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Gains to Agricultural Research: What We Know and What We Think We Know

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Abstract

The economic effects of agricultural R & D have generated a plethora of literature. Some of which has obtained the level of holy writ in agricultural economics. According to this write, public investment in agricultural research has increased productivity of output in general. While some may disagree, the literature suggests that farmers may be made better off from agricultural research. The social returns to agricultural research have been high ranging from a maximum of 79 - 96 percent on rice in Columbia to 21 - 25 percent on hybrid corn in the United States [1]. Some argue that these rates may even be understated due to the effects of yield maintenance. These rates of return far exceed any reasonable rate of return observed by stock market aggregates such as the Standard and Poors 500 and, if accurate, justify significant public investment in agricultural research at both the federal and state level in the United States. However, most of the gains to agricultural research accrue to households in the form of lower food prices, so productivity growth has a distributional effect - primarily benefiting lower and income households.

Furthermore, the rate of return on any particular project is very uncertain; Tables such as the one presented by Schmitz et al. [1] focus on the "winners." A second objection to the argument that agricultural research is high and justified is the conjecture that public investment on other issues may be even higher. The foil of this argument is the question – what is the rate of return on public investment in cancer research? The framework used to evaluate rates of return to agricultural R & D is relatively narrow. This paper broadens the discussion of the returns to agricultural research for future development by including type of technology, supply chains, public vs private investment, and learning by doing. Innovations in technology include chemical, mechanical, biotech (CRISPR/genomic modification), greenhouse technology.

Keywords: Gains to Agricultural Research; Genomic modification; Frankenfood effect; Mechanical harvester; Greenhouses

Abbreviations: HLB: Huanglongbing; BST: Bovine Somatotropin; CAFOs: Confinement Animal Feeding Operations; CRISPR: Clustered Regularly Interspaced Short Palindromic Repeats

Plant Breeding

One of the gains from agricultural research has been the development of new crop varieties, which was pioneered by Grilliches [2-4] who examined the gains to hybrid corn in the United States. The impact of these innovations accrues at several levels. From the most simple model, gains accrue primarily to consumers if the demand is inelastic. However, consumers do not directly consume yellow dent corn, but rather products that are generated from this corn. Consumers in the United States typically consume corn through their consumption of meat; corn is used to fatten beef cattle, produce milk, grow pigs and produce poultry. Thus, the appropriate market channel would be to estimate the effect of lower corn prices on the marginal cost of livestock production. At least some gains from lower corn prices are transferred to consumers, but a portion of the gains may also increase return to other fixed factors of production such as other agricultural labor. Of course, we can expand this critique to other elements of the supply chain including meat packing industries, wholesalers, and retail. A second critique involves agricultural support programs such as the old loan rates and target prices. Under a variety of agricultural policies, U.S. Farm programs have created a price floor so that the increased supply implied by hybrid corn is paid by the United States Department of Agriculture.

The issues raised by the adoption of hybrid corn which dates back to the 1930s, continues into the modern day with the emergence of genetically modified organisms and gene editing. Of course, these most recent innovations have added other dimensions to the policy question. Specifically, some have questioned whether modification of a crop's genetics poses potential health effects (i.e., the Frankenfood effect). Another wrinkle growing out of genetically modified organisms is the potential complementarity of inputs. Specifically, one of the most popular genetically modified crops in the United States has been Round Up (glyphosate) ready soybeans in the context of Monsanto's Round Up patent.

