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It's traditional of course for wrap-up speakers to scan through the abstracts of the papers, say something nice about each speaker, and then talk about their research, which is really valuable. I'm an Emeritus, so I'm not going to talk about my research. And I have 19, I sat last night and counted, 19 paper presenters, discussants, and respondents. So, I'm not going to bother to say something nice about everybody. It would take up too much time. I'm going to try and work out some themes, questions, omissions from the conference.

The themes, the overall theme is growing water scarcity under uncertainty, and remember the uncertainty is not stationary; it's non-stationary due to climate change. And what would one do about it? And I think one of the really interesting responses comes in the concept of information, and if you stand way back from agriculture and look at it, it's a process of changing the entropy of the natural ecosystem towards those species that we favor, or that generate food for us. And if anyone's tried to weed a vegetable garden with a four year old helping you, you would realize that identification of the difference between weeds and carrot seedlings is as important as pulling them out. What we've done in agriculture is we've had a vast investment of energy related inputs, started with mechanization, running through chemistry, and then also going to research. What I'm interested in, and what I think shows a path forward is something that several of the speakers, John, Rich Sandor and so on mentioned, which is the breakthrough we're getting now on information about our natural resources. And so I'm going to come back to that as information and shifts in information systems about natural resources as the thing that can lower the transaction costs and enable better management. So here's the theme—scarcity, uncertainty, and of course, commodification of water.

So, what responses have we got? We've got two responses, technical and institutional. The environment we've dealt with in the research environment is both developing countries and developed countries. For instance, this morning we had a masterly discussion on water markets, their development, their application, the theoretically best ones, the ad-hoc adjustments. Those are very applicable to economies where we have clear property rights assignable, but get more complicated and more difficult for places where the stresses are really great. So going back, if I can spend some time before we go back to information theories and so on, to talk about the developing agriculture environment where we started out. And I was sitting there, and I really enjoyed Mark's talk, and I like the impact model because it's incredibly comprehensive; it also takes into account lots of things I value. But I was left with thinking that's pretty optimistic. We had a substantial reduction in the number of people under hunger stress; we had an increase in the consumption; we had a decrease in prices. Interesting. And Mark's shaking his head, yeah. And yet, we had a rate of technological trains driving that, which in one slide he put 0.23 per annum, which is significantly lower. It's got to be higher than the agronomists rate of 1.2 percent.

We have the other thing that came up with Pat's comments about the dietary shift. And so we have the dietary shift, and you remember that curve where all those countries are clustered down there wanting to have their animal protein, but not getting it, and the question is how far up that curve are they going to go?

Finally, we have Susanne's paper which was looking at the fundamental water stocks, and in particular of course we have Tom's question, how much of our current supply is not in steady state? And the truth is, I didn't get a simple reconciliation between the food consumption question, the population question, which from Pat and Mark seem to be fairly optimistic. From Ken it was fairly pessimistic. And Susanne, I'm not quite sure whether she was pessimistic or optimistic because she showed some really heavily stressed places, the middle east serious problems, Qiuqiong tells us that China has gotten most of it under

control, but there are regions, and we have serious problems in India and other places. So, what to do?

We can't go to the Indo-Gangetic Plains, walk into a 2,000-year-old society and yell, "Markets, guys, markets!" It's not going to work. One of the missions that I heard, and we talked a lot about institutions and transactions. One of the admissions from this conference is I never heard the name Elinor Ostrom mentioned by anybody. She is the only person to get a Nobel Prize for resource economics. She actually is a political scientist, but she had some brilliant insights into self-governing systems for common properties, and that's what she got a Nobel for. And if you look at her writings, and this is coming from someone who's a real die-hard market person, she has eight principles of self-governance. But some of them have real echoes in some of the other characteristics we've heard about the Natural Resource Districts in Nebraska for instance, the one place in the Ogallala that is not mining its water down. Not that mining's bad, by the way; it's a question of are you mining at the right rate? But nobody mentioned Ostrom, and yet she has had significant influence and input into talking about self-reinforcing institutions. For instance, she has an important point that monitoring and enforcement must be done indigenously by the people who are being regulated. And so one possibility is that we will see commodification and markets in developed economies, no question about that. We've had a tremendous discussion on that this morning. But in underdeveloped countries, we have the problem of putting an institution which is not alien to the culture on systems. And so what I would think is a possibility is to utilize Ostrom's insights into collective communities managing their own natural resources, but what we can do from a policy perspective is we can give them information, and we can give them information from a scalable and hopefully unbiased source, which I get to talk about remote sensing later. So, on one side, we have markets fully developed in Australia and a mishmash in the western United States. In fact, I would argue we have lots of trades, quite a few transfers, and no markets. I define a market as something

