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Agricultural Science and Technology

Tensions and Contradictions

Leland Glenna and Elizabeth P. Ransom

Introduction

Agricultural science and farm-based technologies have been important forces behind the dramatic rise in agricultural production in the industrial world during the 20th century, as well as in large portions of the developing world (Stanton, 1998). In the United States, mechanisation, improved seeds and breeds, chemical inputs, and other scientifically inspired production technologies and techniques are often credited with productivity gains (Dimitri, Effland & Concklin, 2005). After the Second World War, the Marshall Plan exported many of these technologies and techniques to Europe, along with aspects of the political economy of agricultural science and technology. The Green Revolution in the 1960s and 1970s diffused new crop and animal husbandry technologies and techniques to developing nations. Between 1950 and 1990, irrigated cropland around the world expanded from 94 million hectares to 271 million hectares, grain production expanded from 618 million metric tons to 1,938 million metric tons, numbers of tractors in use expanded from 6 million to 26 million, commercial fertiliser use expanded from just under 5 million metric tons to nearly 27 million metric tons, and livestock production also saw dramatic increases (Stanton, 1998). More recently, agricultural research and development has turned towards even more sophisticated high-technology approaches, including computer- and satellite-monitored precision agriculture and genetically engineered (GE) crops and livestock. However, the shift to expensive, high-tech solutions raises questions concerning the affordability and appropriateness for smallholder agricultural producers who make up the vast majority of producers in the world.

One pitfall when discussing how agricultural science and technology fosters productivity gains is that it is easy to treat science and technology as determining outcomes. Moreover, narratives about agricultural science and technology tend to perpetuate ideological agendas and fail to capture the conflicts and competing processes that have been present at important moments in the historical trajectory (Glenna & Henke, 2014). It is important not to overlook the role that institutions and structures play in shaping people's decisions and actions, as well as the distribution of beneficial and negative consequences.

In industrialised countries, science- and technology-driven agricultural industrialisation is associated with declines in farm numbers, expansion in farm size and specialisation in production.

In the case of the United States, farm policies were often directed at limiting farm number decline, but some of those same policies also contributed to agricultural specialisation and expansion (Dimitri, Effland & Concklin, 2005). Other industrialised nations have adopted similar policies, such as price supports for farmers and regulations directed at reducing negative environmental consequences, including soil erosion, water pollution and deforestation (Stanton, 1998; Potter & Burney, 2002).

In developing nations, the Green Revolution had similar impacts. The introduction of improved crop technologies enhanced production, but it also tended to favour larger and more prosperous farmers (Evenson & Gollin, 2003). It is important to recognise that there are debates about how science and technology lead to these negative outcomes. For example, Birner and Resnick (2010) contend that Green Revolution technologies were scale neutral. Indeed, agricultural science and technology do not carry with them any inherent qualities that determine outcomes. Yet, it is also important to recognise that political-economic contexts influence the agricultural research and development agendas, as well as the adoption and diffusion of the products of that agenda. Griliches's (1957) research on the diffusion and adoption of hybrid maize in the United States found that private firms strove to promote the new technology to the largest farmers, first. It is common sense that a firm could sell as much hybrid maize seed in one transaction to a 100-hectare farmer as it could in ten transactions with 10-hectare farmers. The same logic would hold for an agricultural extension agent charged with promoting the diffusion of seeds or other technologies. Birner and Resnick (2010) concede that agricultural political-economic conditions and ideologies shaped outcomes that disadvantaged smallholders.

The Green Revolution has also been linked to environmental problems (Pretty, Toulmin & Williams, 2011) and to mass migrations of rural people to major urban areas in developing nations (Araghi, 2000). It has long been assumed by many development proponents that rural–urban migration is an effective poverty reduction strategy. However, following migration from poor rural areas to urban areas that do not have employment opportunities, as was the case with the Green Revolution, poverty is transferred, but not reduced (Pingali, 2012). Despite the failure of policies to benefit smallholder agriculture, smallholder producers remain prominent in many regions of the world, particularly in parts of Asia and Africa. Moreover, in recent years, there has been an expansion of smallholders (or what some refer to as peasants), even in many industrialised countries (Van der Ploeg, 2009).

