Understanding Agricultural Biotechnology Innovation in the Context of Development

Beumer, Koen; Swart, Jac. A.A.

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Koen BEUMER[ab,1] and Jac. A.A. SWART[a]
[a]*Science and Society Group, University of Groningen, Groningen, The Netherlands*
[b]*Copernicus Institute of Sustainable Development, Utrecht University, The Netherlands*

Abstract. The possible impacts of modern agricultural biotechnology on developing countries have widely been discussed. Optimistic perspectives stress that it may bring development and prosperity to poor countries whereas critics warn of the further marginalisation of already vulnerable communities. In this chapter we outline dominant notions of ‘development’ underpinning different visions regarding the impact of agricultural biotechnology on developing countries. This chapter contributes to greater conceptual clarity about the impact of agricultural biotechnology in developing countries. It is particularly helpful to compare the impact of agricultural biotechnology in developing countries to Green Revolution technologies. We found that the Green Revolution can largely be understood from the perspective of modernisation theory that emerged after World War II, a perspective which holds that technologies developed in the public domain in Western countries can be transferred to developing countries. Agricultural biotechnology, in contrast, should be understood from the perspective of neoliberal development theory as it is characterised by globalisation, free trade, patentable knowledge, and innovations led by multinationals. We conclude by highlighting that this situation may be currently shifting, as charities take a larger role in funding agricultural innovation and as recent developments in gene-editing technologies possibly open up a window of opportunity for the enhanced autonomy of poor countries in developing agricultural biotechnology themselves.

Keywords. Agricultural Biotechnology, Development, Genetically Modified Organisms, Genetically Modified Crops, Developing Countries.

7.1. Introduction

Agricultural biotechnology refers to the use of a variety of scientific tools and techniques to modify agricultural crops in ways that are not possible with traditional breeding. In particular, the use of genetic modification or engineering has attracted substantial attention. Since the commercial introduction in 1996 of genetically modified (GM) crops like maize, soybean and cotton, a lively debate has emerged about the benefits and downsides of this new technology both within and outside of academia (Motta, 2014).

Scholars in innovation studies and science and technology studies have actively engaged in these discussions by highlighting the different notions of ‘innovation’ that underpin various claims about the impact of agricultural innovation. For instance,

[1] Corresponding Author. Email: k.beumer@rug.nl

Friedman (2009) has pointed out that most biotechnology innovations can be characterised as a form of technology push, in which expert-based scientific and technological developments are the main driving forces of development. Others have argued for more inclusive models of innovation, through including publics and civil society organisations in biotechnology decision-making (Levidow, 2007; Toni and Von Brain, 2001), including users such as smallholder farmers in setting priorities for innovation objectives and by developing ‘appropriate biotechnologies’ that are well-suited to local circumstances (Ruivenkamp, 1993). More recently, Macnaghten (2015) stresses the need for responsible innovation, implying collective stewardship with respect to science and innovation and encompassing concepts such as anticipation, inclusion, reflexivity and responsiveness.

Although these studies offered insights into the conditions and challenges of modern agricultural technologies, as for example the application of high yielding varieties and genetic engineering, little attention has been paid to the role of these technologies on what is called ‘development’–the various societal changes that are commonly understood to improve the lives of people whose life-standard is well-below the world’s average. However, like the concept of innovation, the notion of development too is marked by substantial interpretative flexibility (see, for example, Sen, 1988; Desai and Potter, 2002; Potter and Conway, 2017). As Jasanoff has noted,

> ‘development is a flat word for a world of contradictions. (….) It consumes meaning and seeks to remedy the multiple varieties of human misery and disempowerment through a single, undifferentiated, technocratically certified model of forward movement’ (2002:270).

It is thus unsurprising that there are many different ideas about how agricultural biotechnology impacts upon development. In the most optimistic scenarios, genetic modification is portrayed as the *Gene Revolution*, suggesting it is a follow-up of the *Green Revolution*, which centered around the development of hybrid varieties, and which has been responsible for a massive increase in agricultural production worldwide (Evenson and Gollin, 2003; Juma, 2011). In this optimistic scenario, agricultural biotechnology is seen as a silver bullet that can bring development to the continent, while in the most pessimistic scenarios, the technology is regarded as a Trojan horse that will bring despair to already vulnerable communities (Gurian-Sherman, 2009).