that I get on my iPhone from Tom's organization, and he can tell me what the price right now is of water at a certain place. So if I wanted to find that in California where we have an active market, I just cannot go to a market and see a price. So we have lots of trades, quite a lot of trading, but no real markets.

So my question number one is, how do I reconcile those four, really similar, nice discussions and analyses of water, agriculture, and developing economies? I'm not sure yet quite how bad the situation is. In one way, I look at it and I think, yeah, China is not so bad, and overall we can balance it out with trade and virtual water trades. And then another way I look at some of Susanne's extreme water stress maps and think, we are in serious trouble, because on top of that, I'm adding population growth, I'm adding climate change temperature increases, I'm adding glacial melt. For instance, I spent some time in Chile where their entire storage system is in the glaciers. That's going to change. And so generally, I think I'm a bit more pessimistic. The response is to of course, I think, recognize the difference between institutions which can be adapted to prices, and institutions that have to be left to local control and local institutions. And we can see that the system can accommodate both. We can accommodate Nebraska's, and we can accommodate the tradeoffs in California.

So, technical. We've got a technical response and an institutional response. The idea of rushing in and subsidizing field level water efficiency improvement has been fairly generally discredited in this conference. I agree. I've had a look at, I had a student who was cited by Susanne on Kansas, superb Kansas data. There is no question we're going from regular center pivots to drop tubes, financed by Equip, made you grow more crop per unit of water. But there's also no question that for any water use, there is a behavioral side and there is a technical side. And if you fix the technical side, or subsidize the technical side without changing the behavioral side, the farmer's behaviors will and profit maximization wins out, and total water use and the rate of abstraction from the Kansas aquifers went up, subsidized

by the US taxpayer. It probably wasn't what they meant to happen. And so whether it comes down to quality or quantity policies, we have to take into account the behavioral side and the technical side.

So, what about the institutional side? We've had a really good discussion on market institutions and Bonnie gave us an overview of those with some disturbing pictures of what happens when the institutions don't work, and you have walls of shame and so on. What we didn't get was how to correct them. And I think the answer is that the correction factors have to be along the lines that Elinor Ostrom laid out of local self-governing institutions rather than trying to impose institutions from above. And so we do not want to fall into the trap of being the neoclassic, arrogant economist who says we can fix everything.

So what did we miss here? We've had a long water conference about quantity but not quality. It's inherent in irrigation that we have an accumulation of environmentally and physically damaging characteristics in our groundwater from irrigation—salt, nitrates, heavy metals. In fact, so much so that going back to my state of California, I am more worried about the degradation quality of the groundwater running out before the quantity runs out. And again, we have both technical fixes and behavioral fixes because if you look at attempts to minimize the salinity load going to the groundwater, first of all you see something like drip irrigation is extremely valuable because it slows down the residence time in the zone, a greater proportion of the water gets taken up, less is leaching down, and less is generating salts. But, you have to take into account the fact that farmers have incentives to modify the mix of water, the types of crops, and the rate of application that they're doing it. So water quality degradation and the sustainability of the water quality in groundwater is very significant.