Private vs Public Agricultural Investment

The relationship between Round Up and plant breeding raises the salient point - who is paying for this research and does that matter? Most of the studies on the rate of return to agricultural research have focused on public investments. The federal and state governments support research conducted by the United States Department of Agricultural, The Agricultural Research Service and the experiment stations of the land grant university system. Simply put, the results of this research are innovations such as hybrid corn and genetically modified organisms that yield increases in societal welfare. Public entities tend to be very good at more basic research. Once the basic research is accomplished, private entities implement these technologies to create inputs that are more useful to producers. In the case of seeds, Pioneer uses the general concept of genetically modified organisms to identify gene segments that are useful combined conventional breeding programs to create seed varieties specific to producer requirements (e.g., growing periods specific to farming regions). The relevant question is then the transfer of the publicly created technology to the private sector (i.e., licensing agreements for publicly created technologies). In addition, this scenario raises questions about the value of the private side of this relationship - what is the value of the conventional breeding programs maintained by Pioneer? And, how much of this value is transferred to the public versus extracted through imperfect competition? Answering these questions tends to be difficult because as opposed to the public sector, most of the data on gains from conventional breeding are proprietary.

Mechanization

Over the past quarter century, a significant portion of the literature on agricultural research has been focused on seeds and agricultural chemicals with little work on mechanical developments. Schmitz and Seckler [5] seminal work on the mechanical tomato harvester provides a clear marker on the effects of mechanical innovation on the agricultural sector. Their work examines not only the potential gains to the farm sector, but also the loss to farm workers and rural communities. The relationship between publicly funded research and mechanical innovation is more nebulous than the traditional basic versus applied science division exhibited by the process of seed development. Public investment contributed to the development of a viable mechanical tomato harvester while Florida's investment in mechanical citrus harvesting was less successful. The current trend is the integration of artificial intelligence with mechanical technologies to weed and pick strawberries. Time will tell whether these innovations are fruitful. Apart from the creation of innovative mechanical technologies, gains to agricultural research have gone hand in hand with increases in the scale of production.

Case Studies

Malting Barley

The case of malting barley illustrates the interaction between private and public research interests. In a case study, Ulrich et al. [6] found high rates of return by the malting barley industry investing in University research largely through scholarships to PhD students.

Cotton

The effect of R & D on the development of a crop and the interaction between past and future innovations can be highlighted by the development of mechanical cotton harvesters. At one time, cotton was a marginal crop because separating the seed from the fiber required significant amounts of hand labor. Eli Whitney's development of the cotton gin significantly increased the value of cotton. However, other characteristics of the crop significantly affected its production, such as the need for labor for weed control and harvesting. One hypothesis is that this need for hand labor helped support slavery in the southern United States as an institution up until the civil war and afterwards supported the institution of sharecropping. The development of mechanical cotton harvesters can be traced to the late 1920s, but the cotton stripper which harvested short-staple, high mic cotton emerged in the early 1950s. This innovation radically shifted the cotton industry in the United States. Investment in capital (cotton strippers and tractors) replaced day labor, and the average size of cotton farms grew, causing the sharecropping institution to become phased out.

The use of mechanical harvesters also contributed to changes in cotton genetics through the need for hybridization of cotton as a semi-dwarf crop. The industry attempted to address the problem of hand weeding. One chemical commercially available as Treflan (Trifluralin) was developed to help prevent weed growth in cotton. Unfortunately, this herbicide had questionable effectiveness. As such, the weed control problem was largely addressed with the introduction of a genetically modified cotton which allowed the application of glyphosate directly on the cotton. It is also important to note that external technology has also hurt the cotton industry over time; Technical change has led to creation competitive fabrics such as polyester. In addition, it is possible that future R & D could reduce the cost of producing alternative natural fabrics such as linen.

Sugar

As a global commodity, sugar is produced in many countries with the top ten global producers supplying 80% of world sugar (ERS). Processed sugar yield from sugarcane is an important measure for determining the efficiency of the crop. Historically, sugarcane has been a major economic crop, which has made it a desirable crop for investment. The majority of research in

