a measure of what's likely given current trends not a measure of what's desirable, what needs to happen for food security, is what current trends tend to imply, whereas the other study, the Tillman study, is more where would global food demand be if current income trends were to continue, etc. if there weren't constraints on supplies

So to try to put this into perspective. Let's look back to try to look forward. So between 1980 and 2015, the world's population increased by how much do you think? Sixty-three percent, 63 percent of the last 35 years. World use of major grains and oilseeds, when I say major grains I mean wheat, corn, rice, sorghum, barley, oats, millet, rye, and rich grains.

The nine grains that the USDA maintains our supply and demand database each month. So again that increase, and that's the grains that I'm counting here are soybeans, grape seed, sunflower, peanuts, and cottonseed. So add those crops altogether, the total increase in their production rose 86 percent over this period of time. So that implies an increase in per capita use over the last 35 years of 14 percent; 63 percent increase in population, 86 percent increase in production, and usage I should say is 14 percent for implied per capita use.

Just two factors explain the entire increase in per capita use since 2005, or since the 1980s, over the last 35 years. More recently, biofuels in the United States deliver longer haul, and more importantly by far frankly, China. China is using more grain, more oilseeds in feed rations, those two things combined explain the entire increase in per capita consumption that the world has experienced since 1980. So in other words if you took out China, if you took out ethanol production and consumption in this country, global per capita use of grains and oilseeds in 1980 was 380 kg, today it's 378 kg, essentially the same number in a 35 year period of time. On supply side, and has been talked about already both area and yield have increased. Total grain and oilseeds have increased 11 percent over the period as a whole with most of the increase occurring just the last several years. Average global yields have increased by about 70 percent. Linear growth path as Dr. Cassman pointed out. So therefore, total production increases are consistent with U.S. change that I talked about.

So let's look at ahead now. Looking forward over the next 35 years the U.S. Census Bureau projects a population in 2050 of 9.4 billion. That would be an increase of 30 percent above the 2015 level, and UN's projections that just came out last year; more recently numbers that the others talked about, some of the higher numbers that were talked about in the press on earlier discussion, the talk about 9.7 billion people in the world by 2050. That would be a 34 percent increase from current levels. In the Census Bureau estimates, global population growth slows from the current 1.1 percent per year to roughly 0.5 percent per

year by 2050. So a big slowdown, not just in the absolute numbers being added each year, but in percentage rate of growth. We're currently adding about 78 million people per year to the level population; by the Census Bureau estimates, that drops to 45 million people per year in 2050. Now mind you, these estimates are going to be proven wrong. It's not too hard to give a good estimate of demographics for the next 10 years. Once you start going much beyond that though, very sensitive assumptions make a huge difference.

So the big question I would ask is, how much is per capita use going to increase? Currently, it appears at least to me, that unless there's a major change in policy, unless there's a fundamental change in petroleum markets, we are probably near the end of growth I should say, at least of rapid growth in biofuel production. I may be proven wrong about that but let's take that as an assumption for now. China's per capita growth has been astounding; they probably have more growth to go as their incomes continue to rise, as their diets continue to change, but it can't keep growing at the current pace forever. It can't keep growing at the current pace for 35 years. China will be consuming far more meat per capita than we are. Maybe that happens, but it doesn't seem very likely to me. So eventually there will be some slowdown in China. So biofuels is largely done as a source of risk if you'll take that assumption from me. And of China is bound to slow down at some point, what's our new engine of growth? And yes, we have rising incomes around the world, but are they going to be enough to cause the types of growth we've seen in the past due to China and due to biofuels? So suppose for example that the growth rate of per capita use is about the same for the next 35 years as it has for the last 35 years. With 30 to 34 percent increase in the population, with another 15 percent increase in per capita consumption, rules imply roughly a 50 percent increase in use. So that's more action than implied by the numbers from FAO. FAO's numbers implied something more like 30 percent from current levels, but of course is far less than the higher numbers that were talked about before.

So if yields were to continue to increase in linear fashion, that's a big if, and Dr.

Cassman agrees about that, may not happen, but if they were to continue to rise at a constant year-over-year absolute rate, that suggests roughly 39 percent global yields over the next 35 years for grains and oilseeds, and therefore to match supply and demand you need roughly another 8 percent of area. Again, would you want to get 8 percent of area, could you get 8 percent of area? Those are important questions that we would have to think about hard.

One assumption is to try and suggest or try to feed a hungry and growing world is an easy thing, and I'm not saying that at all. And I'll also be the very first to say the farther you look in the future, the greater the uncertainty actually is. But I do think it's very important because so much that we do depends on the use projections of these assumptions. But we have to come back and look at this more closely. I was just in a meeting a couple of weeks ago in Amsterdam, of other people who also do our sort of work for a living, and I was very pleased to hear that FAO is going to reopen this issue again. And try and look at not just 2050 but even 2080 now because of the time where peak pressure is may happen to be beyond 2050 as it currently appears.