The second thing we didn't hear much about was risk and supplemental irrigation. I've been working with some colleagues in Brazil where supplemental irrigation is key. And we looked at one of these national worldwide maps, and when you think about Nebraska, Kansas to a lesser extent, depends on which part, throughout China, India, for most of the

world, irrigation is supplemental irrigation. It's a function of the monsoon, it's a function of the rainfall. And it is a risk-reduction mechanism. And it's quite possible that the risk reduction from supplemental irrigation has a greater value marginal product as economists would call it than the 100 percent irrigation that we practice in fully arid areas.

The second point I want to think about risk is the possibility of going back to Ken's yield gap, and he had that 80 percent rule, and he looked at people in Nebraska and he looked at people in other places, and the farmer will run up to 80 percent and after that, it just gets too risky. One thing we could possibly do, and I have a colleague Michael Carter Davis who's doing this, is to use the concept of index insurance, which is an insurance policy, not based on what the individual does, but some overall index. And he has an active system of insuring grazing for itinerant grazers in northern Kenya, and it's reinsured by Geneva. So you've got Swiss bankers reinsuring itinerant grazers in Kenya. My point is here, that if you have insurance for the drought, you're going to treat your animal stocks differently. For irrigation, I see no reason why we shouldn't use an index insurance policy based on the water year, and essentially add a policy layer of insurance, and it could be a market insurance to encourage farmers to move beyond that 80 percent towards the 100 percent.

And finally, we come to the point that was mentioned quite a bit in the last discussions of transactions costs. This is going back to my starting theme of information. It's information about resources, about natural resources, because one of the reasons why we have these really ad-hoc rigid rules is it's so hard to measure. We need to measure consumptive use—Mike, notwithstanding your gross accounting—and we need consumptive use, and we need it measured by an impartial, trusted source. I've been working for the last few years with a system called Metric, which is a clever piece of Dutch programming implemented which can turn radiant energy measures from lands sat into measures of vapor transpiration. It's done on a 40-meter pixel, so this room we can figure that out. A bit bigger than this room. Not much. 120 foot. We can get it every week

depending on cloud cover, and we have used it in a number of experimental situations. I had an interesting experience. Last week, I was at a conference sitting next to a water district manager, and the conference was about this new law in California which is going to force people kicking and screaming to manage their groundwater. And I was talking to this manager who is a very forward-thinking person that I said, “Well, what are you going to do? How are you going to do this rapidly because we don’t any meters on the wells?” He says, “Oh, well, that’s not a problem, we just use the satellite.” And I said, “Really, the farmers went for it?” And he said “yeah”, he said, “I told them about it, and they said huh?” And we went out and we got, it was Cali Poly San Luis Obispo who have a very well respected water measurement thing. And they said, “Ground truth based on so and so’s field, ground truth so and so’s field, and ground truth in here.” And they ground-truthed it, and the farmers have bought in. They would rather have the eye in the sky than bother with the metering. So we’ve got not only a quantum shift, and it’s just going to go, and I noticed that John was talking about this, and he mentioned this outfit that I visited last year, Planet Labs. If you want to have pretty pictures, Google them up. They’re only pictures at the minute, so we have to use land sat to get a vapor transpiration. But when the farmers accept it, we’re really, really close. The other characteristic which is coming up the line, which is harder to do but it’s coming on, is of course crop identification remotely.

So to summarize then, we are moving in and several people have said this, we are moving into the information age for natural resource management. As we move into that information age, transaction costs will go down, public policy, but information is of collective good, and is a highly scalable cost function on satellites. So I see that instead of subsidizing people to convert to more efficient irrigation systems, let them do that on their own dime, but tell them exactly what they’re using and what their neighbor is using, and have it open access information on natural resource use and we will end up hopefully with a bunch of Nebraska natural resource management districts trading with each other. Thank you very much.

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Discussion

Moderator: Nathan Kauffman

Assistant Vice President and Omaha Branch Executive

Federal Reserve Bank of Kansas City

Audience Question: A question on your last point about open information on who's using what water and where. Do you think that's a function of the federal system, a state agency, or the private sector?