In this chapter, we outline dominant notions of development in the context of innovation and relate them to the rise of agricultural biotechnology. Just like general accounts of innovation (like the linear model of innovation or National Systems of Innovation) can be helpful in highlighting particular features of innovation practices at lower aggregate levels, so can theories of development be used as a heuristic tool to highlight features of innovation, without reducing innovation to the confines of theoretical accounts of development. By this we aim to contribute to greater conceptual clarity about the impact of agricultural biotechnology in developing countries, demonstrating that the diverging views of the impact of agricultural biotechnology on development are often underpinned by diverging ideas of how development does and does not work.

Because the discussions on agricultural biotechnology do have a certain analogy to the arguments pro and contra the Green Revolution, we found it helpful to draw upon literature comparing biotechnology to the Green Revolution, as this contrast helps to provide more clarity on the notions of development underpinning biotechnology. The methodology we use is that of a narrative review, which is an exploratory, expert-based synthesis of key literature, and unlike systematic reviews or meta-analyses, does not seek to capture all literature in order to test a particular hypothesis (Baumeister and Leary, 1997; Green *et al*., 2006). We firs explore different notions of development. We then apply these notions to the Green Revolution and to agricultural biotechnology in order to clarify the notions of development underpinning claims about the impact of agricultural biotechnology on developing countries.

7.2. Main approaches to the role of technology in development

So, what are some of the most important notions of development, and what is the role of technology and innovation therein? In the following section, we discuss modernisation theory, dependency theory, and globalisation theory.

7.2.1. Modernisation theory

In his inaugural address as President of the United States (US), Harry Truman famously said that:

> 'For the first time in history humanity possesses the knowledge and the skill to relieve the suffering of these people. (…) I believe that we should make available to peace-loving peoples the benefits of our store of technical knowledge in order to help them realize their aspirations for a better life. (…) Greater production is the key to prosperity and peace. And the key to greater production is a wider and more vigorous application of modern scientific and technical knowledge' (Truman, 1949).

This speech is often considered to be the symbolic start of the 'development project' and one can clearly see the central role of science and technology in what became known as the so-called *modernisation theory* (Desai and Potter, 2002). According to this line of thought, which emerged after the end of World War II, 'developed countries' can be contrasted to 'underdeveloped countries' and the path to development taken by the former is regarded as a blueprint or recipe for the latter, as illustrated by Figure 7.1.

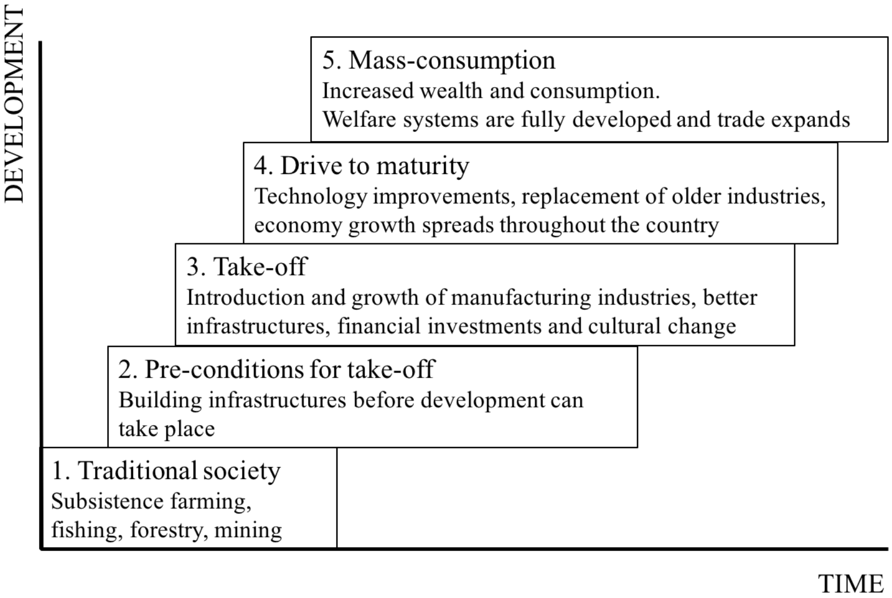

Figure 7.1. Stages of economic growth

Source: Adapted from Rostow (1960)

According to this theory, developing countries should work towards industrialisation, decrease their dependency on foreign imports, and realise political reforms (Burch, 1998). Next, they should aim for integration into the world market and finally, transform into a mass consumption society so that the benefits of development can 'trickle down' to the poor (Rostow, 1960).