So just to wrap up more briefly, tying this back to water issues, we've been working back since the year 2000 with colleagues from South Africa and other countries in the region. The recent El Nino event as most of you know has done a number on production in that part of the world. In South Africa, for example, its corn production this past year is roughly one-half of what it was two years ago. The country about two years ago was exporting two billion tons of corn mostly to other countries in the region. They use it as a basic staple food for human diets. But now this year, expected to have net imports of two million tons. South Africa is a rich enough country that it can do that and they can keep going without a huge problem. But some of the neighboring countries that have been relying on South African imports, this is a tremendous and horrible problem. Certainly, this water issues is of course very important as we look forward. And you've got other complications

are yellow corn versus white corn, transportation, all the policy issues that all come into play. Even population projections indicate that more than half of the world population growth between 2015 and 2050 occurs in just nine countries—India, Nigeria, Pakistan, Democratic Republic of the Congo, Ethiopia, Tanzania, United States, Indonesia, and Uganda. Again I'll just point out, many of these are African countries where these issues are front and center for food security. Much of the global challenge will be increasing supplies and areas were current productivity is low and water is a very serious concern. Thank you very much.

Discussion with Kenneth Cassman and Patrick Westhoff
Moderator: Cortney Cowley
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Les Lampe: My name is Les Lampe. On my own, used to be with Black and Veatch for a long, long time. My question relates to climate change. It appears to me, maybe I misunderstood, that there was some assumption of climate stationarity in terms of these projections. Looking in the past, the rearview mirror, and showing the yield increase, the linear yield increase, and I'm thinking particularly of something like Nebraska where in the western part of the state, the average rainfall is less than 20 inches. In the current climate change projections from the IPCC, show that by the end of the century, the increase in temperature will be between 3 and 9 degrees, maybe 6 or 7 degrees. Well, that takes it from semi arid to arid, and when you saw those blue, non-irrigated corn yields or wheat yields in that kind of a condition, how are all of these, all of these, models and projections and everything else related to that impact of climate change and what that might mean to us?
Kenneth Cassman: The funny thing is, if you were to go to West Nebraska and ask those farmers how worried they are about climate change, they're not very worried. They see as much climate change in the 10 year span that almost is predicted by those models. I think the big picture here is even those IPCC reports, when they look globally, don't see a big change in total food production. That's because there are winners and losers. Remember every climate zone here today will have a proxy in the future climate world somewhere. And so long as those areas have decent soils, that's probably the ace in the holes, how the change in climate overlays with soil quality, but there will be winners that are able to double crop where they were only producing one crop before, plant early or longer maturing hybrids, tremendous adaptation is possible and opportunities with warming climate in many parts of

the world. Poor Nebraska farmers may not be the winners, but globally it's not as dire I think as the social consequences of that.

But having said that, the other problem, and Mark mentioned it, is that these models are not very good at predicting changes in the water regime. Remember that the most important greenhouse gas of all, much more important than carbon dioxide, the nitrous oxide, the methane, is water vapor. So if you do a poor job of predicting water vapor in the face of climate change, that's the reason for large swings in the projection of future climates.

Don Halcomb, Walnut Grove Farms: Dr. Cassman, I think a great speaker is one you agree with. I really appreciate what you said, enjoyed it. But my concern as a corn farmer is that sometimes I feel like I might be working at Sears Roebuck about 30 years ago and not realizing that Amazon's on the horizon, because I wonder if a better corn plant is about equivalent to a better Craftsman wrench. It's really, you know, we may not be seeing where food is going to be produced because earlier you said in your speech that your idea would be to increase agricultural production in a sustainable manner. But what if you'd said you wanted to increase food production in a sustainable manner, it might be a different idea. So my question is, what if food is no longer produced on a traditional farm, but it's produced in a manufacturing plant like Impossible Foods is doing in California making hamburgers? So really my question is, Pat, when are we going to, in our presentation so far, we don't have, there is not an element of looking at alternative food production systems. Could that ever amount to 10 percent or 5 percent of the production, and what would the impact be?

Pat Westhoff: Obviously, questions remain, and I don't have a clue. You raised very important questions, obviously, and I think there's a lot of disagreement out there about just how important some of these alternative things may prove to be. Some things are hype. I mean, obviously, some of these things I don't take very seriously. I think we're going to continue to rely on cereals and oilseeds for much of the world's food supply for a long time to come. But just as 20 years ago, if you had told me that we'd have the level of biofuel that

we have today, I'd say that was crazy. You know, likewise we're going to have something else that's going to come up that's going to be a big surprise to us, so yes we should be trying to get on top of that.

Kenneth Cassman: So I think the key answer is if we can produce the substrate required for our food supply, and I won't even call it corn, with less energy, less environmental damage, in a test tube, or in a manufacturing plant, so be it. But there is where the proof of the pudding will come. So don't get hyped out by the reports. At the end of the day, it's all energy and mass and we can calculate those things very quickly. And if anybody is proposing that they can do it better then you as a corn grower, ask for the underpinning data.

Audience Question: I wonder if the speakers could comment on some of the work by Jesse Ausubel at the Program for the Human Environment at Rockefeller University. So Jesse published a couple of papers on the land sparing capability in the future of agriculture that in fact we may be entering a phase where we're going to decouple sort of land-use from productivity, and we may face a future where we're going to be returning land back to nature as opposed to putting more under the plow. One of the calculations he shows is that as societies become more developed, we actually begin to reduce our meat consumption, our diets begin to dematerialized, and in fact the dematerialization of Western diets can lead to some of this land sparing capability. But I wonder if you guys could comment on that.

Kenneth Cassman: I would just say quickly that you may be right by 2100, but before you can get to a reduction in consumption on a global basis, you've got to get the low income, low consuming countries up to a point where they feel quote "comfortable enough" or secure enough to then look at a transition lower. So I think if you look long enough, it's possible you might be right, but you'll lose the dynamics that you still have to get through that transition period.

