The Future of Agriculture

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Peter Berck started his career as a resource economist applying dynamic systems to study forest management. Over the years, his attention shifted toward other resource challenges, including land use and water management, and his range of techniques expanded to include econometrics and computable general equilibrium models. He immersed himself in various aspects of agricultural problems and policy in both developed and developing countries. As a scholar and especially as an editor of the American Journal of Agricultural Economics, Peter had a significant impact on the evolution of agricultural economics. In this chapter, we address a topic that engaged Peter: the future of agriculture and its relationship with other natural resources. The first section of the chapter will discuss the emergence of agricultural systems and the transition from extraction systems to sustainable farming. The second section will address the challenges of modern agriculture in developed countries, and the third will address the future of agriculture, introducing three alternative themes: organic eco-agriculture, food plus, and the bioeconomy.

1 Transition from Hunting to Farming

Early humans were hunter-gatherers and the transition to agricultural systems was a gradual process that took thousands of years. Agricultural systems generated economic surpluses and locational permanence that were crucial to the development

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of civilization. There were many stages in the emergence of agriculture – including the domestication of animals and the production and harvesting of crops. The emergence of agriculture can be viewed as an economic decision. Farming required that humans be involved in growing food before harvesting it, which means breeding and feeding animals or seeding and protecting plants as they grow. Only if the gains from the greater quantity and more reliable food production of farming systems were greater than the extra costs would the transition to farming make economic sense. Harari (2014) argues that humans probably had better lives as hunter-gatherers than as farmers, as hunting-gathering required less effort and more knowledge and was more interesting.

His argument has some validity in certain circumstances when game was abundant and population density was low. Therefore, farming was probably more likely to emerge where the population was growing and the ratio of game to people became sufficiently low. One of the most important themes in Peter's work is the centrality of heterogeneity, and indeed we see that agriculture emerged in different regions at different times. Agricultural systems have evolved over time through the processes of learning-by-doing and learning-by-using. They gave rise to the emergence of knowledge, which in turn improved agricultural productivity and expanded the reliance on agricultural systems. As agriculture expanded and knowledge was accumulated, an early "bioeconomy" emerged. It included processing and preservation of foods that allowed subsistence during the cold season and stabilized the availability of food, production of clothing from fibers and skins, and the introduction of wine and beer, which preserve calories.

The transition from extracting systems to agricultural systems has not been limited to crops and livestock. Over time, humans engaged in forestry, which included breeding and growing trees for lumber, paper, and other uses. As we mentioned earlier, Berck's early research was focused on optimizing for forestry activities. Aquaculture is another form of cultivation and its importance for the food supply is increasingly significant now. Berck and Perloff (1985) developed a conceptual framework to understand how dynamic processes of learning and the decline of fish populations have led to the emergence of aquaculture and the coexistence of aquaculture with traditional fisheries. Their framework can explain other types of transitions from harvesting systems to farming systems. They identified conditions resulting in a steady state of sustainable coexistence of aquaculture and fisheries. They also discovered that the emergence of farming systems was able to maintain populations of certain wildlife that might have disappeared without high-productivity farming. Their work suggests that population growth may lead to expansion of both harvesting and farming (fishing and aquaculture), while technological change in farming may lead to preservation of wildlife species. The conceptual approach presented in Berck and Perloff (1985) can be extended to explain transitions from nonrenewable to renewable resources – for example, from the use of coal to the use of biofuels and from the use of petroleum-based chemicals to the use of plant-based chemicals. This approach applies to the bioeconomy, which relies on growing and utilizing biological feedstock to produce a large range of products that include foods, fuel, pharmaceuticals, and other chemicals, which will be discussed below.