Science and technology have an important role in this theory. The core assumption in this model is that knowledge and technologies that have already been proven to be successful in 'developed' countries can be applied without much difficulty in 'underdeveloped' countries (Rist, 2014). In the first decades of the development project, this notion of development was translated into large technological projects and the provision of technical assistance, as in the introduction of new varieties, irrigation technologies, tractors and large dams. Khandekar *et al.* write:

> 'Rapid technological advancement–through aggressive industrialization, agricultural modernization, and infrastructural expansion for instance–was the very cornerstone of development. It was hence that large-scale technological projects, such as the commissioning of large dams and heavy industries and interventions such as the mechanized and chemical and water intensive technologies of the agricultural Green Revolution came to be championed by development agencies such as the World Bank. Providing technological assistance and expertise to replicate the successes of the West became the modus operandi of such developmental interventions' (2016:667-668).

This description of the modernisation theory shows that the role of science and technology in modernisation theory strongly resonates with a linear model of innovation, according to which innovation should be understood as a linear process in which scientific insights are generated, then applied to the development of novel technologies, and finally released to society, as illustrated by Figure 7.2. below. This way of thinking also resembles a technology push account of innovation in which scientific and technological developments–which originate in the 'developed' world–are viewed as primary driving processes of social change.

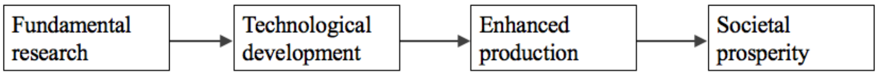

Figure 7.2. A schematic representation of the linear model of innovation

Modernisation theory emerged in the post-War period and opened up space for foreign intervention in an era marked by decolonisation and Cold War politics. It enabled the global expansion of markets for US products and thereby US hegemony in the world capitalist system (Rist, 2014; Escobar, 1995). In this context, institutions like the World Bank and the International Monetary Fund, national funding agencies in 'developed' countries, and donors like the Ford and Rockefeller Foundations subsequently began to fund activities in 'underdeveloped' countries.

7.2.2. Dependency theory

From the 1970s onwards, modernisation theory was increasingly criticised. Prominent among critics were dependency theorists who argued that the poverty of developing countries was not caused by the absence of industrialisation but by their *dependence* on Western countries. These authors argued that capitalist production machineries were mainly beneficial for countries at the 'core', i.e. Western countries, and attempts to incorporate poor countries in the 'periphery' would only strengthen the dominance of 'core' over 'periphery' (Escobar, 1995; Desai and Potter, 2002; Nederveen Pieterse, 2010). According to these critics, rather than imitating the pathway of developed countries, developing countries should pursue development in ways that are better suited to their cultures (Herrera, 1981; Herrera, 1989; Escobar, 1995; Desai and Potter, 2002; Nederveen Pieterse, 2010).

In line with this critique, scholars have also criticised the transfer of modern technologies, pointing to various negative consequences of science and technologies, such as the detrimental impact on health and the environment (including, for example, the Bhopal disaster, see Jasanoff, 2007), the increase of inequalities (Shiva, 1991), and the loss of local knowledge (Nandy, 1988; Visvanathan, 1997). In line with the critiques to lessen dependency on Western countries, scholars emphasised the value of indigenous knowledge and practices in the pursuit of innovation (e.g., Needham, 1954-1995; Harding, 1998). Innovation scholars similarly proposed the development concept of 'intermediate technologies', in an attempt to create a space for science and technology that would lessen dependency on the Western countries (Schumacher, 1973; Kaplinsky, 1990). According to this notion, simple and practical tools and machines that could be maintained and repaired with locally available skills and materials were deemed better suited to the task of facilitating development (see, for example, Schumacher, 1973; Kaplinsky, 1990).

7.2.3. Globalisation theory

From the early 1980s onwards, globalisation theory gained prominence in development debates. Contrary to dependency theory, which tends to regard linkages between developed and developing countries with suspicion, globalisation theorists regard integration into the world market as an essential condition for achieving development. It is guided by a set of policy prescriptions, put forward by the World Trade Organisation, the International Monetary Fund, and the World Bank (the so-called Washington Consensus) (Desai and Potter, 2002). Within this general line of thought, several different streams of thought can be discerned.

