Agri-food R&D: re-examining the rewards and the risks

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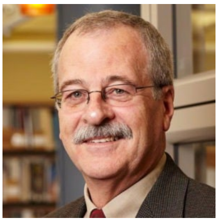


It is a delight to be back in Australia and to be here at the Crawford Fund annual conference, this year celebrating the 35th anniversary for the Crawford Fund and the 40th for ACIAR. My brief is to reflect on the impacts of international and national agricultural research, through the lens of a sceptical hard-nosed economist.

I am going to benchmark my remarks by looking at the evolving investment scene in food and agriculture R&D worldwide. I will show that this scene has changed dramatically over the past decades and looks very different now from how it was when the CGIAR was formed in the early 1970s. This investment benchmarking can help us understand the risks and the new headwinds that we face going forward, and reflect on those risks compared with those that prevailed when the CGIAR was formed from its antecedent agencies that came on line in the 1960s. I am really worried about what I see, having looked at these data for many years over my career, relative to what needs to be done. And I hope we can collectively galvanise a different trajectory from the one evident in the data that I am presenting today.

Global agri-food production and R&D investment trends

Before going into the R&D story, I will benchmark what the world of agricultural production looks like today relative to what it looked like when the CGIAR was formed. The good news is that we have almost increased the value of agricultural output in real terms four-fold, from

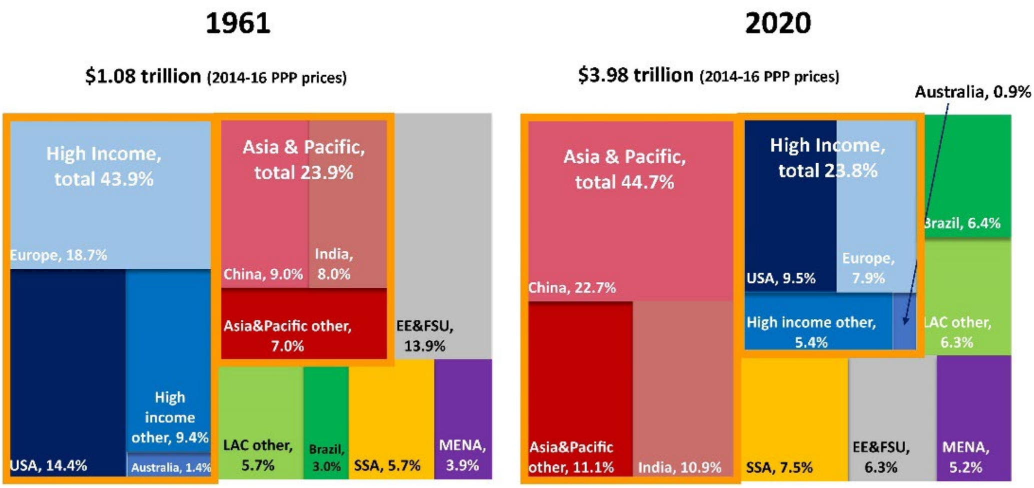


Figure 1. Where agriculture happens across the world, 1961 vs 2020. *Source*: FAO 2022.

about $1 trillion in 1961 to nearly $4 trillion today (Figure 1). That fourfold increase is a greater increase in the value of output than the increase in population; thus, the world has increased the value of agricultural production per capita globally over this period.

Now look at where in the world that production takes place (Figure 1). We have had a huge geographical shift in the location of production. Formerly, the rich countries accounted for around 44% of that total agricultural production, and today their market share has dropped below a quarter. The Asia–Pacific region is the flipside of that story. They have gone from around 24% of the total to 45% of the total. So, the geography of production – and the implications of that with respect to the impacts of markets and climate on agriculture – are now very different from how they were 60 years ago.

Australia, notwithstanding its significant increase in agricultural output, has not increased its output as fast as the rest of the world. Consequently, Australia has lost about a third of its market share over this period. If you look at other countries, such as Brazil, they have nearly doubled their market share (Figure 1). This has very significant implications in terms of the types of technologies, institutions and policy instruments that will be required to foster agricultural growth in the years ahead. …

***Editor's note**: Since this presentation at the Crawford Fund conference, Professor Pardey has been encouraged to submit a policy piece to a major international journal, reporting on and drawing lessons from his team's newly collated data in relation to 'Global agri-food production and trends in R&D investment', and 'Investment in the CGIAR'. Therefore, content related to those two sections of his talk (and Figures 2–6 and 13) are omitted from this record of his conference presentation. Pending prospective publication of that material, the full record of Professor Pardey's conference paper will then be published on the Crawford website.*