Pat Westhoff: Yeah, I will point out that the United States may be one of the places people have looking for this sort of data. Between 2007 and 2012, real quickly, total meat

consumption in this country dropped by about 8 or 9 percent per capita. It's rebounded more than half of that already just since 2012. Prices matter. Elevated meat prices brought down consumption, meat prices have been slack relative to other products and meat consumption has rebounded again. Europe's had relatively flat per capita meat consumption for a very long time. So I do think, yes, you don't keep growing forever, that's certainly true. I think all of our charts would be consistent with that. But I think what we've seen in China and elsewhere, lots of demand for more protein as incomes increase. China, as some of you may be aware, just announced recently they're going to try to push their people to consume less meat for environmental reasons and for health reasons. That hasn't happened yet, but we'll see if that goes anywhere. That can be incredibly important obviously.

John Ambroson, John Deere Financial: I haven't seen any comment yet or talk about correlation between the size of farming operations and the potential efficiency of water usage or productivity. The last 15 years, we've seen a lot of consolidation. If there is a significant correlation, I think about sub- Saharan Africa, India, and China many, many two, three, or five-acre farms, governments wanting those people out on those farms and not in the cities, and is there a likelihood of gaining scale in those areas to address any of these issues?

Pat Westhoff: This is beyond my level of expertise, but I will say my colleagues in southern Africa have been looking at some of these questions. As I understand what they're telling me, obviously the very smallest operations have a difficult time taking advantage of new technology, adapting new practices that would meaningfully increase their production on a larger scale. But it doesn't take much scale to be able to allow those benefits. We don't have to have a thousand acres. Even a 10 to 20 hector farm can start taking advantage of all these things. But I will say this, a huge area of argument in our profession is just what is the scale effects of what is possible and what is not.

Panelist: Christopher Hartley
Environmental Markets Analyst
United States Department of Agriculture

The United States Department of Agriculture has a long-standing relationship with the Bank and a strong commitment to supporting farmers, ranchers, and small business through job conditions and preparing them for our future. Several agencies at USDA contribute to the Department's Drought Resources and Programs. Their contributions range from providing basic science and economic analysis that informs drought policies and programs, to crop insurance and providing infrastructure and technical assistance directly to growers.

Today, my comments will largely focus on recent efforts by the Economic Research Service, the Climate Change Program Office, and the Office of Environmental Markets to address drought. Droughts are among the most costly weather-related events around. In 2012, roughly 71 percent of the counties in the United States were experiencing droughts so severe as to warrant national disaster declarations. It's estimated that $30 billion in damages occurred as a direct result of drought. Nonetheless the damages could have been far worse. In many areas of the country, farmers were able to reduce potential losses by increasing the use of ground and surface water resources for irrigation. Roughly 56 million acres or 7.6 percent of the cropland and pastureland were irrigated in 2012, three-fourths of which are in the western United States where droughts are becoming increasingly common. There again, agriculture supplies about one half of the value of crop sales in the United States, on only 17 percent of the land. Typically, less irrigation water means fewer crops, creating tighter supplies and higher prices, but not always. Despite four years of drought, this has largely not happen in many of the fruit and vegetable crops grown in California where 70 percent of the nations fruits and tree nuts, and 55 percent of its vegetables are grown.

The state's $43 billion in agriculture production has only experienced marginal decline. California's farmers focused limited water supplies on highest value crops, invested in new wells and technologies to increase irrigation efficiency. The immediate result was a relatively small impact on yields, and a decrease in total crop value of less than 3 percent. Similarly consumers have not seen substantial differences in what they pay for food at the grocery store. According to the Economic Research Service, as of June, the outlook for 2016 for slightly lower than average retail food price inflation, with supermarket prices expected to rise between 0.5 and 1.5 percent over 2015 levels. Even the prices for fruits and vegetables, which are dependent upon irrigation, are forecast to increase a maximum 3.5 percent this year.

Factors contributing to the limited impact include the increasingly global marketplace for food to address supply gaps that occur, the strong value of the dollar which has made imports relatively less expensive, and low fuel costs which have kept energy and transportation costs down. Less apparent is that water users rarely pay the full cost of water. Prices typically reflect the energy cost of delivery, and not its resource value or the impact that unsustainable withdrawals can have on the environment. Most of California's aquifers are experiencing severe overdraft and growing demand for water resources, leading many to question the long-term implications for irrigated agriculture. Researchers from the University of California-Davis estimated that farmers use as much as 5.1 million acre feet of groundwater to make up for surface water deficits in 2014. Continued over withdrawal of groundwater can result in the deterioration of water quality, increase pumping costs alongside the lowering water table, and land subsidence. It also substantially contributes to sea level rise. Although the state received normal rainfall in 2016 and many reservoirs are at or above their historical averages, it will take many years of above-average rainfall and reduced withdrawals to replenish aquifers that have been heavily overdrawn.

I guess the question for you is, are recent drought events an indication of what we can

expect going forward? USDA recently issued a major assessment of the effects of climate change on global food security, and found that climate change can undo all of the gains in improving global food security over the last 30 years, placing up to 200 million more people at risk of food insecurity over the next century. The risks are greatest for the poor in the tropics, and are magnified as the rate of magnitude of climate change increases. Projections indicate that 4 percent of the Earth's cropland is currently experiencing drought, and that by the end of the century, more than 18 percent will be as a result of climate change.

