Food Policy 70 (2017) 71–83

Contents lists available at ScienceDirect

Food Policy

journal homepage: www.elsevier.com/locate/foodpol

Agricultural research spending must increase in light of future uncertainties ☆

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ARTICLE INFO

Article history:
Received 21 September 2016
Received in revised form 12 June 2017
Accepted 15 June 2017

Keywords:
Agricultural productivity
Lagged response
Research and development
Uncertainty
Min-max regret

ABSTRACT

Agricultural productivity depends critically on investments in research and development (R&D), but there is a long lag in this response. Failing to invest today in improvements of agricultural productivity cannot be simply corrected a few decades later if the world finds itself short of food at that point in time. This fundamental irreversibility is particularly problematic in light of uncertain future population, income, and climate change, as portrayed in the IPCC's Shared Socio-Economic Pathways (SSPs). This paper finds the optimal path of agricultural R&D spending over the 21st century for each SSP, along with valuation of those regrets associated with investment decisions later revealed to be in error. The maximum regret is minimized to find a robust optimal R&D pathway that factors in key uncertainties and the lag in productivity response to R&D. Results indicate that the whole of uncertainty's impact on R&D is greater than the sum of its individual parts. Uncertainty in future population has the dominant impact on the optimal R&D expenditure path. The robust solution suggests that the optimal R&D spending strategy is very close to the one that will increase agricultural productivity fast enough to feed the World under the most populous scenario. It also suggests that society should accelerate R&D spending up to mid-century, thereafter moderating this growth rate.

1. Introduction

Despite abundant and affordable food throughout much of the developed world, currently 12.9% of the population in developing countries is undernourished (World Food Program, 2016). From 2005 to 2050, world population is expected to increase by 50%, from 6.5 in 2005 to 9.7 billion (United Nations, 2015). When coupled with increases in income and changing diets, this translates into substantial growth in the demand for agricultural production (Pingali, 2007), which is expected to rise by somewhere between 60 and 100% (Alexandratos and Bruinsma, 2012; Tilman et al., 2011). Studies looking at the future supply and demand for food indicate that meeting this demand may pose significant challenges for the food and environmental systems (Piesse and Thirtle, 2010). The extent of environmental pressure and the resulting food price changes will hinge critically on the evolution of productivity growth in agriculture (Baldos and Hertel, 2015).

Since the 1950s, increased agricultural productivity has allowed food availability to outpace demand on a global scale, resulting in a long run downward trend in world prices. Public and private investments into agricultural research and development (R&D) have been the foundation for this achievement. Studies have shown that public investment in agricultural research has resulted in significant economic benefits (Fuglie and Heisey, 2007).[1] However, while R&D spending globally has continued to rise, its rate of growth has fallen, and this growth has shifted in favor of developing countries (Pardey et al., 2016).

Global R&D picked up strongly over the 2000–2008 period, rising by 22%, coinciding with rising food prices. Accelerated spending in China and India accounted for close to half of the increase

☆ Y.C., A.A.G., and T.W.H. had financial support from United States Department of Agriculture NIFA-AFRI grant 2015-67023-22905, and the National Science Foundation (SES-0951576 and SES-1463644) under the auspices of the RDCEP project at the University of Chicago. We would like to thank Keith Fuglie, Ken Judd, Brian O'Neill, Robbin Shoemaker, Brent Sohngen, and participants in the 19th conference on Global Economic Analysis and the USDA-NIFA AFRI Project Directors Workshop. Cai would also like to thank Becker Friedman Institute at the University of Chicago and Hoover Institution at Stanford University for their support.

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[1] The magnitudes of returns to investments into agricultural R&D vary across studies. For example, range of returns to public agricultural research reported in Fuglie and Heisey (2007) is 20–60% per year. On the other hand, Hurley et al. (2014) report much wider range with the mean return over 270 prior studies just 13.6%.

http://dx.doi.org/10.1016/j.foodpol.2017.06.002
0306-9192/

(Beintema et al., 2012). Several studies report estimates of the additional investment in agricultural R&D needed to meet projected increases in demand by 2050 (Beintema and Elliot, 2009; von Braun et al., 2008; Rosegrant et al., 2008). It is likely that an increasing part of the R&D expenditures over the coming decades will be focused on adaptation to climate change which is expected to act as a brake on productivity growth (IPCC, 2014). The most important determinants of the demand for food in the future are the size of global population and per capita income growth (Baldos and Hertel, 2016). Developments in these variables in the 21st century are very uncertain. Based on the Shared Socioeconomic Pathways (SSPs) (O'Neill et al., 2014; IIASA, 2015), the spread between low and high global population levels in 2100 is 5.8 billion people, and average global per capita income in 2100 ranges between 22 and 138 thousand 2005USD across the SSPs. This translates into greatly differing global food requirements by the end of this century. On the supply side, future agricultural productivity is also highly uncertain—a problem which is confounded by the uncertain impacts of climate change on agriculture (Rosenzweig et al., 2014).