Summary of the messages of the omitted sections:

> Over the past four decades there have been unprecedented structural shifts in the geography, research orientation, and public–private performance of agri-food R&D worldwide. These kinds of large structural differences need to be reflected in innovation opportunities and institutional instruments in ways that recognise the investment needs and environments facing different countries in different regions of the world. Currently new funding is often directed to newly important issues including health, nutrition and environmental concerns, at the expense of continued funding for research aimed at sustaining productivity growth in agriculture. However, Prof Pardey considers the funding scene with respect to food and agriculture R&D is amenable to policy change. He says these R&D investment trends are not 'set in stone'; we can change these trajectories.

The remainder of the record of Professor Pardey's conference talk continues below.

Does agricultural research pay?

For this talk I was asked to present an up-to-date sense of the evidence regarding the returns of investment in agri-food R&D. For this I will draw on a recent study conducted by myself and colleagues, with funding from the Bill and Melinda Gates Foundation and under the auspices of the SOAR Foundation (Supporters of Agricultural Research, in Washington, DC, which has a mission highly aligned with that of the Crawford Fund).

For this study we were asked to tackle the question 'Does agricultural research pay?' and to also reflect on some related issues that I am often asked about. For example, questions often arise like 'Maybe we made the easy gains back in the early days of the CGIAR (or back in the mid-fifties for, say, national agricultural research) such that research is much more costly now, but the benefits haven't grown commensurately?', or 'Has the return on investment declined over time?', implying 'Perhaps agri-food R&D spending in general is not as good an investment now, or perhaps investment in the CGIAR no longer provides as good a payoff as investments made during its founding years?', or finally 'How do the R&D investment trends I just described square with the economic evidence about the impact of these investments?'.

To undertake our study and address these questions, we conducted a hard-nosed data-driven assessment of the published evidence over the past 50+ years regarding the economic returns to investments in research performed by the CGIAR (and national agencies).

- A hard-nosed, data-driven assessment of the past payoffs to CGIAR research investments
- To do so we
  - Compiled all available ROI evidence for National (and CGIAR-related) R&D
    - 430 (115) published studies, 2,600 (363) ROI estimates , spanning 1958-2015
  - Standardized ROIs into comparable benefit-cost ratio (BCR) estimates
  - Conducted a formal meta review of the ROIs
  - Benchmarked that ROI evidence against other relevant information
    - Identified 9 studies of CG-related R&D with payoffs in excess of one billion
    - Assessed value of TFP growth attributable to R&D for 1961–2020.

Figure 7. What we did.

Figure 7 summarises what we did. Specifically, we compiled evidence from hundreds of studies, including those published in journals, books and elsewhere, that reported estimates of the return-on-investment (ROI) to research conducted by the CGIAR and national research systems, and then standardised the different types of ROI estimates into comparable benefit–cost ratios (BCR) estimates. We then undertook a formal meta-review of the evidence and benchmarked that ROI evidence against other information related to the payoffs to research, including an assessment of the plausible share of the growth in agricultural TFP (total factor productivity – that is, the ratio of aggregate agricultural outputs to inputs) attributable to the associated R&D spending.

Figure 8 summarises what we found. It includes a graph of the counts of the standardised returns to research (i.e. benefit–cost ratios) evidence related to CGIAR research, ranging from low benefit–cost ratios on the left to high benefit–cost ratios on the right. Many of the studies reported BCRs in the 2–7 range, indicative of a payback of $2–$7 (in present value terms) for every dollar invested in research conducted by the CGIAR (often in partnership with research conducted by national agencies). Notably there are a number of estimates at the high end of the distribution, indicative of research with very large payoffs (more than $47 of benefits for every dollar of spending). That is just the nature of R&D. It is a risky endeavour so that some research yields modest to no returns and some research pays off 'big time'. The pertinent question is, overall, is the investment in a portfolio of R&D such that the investment overall yields sufficient return to justify that investment?