The report also showed that this outcome is not inevitable. Building the adaptive capacity, improving the flow of goods and services by breaking down international trade barriers, and mitigating greenhouse gas emissions improved food security outcomes. USDA's Economic Research Service is working to link the latest climate projections, crop production, and economic models to assess the economic impacts of the changing climate and the associated impacts on the agricultural sector and food systems. Recent results suggest that average commodity yields are projected to decline as a result of climate change for corn, soybeans, rice, sorghum, cotton, oats, and silage under both irrigated and dry land production as early as 2020. Corn yields are projected to decline between 8 and 16 percent. Commodity prices will rise as a result of climate change under most climate projections. However despite higher prices, farmer well-being, measured as producer welfare, declines due to declining crop yields and crop returns. Agriculture will face increased water scarcity in major irrigated areas with projected service water rejections ranging from 20 percent to more than 50 percent across areas of the central and southern Mountain, Pacific, and Plains regions by 2060. That does not bode well for groundwater resources. Gains in efficiency and productivity in agriculture water management and utilization can reduce these risks however. Successful management strategies must address the larger drivers, including population growth, economic development, land-use change, improvements in technology, and ensuring that ecosystem function is maintained.

I would like to suggest that market-based solutions provide one of the best opportunities to do so, and can promote more sustainable, equitable, and efficient water use. Market-based approaches can be extremely effective at changing behavior. Market-based approaches create innovative financial incentives for better resource management, and can complement traditional government programs by increasing private-sector investments in rural America, accelerating resource conservation activities and compensating landowners for the public benefits that they provide on private lands. Markets can also support improved environmental quality by allowing society to achieve higher environmental standards at low overall costs. However while markets can do these things, most markets are notoriously thin, and have failed to achieve their potential.

USDA's Office of Environmental Markets was created under the 2008 farm bill to develop the tools and infrastructure needed to facilitate the participation of farmers, ranchers, and forest landowners in the emerging environmental markets for water quality, water quantity, wetlands, climate mitigation, habitat, and biodiversity. USDA's environmental market strategy focuses on catalyzing the potential of these markets through the development of science-based metrics, market infrastructure, and policy that will ensure that markets are credible, robust, and accessible to all landowners. Environmental market activity in the United States currently averages about $6 billion per year, with the bulk of transactions occurring in wetland and habitat markets. Environmental water quality transfers, or sorry, water quantity transfers averaging more than $50 million per year, and intra-agricultural transactions, although not currently tracked, but are easily several times greater than that number. All Western states allow for water transfers. Transfers can include permanent sales, short-term leases, and longer-term leases of water, of surface and groundwater rights. In most cases, Western water markets are local, by trading conducted through bilateral agreements.

In recent years, there's been significant movement towards developing more efficient

market structures and more organized trading platforms for agriculture water. Policy changes that more clearly define who owns what water, including groundwater, and when that water can be stored, withdrawn, or sold to another user could further facilitate water transfers and the most valuable crops, and provide greater incentive for more efficient water use.

In addition to the direct water transfer markets, there is reason for hope that market-based approaches can help improve water-use efficiency. In particular, the growth of consumer-driven agriculture may play a substantial role in agricultural water management. Dietary preference in the United States is becoming increasingly green. People care about where their food comes from and how it's grown. It's not just the foodies, hipsters, or hashtaggers, as the U.S. population has aged and become increasingly affluent, I'm talking about the baby boomers here, consumers have tended to spend more on healthier foods. There is growing evidence that our changing food preferences in the United States may lead us away from the type of luxury consumption, which has made us increasingly obese, and towards luxury conservation where we're willing to pay more on healthier foods grown under more environmentally friendly production practices.

Agricultural producers and markets have taken notice. There's been a proliferation of voluntary labeling efforts, all-natural, organic, local, sustainably harvested, dolphin safe, cage free, grass fed, hormone free, non-GMO, in addition to plenitude of local and regional labels developed to inform or at least to differentiate between products. Given the success of the certified organic program which boasts total retail market of more than $39 billion in the United States, and over $75 billion worldwide, it's not surprising. Similarly the number of farmers markets has nearly doubled in the past 10 years. There are more than 8500 currently operating in the United States, and the Department of Agriculture has invested more than $1 billion in over 40,000 local and regional food businesses and infrastructure projects. There is substantial interest in developing sustainability labels that recognize

water conservation and strong indications that the public is willing to pay a premium for sustainably produced foods. The questions that remains to be answered are: how much are they willing to pay, and is it enough to change production practices?

A few closing observations. Agriculture has been and will continue to be significantly affected by water scarcity. Quantity, quality, and the cost of delivery. Water scarcity is likely to have limited impact on food prices or availability for the US consumers, however in the near-term, it will have significant local and regional impacts in agricultural production. Existing support mechanisms can help offset many of these efforts, but not all. The decline of availability of renewable water resources will put additional pressure on agricultural producers to re-examine cropping decisions, invest in water conserving technology, and find new sources of water. And finally, improving the resilience of agricultural systems to drought will require continued commitments to conservation and the development of innovative, new policies, tools, and practices for adaptation. Thank you for giving me the opportunity to share some thoughts with you.

Panelist: Guillaume Gruere
Senior Policy Analyst
Organisation for Economic Co-operation and Development

I wanted to structure my speech here on three parts. First, talking a little bit, we heard all speakers talking from the agronomy and moving up to policy, and now we're going to go to the international policy area. You know, the growing importance of long-term water issues that I'm seeing in the political debates at the international level, I want to say a few things about that, and then move along to how you characterize this issue, how do you deal with those future or long-term water issues. We heard some solutions more practical, close to the level, but there's another way of framing it, is to look at water security and how to manage water risk for agriculture. So I'll talk about the project on hotspots and then I'll finish with some remarks on the policy side. But again I'm trying to complement what has been said before, and not repeating all the same solutions.