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sugarcane studies improvements in cultivars and harvesting technology. Case studies by Schmitz and Zhang [7] and Schmitz et al. [8] examine sugar yield in Florida and Louisiana, finding that investment in sugarcane breeding to develop new varieties has been integral in developing both disease resistance and high sugar yields in sugarcane cultivars. They were able to determine specific break points of yield increases that correspond to the timing of widespread implementation of improved cultivars. Furthermore, Schmitz, Kenedy, and Zhang examine the introduction of the mechanical sugarcane harvester drawing on work from Schmitz and Moss [9]. The implementation of mechanical harvesting both globally and in Louisiana has had a large impact on farm labor and labor reallocation. In general, mechanization has reduced the need for large amounts of hand harvest labor and moved the need towards a lesser amount of more skilled operator labor. They also find that while the introduction of mechanical harvesting had a major impact on farm labor, it did not directly affect the amount of sugarcane harvested. More importantly, the introduction of the mechanical harvester allowed for the adoption of different high-sucrose yielding cultivars that were not able to be harvested by hand.

Contrastingly, da Silva Girio et al (2019) examine some of the consequences of mechanical planting and harvesting of sugarcane in Brazil. Brazil has set goals for adoption rates of mechanization in the sugarcane industry in order to eliminate crop burning (which is required for semi-mechanized and handpicked harvesting). They find that in the short term, mechanical harvesting has caused decreased yields due to trampling and decreased seedling quality. New harvesting and planting techniques will need to be implemented to reduce this impact. The three countries that participate most heavily in sugarcane research are Brazil, the United States, and India. While sugarcane is a substantial crop in many developing countries, there is not a vast amount of public or private research investment for sugarcane improvement in those countries. This will show in sugar yield data, especially as larger producing countries have begun to invest in climate resilient cultivars with the expectation of potential crop loss due to rising temperatures and changing precipitation (Voora et al 2023).

Rice

While most current investment in research for rice applications is with reference to Asia and Africa, this review takes the example of the changes in Louisiana's rice production to exemplify an interrelation between a chemical technology allowing for a change in planting technology. More specifically, Kennedy et al. [10] examine the impact of the introduction of Clearfield Technology on rice production in Louisiana. The Clearfield herbicide resistant variety of rice has transformed rice seeding in Louisiana. Since the late 1880s, indigenous weedy/red rice has significantly and negatively affected rice production in Louisiana. Weedy/red rice is taller than most current cultivated varieties and out-competes other varieties for energy and nutrients. Weedy/red also re-seeds itself, making it difficult to control. If weedy/red rice grains make it into a harvested sample, they create a substandard and less marketable product. Historically, cultural methods have been implemented to control the weedy/red variety.

These methods include water seeding and implementing rice-crawfish sequential systems. Water seeding can help prevent weedy/red rice from getting oxygen to germinate, but comes with a host of other inefficiencies and challenges. Rice-crawfish sequential systems have steadily grown since the 1970's; the presence of crawfish in rice ponds can reduce the amount of weedy/red seed in the soil, hence creating a joint production increase [11]. Because the weedy/red variety is so closely related to cultivated rice, creating an herbicide to selectively control weedy/red was not possible until Clearfield used plant breeding methods to produce a modified conventional rice variety that is herbicide resistant. Furthermore, the Clearfield product allowed for the transition from water seeding by air to dry seeding. In turn, this has brought about significant yield increases in Louisiana from 2001-2019 Kennedy et al. [10].

Greenhouse - Tomatoes

Greenhouse technology has revolutionized the tomato industry. Amongst protected agriculture methods, greenhouses are the costliest to implement, but also have the potential for high returns to investment (EDIS, 2024). The implementation of greenhouse technology represents a structural change in production and generally has market consequences. For example, the most widely produced greenhouse crop is tomatoes (ACES 2023), and both Mexico and Canada have invested in a substantial greenhouse tomato industry. While the US does have greenhouse grown tomatoes, especially in non-market leading Northern states such as Nebraska, Minnesota, and New York, much of the U.S. crop is field grown in California and Florida (ERS 2019). Over time, the production efficiencies of greenhouse growing have contributed to Mexico becoming a major exporter of tomatoes to the U.S. In 2022, the US imported $ 3.14 billion in tomatoes, $ 2.64 billion of which came from Mexico and $ 451 million from Canada. In contrast, in the same year, the US exported only $ 227 million total in tomatoes, with the main destination being Mexico (OEC data, 2022). This relatively new trade structure is a sharp contrast to the market prior to the introduction of greenhouses.