Simultaneously, there has been an emphasis on high-technology approaches to address agri-food challenges, combined with a reliance on the private sector to generate these high-technology solutions. The approach has been pursued in both developed and developing nations. The rationale for the political-economic shift seems to be premised on two basic ideas. The first is that private firms have substantial resources and capabilities that could be harnessed to meet social welfare needs (Fuglie & Toole, 2014). The second is that private goods generated in the private sector are effectively and efficiently diffused through markets and, indeed, are more effective and efficient than are public goods generated by the public sector and distributed through educational and government agencies (Block, 2011). Furthermore, in the cases where public institutions, like agricultural universities, do generate public goods of potential value, the assumption is that this value is not fully realised until those public goods are converted into private goods and licensed to private firms (Glenna, Lacy, Welsh & Biscotti, 2007).

In past decades, agricultural science and technology have contributed to the productivist goals of maximising production while seeking the greatest efficiency from inputs. However, there have always been tensions and contradictions because the distribution of risks and benefits has not been even. Despite these insights, recent shifts in the political economy of agricultural science and technology indicate a trend that favours the private sector and global markets, a move that tends to exacerbate some of those underlying and persistent tensions and contradictions. We explore these issues by examining how these political-economic shifts are affecting agricultural science and technology in industrialised and developing nations.

Political economy of agricultural research in industrial nations

Perhaps one of the earliest examples of focusing on high-technology, private sector approaches was the development of hybrid corn in the United States in the middle of the 20th century. Between the early 1900s and the early 2000s, corn yields increased from an average of 25 bushels per acre to over 160 bushels per acre (that is, from 17 metric tons per hectare to 108 metric tons per hectare) (Ramey, 2010). Although it is often hailed as a great scientific and technological breakthrough, Kloppenburg (2004) and Berlan and Lewontin (1986) argue that hybridisation was chosen less for its contribution to yield than for providing a kind of biological patent that would attract the private sector's investment in plant breeding. Because it is not possible to achieve the same yields each year from saved hybrid corn seed, farmers needed to purchase seed each year. Berlan and Lewontin (1986) argue that the same yields could have been achieved without hybridisation. To support their claim, they note that corn was not bred for yield prior to the emergence of hybridisation. They also observe that wheat yields increased even faster than corn, but without hybridisation, between 1937 and 1945. They further note that increased corn yields coincided with mechanisation, crop rotation, fertilisers and public subsidies for production. The key point is that an ideological shift towards favouring the private sector's investment in agricultural science and technology development emerged in the middle of the 20th century, and that an ideology of privatisation contributed to the development of hybrid corn because of its built-in intellectual property protection, as distinct from the public availability of open-pollinated corn.

A series of policies in the USA led to more rigorous intellectual property protections for US crops. For example, the 1930 Plant Patent Act provided patent-like protection to asexually propagated plants, the 1970 Plant Variety Protection Act gave patent-like protection to sexually propagated plants, and the 1980 Supreme Court decision, *Diamond v. Chakrabarty*, allowed the patenting of novel life forms (Busch, Lacy, Burkhardt & Lacy, 1991; Kloppenburg, 2004). Furthermore, since the adoption of the Bayh-Dole Act in the United States, many other industrial countries have adopted similar policies (OECD, 2003; Lacy et al., 2014). This has been an important development in agriculture because farmers had always been able to save a portion of their crop to replant the next season. Patent protection changed that. However, the political-economic reasoning is that this transformation is justified because the private sector will have a greater incentive to invest in agricultural research and development if it can secure patent protection.