So the first thing I wanted to say is that in my view, although I've been in the water area just maybe three years, there seems to be a growing importance of long-term water issues in the political debate. As witness, we work for 35 governments around the world—it was 34 until last week, and now it's 35—and we have a committee called the Committee of Agriculture that decides what we work on. In a recent discussion in the committee, thanks to maybe Conference of Party last year on climate change, and the sustainable development goals, have grown from those agriculture minister officials towards natural resource as well as climate change. More and more, we are asked to do more on that, and so that's a good sign for us, but it's also a good sign that maybe things are changing, the link between ag and environment might be also shifting a little bit.

We had a minister meeting in April, we have those every five or six years, the last one was in 2010 and this one in 2016. The theme was better policies to achieve a productive,

sustainable, and resilient global food system. So we had about 40 ministers around the table, and it was co-chaired by the US and France, actually Secretary Vilsak was there as well is the Minister of France as the co-chairs. And so the ministers were invited to discuss what are the key issues for the future, and I was expecting a lot on markets because there was a lot of issues on markets in Europe in particular, and much less on environment, although the climate change will come up. It turns out that even those countries that always focus on trade and markets, the ministers of agriculture were actually saying the big issue for us is climate change, and then there's natural resource, and then there's all the other stuff, food security. So was kind of interesting to see, and of course it was all talking, and it wasn't very official, and I hope this will turn into actions, but there might be some impetus to move forward in those regions that we work in.

At the same time, we've seen some move in the business community. We've seen the World Economic Forum for two years citing water risk as a top risk for international economy. We've seen some global companies in the agriculture sector also taking steps to reduce their water footprints. You know about those. You know, InBev, PepsiCo, Coca-Cola, Nestlé, etc. We've also seen some pushing for disclosure of water footprint by those companies. So maybe also going into the banking sectors, we can discuss that in the next two days.

So anyway, there is a demand for more work on long-term water issues in agriculture. So I wish we would reframe those. So what I would suggest as an alternative to what has been presented by Mark and by other speakers here, is to look at it from a water security perspective. Water security here being defined as the avoidance of four types of risk—too much water, not enough water, too polluted water, and the risk for water related ecosystems. So that's how we define water security. Agriculture, of course, is dependent on the three first ones. If you don't have enough water, we are in trouble. If you don't have the right quality of water, you could also be in trouble. And if you have too much water in some cases, you

could also be in trouble.

So we look at that, we had this project that we were asked to work on water risk in agriculture, and we thought there's a lot of risk, there's a lot of heterogeneity in most types of water risk, the future projection of agriculture, the future projection of water, so how can we deal with all this complexity and heterogeneity. We thought it would be useful to look at hotspots. That's what some companies have actually done. They say, well, you know we are talking about water risk, but where is it in my food supply chain where there will be water risk? And so give them that maybe for 10 years some of the companies and policymakers haven't really looked at where the key risks are, or maybe why they have been in some countries but not in others. More on water quality, less on water quantity. So we have this project on future water risk hotspots for agriculture where we define this hotspot approach has been usable at any different level, at the national level if you have a big country, at the subnational level, at the state level, at even the street level. You think of, where are going to be the concentration of risk for agriculture, and where should we put more bucks to get some more results basically?

We also did in this project, we looked at the global scale. We were asked to look at the agricultural production and where are the water risks going to be concentrated in the world in the future. So we used basically a combination of projections from agriculture, from the IFPRI model, the impact of baseline, so meaning, no climate, nothing. That's for agriculture moving forward. And then on the water risk side, since we didn't really have any in-house modeling, we used literature, so we use like 65 papers, 110 measurements of water risk in the future, quality, quantity, and so on and so forth, each of them having red spots here and there on the maps. And you put them altogether and see a frequency of where there was risks are happening, and you end up with three countries that not surprising to everybody that works in water that are China, India, and the United States. When you get more specifically to regions, there are big, mega agriculture countries that also face a lot

of water risk. But when you look more regionally, there's a concentration of risk around agriculture important regions. So the actual so-called hotspots, we focus on this exercise is really Northeast China, northwest India, and the Southwest US.

Then we moved to impacts. So what does it mean if nothing is done? So we are doing currently some modeling at the international trade level, but we're also looking more specifically in those regions what it means based on evidence from the USDA, from other types of projections. So we have a paper on the U.S. Southwest that will come up in the fall we hope. That shows, you know, what is evolution you can expect for agriculture? You know, you think more high-value crop as you've seen in the recent drought, you would see less dairy perhaps, less livestock. You know what can we expect if nothing is done? Of course is not very realistic, but just to give a sense, just like a stress test in a bank, could we do a water stress test in agriculture in those regions and see what happens?

We're moving also in looking at trade because our countries are interested, New Zealand is interested to know what does it mean if China doesn't produce as much, etc. There is obviously differences in those three regions and for their abilities. So even though I'm thinking there are huge risks in those regions, actually California is not the same in northwest India for sure, and Northeast China as well. So we have to take into account the fact that farmers will not respond the same way, that they don't have the same capacity to move, etc.