Prominent among these have been neoliberal ideas of development. Whereas dependency theorists and adherents to intermediate technologies focus particularly on the local or peripheral circumstances, neoliberals mainly emphasise the role of both governance and the private sector. According to this line of thought, underdevelopment is often related to corrupt states and failing planned economies (of, for example, former communist countries). As an alternative, globalisation theory emphasises the role of the individual and international markets, arguing for a minimisation of the role of the state (Reid-Henry, 2012; Nederveen-Pieterse, 2010).

This approach to underdevelopment is associated with privatisation, corporate ownership, the removal of barriers to foreign investments, the restructuring of the labor market and increasing transparency of government activities under the heading of ‘good governance’ (Nederveen-Pieterse, 2010). Thus free trade in an international context is considered key to development: ‘trade, not aid’ (Reid-Henry, 2012). Development policies should not focus on aid but rather on creating conditions making trade and entrepreneurship possible as the route to socio-economic development. As the Guardian aptly formulated: ‘the only viable object of development policy was to do whatever was necessary to make local markets and societies "fit" with the new global imperatives’ (Reid-Henry, 2012).

This approach can be linked to several market-based development strategies that focus on the poor by enabling them to become entrepreneurs through e.g. microfinancing and microcredits. Related to this is the recognition that the poor may be a promising market themselves. For example, the so-called Bottom of the Pyramid approach rejects the assumption that the poorest people are not of commercial interest. Given the sheer number of poor people who would like to buy products, a market strategy focussing on them can be profitable in spite of the small profit margins. When companies innovate with these poor consumers in mind, the theory claims, both companies and the poor will benefit (Prahalad, 2004).

Like modernisation theory, innovation is considered to be important in globalisation theory but it gives greater emphasis to the importance of linkages between different actors (Godin, 2009). Innovation studies scholarship has recognised that innovations are most successful given strong linkages between various innovation actors. This insight has been articulated through the concept of National Innovation Systems (Freeman, 1987; Lundvall, 1992; Nelson, 1993; Godin, 2009). Although this literature often focuses on the nation, it often builds on notions of development that emphasise the benefits of globalisation: such innovation systems are thought to be required for developing countries in order to benefit from newly emerging technologies developed elsewhere and the increasingly global distribution of labour (World Bank, 1998/1999; Burch, 1998).

However, a country does not always aim to develop these technologies themselves; it is equally important to develop a capacity to acquire, and to adapt to, available scientific insights, technologies, innovations to local circumstances (Romijn, 1999). As Szirmai (2015:125) suggests,

> ‘An important lesson to be derived from the technological capability literature is that acquisition of technology is neither easy nor free of cost, as suggested by older neoclassical theories of growth. Acquisition of existing technology requires considerable skills, effort and capabilities. The adaptation of international technology to local conditions requires efforts and capabilities. These capabilities themselves have to develop or be developed through education, training, experience and investment in human capital’.

A third trend in globalisation theory stresses the importance of high-end innovation in developing countries themselves. Whereas the literature on technological capabilities generally departs from the view that innovations are developed in ‘developed’ countries, this body of literature stresses that developing countries themselves need to develop science and technology (World Bank, 1998/1999).

The rapid economic growth in ‘emerging economies’ like India, China and Brazil not only increased their influence in the global political arena, but also came with a steep rise in expenditures for research and development (R&D), often growing faster than developed countries (United Nations Educational, Scientific and Cultural Organisation, 2010). Furthermore, multinational companies increasingly outsource their R&D to developing countries, especially in Asia (so-called reverse innovation). They locate their R&D facilities in countries like India and China, close to the markets of the new middle classes (Szirmai, 2015). These innovations are usually not conceptualised as indigenous knowledge or ‘appropriate’ technologies but rather as high-tech endeavours, the benefits of which are expected to trickle down through market-driven development in a globalising world. As a result, while in the early days of development approaches technologies were transferred from Western to poor countries, innovation in the present day also implies the transfer of technologies the other way round (Immelt *et al.*, 2009).

A fourth trend evident in the globalisation theory of development is the prominence of societal objectives in steering science and technology. Earlier development notions had already stressed that development should not be limited to economic indicators alone and must include other poverty dimensions, such as social, cultural, physical and political factors (Sen, 1989). This perspective has recently been translated into various global objectives such as the *Millennium Development Goals* and the *Sustainable Development Goals* in which it is stated that,

> ‘We are determined to ensure that all human beings can enjoy prosperous and fulfilling lives and that economic, social and technological progress occurs in harmony with nature’ (United Nations, 2015:2).