Richard Howitt: Well, it's been generated by the private sector at the minute, but I'm trying to encourage a consortium of two state agencies and one federal agency in California to put together and buy this analysis from private firms. So the private firm would do it, but of course, the machine that actually, that land sat, is again like the internet. It's a collectively provided good through the US federal government. But I ceded both the agencies having a tremendous benefit of combining and scaling this information. And then just make it open, open information.

Bruce Royer, Northwest Iowa Farmer: I come from part of the country that doesn't deal with the shortages that we've been hearing about. Our crops are grown totally by rainfall. We don't irrigate. And the change that we are seeing is excess moisture and the deleterious effect that that is having on us. We have rain events now that can be as high as 8 to 10 inches in one event, in an overnight or less. And that is very devastating, creating the flooding end of things. And so we look into things like draining the excess out quickly so as to be able to have the sponge wrung out so it can catch the next one. Now that doesn't mean you don't have periods of minimal rainfall in between, but the pendulum is swinging back and forth much more rapidly and much further is the change that I am seeing in this part of the country. The other thought I have, you mentioned quality of water. We had in an attempt to clean the air, we had oxygenation of our gasoline. We had the MTBE, and we had the

ethanol. MTBE went away because of its creating carcinogens in groundwater. My concern is internationally. MTBE is still being produced at the same rate as it was when it was sold in the States, but it's all being sold overseas. And so you have developing countries that are polluting their groundwater with carcinogenic vapors from the MTBE so they're losing quality as they're trying to clean their air. So that is something I think that will need to be watched in the future. When you mentioned quality, that thought came to me. Now, no real question there, but just comments.

Richard Howitt: I take your points and I remind you on Ken's little plot of low coefficient of variation, high yields. Ideal place to grow corn. The best ever. You might just have to put in a few drains though. Other places have put up with that, but you're still going to be a great place to grow corn. And the MTBE question is a classic international externality question. It's one that we can only help by providing information and perhaps monitoring what those levels of MTBE in the groundwater are in these developing countries. It might not be their only pollutant. Sometimes arsenic is a real problem too.

Bruce Royer: Just following up on that. There's a court case in Iowa now that deals with runoff from the operations and the quality of the water in terms of nitrogens. And so there's this whole debate now in many parts of the corn belt and the Midwest are dealing with what's flowing through the Mississippi River system down to the Gulf, and causing problems down there. What do you think about the long-term consequences for some of those natural water events and how we're going to deal with that in terms of the water quality.

Richard Howitt: That is a very serious problem and it's under significant study. But again, that interestingly enough, comes down to microbe management of the agronomy on the farm. We clearly have to simultaneously have nutrient control and runoff control. One possibility that's actually starting to come in in California more is the use of winter cover crops to stabilize. I don't know whether that's a practical solution for Iowa or not. But it both stabilizes the surface and of course helps infiltration rather than direct runoff. And the

other thing of course is what you're already doing which is minimal tillage.

Cortney Cowley, Federal Reserve Bank of Kansas City: Hi, thank you so much Dr. Howitt for wrapping us up so completely. I want to go to your comments on risk, and you talked about the situation in Brazil where irrigation used as a supplement on land that got some rainfall was, did you say more valuable? Or, helped reduce risk more than in arid areas where there's less rainfall. I was kind of wondering how you came about that conclusion because my research here in the district involves farmland values, and I've seen in some research in California looking at the differences in farmland values on irrigated land compared to non-irrigated land, and a lot of the models precipitation is not significant whereas similar models in our district, precipitation is a significant variable in contributing to farmland values for irrigated crop land. And so that kind of reminded me of some of the things you discussed on Brazil, and I was wondering if you could comment on that.

Richard Howitt: Yes indeed, and that's exactly it. In Brazil, as in many Midwestern situations, summer rainfall is an important component of the vapor transpiration. And as we saw on Ken's slides, going back to them again, that one with the curve, and there was all those ones going to the western part of Nebraska which had both highly variable climate and rain, and of course lower yields overall. The question is if we could have added more supplemental irrigation to those regions, then they would have moved down, reduced their risk, and raised their average. So clearly rainfall is critical, as is soil type and micro climate. But the access to supplemental irrigation, even as a much smaller level than full irrigation, can be very valuable in reducing the risk in those peak periods, and we found the same thing in central Brazil.