2 The Economics of Modern Agriculture

Agriculture in the future will build on the present agriculture. There is extensive literature that investigates the main features of modern agriculture. The seminal works of Schultz (1953), Cochrane (1979), and Hayami and Ruttan (1971) have shown that modern agriculture leverages applications in science, entrepreneurship, and innovation, resulting in both higher productivity and welcome economic growth. They develop a basic conceptual understanding of the main features of modern agriculture that allow the development of policies to address some of its challenges. The main features of modern agriculture include:

1. *High rates of innovation resulting from the educational-industrial complex* (Graff et al., 2002). Public investment in research has resulted in discoveries and intellectual properties that have been transferred to the public sector. Agriculture benefitted from innovations in the general economy (internal combustion engines, telephones, etc.). It has taken advantage of the development of the sciences. Dedicated land grant colleges have developed innovations, including the use of chemical fertilizers and pesticides, modern irrigation technologies, and farm equipment. These technologies tend to increase the supply of food and reduce demand for labor.
2. *Inelastic demand for agricultural commodities*. The demand for agricultural commodities like corn, soybeans, and wheat is very inelastic, which means that small increases in supply result in significant price reductions. At the same time, income elasticity of demand for food commodities tends to be high for developing countries. Specifically, higher incomes result in significant demand for food. At sufficiently high income levels, there has been an increase in the demand for meats that require significant amounts of feed. Once income increases, the elasticity of demand for food quantities may decline, but the elasticity of demand for food quality increases.
3. *Varying weather and other environmental conditions*. Agricultural systems are subject to the vagaries of nature and, thus, supply may fluctuate depending on climatic conditions.
4. *Asset fixity*. Certain agricultural equipment and specific skills obtained in agriculture are not easily transferable to other sectors. This suggests that there is migration from agriculture, even when the decline in income from farming is slow. The higher-income lifestyle and the allure of city life have induced young people to migrate to cities.
5. *Negative externalities stemming from intensive farming*. Agricultural activities may generate negative side effects, including polluting groundwater, depleting soil resources, and harming wildlife.

6. *Agricultural producers may encounter credit constraints*. Many worthwhile investments are not able to obtain financing, especially when financial conditions are strenuous.
7. *Economies of scale in production and processing of agriculture*. Farm machinery, such as tractors and combines, have strong economies of scale, meaning that larger operations can benefit from these technologies much more than smaller ones. Similarly, knowledge has significant economies of scale.
8. *Heterogeneity*. Agriculture is heterogeneous, as agroclimatic conditions, space, human capital, infrastructure, institutions, and conditions vary across locations between states and nations.
9. *Agriculture is part of an agribusiness sector*. The productivity and profitability of agriculture depend on input suppliers, processors, and retailers that sell agricultural products. Agribusiness is a global enterprise. Agricultural commodities are transported and traded globally.
10. *Agriculture is affected by policies and regulations*. The agricultural industry uses its political influence to manipulate policies. It's important to understand political-economic landscapes in order to understand agricultural policy and its evolution (Rausser et al., 2011).

The phenomena listed above have some important implications. First, a high rate of innovation combined with inelastic demand suggests that supply may grow faster than demand, resulting in lower prices. Indeed, the documented tendency of agricultural prices to decline over time has been a major feature of what was called the "farm problem," and governments have developed policies to protect farm incomes. At the same time, an increase in income in developing countries may result in increased international demand for food, and that may lead to increased export opportunities for regions like the American Midwest that have relative advantages for the production of agricultural crops.

Second, it has been difficult to move assets out of agriculture, resulting in rural poverty of both farmers and farmworkers. Thus, the US government introduced a wide array of policies like price support, income support, deficiency payments, and crop insurance that aim to increase rural incomes. However, some of these policies, like price supports, have exacerbated the problem by providing incentives for excess supply. This has led the US government, for example, to provide incentives to take land out of agricultural production.

Third, unstable climatic conditions, as well as a disruption of supply of agricultural inputs, may destabilize the supply of agricultural outputs, which in turn may lead to unstable prices, harming both farmers and consumers. Furthermore, demand for agricultural food products may be affected by shocks, such as economic recessions, inflation, etc. To stabilize the prices of agricultural commodities within price ranges, governments have developed inventory control programs, with often very high deadweight losses (Koester & von Cramon-Taubadel, 2023).

Fourth, the environmental side effects for agricultural production have led to interventions that reduce the immediate damages of agricultural pollution, with the aim of sustaining agricultural systems. This results in policies like conservation reserve programs that compensate farmers for providing environmental services by, for example, not capturing the highest commercial potential of the land but instead engaging in environmentally friendly practices. Agricultural extension agencies educate farmers to modify their choices and adopt green technologies. Governments may introduce penalties on polluting activities. Many governments have established very strong administrative and scientific infrastructure to regulate pesticide use, by approving the introduction of new chemicals and banning other chemicals. One of the most controversial issues is the regulation of biotechnology, which we visit later under the major theme of bioeconomy.