But there's also a difference in the policy setting. It's quite interesting because, you know, I went to actually those three regions in the last three or four months. In China, we're doing a study on productivity, barriers to productivity growth in the future in agriculture, and that includes water policy actually. What I've seen in China is that there has been some progress on the political level to bring the water agenda more to the forefront and not just supply-side, now moving through regulating water on the demand side, being more efficient, being less pollutant. It doesn't trickle down so far to the rural areas, and it's going

to take more time, but at the central level, there was the number one document which is the official document every year. In 2011, instead of being about agriculture, which is every single year about agriculture, 2011 was about water, because it was a big, big deal. They had to take a position, then they took three red lines to limit the number of water factors. So in China there is some progress. In California, they already passed a big law that is being implemented. Last week when we were in California. Some of us discussed the Sustainable Water Management Act and now it's being implemented right now. It's going to be probably a game changer for agriculture in the future in central California. So it's already there. For us in India, it's perhaps a little bit behind, but there is some impetus to move, but it's still not there, and it still in development.

So to finish, I have a few remarks about the policy side. We've done some work on droughts and floods in the last few years, climate change, water, and ag, and groundwater in the last three years. So we looked at different types of policy at different levels. What I wanted to say here rather than talking about design options, is that two things frame our recommendation. One thing is that we think that there are different actors that are key to this service of resolving those water risks for agriculture. These are farmers of course that are also bearing the risk already and will bear the risk in the future, that has the responsibility to be part of the solution. There is a sector around it that's also taking actions in some cases, but perhaps not enough another's. And then there's the policy makers. So policy makers on the national level, the state level, and also cities taking more and more action with rural areas.

So all of these are to share some kind of a position, part of the responsibility of moving forward. They have different incentives, different response about the public, the government policy should probably step in where the other two actors are either incapable or unwilling to move forward in those challenges.

The second thing I wanted to say is that policies should also look at what's already

being done. There are government policies together today that are inconsistent with this objective of moving toward sustainable goals. You have some policies sporting, say, water intensive activities in food supports, electricity supports in India, for instance, that really are not compatible with us moving towards a more sustainable and productive types of agriculture. So we should also look at the backyard there. So that's all I wanted to say on the policy.

To conclude, these are my three points. I think long-term water issues are growing. Might be just the fashion, but I think it will continue to grow even though the extreme events that we heard about and the concerns are growing everywhere. I don't see just one tool managing water risk for our new culture, identifying and managing water risk, so hotspot approach is just one possibility. And then policy responses should be nimble and targeted taking into account does different actors. Thank you very much.

General Discussion
Moderator: Cortney Cowley
Economist
Federal Reserve Bank of Kansas City

Cortney Cowley: One of the things that struck me as you put together Mr. Rosegrant's keynote with some of the things we heard in this session is the importance of adapting, yet the rate of return, as Dr. Cassman pointed out, on some of the most common adaptations has declined, and that with climate change, a lot of those improvements as Mr. Hartley pointed out, could go away. So my question perhaps for Dr. Cassman again here, or anyone, is: are there some of these improvements that you talked about—the technologies, agronomics, biotechnology— that have better rates of return than others? And are there some that are more, let's say, resistant to climate change?

Kenneth Cassman: Well I think Mark's paper made the key point. That is that anything you can do to increase yields with existing water supply is perhaps the single most climate change adaptive goal you can work on. So the question really becomes I think the nuts and bolts of how you prioritize. You know you talk to scientists, and every scientist has the answer, and their research is best in the world. So you need some way of sifting the kernels from the chaffe, and I guess I'm just going to say here, we don't do a good job of it. I spent a lot of time on research prioritization, and when I look at what the federal government's spending, when I look at what's being spent internationally and in Europe, that is the Achilles' heel, that when you do get public financing, which is harder and harder, for public goods research in agriculture, you've got to spend it wisely, and I would just say that alone is something we've got to focus on like a laser beam and do a much better job.

Mike Young, University of Adelaide: When I reflect over what we've heard from the panel, the comments, and actually the superb paper, looking at essentially yield gaps, there's a

lot of discussion about environment versus agriculture and risks of climate change, of shifting environmental failures. And the question I'd like to ask the panel to think about carefully is, how should responsibility for risk be distributed? What I'm hearing, and this is specifically to the United States, nowhere else, just in the United States, what is the best way to assign risk? And as background, as you think about this, I think one of the most important innovations that really drove water reform actually in my country Australia was the development of a national water initiative that made it crystal clear who was responsible for bearing 100 percent of which risks. The nation agreed that climate change risk would be borne 100 percent by water users without compensation. That was a very clear message. It meant that we had to rebuild our water rights systems so that nobody had a guaranteed right. It's very fundamental, and it drove a lot of investment and a lot of planning. And when droughts came, the impact of drought was much, much less then it is even in this country, the United States. That's because we told people to plan for it, and that's what happened. When you plan for things that don't go wrong, clarity around the tension between environment and agriculture, if that responsibility is borne 100 percent by society, then governments have to plan to purchase rights for the environment. If it's vague that it might be through changes in things like endangered species legislation, the courts might impose costs on you or the state saw private investors might have to go in, then nobody knows what to do, so it's putting to too hard a basket and nobody plans and everything gets worse. So my question to you is, how should risk of change be assigned throughout the United States? Should it be taking 100 percent for everything by the federal government, 100 percent by states, or which bit should be allocated to private resource users?