Private sector investments in agricultural science and technology research did increase between 1981 and 2000. In 1981, in OECD nations, the public sector contributed US$8,339.8 million and the private sector invested US$6,478.4 million, which amounts to 44% of the total. By 2000, the private share of agricultural science and technology research had risen to 54%, US$12,184.5 million from private sources and US$10,267.6 million from public sources. Information relating to the private investments in agricultural science and technology was not available for all nations in 1981. By 2000, the private share of agricultural science and technology research investments amounted to 39% (Alston, Andersen, James & Pardey, 2010, p. 144).

It appears, at first glance, that higher private sector investments are positive. Private agri-food businesses have substantial scientific expertise and resources that can be mobilised to improve agricultural production, which may contribute to more food availability and lower food costs. However, greater investments from the private sector have not yielded the same levels of agricultural innovation across nations (Fuglie et al., 2012), and the impacts have not been the same across all crops. To explain the variation in impacts, Glenna, Shortall and Brandl (2015) compared crop yields in the United States, the United Kingdom, Germany and Ireland. They point out that the private sector tends to invest in crops that have intellectual property protections, such as patents or hybridisation, which enable the holder to exclude others from using those private goods. These crops include maize, canola, rice and soybeans. Public goods, by contrast, can reasonably be accessed by anyone. Before hybridisation, and before it became possible to patent genetically engineered (GE) crops, seeds were predominantly treated as public goods. Today, GE crops and hybrid crops are treated as private property, while open-pollinated crops that are not GE or hybrid, such as wheat and barley, continue to be treated as public goods.

One of Glenna, Shortall and Brandl's (2015) findings is that hybrid crops and GE crops had yield increases in the USA over the last three decades. However, open-pollinated crops, like wheat, saw a decline in yield growth over the same time period. They argue that this outcome is likely because intellectual property protections enticed private sector investments in improving GE crops and hybrid crops, whereas the private sector considered open-pollinated crops to be a risky investment. By contrast, Germany has banned GE crops, even though it does have hybrid maize. Germany had modest increases in multiple crops, including wheat. They argue that this is likely because Germany emphasises the enhancement of public goods, even from research that is conducted in the private sector.

This outcome raises concerns because it indicates that, in the absence of strong government policies to promote public-goods research, the private sector tends to invest in research that yields private goods. However, there are many food and agricultural problems, including concerns over water management and environmental protection, for which privatisation is not conducive to generating a solution. Glenna, Shortall and Brandl (2015) conclude, therefore, that many agri-food challenges require public-goods research and that the increasing emphasis on private goods may inhibit the broad innovations needed to address global agricultural and food problems.

A second problem related to the increasing reliance on private sector research funding and the trend in generating more private goods is that intellectual property protections may restrict agricultural research at universities and, therefore, may be stifling agricultural innovations (Glenna, Tooker, Welsh and Ervin, 2015). In the USA, where GE crops are widespread, a group of public sector entomologists submitted two letters in 2009 to the Environmental Protection Agency claiming that intellectual property restrictions were preventing them from doing research on the efficacy and environmental impacts of GE crops. Glenna, Tooker, Welsh and Ervin (2015) conducted a survey of those entomologists and found that 31% claimed that their research had been hindered by an industry partner; and nearly 59% said that there is research on the efficacy or environmental impacts on GE crops that they would like to conduct, if it were not for the intellectual property restrictions that prevented such research. One respondent reported that research findings were suppressed. The authors conclude that there is conflict between public and private sector scientists, that current policy arrangements have not removed obstacles to undertaking important research, and that the integrity of the regulatory review process may even be in question. Moreover, they claim that these findings support arguments that strict intellectual property protections are hindering innovation (Glenna, Tooker, Welsh and Ervin, 2015).

There are limits to the generalisability of the entomologist study. First, it was a small sample. Second, the sample focused exclusively on entomologists who do applied research.

However, their findings support those from other research. For example, Lei, Juneja and Wright (2009, p. 36) found in a survey of agricultural biologists in the University of California system that a majority of the scientists concluded 'that patenting impedes the progress of research'. In the same vein, Schimmelpfennig, Pray and Brennan (2004) found that concentration in the seed industry has been linked to a reduction in research intensity in the agricultural biotechnology field.