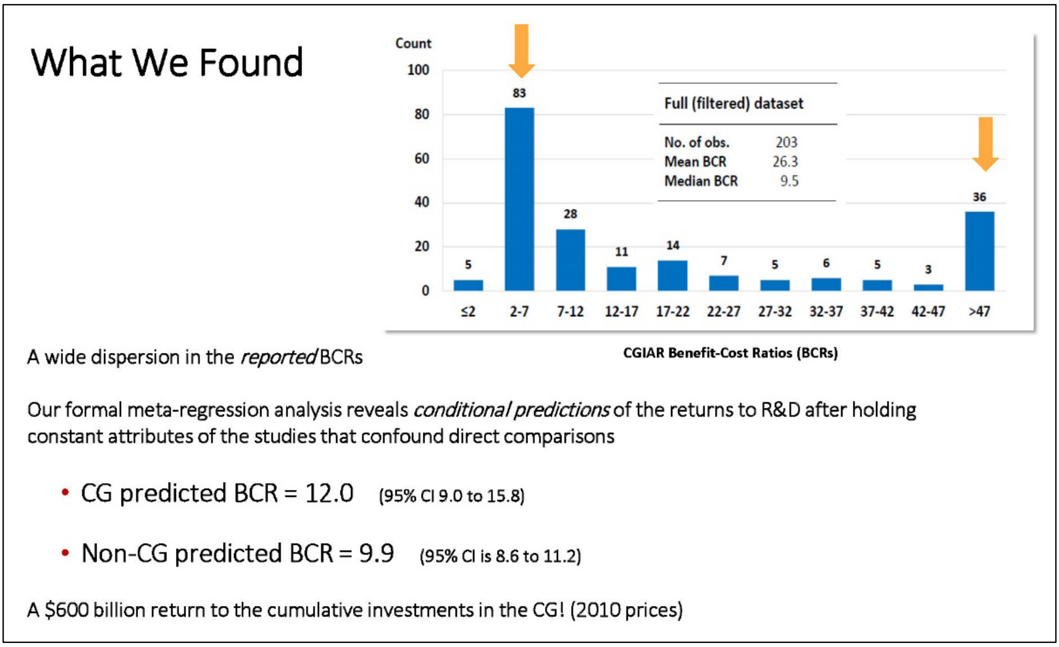


Figure 8. What we found

One way to summarise the ROI evidence is to take the mean (or better still in this instance the median) of the distribution as an indication of the payoffs on balance (i.e. averaging across the low and high payoff research). However, the studies from which these ROI estimates were drawn differ markedly in terms of the types of research being evaluated, when and where and by whom that research was undertaken, and, critically, the technical evaluation details as to how each of the studies was carried out. To improve the comparability of the studies we used regression procedures to undertake a formal meta-evaluation of the evidence from which we produced conditional predictions of the BCRs that hold constant all the potentially confounding factors that would mean one study is not directly comparable to another.

The good news is that, despite being sceptical economists, we got an incredibly robust result from our meta-analysis. Specifically, after due allowance for the confidence intervals (CI) around the conditional point estimates of the BCR on average, we found that investments in both CGIAR and in national research agencies are returning about ten dollars for every dollar of investment. That is a very big return. It indicates that the CGIAR, overall, returned globally $600 billion of economic value back to society from the $6 billion in cumulative investments made in the system over the past decades. That's a really big number from one institutional organisation, which constitutes a fairly small share of the world's total R&D expenditure on food and agriculture.

Figure 9 highlights some other important nuances that arose from our analysis. For most if not all agriculture R&D there are long lags, often multiple years or decades, before the returns to the investment in the research are fully realised. Thus, reaping the full potential from agricultural research requires very far-sighted and sustained investment. As I mentioned, these BCRs are especially high. In fact, investments in food and agriculture R&D appear to be more profitable to society than many other areas of government spending. Also, importantly, there is a natural built-in equity bias with respect to investments in food and agriculture R&D. Low-income people spend a much higher proportion of their income on food consumption – 60% or 70% – as compared with high-income people who spend about 10 to 15%. So, the equitable impact of investments in agricultural R&D that tend to lower the price of food pivots towards low-income people, who benefit more than richer people particularly when the R&D work is focused on food staples.