Strategy documents accompanying these objectives highlight the importance of information and communication technologies (ICT), biotechnology, and nanotechnology for attaining the development goals (Juma and Yee-Cheong, 2005).

These critical perspectives on the modernisation thesis, although very different, all complement the notion that innovation does not, and should not, follow a rigid linear path of development. Rather innovation is understood to occur in socio-technical systems in which actors are connected in networks and technological and societal developments co-evolve (Nelson and Winter, 1982; Dosi *et al.*, 1988). This implies that innovation should not only focus on technologies alone but also on the environmental, socio-economic, political, and cultural circumstances in which a technology is embedded.

7.3. Modern agricultural technologies

How do these notions of development underpin the rise of biotechnology? How do these diverging ideas of the relation between technology and development help us to provide conceptual clarity regarding the development impact of agricultural biotechnology on poor or developing countries? In order to answer these questions, we first look at the relation between agriculture, innovation, and development during the Green Revolution. Like agricultural biotechnology, the Green Revolution is based on modern scientific insights and aims to contribute to development by focusing on agriculture. The Green Revolution, however, emerged in a different time and in a different socio-technical system. By comparing the Green Revolution and agricultural biotechnology, we get a better insight into the relationship between technologies, innovation, and development.

7.3.1. The Green Revolution

The Green Revolution is an umbrella term that aims to capture a broad variety of innovations in agricultural practices that were transferred to developing countries by research institutes funded by Western donors (Herdt, 2012). It includes, in addition to hybrids, high-yielding crops, synthetic fertilisers, pesticides, mechanisation, and irrigation techniques. The most central technology is the hybrid seeds technology. Hybrid seeds are created by crossing two inbred lines, which results in seed with high productive features as compared to conventionally bred plants.[2] As high yielding varieties also require high inputs of fertilisers, water, and pesticides, in addition to modern agronomic knowledge, the introduction of these seeds comes with a package of other technologies.

These Green Revolution technologies were widely adopted in the early 1960s in large parts of Asia and Latin America. The main incentive for the implementation of these agricultural technologies was a series of looming famines in India, Indonesia, and

[2] Inbreeding refers to the reproduction of organisms through self-pollination or through crossing of individuals with identical or nearly identical genetic constitution. Inbred individuals often have a weak biological constitution. They are vulnerable to diseases and demonstrate low productivity. However, remarkably, crossing two different inbred organisms leads to a ‘hybrid’, which are often very strong, productive, and healthy. However, this is only the case for the first generation, next generations of the plant demonstrate declining qualities.

the Philippines, which strengthened the desire of these countries to become self-sufficient and increase productivity (Birner and Resnick, 2010).

However, this was not the only factor. The new technologies that were transmitted to developing countries by international public research institutes could be realised as a result of the political and financial support from American foreign policy institutions in particular. In their view, 'food security problems, particularly in Asia, were considered as a driving factor to political instability and the spread of communism' (Hall *et al.*, 2000:74), and providing support for agricultural technologies was hence considered to directly contribute to American foreign policy objectives. In terms of productivity, especially of cereals, the Green Revolution was an outstanding success in large parts of the world. In many countries, excluding the African continent, production doubled between 1966 and 1990, as highlighted by Figure 7.3.