Glenna and Cahoy (2009) explain that, since GE crop research expanded in the 1980s, 37 companies have secured patents on GE corn and 118 companies have secured patents on non-corn GE crops. However, through buyouts and strategic alliances, just three companies now control 85% of patents on GE corn, and just three companies control nearly 70% of patents on non-corn GE crops (Glenna & Cahoy, 2009, p. 122). These findings raise questions about how competitive the market is for agricultural seeds. The findings also lend support to the claims that strict intellectual property protections are inhibiting innovation, since concentration in the seed industry is likely to enhance the power of the large seed companies, which they can use to control the types of research that university scientists are able to conduct.

Political economy of agricultural research in developing nations

As noted at the beginning of this chapter, promoting increases in agricultural production has been a preoccupation of many agricultural science and technology programmes. Specifically, the emphasis on agricultural productivity in developing countries at the international level came by way of the Consultative Group on International Agricultural Research (CGIAR), which evolved into several commodity-specific affiliated research programmes, including the International Rice Research Institute (IRRI), International Centre for the Improvement of Maize and Wheat (CIMMYT) and later the International Livestock Research Institute (ILRI). From the outset CGIAR grew out of the partnerships created during the development of the Green Revolution, particularly between the Mexican Ministry of Agriculture, the Rockefeller Foundation and the Ford Foundation (Shaw, 2009).

Officially founded in 1971, CGIAR's focus was on increasing production of staple foods, with an implicit goal of focusing on the production of international public goods that 'are non-exclusive in access and non-rival in use, and have widespread applicability beyond national boundaries' (Shaw, 2009, p. 88). A large part of CGIAR's work has focused on improved crop varieties. The mandate has shifted noticeably over the past 40 years, moving from solely focusing on food production to focusing on the environment, biodiversity and policy improvement. Shaw (2009, p. 93) also maintains that funding to CGIAR is increasingly restricted, meaning donors limit how and where the money can be spent, a situation that 'threatens the integrity and functioning' of CGIAR as a system for coordinating research and funding. CGIAR funding continues to be dominated by the industrialised countries. The developing nations that stand to gain the most from CGIAR research contribute only 5% of the budget, which in its entirety stood at approximately US$430 billion in 2006 (Shaw, 2009, p. 92). Thus, despite being the intended target of agricultural research, CGIAR is not financed or managed primarily by these countries. In addition, CGIAR recognises the limited pace and scale at which the outcomes of their research have been adopted by farmers. They are now working with private foundations, including Gates and Rockefeller, to increase the dissemination of their work. However, the influence of private philanthropists is not without its downsides. The Gates Foundation is third only to the USA and the World Bank in financial contributions to the CGIAR. By emphasising high-technology and private sector solutions, Glenna, Brandl and Jones (2015) argue, the Gates Foundation's impact on the

CGIAR research agenda is similar to the impact that private firms are having on public sector research organisations in OECD nations.

At the national level, with heavy influence from development programmes emanating from industrialised countries, especially the United States, most developing countries have some type of National Agricultural Research Institute (NARI). However, these publicly funded agricultural research and development institutions, along with agricultural extension and investment in production systems, have experienced a general weakening since the 1970s (Collinson, 2001; Pretty, Toulmin & Williams, 2011). NARIs, like the CGIAR consortium, have historically been commodity focused and discipline based in their research agendas (Collinson, 2001). In addition, much of the university agricultural curriculum and education and, by association, agricultural extension services, has been based on a Western curriculum which, many argue, fails to be relevant to the context of developing countries, particularly for smallholder farmers. This is because smallholders tend to operate multi-enterprise systems, with no one commodity being the primary focus (Collinson, 2001). When agricultural research and extension focus solely upon one commodity (such as rice or wheat or milk), the real needs of smallholders – to manage a variety of commodities – is largely ignored.