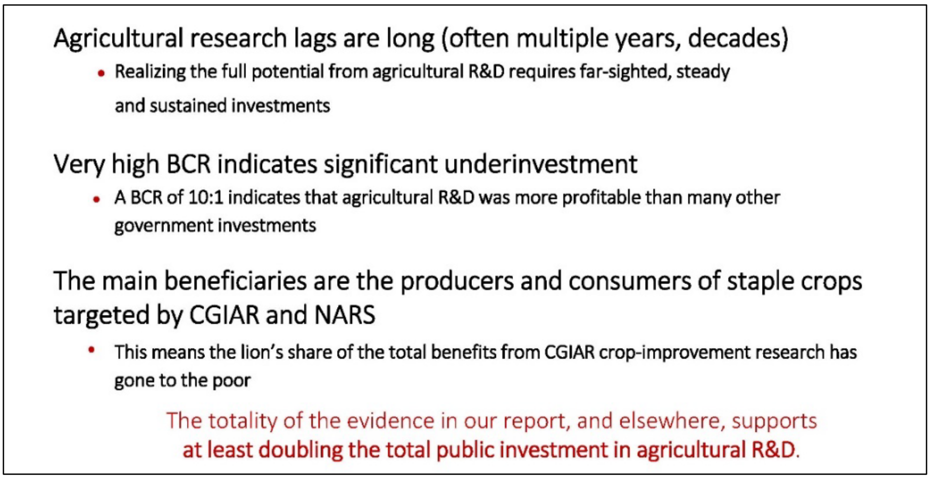


Figure 9. Aspects of the findings.

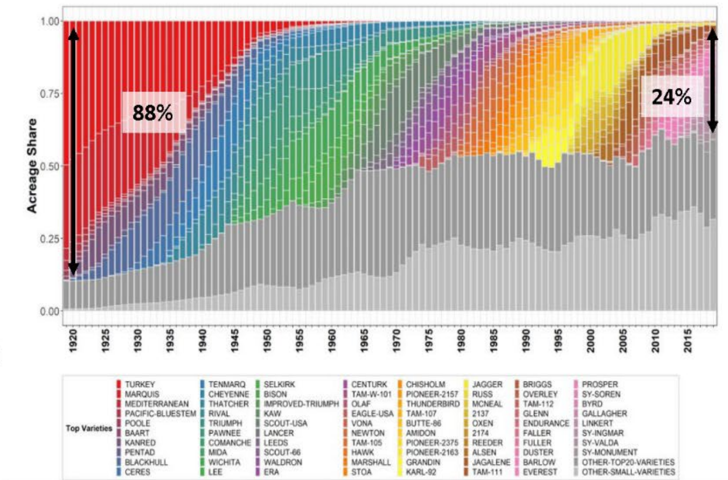
Our conclusion, from looking across the totality of evidence, including our own work and that of others, is that the economic evidence justifies at least a doubling of the total investment in food and agriculture R&D. From an economist's perspective, a benefit–cost ratio of 10 to 1 indicates that you have grossly under-invested. The optimal benefit–cost ratio is 1:1 – which means that the last (marginal) dollar you invest gives back a return of the margin of a dollar. So ideally you keep investing in R&D up to the point where the marginal benefit equals the marginal cost. That is a core principle of economics. And when you are producing a lot of benefits relative to a smaller total cost, in principle you need to keep investing into that space until you drive that return down. Therefore, the hard economic evidence, let alone all the equity and other impacts arising from research conducted by the CGIAR and national research agencies, points to a substantial underinvestment in agri-food R&D.

Some new insights on crop production

The impacts of investment in agricultural R&D are multifaceted. I'd like to briefly step back from the ROI evidence a little to highlight some new insights from some new research. Hopefully the insights that are arising from some of the current work we are doing may help you to see the agricultural world (and the importance of R&D) in a different way than in the past. Some of this research is in a publication pipeline; some is still a work in progress.

One strand of research is seeking to understand in much more depth the *long-run* processes and implications of the genetic gain in crop development, focusing first on wheat production in the US because this is where we have been able to compile very long-run data (Figure 10).

	1919	2019
Top 5 varieties (area)	88.1%	24.3%
New varieties (<5 yrs)	1.3%	35.9%
Average age (yrs)	36.4	9.3
Varieties /million acres	0.83	9.2



Consequences of Scientific Selection

Increased

- Spatio-temporal varietal diversity
- Yields
- Output
- Crop resilience

Reduced

- Cropped area

Figure 10. Genetic gain in US wheat, 1918–2019.

The graph shows changes in the farmed area share of each wheat variety year by year from 1918 to 2019. The coloured parts of the graph indicate the respective area shares of the top five varieties, from then (being 1918) to now (being 2019). A century ago, just five varieties accounted for 88% of the entire wheat production in the US, while now the area share of top five varieties has shrunk to just 24%. The darker grey area plus the coloured area indicate the area shares of the top 20 varieties, and the lighter grey area shows the area shares of the minor varieties. The shifting spectrum of these colours reveals the waves of new varieties sweeping across the cropped landscape over time: indicative of a persistent wave of innovation within the wheat sector over the past century. The number of new varieties (i.e. varieties less than 5 years old) that farmers sow in their fields has increased from barely 1% of total wheat acreage to 35% over the century. In addition, the average age of those varieties has dropped. And, importantly, there is increasing pattern of environmental niche-filling evident in these data – that is, a better matching of varieties to the spatial variation in local agro-ecologies, as evident by the increasing number of varieties per million acres. This has had all sorts of beneficial consequences. In the US there has been a 3.5 increase in yield associated with a doubling of output despite a major decline in the acreage sown to wheat. Having a much richer mosaic of varieties on the landscape, and changing them often, means there is a lot more resilience built into that system as it confronts new shocks from changes in climate, pest and disease pressures, and things of that nature.