Fifth, the difficulty of financing agricultural activities both in the short and long run have resulted in government policies allocating financial resources into agriculture, leading to the emergence of institutions that enhance the ability to finance agricultural activities (i.e., sharecropping, cooperatives).

Sixth, the economies of scale of agricultural equipment and long-run structural changes have led to increased farm size over time. Smaller farms may be viable when entrepreneurs offer rental services of expensive capital equipment (Lu et al., 2016) or when extension provides advice that augments farmers' human capital. Heterogeneity, in terms of ability, is another cause for differences in farm size and performance. Individuals with more resources and/or skill may accumulate more land, while others may cease to be independent farmers. Emerging economic opportunities in cities, as well as an attractive lifestyle, have contributed toward significant migration to cities and reduced agricultural employment in developed countries. Farm size agglomeration also has occurred in developing countries.

Seventh, in modern agriculture, much of the value-added is produced beyond the farm gates. Farmers depend on purchased inputs, and their products frequently require processing before they are sold to the final consumer. Supply chains are crucial for the survival of agricultural systems globally, and they evolve with improvements in technology and infrastructure. In some agricultural sectors (e.g., production of chicken and swine), spot markets play a smaller role than forward contracting. In some locations, complete production may occur within vertically integrated organizations. These are the cases of palm oil in Malaysia and sugarcane in Brazil. Innovations, both technical and institutional, may lead to the establishment of supply chains that will be crucial in the introduction of new agricultural industries. For example, the entrepreneurs that started producing and exporting flowers from Kenya and other African countries established supply chains, where they contracted with local farmers to produce flowers, which were then shipped to Europe (Barrett et al., 2020).

Eighth, government regulations affect all aspects of agriculture; they include health and safety regulations, as well as regulations in biotechnology. Governments have applied antitrust policies against companies on the one hand and policies that allow farmers to form cooperatives against traders on the other hand (the Capper-Volstead Act). Several agencies affect the economies of agricultural producers in the western United States. These policies include investment in infrastructure, research support for different types of fruits and vegetables, subsidization of agricultural practices, and many more. Lobbying and political-economic considerations have enabled farmers in the United Stated to obtain policies that are relatively friendly toward agriculture.

Ninth, agriculture has benefited quite a lot from globalization since the late twentieth century. Government intervention in agricultural markets has declined with growing international trade (Anderson et al., 2013). Countries like the United States, Brazil, Canada, and Australia have become major exporters of agricultural commodities, while densely populated countries in Asia and some African countries are significant importers. While there are substantial differences in productivities, practices, institutions, and technologies between agricultural systems in developing and developed countries, the main features of agriculture presented here apply to a large extent to most countries.

With globalization, modern technologies and institutions have emerged across many countries. For example, supermarkets originated in the United States in the 1930s, first in New York, and then spread gradually elsewhere. Supermarkets appeared in Europe in the 1940s, Asia in the 1960s, Latin American in the 1970s, and Africa in the 1990s. Their spread has been gradual in each region, but they played a crucial role in transforming agricultural systems across the world.

Tenth, the main features of agriculture are common to developed and developing countries; however, there are several major differences in the parameters of the system. The distinction between “developed” and “developing” is arbitrary, as there is a continuum in terms of economic conditions and performance between very poor and affluent countries.

One major difference between developed and developing countries are financial conditions. Rich countries tend to generate revenue through taxation, which allows them to provide public goods, including support of research and infrastructure, and to establish safety nets that support agriculture. Governments in developing countries frequently lack the capacity to finance public goods. As a result, many public goods are provided through international donors or lenders; these, in turn, impose their priorities in setting the direction of agricultural development. A second major difference is the extent to which the rule of law is applied. In developing countries, the informal sectors are much more substantial, and there is a higher rate of corruption. A third major difference among countries (not necessarily linked to development) is the speed and capacity to establish new businesses and build a culture of entrepreneurship. Heavy regulation and under-functioning financial systems may limit the introduction of new technologies and innovation.