Christopher Hartley: I'd be happy to take a shot. So if you look at the history of U.S. agricultural policies and production, going back to the 1890s with the progressive conservation movement, the initial feeling really was that the government should help to ensure that society did have the timber and water resources that they required. As a result,

between the wetlands reserve programs, the wildlife programs, the forest reserve programs, roughly one-third of our country is in federal lands. Most of those lands exist out in the west on the frontier, and if you notice the services that they're providing largely are water related and timber related. Unfortunately, they don't necessarily happen to coexist in the same place that those services are needed. Much of our population sits on either of the coasts where those resources are not present. That really does cause U.S. government to look at the need for resource protection, conservation, ecosystem, service provision, however you want to describe it, as something that has to occur jointly between the federal system, which is taking tax dollars to help preserve those things that the general public wants, and the private lands that are generating them. Our property rights system really has gone a long way in both providing those rights, or those responsibilities, to agricultural landowners to protect them. It wasn't really until the 1970s though that we had strong legislation on the books to do that. Over the past 35 years, you can see how that regulation, both through the Clean Air/Clean Water, Endangered Species Act, and several other regulation-based approaches has worked to some degree; it hasn't worked well enough. We need to extend our protections of those things that we feel are important—the clean water, the clean air, the species and habitat—to be more greatly accepted by the private sector, and how do we do that? It would be very difficult in this country to arbitrarily take or assume those property rights. It can be done, but it would be very painful to do it. There's far more likelihood of being able to do that through pricing incentives, through increased participation in greater policy opportunities to make it happen. I don't think that we could follow the Australian lead of assigning 100 percent of the risk to the producers, or to the water users. On the other hand, I don't think that we can wholly assign it to the federal government either, both because we don't have the budget resources to do it or the land base to make it happen. So looking forward, I really think we need to see a combination of approaches. Although it's not an ideal answer, it's one that I think in practice can and will work.

Guillaume Gruere: I think something, but maybe a little bit on the side of that question. There's a lot of discussion about the recently adopted farm bill; I mean some of you may be more aware about the details than I am, but shifting to once more support towards insurance. Other countries are looking at that with a lot of interests, but there's been papers and other literature also saying that because farmers insurance is basically supported more with this new program, that some farmers may not have as much incentive to adapt to climate change, they might also take a risky approach if they're going to be reimbursed if there are risk for their own production. I don't know if that's true, and people here may be interpreting that. But I think it's an interesting debate of shifting income support for farmers towards more of depending on the prices and on the products, which the shift that is happen with this new farm bill, that might happen in others. UK is talking about it when they go out of the EU. So it's a real debate at the ag policy community; I don't know if it's a good thing, but for climate adaptation and water risk it would also have an impact on what's happened.

David Opendahl, Federal Reserve Bank of Chicago: Thinking about water, I don't think I've heard us mention the largest source of water in the world, the oceans, how do those impact the feeding the world, and are there some potential game changers there in terms of technologies or, you know, you hear about lots of things in the past. But it doesn't really seem to be on the agenda right now.

Kenneth Cassman: So I live 7 miles from the first major desalination plant that's come online in the U.S., I don't know, the last decade or so. It's going to supply 10 percent of the water for San Diego, and there are others here, Pat I talked to earlier, that know more about the specific costs. The point is, there is significant water that can be had there. It just means that within the foreseeable future, and the technologies therein, it means if we were to use that for agriculture, it means a substantial increase in food prices.

Guillaume Gruere: I'm not a specialist of desalination either, but I've heard about the experiences in Australia where they have invested so much in desal in some cities, and

then at some, they actually are not using it, and they have to support the cost of investment continuing on. The factories have been built but they're not used as much because water is actually flowing some years. So it's important also to take into account this investment that can take a long time to….

Christopher Hartley: And I don't think you should only look at desalinization. I think there's an awful lot of recycled or reuse water available to wastewater treatment plants. That could potentially provide resources both in terms of added available crop nutrients, and clean water. Tertiary treatment is realistic; it does happen; and there are examples of it throughout the country. Whether that water is used directly on agricultural crops or for human consumption, both are viable options. There are several very good examples in the US where they're taking tertiary treated wastewater blending it with high salinity waters to use water that is available for agriculture. I think we really do have to look at all options, whether it's desalinization or a better use of the water resources that we have.

Pat Westhoff: Actually, I thought the question might've been more focused on aquaculture and what might be the future there. Currently, we've seen just very different trends in ocean catch of fish versus farmer-raised fisheries around the world, and a very major source of growth in meat and fish supplies in China in particular have been from aquaculture domestically farmed. What the future is there are, are incredibly important not just for China and Asia in general, but for Africa as well.

Cortney Cowley: One question I also had was, talk about in the long-term you keeping supply on pace with demand through improving yields. But here more recently, we've been in more an era of production outpacing demand. We've had a couple of years of really good weather all over the world, record production in the US, and then in some of our competing countries, and so my question is, in terms of water and food scarcity, are there any improvements to be made in, say, distribution and storage that can be done in some of these countries where hunger is even more prevalent than in some of the more developed

world? Can any of you comment on that type of the situation?

Pat Westhoff: Obviously treating loss and waste as we talked about earlier, is incredibly important. It's a mixed bag, let me be clear about that. If you reduced to the level of waste at the consumer level for example, that's a way of making existing food supplies go further it probably means lower food prices for farmers though too. You know so the effects are not all one-sided. Those are some of the attempts. But clearly as you're looking forward, it takes only really minor changes in assumptions about future trends on supply or demand to get a very different price environment. I think Mark would probably concur with that. We did some analysis three years ago looking at a very aggregated model, a much simpler model than the impact model maintained by IFPRI, and just tiny, tiny changes in assumptions going forward can be 10, 20, 30, 40 percent difference in food prices when you get out 30 to 40 years into the future.