We have also been thinking about the multi-peril risks faced by wheat (and other crop) producers. Crop breeders and farmers know they are facing not just one pest at a time; rather they must contend with a whole portfolio of pests. We have been developing a capability to spatially assess the (changing) strategic pest risk exposure of wheat, maize and other crop producers worldwide.

Just as there have been big geographical regional shifts *between* countries in the location of production over the past 60 years (see Figure 1), there have also been similar shifts *within* countries. Figures 11 and 12 draw together our on-going work regarding the movement of crops within countries and spatial differences in multiperil pest risk exposure, in this instance for maize producers in Brazil and the US. The darker reddish colours are indicative of locations exposed to more pest risk. The green shading indicates the location of maize production in 1920 for Figure 11, and 2015 and 2007 in Figure 12. We can estimate the geographical centre of production of maize in Brazil and the US, and we find it has moved considerably within

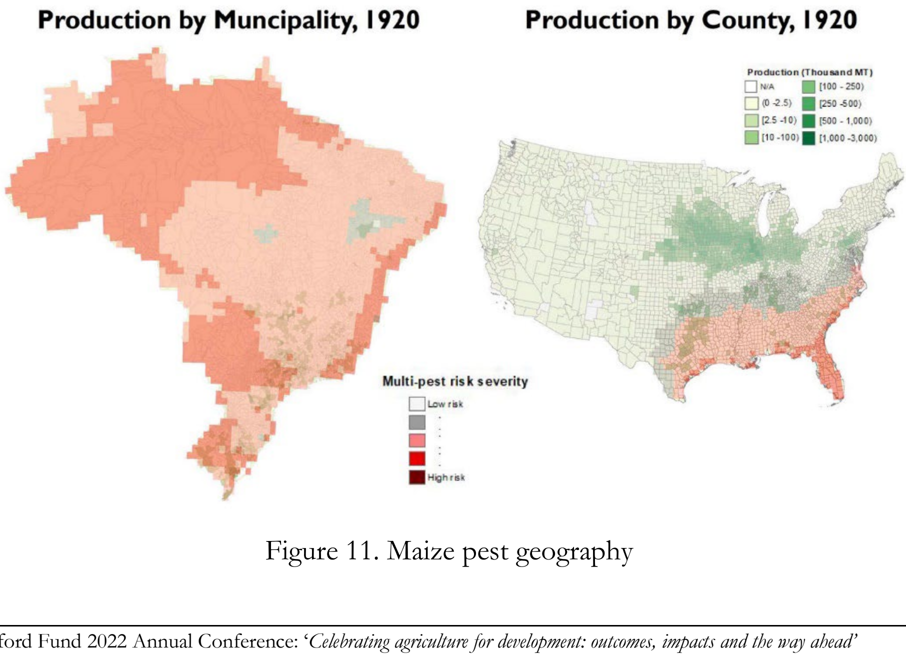


Figure 11. Maize pest geography

those countries over the past century: roughly 400 km in a north-westerly direction for Brazil and around 200 km in the same geographical direction for the US.

This is amazing. Although maize production in both countries has moved in the same geographical direction, it has moved in exactly the opposite agro-ecological directions. In Brazil, maize growing is moving close to the equator and in the US it is moving further away from the equator. Moreover, we have overlaid these maps with long-run climate data (Figure 12), and we find that the average corn plant in Brazil is now grown in a climatology that is 2.4 degrees centigrade warmer, while in the US it is now grown in areas that are over 1 degree centigrade colder compared with the location of production in the early 20th century. In addition, we find that maize production in Brazil is now located in a much riskier climate and pest-risk environment than maize production in the US. Once you start moving the location of production, for market or other reasons, you have fundamental and possibly profound changes in the production risk implications facing agriculture. These are among the risks that lie ahead and are yet to be addressed.