2.1 The Three Scenarios of the Future

There is an ongoing debate about the direction of agriculture. It is evident in the literature, public discourse, government agencies and policies, and multilateral organizations. It was quite apparent in the debate surrounding the United Nations

World Food Systems Summit of 2021 (von Braun et al., 2021). While there is a wide range of perspectives, we reduce them to three major themes.

Green agriculture This category consists of a wide range of approaches. Rausser et al. (2015) present an overview of these alternative “naturalist paradigms” that include organic farming, agroecology, the slow food movement, animal welfare, and many more. The European Union’s agricultural policies tend to support these approaches, with a requirement that 25% of its payments will target organic farming by 2025. The common thread of these paradigms is their objection to the dominant “industrial paradigm.” They tend to be suspicious of modern biotechnology and to emphasize “purity.” One feature of some of these paradigms is their appeal to high-income individuals. Foods tend to be bifurcated and the well-off distinguish themselves by the food that they eat, even when nutritional benefits are not always apparent. Meemken and Qaim (2018) survey the literature of organic agriculture; they suggest that there is significant evidence that organic agriculture is not likely to improve food security or to enhance resilience to climate change. It can support the food requirements of a smaller population, increase the footprint of agriculture, and increase greenhouse gas emissions. Furthermore, organic agriculture has been applied at locations and by individuals where it has relative advantages. It requires extra skills and is especially less effective in humid regions with high rates of pests, with the exception of “vertical farming,” which provides opportunities for organic agriculture in urban centers. There is evidence of an underestimation of the relative losses from organic agriculture based on the locations where it is being applied. Rausser et al. (2019) suggest that the naturalist paradigms, in general, tend to be inefficient in terms of resources and result in excessive greenhouse gas emissions and land use compared to systems that use chemicals and biotechnology. By taking advantage of consumer desire for distinguishing characteristics, alternative agricultural approaches may increase the income of the agricultural sector. The inefficiency of organic agriculture might substantially decline if it incorporated agricultural biotechnology (Ronald & Adamchak, 2018). By contrast to naturalist paradigms, recent developments in food production have a huge potential to increase food security, reduce greenhouse gas emissions, and support animal welfare (Wesseler & Zilberman, 2021).

Agriculture + This perspective sees the main role of agriculture as providing food, with a limited role to produce biofuels. It also suggests that modern agricultural biotechnology can be applied mostly to animal feed (corn, soybean) and fiber (cotton), but less so to food products. These views stem from political, economic, and historical considerations.

The traumatic experience of the high food prices between 2008 and 2013 and the perceived food vs. fuel choice, the decline in the price of fuel in the 2010s, and the emergence of electric cars have reduced the urgency of developing biofuels. Despite the concerns about “fuel vs. food,” rising food prices, and “indirect land use,” Khanna et al. (2021) identified no significant increases in agricultural prices and a minimal expansion of agricultural land due to biofuel production.

Regarding genetically modified (GM) crops, at present, there is no GM rice or wheat in production, and there is limited use of GM in fruits and vegetables (Herring & Paarlberg, 2016). Differences in perspectives between the United States and Europe and the concerns of producers about a reduction of food prices resulting from increased supply with biotechnology were some of the reasons leading to compromises with regard to the use of biotechnology (Zilberman et al., 2013).

Biofuels and genetic modification are related. If the use of transgenic varieties had been allowed in crops like wheat and rice in the United States and corn production in Europe, there would be sufficient land to produce and expand biofuel production globally. For example, with higher yields in rice, India could allocate land to sugarcane that would provide ethanol, which can moderate its rising energy demand (Debnath et al., 2019).

There is further evidence of immense opportunity costs suffered when biotechnology is heavily restricted. In the case of India and restrictions on the use of "Golden Rice," hundreds of thousands of lives were lost and billions of dollars were unnecessarily lost (Wesseler & Zilberman, 2014). The restriction on the use of a new transgenic banana and other fruits and vegetables in Africa has had an immense social cost (Wesseler et al., 2017). Limitations placed on the use of transgenics and CRISPR in veterinary medicine have cost billions of dollars and increased vulnerability to zoonotic diseases (Van Eenennaam et al., 2021). The above examples suggest that, under the status quo, the promise of agricultural biotechnology is not being fulfilled to meet global challenges. We believe that countries need to unleash the potential of advanced knowledge in biology and other sciences.