Audience Question: Richard, you mentioned the work Michael Carter is doing on weather index insurance. There are a lot of other pilots out there. From what I've seen though, there still hasn't been a system designed that gets rid of the basis risk without very heavy subsidies to make it viable, and the reinsurance companies only come in when they have pretty strong

guarantees from the government. Do you see any way of designing those kinds of systems so they'd be commercially viable without subsidies? It's perfectly fine if the government decides that's a priority for public money, but so far I haven't seen any way that get away from significance, even on index insurance.

Richard Howitt: No, I take your point, and the basis risk is still there because what we're doing is we're trying to improve the productivity of people who are living in inherently low productivity, risky situations. I think the question is not that we get a free lunch, but the fact is if we're going to buy lunch, do we pour our money into one characteristic where we try and influence the day-to-day operations of individual farmers when they make decisions, or do we invest in something that's both scalable and has a public good characteristic. And then, so 'look farmer if you want to buy this risk, here's the discounted price.' Then you make your production decisions conditional on less risk. I just think it's a way if we're going, and we have to, and we have a moral obligation to transfer wellbeing from the developed to the developing countries, and I think this is perhaps a more effective way, or one effective way of doing it because it has the characteristics of not trying to substitute for the farmer's decision making. I belong to the Theodore Schultz theory that they're poor but rational.

Mike Young, University of Adelaide: Following on to that, I think that once you have a market in the sense you're talking about where prices are really transparent and rapid, the case for insurance becomes much less. When you look at what's happening now in Australia, rather than buying an insurance product, if you want security, you buy more shares, the long term entitlement, and plan in most years to sell off the water you don't need. And that is the cheapest form of insurance you can get. If you look at the market in fact, what's happening now in Australia is farmers tend to pay too much for entitlements, the long term share, rather than being prepared for being risk neutral which means you just buy water as you need it. And so you've got a market which does this, and particularly when you allow people to actually carry forward water from year to year, and use it in storage

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or put it into groundwater systems, and you have actually exchange between the two, as you're starting to see occur in parts of California, essentially the market collectively and everybody's behavior probably supplies the most efficient form of insurance. So the fact you have insurance means you've got a design problem in your rights system.

Richard Howitt: And it might be that, but I think the most likely explanation goes back to something you emphasized, which was you've got your transaction costs down, right down, your 40-minute deal. And so in that situation, it becomes much more efficient as you point out. The other thing which I think is interesting following from your remarks is something that Richard Sandor said about going straight to futures markets and not worrying about the spot market. And really that's something that in the west, I've always thought we should have, and yet it just seems to be too hard to do. We have contention contracts which are a sort of futures market, but we don't have a proper futures market.

Susanne Scheierling, World Bank: You mentioned the work of Elinor Ostrom and one could comment that without, again without policing institutional arrangements, these self-governing entities may not work for a long time. And if there is small security provided by some kind of natural framework, there are usually problems except maybe in cases where people are very remote and nobody interferes with them. So I think one has to also see Elinor Ostrom in a larger framework.

Richard Howitt: I think I get your point, Susanne. I agree. We need some larger structure to keep the small structures in place, but I think that's okay. I mean, things have worked. For instance, the Spanish-Mexican systems of allocating water, not without strife, but they have been there for 600 years or thereabouts. I think I know Ostrom's study various allocation systems for water in Peru and so on. What I haven't found yet is one of groundwater because the information is not there. So I think, yes, you're absolutely right, we need an overall structure to encourage people to form these districts like Nebraska for instance. But we also need to provide information cheaply and reliably to allow them to

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make their decisions. This really goes back to something that QQ was talking about in China where decisions are made within the villages. I think this is the natural format, that everybody in the small village or even a large village knows exactly what everybody else is doing, and particularly that you have satellite pictures that you can look up on your iPhone and there it is. So, add information to traditional institutions and they should go better.