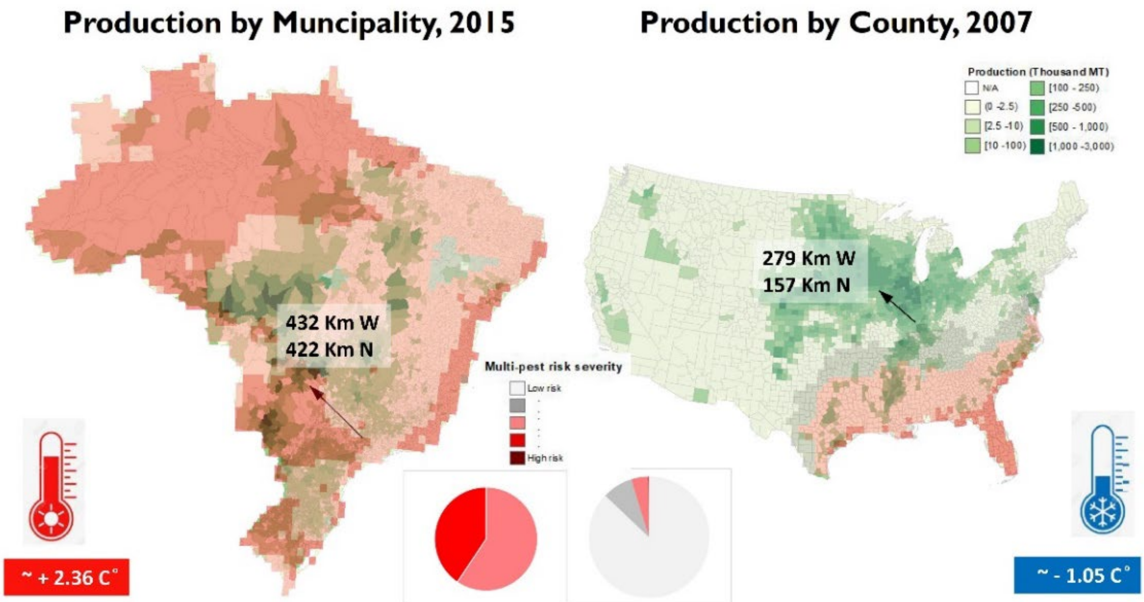


Figure 12. Maize movement and pest risk

If the current under-investment trends in agri-food research continue, we can expect further slowdowns and possible reductions in sectoral productivity growth in the future. That can have implications for the national competitiveness of those countries who fail to make the necessary investments in R&D, without which agricultural productivity growth is in peril.

Notably, the payoffs to investments in agri-food research are high, and, importantly, they show no signs of diminishing over time. From my vantage point, the multitude of risks facing the world's agri-food sector now and looking forward is larger than it was when the CGIAR and its antecedents were founded in the 1960s and 1970s. That might be an arguable proposition, but it is my considered judgement.

That said, the worrying thing is that instead of doubling investments in agri-food R&D, we see that many of the trends are heading in the wrong direction.

Investments in food and agricultural R&D are still ‘slow magic’; it takes considerable time to reap the full rewards from those investments, but the overall payoffs are large. The generally worrisome investment trends revealed in this talk, coupled with the payoff evidence I presented, calls for a revitalisation in the amount of investment and a rethinking about the cross-country and public–private innovation opportunities, both within and outside the agri-food sector required to spur sustainable productivity growth in the sector going forward.

Philip Pardey has been at the University of Minnesota since 2002. He is a Professor of Science and Technology Policy, in the Department of Applied Economics, and Director of Global Research Initiatives for the College of Food, Agricultural and Natural Resource Sciences (CFANS). He also directs the University’s GEMS Informatics Center. GEMS brings together CFANS and the Minnesota Supercomputing Institute to develop and deploy computational systems that address complex problems to unlock innovation in the agri-food sector. Previously he was a senior research fellow at IFPRI (International Food Policy Research Institute), Washington, D.C., and ISNAR (International Service for National Agricultural Research), The Hague, Netherlands. Philip’s career has focused on informing and enabling data-driven innovation and sustainable productivity growth in the food and agricultural sectors worldwide. He has authored more than 400 books, articles, and papers. He is a Fellow of the American Association for the Advancement of Science (AAAS) and of the Agricultural and Applied Economics Association, Distinguished Fellow and Past President of the Australasian Agricultural and Resource Economics Society, Distinguished Life Member of the International Association of Agricultural Economists, and winner of the Siehl Prize for Excellence in Agriculture.