The Bioeconomy Under the "green" scenario, it is unlikely that agriculture will be able to feed the growing human population. The "agriculture plus" scenario would allow agriculture to feed the world, but its contribution to the control of climate change would be limited. The bioeconomy scenario aims to unleash the power of modern biology and science to address the challenges of food security, loss of biodiversity, and climate change. There are multiple definitions of the bioeconomy. Enriquez-Cabot (1998) defines the bioeconomy as "part of the economy that utilizes new biological knowledge for commercial and industrial purposes and for improving human welfare." The European Commission (2020) definition suggests "The Bioeconomy – encompassing the sustainable production of renewable resources from land, fisheries and aquaculture environments and their conversion into food, feed, fiber bio-based products and bio-energy as well as the related public goods." We accept the union of both definitions. The bioeconomy uses advanced knowledge and technologies in the life sciences and physical sciences to produce agricultural and natural resources products to improve human welfare.

The bioeconomy can and should play a major role in attaining sustainable development by contributing to the replacement of nonrenewable resources with renewable resources and containing the level of greenhouse gases in the atmosphere (Zilberman et al. 2018a, b). The modern economy has relied on nonrenewable resources. Petroleum, in particular, provides both fuels and chemicals. Renewable resources like wind and solar energy can reduce much of the dependence on fossil fuels, but they need to be complemented with other renewable sources. The expansion of solar energy may be constrained by resource availability, and the use of solar energy may be limited by timing issues and the cost and capacity of batteries. The modern tools of biotechnology combined with information technology may allow the utilization of plants as feedstocks for fuels and valuable chemicals (Woodley, 2020).

Moreover, modern biotechnology is in its infancy. The critical importance of science was reflected during the pandemic, and the capacity of modern biotechnology was demonstrated with the expedient application of mRNA technologies to produce vaccines. Researchers have identified new traits that can enhance photosynthesis and fix nitrogen, with the potential to significantly improve agricultural productivity and reduce greenhouse gases. Research into the microbiome is likely to develop a new avenue to improve the production of crops and livestock. Combining biotechnology with precision agriculture, leading to adapting the use of genetic material and other inputs to varying environmental conditions, holds much promise.

A continued investment in research is likely to lead to innovation that will improve the productivity of agricultural resources and natural resource systems and reduce the costs in producing food as well as fuels and chemicals. Plants can provide feedstock for energy generation and biofuels. Biofuel may play a major role as aviation fuels. Sugar cane and palm oil are biofuels with much lower GHG emissions than gasoline. It is crucially important to recognize that plants are "chemical factories" and can produce many valuable chemicals that can be used for pharmaceuticals and other industries. As Debnath et al. (2019) suggest, the costs of biomass and biofuel have declined over time due to "learning-by-doing." With continuous learning and increased productivity of food crops resulting from the use of biotechnology, more land can be allocated to produce feedstock for biofuels. Furthermore, modern agriculture can develop plants (Kell, 2012), trees (Sedjo & Sohngen, 2012), and other organisms (i.e., algae – Singh & Ahluwalia, 2013) that can sequester greenhouse gases. Tools of modern biotechnology have the potential to mitigate greenhouse gas emission by developing plant-based meat, as well as traits that reduce greenhouse gas emission by domesticated animals (Howitt & Rausser, 2022).

However, the use of modern biotechnology and agriculture in natural resource management is hindered by regulation, which, to a large extent, impedes the evolution of the bioeconomy (Purnhagen & Wesseler, 2021). While scientists have identified multiple new transgenic traits, the heavy and uncertain regulation of crop and animal biotechnology disincentivizes their development and commercialization (Bennett et al., 2013). The regulatory approval time is frequently excessive and uncertain and varies across locations (Wesseler et al., 2019). Thus, we are challenged to harmonize the regulation of biotechnology globally. The regulatory process should aim to maximize the expected benefits of regulation while adjusting for risks. Regulators need to consider that regulatory delay is costly and may lead to underinvestment in valuable innovation. In particular, it may lead to underinvestment in technologies that affect small crops and benefit the poor. Such underinvestment also would reduce the capacity of smaller enterprises to compete with larger corporations, which have the resources to survive costly regulation (Zilberman et al., 2018a, b). Furthermore, regulatory delay will reduce the capacity to adapt to climate change by adopting new varieties that can cope with rising temperatures or more volatile weather conditions.