Smallholders and agricultural science and technology

Focusing on smallholder farmers, whether in industrialised or developing nations, is important because they continue to represent the vast majority of farm producers. According to an analysis by the United States Census of Agriculture, around 12% of large farms (annual sales exceeding US$250,000) account for 84% of the value of agricultural production (Hoppe & Banker, 2010, p. iv). However, that means that there are still approximately 1.5 million small and medium-sized farmers in the USA. Although these farmers may not be making substantial contributions to overall production, Lobao and Meyer (2004) contend that, for these smaller operators, farming still accounts for a substantial portion of their household livelihood strategy. In other words, when agricultural research and development focuses on high-technology and market-based approaches to increasing productivity, it may be ignoring the specific needs of farmers who still provide important social and economic contributions.

Smallholders are located throughout the world and, in fact, smallholders have actually increased in the past few decades in both industrialised and developing nations (Van der Ploeg, 2008). Van der Ploeg (2008) admonishes much of the existing literature for separating peasants into two geographical categories – industrialised and developing countries – and then applying different theories and concepts to these two groups. Despite this rebuke, much of the recent literature focuses on Asia and the Pacific, or Africa. In part, this is because some 90% of the world's one billion global poor live on small farms (Birner & Resnick, 2010, p. 1442) and are largely located in developing countries. For example, it is estimated that about 87% of the world's 500 million small farms (less than 2 ha) are in Asia and the Pacific region (Thapa, 2009, p. 1). In Africa, agriculture accounts for 65% of full-time employment, 25–30% of GDP and over half of total export earnings (IFPRI, 2004, p. 2), and it underpins the livelihoods of over two-thirds of Africa's poor (Pretty, Toulmin & Williams, 2011). Thus, when discussing the tensions and contradictions surrounding smallholders and agricultural science and technology, much, though not all, of our discussion is limited to smallholders in developing countries.

While the conventional definition of 'smallholder' in developing nations is farming less than 2 hectares of land (Hazell, Poulton, Wiggins & Dorward, 2007), other definitions of smallholders extend to farmers with limited resources, including capital, labour and skills. This is important to bear in mind in terms of thinking about the relevance of agricultural science and technology. Smallholders generally feed their households and, to varying degrees, may sell a portion of their production in the marketplace. Despite the broad application of the label, smallholders represent a diverse group, with some evidence of growing disparities between smallholders in terms of land and asset holdings (Jayne, Mather & Mghenyi, 2010; Ransom, 2015).

Smallholder is, of course, a contested category. Many view smallholders as an obstacle to change and predict they will disappear as economic development accelerates (see Collier & Dercon, 2014). Others view smallholders as providing abundant opportunities, particularly in terms of environmental sustainability and economic opportunity (Van der Ploeg, 2008; Pretty, Toulmin & Williams, 2011). Our interests are less in debating the role of smallholders and more in recognising how the new trends in agricultural research and development are failing to meet the needs of a large number of farmers in the world. Generally, high-technology solutions being developed in the private sector, such as new biotechnologies, are unlikely to benefit smallholders. Thapa (2009) observes that the development of private GE crops is generally disadvantageous to small farmers because private research companies lack incentives to address small farmers' concerns. Similarly, Muzari, Gatsi and Muvhunzi (2012) argue that some of the most important crop improvements that need to happen for smallholders are 'in situ' (i.e., in the field) where interbreeding of traditional crops with varieties that have improved characteristics would be beneficial. But the authors observe there is little to no interest from commercial seed enterprises in such research and development, because the profits are too low, even though this could improve productivity for smallholders (Muzari, Gatsi & Muvhunzi, 2012, p. 75).

Of those interested in the role smallholders could play in creating a more sustainable agri-food system, there are several who believe in the opportunity to create sustainable or agro-ecological intensification (Pretty, Toulmin & Williams, 2011; Nelson & Coe, 2014). For example, in a study of rice production in northern Ghana, Glenna et al. (2012) found that, given the right policies to provide inputs and guaranteed markets, smallholder rice farmers were able to dramatically improve rice yields using conventionally improved rice varieties. They also note that such efforts to enhance productivity of smallholders were being hampered by World Bank policies that discourage public investments aimed at supporting smallholder farms.