Citrus

During the 1980s, Florida experienced three major freeze events in 1983, 1985, and 1989. Research responses to these events included analysis of issues such as replanting and changes in varieties, which would determine the industry's survival [12]. Adams et al. [13] developed an approach to measure the effect of the freeze events on a perennial crop where the farmer not only loses output in the current year, but also loses future production due to the freeze killing part of the tree's canopy. One response to the freezes of the 1980s was a geographical shift in production in Florida.

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Historically, citrus production in the state was concentrated in the state's 'ridge'. These freezes provided an impetus for planting in the southwest portion of the state which is slightly more swampy. This move led to research into drainage systems to keep the roots of the citrus tree above the water line in addition to improved irrigation systems. Separate from the freeze responses, research in Florida has also analyzed tree spacing and mechanization. Historically, citrus in Florida was planted sparsely from 60 to 80 trees per acre so that the tree should be given space to grow over time. An alternative approach that emerged in the 1980s was to increase the tree density to 145 to the acre (and even 290 trees in some places) [14]. This research pointed out that the objective function was the citrus yield per acre and not the citrus yield per tree. Increasing the tree density produces a more complete tree canopy in a shorter period of time. Another traditional area of research in citrus includes the development of a mechanical citrus harvester in an effort to mitigate the cost of labor and labor availability.

Much of the traditional citrus research program in Florida has been replaced by research efforts to combat citrus diseases that threaten the commercial viability of the crop. The first serious disease to strike Florida's citrus grove in the recent past is citrus canker, which is caused by the bacterium Xanthomonas citri and causes visual lesions on the fruit, leaf loss, and early fruit drop. This disease has occurred sporadically in Florida dating back to 1910 [15] with the most recent outbreak occurring in Miami-Dade county in 1995. Research into the control of canker included the definition of an eradication zone around an infected tree. However, eradication efforts were significantly hindered by the effect of a series of hurricanes in 2004 and 2005.

While citrus canker raised significant challenges for Florida's citrus industry, Huanglongbing (HLB) disease (often refered to as citrus greening) represents a significant threat the industry's existence. HLB is caused by the bacterium Candidatus Liberibacter. This bacterium is spread by the Asian citrus psyllid (Diaphorina citri). The infected tree suffers limb loss as sections of the canopy dies off leading to the death of the tree. In addition, the fruit from infected trees are misshapen and have an off taste. The onset of citrus greening has been significant. Consequently, research response to citrus greening has been significant. From a funding perspective, the National Institution of Food and Agriculture implemented a 'Emergency Citrus Disease Research and Extension Program' with the goal controlling HLB and its complex. This research program has funded a variety of efforts including non-transgenic approaches for managing HLB, identifying candidate genes to develop HLB resistant cultivars (basically the creation of a GMO to reduce the effect of HLB), and the use of antibiotics to treat HLB infected trees. While the last approach was originally considered farfetched, trunk injection has shown promise.

As Dr. Jude Grosser, plant geneticist at University of Florida states (pers. Comm. Dec 2017) "....HLB (Citrus greening disease or Huanglongbing) can be solved by both biotechnology-facilitated conventional breeding and by a transgenic solution...However, there remains a significant problem with consumer acceptance of a GMO solution. Manufacturers still want to retain consumer confidence in the European Union- thus I am not sure how eager they would be to commercialize a GMO solution. Moreover, they both have anti-biotechnology labels currently on their orange juice products..... In my view, a transgenic solution to HLB will require trees to have at least two transgenes that provide resistance by two different mechanisms... we are now producing transgenic plants with stacked genes in an effort to achieve this 'long-term, stable' resistance."