Kenneth Cassman: With regard to food waste and food losses, I just urge caution in the assumptions about how far that can take us. First off, it requires changes in human behavior with regard to food. There's very little evidence of successful models of doing that. So you're out, and possibly it can occur, but if you're evidence-based, there is not much evidence that large investments in campaigns of some kind for food waste and food loss are very successful. But the bigger point is that I think the numbers, when you say one third of the supply is lost, it doesn't mean that you can gain one third. It means that you can cut it back a little bit. So it's not a large number, and it's highly uncertain, and I think that policymakers, particularly in the countries where food is going to be needed, you mentioned nine countries, Pat. Right? That essentially most of those are not countries where the ministers of our culture, the planning ministries, are going to put much credence in their strategic plans based on assumptions about how much food waste can be cut back.

Christopher Hartley: And I think that raises a larger issue, which is for a lot of these questions, the developed world including the United States, are sitting in almost the

catbird seat. We're talking theoretically about the need for environmental benefits and improvements in water use and water efficiency over the next 10, 20, 50 years. For many of these places that were talking about, they don't have that luxury. It's important that they feed their populations now. It's important that they have the water resources now. And not to do so definitely raises the potential for political instability both in their countries, but also the off flow effects into other countries that surround them. So from that perspective, I think it's all of our problems, and that we really should look more not only from the catbird seat, but really trying to understand what some of those issues are, and what they mean not only for us, but for overall world stability.

Kenneth Cassman: Your comment just provoked something I wanted to comment about, that my colleague Pat talked about. That is, if we go back to the late 90s, if you live long enough, work long enough, you see almost everything again. But in the late 90s, I'm an agronomist, and I would be at these meetings where there were economist telling us about their econometric models, and every one of them in 1999 predicted that the real food prices would decline into the foreseeable future to 2050. Every one. What changed? Well, Pat said it, it was China and biofuels. But China is not going to be there in that extent, and biofuels probably not. But I guess every model today is now predicting very modest, I would say changes. But what's likely to happen, for instance, I don't see how you stabilize the political situation in sub-Saharan Africa, the Middle East, and Southeast Asia, unless development there accelerates. I just don't.

So if that becomes an important policy concern of the West, and if you want to reduce migration of millions of people from leaving where they are and going somewhere else, we're going to have to accept this policy were going to have to accelerate the rate of development in these places so that people are not motivated to leave. And what does that mean? If that really becomes a policy goal of the developing world, it means that the rate of development has to be faster than what were projecting right now. So I guess that means that there is

all kinds of uncertainty in these projections, and I don't think that we should be shooting low and how were looking at the future demand. That's a recipe for disaster. You've got to build in a buffer. It's like humans are an amoeba on a Petri dish. You know how much do they need on a daily basis? Drop it in. It's not like that. Every one of them has a aspiration to eat like we're eating now, and it's probably not a very stable world unless a much larger percentage of the population get there more quickly than we're currently projecting.

Pat Westhoff: Just a real quick comment. I'd agree with most of what Ken just said, but point out that the uncertainty is in both direction. So if you're a banker in the Midwest, worrying about what's going to be land values in the future, yes, we could have a world where food prices increase with one set of implications, and also a very different world. Now several years ago, at the Farm Progress Show, there was a little board put up where people could put on their expected price of corn in five years time. This was in like 2013, I believe. The average price point was maybe six bucks a bushel. If people were making plans around six bucks a bushel of corn, that's what had to happen, it kind of explains how we get to where we are today. There's lots uncertainty in both directions on these things.

Daniel Heady, Kansas Association of Wheat Growers and Kansas Wheat Commission: One thing were dealing within the state of Kansas specifically is the shift in acres from one crop to another, specifically Kansas wheat acres are at their third lowest level since World War I. Were losing a lot of acres to corn due to genetics. You know they can move and grow corn further and further west in Kansas where it's dryer. An aquifer through irrigation and other processes like that has been depleted, and then there's talk about how there's not going to be any water in western Kansas anymore. A lot of that has to do with the shift from wheat acres to corn acres. So I guess, the bigger question I have here is, what you think the long-term effects of, like you are talking about, advanced genetics and how it's important to increase yields, but advanced genetics are also depleting water in western Kansas. So if we see trends like that, you know, is there a long-term impact, which I believe there is, but I'm

sure you guys have much better opinions on that than mine, but is there a long-term impact to that? And what opportunities do you see for crops like wheat and sorghum, which aren't as water dependent as corn? So I'm interested to hear your thoughts on that.

Kenneth Cassman: So if you consider a groundwater aquifer a depreciable asset, and you don't care if you sustain it, then you would not regulate withdrawal rates, and you would use it up for the highest value use at any point in time. And it seems to me that in many parts of our Ogallala aquifer that's what we're doing, and fine, that's one way to do it. In that event, your wheat will come throttling back and very quickly, as the cost of pumping, and aquifer depths decline to where maize is no longer profitable. On the other hand the other way to do it is to identify what the recharge rate is, and allow on average a long-term level of extraction and work on a way in which it allocated within the law. In that way, you would also see a shift back to more wheat I think because you're clearly over drafting now heavily. And so I think wheat has a tremendous future, it's just a matter of time. Someone said today that in Texas, there sustainable goal is to deplete the aquifer to 50 percent of its original capacity, and then the question is what after that? Apparently, they don't really have a plan after that. But that's kind of the goal. So I think it starts with, the answer to your question starts with the governance of the resource, and the market over the immediate term as to what crops are going to be going.