Gender and agricultural science and technology

Alongside the continuing presence of smallholders has been the so-called feminisation of agriculture. Women in low-income countries have typically been involved in a range of livelihood strategies that include growing, processing and preparing food (Ransom, Wright & Bain, forthcoming). However, these roles are also changing as social and economic forces transform the agricultural sector in many places. Agriculture is becoming feminised, especially in sub-Saharan Africa, where women are increasingly responsible for the farm as men exit from the sector to migrate to urban areas in search of paid work, or as a result of involvement in civil wars and conflicts, or deaths and illnesses from HIV/AIDS. Meinzen-Dick et al. (2011) have highlighted that, despite the fact that women play a central role in food production in most developing countries, only one in four agricultural researchers in sub-Saharan Africa and one in three in Latin America are female. The authors elaborate that, although male researchers can address the needs of women farmers, 'the lack of gender balance among agricultural scientists diminishes the likelihood that the specific needs of rural women will be met' (Meinzen-Dick et al., 2011, p. 49). This lack also means that 'women's voices are less heard in critical, often male-dominated, policy debates and decision making processes' (p. 50).

The feminisation of agriculture is also relevant to the topic of technology adoption. Agricultural technologies that were created, but never adopted, litter the agricultural development landscape. There is a long line of technologies that were either not perceived as appropriate by smallholders and/or the policies that were needed to support adoption were never implemented (Birner & Resnick, 2010; Muzari, Gatsi & Muvhunzi, 2012). There has been a renewed focus on agricultural development in the past decade, and with this focus has come renewed attention to the factors that facilitate technology adoption among smallholders. Factors affecting technology adoption include assets, vulnerability and institutions. Generally, smallholders with limited material and non-material (e.g., education) assets will be less likely to adopt asset-intensive technologies. So, for the poorest farmers, technologies with low-asset requirements are more likely to be adopted (Muzari, Gatsi & Muvhunzi, 2012). A high degree of vulnerability is identified among smallholders because they have very little protection from climatic or market fluctuations. Generally, this means technologies should be perceived by smallholders as low risk (Collison, 2001; Muzari, Gatsi & Muvhunzi, 2012). Finally, an assortment of institutions, including financial, insurance and information dissemination, are viewed as important, but historically absent or ineffectual at working with smallholders in developing countries. Many of these institutions also have a history of gender bias, primarily only willing to work with men, which is problematic as more and more women can be identified as smallholders (Doss, 2001). Moreover, government policies and investment, particularly in Africa, have increasingly come under scrutiny. On average, African countries spend 4–5% of national budgets on agriculture, compared to 8–14% in Asia (Fan, Johnson, Saurkar & Makombo, 2008, p. 2).

Conclusion

Scientific research and technology have made great contributions to agricultural productivity gains over the last century. Yet, these gains have come with costs, most notably social and economic inequality and ecological problems. These outcomes have led some commentators to highlight the contradictions and tensions of relying on scientific research and new technologies to solve productivity problems while paying too little attention to questions of equity and ecological sustainability. Although the productivist approach has never been free of challenges, recent shifts in the political economy of agricultural science have served to exacerbate some of those underlying and persistent tensions and contradictions.

In general, the share of private funding for agri-food research and development in industrialised and developing nations has grown in relation to public funding. Although there are benefits to having more investments from firms and private philanthropists in research, these investments tend to be directed at securing private goods at the expense of public goods and favour larger commodity producers and market-based approaches over smallholders and collective agro-ecological approaches. As a result, research agendas directed at generating scientific knowledge and technologies more appropriate to smallholder farmers in industrialised and developing nations tend to be underfunded. These missed opportunities may be undermining smallholders' abilities to meet their own needs and to produce a sufficient and sustainable food supply for their nations and the world.

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