The growth of the bioeconomy requires continued and increased support for research and development efforts in agriculture and natural resources. As we have seen, basic research support by the public sector provides the foundation for development and commercialization by the private sector. However, the capacity of developing countries to support and implement research is limited. Since climate change and loss biodiversity are global threats (Nordhaus, 2019), one of the challenges of the global community is to increase the capacity of developing countries to conduct basic research in agricultural resources and to develop mechanisms to enhance commercialization of innovations. The capacity of developing countries to benefit from new innovations will depend on the availability of human capital that can develop and utilize them. High-quality scholars and entrepreneurs can be expected to emerge from investments in high-quality research and education institutions. With dramatically increased support to the Consultative Group on International Agricultural Research (CGIAR) centers, for example, these research institutions can become high-quality life science universities and expand the development of new technologies to improved implementation. Investment in human capital in the developing world should become a bigger priority to donors and governments in developed countries. Universities in the global north should expand their collaboration and contribution on the ground to research institutions in the south.

The expansion of the capacity of the bioeconomy to mitigate climate change depends on policies that incentivize such activities. The establishment of carbon markets and carbon trading, to establish a substantial price for carbon, will set the conditions for the intensive mitigation of greenhouse gases. Carbon markets and trading can be applied to situations where greenhouse gas emissions by individual enterprises (point sources) can be easily monitored. When the emitters cannot easily be observed, economists have developed mechanisms that can reduce greenhouse gas emissions by regulating activities that are associated with carbon emission (Xepapadeas, 2011).

The growth of the bioeconomy, especially in the south, also depends on financial arrangements that allow long-term investments in alternative energy and the development of technologies that will enable developing countries to take advantage of modern biotechnology. These, in turn, can improve agricultural productivity and enhance carbon mitigation. This should be a major priority for multinational organizations, such as the World Bank, the IMF, and the various regional development banks.

3 Conclusion

Agricultural policies are at a crossroads. They can restrict the use of modern science-based technologies in the pursuit of a "green" agenda, they can maintain the status quo where the main objective of agriculture is to meet food demands, or they can engage in building a bioeconomy, where agriculture and other natural resources are utilized to produce food and transition to an increasingly circular economy. Humanity is losing the battle to mitigate climate change. Applying modern science to agriculture and natural resources can come to the rescue and enable humanity to catch up. We are challenged to develop science-based policies globally and provide incentives that will lead to an effective bioeconomy.

Advancement of the political will for policy changes that provide the foundations for the bioeconomy will be a major challenge. There are large groups in the EU that support the green paradigm and oppose modern biotechnology. It is ironic, but some of the proponents of strong policies to mitigate climate change are opposed to science-based technologies that can achieve these objectives. Furthermore, many in the public sector have a negative perception of biotechnology, and thus education and exposure of future tradeoffs is essential. Finally, developing countries that may benefit most from the bioeconomy may need to be aware of its potential; the cost of not taking advantage of modern biotechnology in developing countries needs to become more apparent. While some in the energy sector are excited about decarbonization of this sector, others may oppose a fast transition to renewable alternatives. Consumers support climate change policy in principle but still strongly prefer affordable energy.

Scientists and economists need to engage in modeling that assesses the overall impact of the bioeconomy (compared to other scenarios) on the global community, the environment, and the viability of local communities. Political economy analysts need to identify win-win solutions that can pivot the policy environment toward the introduction of policies that support the bioeconomy. These are major challenges to the research agenda of economic research and science. If we fail, the costs will be immense.

Peter Berck believed in the bioeconomy. He did not look backward toward a naturalist paradigm. He insisted on looking at controversies such as biofuels and genetic modification through a lens of evidence. He believed in the power of science, knowledge, and development. Fundamentally, he looked toward the future, with hope rather than fear.

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