Livestock

Research into the benefits from agricultural research in livestock has been limited. One possible exception is research into the effects of Bovine somatotropin (bST) on milk production. Agricultural research into the effect of bST on milk production dates back to 1984 [16]; however, most of the economic debate on bST has focused on consumer acceptance [17]. Another area of advancement in dairy involves improvements in dairy genetics from genomic selection [18].

The rise of confinement animal feeding operations (CAFOs) share several attributes with the bSt discussion. It is hard to find published agricultural research on the gains to CAFOs, but the growing number of CAFOs in pork and poultry operations would indicate that such innovations imply significant reductions in the cost of producing meat. Like economic research into bST, most of the published economic research on CAFOs focus on the potential environmental costs associated with the technology with relatively little focus on the gains in efficiency attributed to the technology. Some traditional lines of livestock research continue, such as the potential gains from diets; Jacob and Pescatore [19] examine the usefulness of using barley in poultry diets. In addition, Favero et al. [20] find that cross-bred cattle have improved carcass characteristics. However, there has been little research into the returns to R & D on cattle research with the potential exception of Widmer et al. [21].

CRISPR/Cas9 and Plant Breeding Research

The field of genomics focuses on mapping and editing genomes, which is different from the science of genetically modified organisms. Genomics alters an organism's own genome, where genetically modified organisms are altered with a foreign gene (transgene) that is not inherent to the organism. Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) and CRISPR associated protein 9 (Cas9) (CRISPR/Cas9) technology is a form of genome editing and therefore does not result in a conventionally defined genetically modified organism. This ties into the consumer acceptability of GMOs vs products made using CRIPSR/Cas9 technology. Because CRISPR/Cas9 does not introduce a transgene, consumers may be more willing to accept this technology going forward, especially put into layman's terms as an acceleration of a traditional plant breeding model. Furthermore, although there remains some dispute over patenting CRIPSR/Cas9 related technology, there have been many successful

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patents issued for CRISPR edited agricultural crops. Cultivars created using conventional breeding methods are only protected under the Plant Variety Protection Act. Because CRISPR/Cas9 created crops are patentable, this presents an incentive for private investors to conduct plant research as there is a clear path forward to reaping financial gains and returns on investment Schmitz et al. [1].

Emerging Issues/Conclusion

The topic of agricultural research is vast and here we provide only an overview. For example, Florida's Agricultural Experiment Station is currently investing in research topics as varied as hops, vanilla beans, and artichokes. There are so many we cannot capture all of them here. In general, most would agree that agricultural research has generated benefits to society, but we may debate the allocation of those benefits. Given that the demand for most agricultural commodities is fairly inelastic, we anticipate that most of the gains accrue to consumers. In addition, under the agricultural policies existing from 1933 through at least 1995, production decisions were affected by farm program payments. These coupled payments would typically imply that increases in output due to agricultural research increased the cost of farm policies.

The question remains - what are the gains from public and private research in agricultural? In Agricultural R & D patent and property issues remain, especially where chemical products, breeding technology, and modern mechanical innovations are concerned. In these areas, there is a benefit for private industry that arises from the ability to acquire patent ownership of the technology (this arose through the original patenting of the Harvard mouse). While R & D has been beneficial to society at large, there are still questions as to how R & D has affected farmers and suppliers. There is a persistent question about the societal distribution of these gains; while there are measurable direct effects, these gains often affect the competitiveness of domestic agriculture, which is difficult to measure.

Finally, the issue of private and public incentives raises the potential for orphan crops such as cassava [22]. It is unlikely that private R & D will ever invest in orphan crops because there is little to no financial incentive to do so due to the regionality and small size of their markets. However, that does not mean that these crops do not have substantial possibility for improvements. Indeed, many orphan crops provide essential subsistence for regional communities. If there were to be public investment in orphan crop R & D, this could potentially make a substantial difference for regional food security and nutrition in areas such as Africa.

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