The problem posed by this future uncertainty in the demand and supply of agricultural products is further complicated by the extremely long lag time involved in translating agricultural research expenditures into realized productivity gains. For example, it took more than 80 years after the invention of hybrid corn for this important innovation to be fully disseminated in the United States and, in the case of Bt corn, this lag was more than a century (Pardey and Beddow, 2013). The fact that it takes decades for research spending to have an impact means plans cannot simply be adjusted in 2050 or 2100 if the world finds itself in food shortfall or surplus at that point in time. Long run planning is required, and this must be done in an environment of great uncertainty. Unfortunately, published work on this topic to date has not brought to bear the necessary tools for robust decision making under uncertainty. This study aims to do so by building on the FABLE model of optimal global land use (Steinbuks and Hertel, 2016). We begin by characterizing the lagged relationship between R&D spending and agricultural productivity and use this to estimate the optimal path of R&D spending over the 21st century. Since this depends on the uncertain global economic environment, we do so for each of the SSPs, generating five markedly different paths of optimal R&D spending. We then find the preferred path of spending by applying a criterion which seeks to minimize the maximum regret associated with making decisions based on one SPP, when another one turns out to be the realization.

2. Literature review and knowledge gaps

There is a rich literature on the impacts of agricultural research on farm productivity, much of it originating with the work of T.W. Schultz and his students at the University of Chicago (Alston et al., 2010). Griliches (1957, 1963) who sought to understand the dissemination of new technologies and their role in determining aggregate productivity growth. Hayami and Ruttan (1970) identified the role of relative prices in 'inducing innovation' in agriculture. Huffman and Evenson (2008) measured the contribution of public and private science to US agricultural productivity growth. Alston et al. (2010) find that the lag between R&D spending and farm productivity outcomes can persist for as long as five decades. Fuglie (2012) has taken this work to the global scale, documenting the links between agricultural knowledge capital, human capital and agricultural productivity growth across many different countries.

More recently, researchers have sought to understand the contribution of agricultural technologies to environmental outcomes, including climate mitigation (Burney et al., 2010; Stevenson et al., 2013). These researchers have found that higher yielding varieties historically reduced the amount of land conversion which would otherwise have occurred, thereby reducing global greenhouse gas (GHG) emissions. Lobell et al. (2013) find that future R&D can contribute to both effective climate adaptation as well as contributing to future mitigation of GHGs. Other recent research has sought to understand the link between agricultural R&D, technology adoption and agricultural development more generally (Maredia et al., 2014). However, to date, none of these studies have formally addressed the question of agricultural R&D investments as a problem of irreversible decision making under uncertainty. Yet, with the extremely long lag between such investments today and their potential future payoffs (Alston et al., 2010; Pardey and Beddow, 2013), along with the sizable demographic, economic and climatic uncertainties which the world faces, developing an optimal investment strategy is a very difficult task. There is a clear knowledge gap calling for the application of robust decision tools to the determination of optimal pathways for agricultural research.

Robust decision making has a very rich tradition (Lempert et al., 2006). It has grown increasingly important in the context of global change and decision making under alternative futures. In this context, there has been a resurgence of interest in scenario analysis (Trutnevyte et al., 2016). In an effort led by Brian O'Neill at NCAR, a set of Shared Socio-economic Pathways (SSPs) have been developed for use in Integrated Assessment Models for global change analysis (O'Neill et al., 2014). It lays out a set of future scenarios for global demographic, economic and climatic changes which are internally consistent, and which, taken together, span the two-dimensional space characterized by alternative socioeconomic challenges for adaptation, on the one hand, and mitigation challenges on the other. Among others, the five scenarios include a low economic growth with high population future, a high economic growth with high emissions future, and a sustainable development future. Together, the five SSPs span the global uncertainty space which should be considered by those formulating global agricultural research policy over the 21st century.

In this paper, we seek to fill these knowledge gaps by leveraging earlier work on the linkage between agricultural R&D and productivity. We combine this knowledge with the latest developments in robust decision making under uncertainty in order to understand how future uncertainties, such as those posed by the alternative SSPs, should influence decision making about agricultural research at the global scale.

3. Theory and methods

3.1. A dynamic model of R&D investment

To understand the impacts of uncertainty in future population, income and climate change on the optimal level of global investment in agricultural R&D over the 21st century, we build on a dynamic, forward-looking, partial equilibrium (PE) model of land use (Steinbuks and Hertel, 2016). In our model, a social planner maximizes the sum of discounted payoffs, subject to endowments, production functions and other constraints. The social planner's payoff in each period takes into account global population and per capita welfare (utility). Per capita utility is derived from the consumption of land-based, as well as other, goods and services. The land-based final consumption goods include: crop-based food, livestock-based food, wood products, and energy (including bioenergy). Consumer preferences are represented with An Implicit, Directly Additive Demand System (Rimmer and Powell, 1996) which has been estimated on international cross-section data (Reimer and Hertel, 2004). This demand system is very flexible in