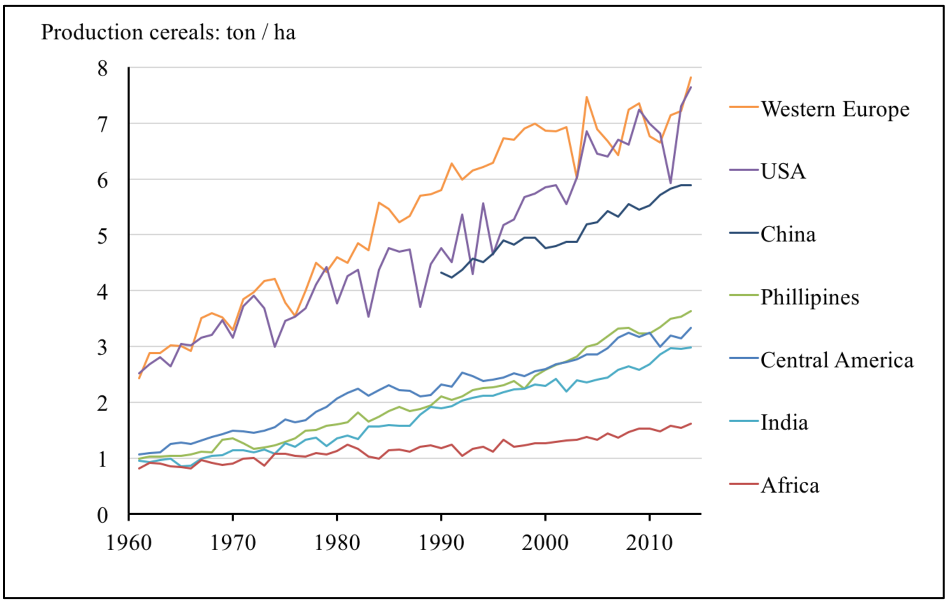

Figure 7.3. Production of cereals in different countries from 1961-2014

Source: Food and Agriculture Organisation of the United Nations (n.d.)

When we look at the notions of development underpinning these technologies in the Green Revolution, we can clearly see the outlines of modernisation theory. The Green Revolution technologies largely aimed to enhance productivity and are often depicted as being particularly well-suited to circumstances of industrial agriculture in 'developed' countries, which are viewed as providing a model for developing countries to imitate.

We may also consider the Green Revolution as an example of the technology push model because most of the Green Revolution technologies were developed in international research institutes, with the technologies provided to local agricultural organisations, which subsequently made them available to farmers–similar to the linear model of innovation. An important role was played by private American foundations like the Rockefeller Foundation and the Ford Foundation, not only in creating high-yield varieties, but also in setting up extension programs and institutions for agricultural research in developing countries in order to provide technical assistance and to transfer these technologies to farmers (Herdt, 2012). The main strategy was to build local research capacity; to that end, several research institutes with an international outlook were established in, for example, India, the Philippines, and Mexico in the two decades following World War II. These research institutes were later turned into public research institutes under the heading of the Consultative Group on International Agricultural Research (CGIAR).[3] Hence, civil society organisations and the public sector played leading roles in the Green Revolution innovation system (Kloppenburg, 2005).

There has been much debate on the positive and negative effects of the Green Revolution for farmers, but it is generally agreed that most benefits have landed at the consumer's side because the increase in yields resulted in lower food prices (Evenson and Gollin, 2003). This is in line with the thesis by the modernisation theory that the dominance of traditional agriculture in developing countries could be seen as an indicator of failed development. According to that line of thought, what was required for economic development to occur was the,

> 'reallocation of factors of production from a backward, low-productivity agricultural sector to a modern industrial sector with higher productivity and increasing returns' (Diao *et al.*, 2010:1375).

Recently these arguments have gained new prominence as development economists have argued that focusing development efforts on smallholder farmers is not efficient and that industrialisation of agriculture and subsequent migration of smallholder farmers to cities provides a better development strategy (Collier and Dercon, 2010).

In line with the critiques from dependency theorists, it can however also be argued that the Green Revolution made farmers in developing countries more dependent on developed countries as hybrid seeds lose their high yield potential when they are reproduced by farmers themselves (Kloppenburg, 2005). As a consequence, farmers have to buy seeds from the seed company every growing season in order to maintain their high yields. This creates a state of dependency of farmers on international seed firms that own the technology, highlighting a tension with the dominant farming culture.

The Green Revolution was certainly not a one-sided success story and much can be said about its ambiguous consequences. Although some studies have found that in some cases Green Revolution technologies were scale-neutral, benefitting both smallholder and large farmers (Birner and Resnick, 2010), there is also a large body of literature underpinning the claim that the Green Revolution increased inequalities (see, for example, Griffin, 1974; Prahladachar, 1983; Hossain, 1988; Galor and Maov, 2000; Pearse, 2015). Stringent requirements in terms of irrigation or reliable rainfall and the input of fertilisers and pesticides were, for example, shown to be better suited to larger

[3] See http://www.cgiar.org/

farmers who were in a better position to get loans. Because these farmers were able to realise higher yields, they could use their profits to buy out smallholder farmers.

In contrast to Asian and Central American countries, the African continent did not witness the same significant increase in productivity experienced in other continents and it is generally felt that the Green Revolution failed in Africa (Evenson and Gollin, 2003; Ejeta, 2010), as is also illustrated by Figure 7.4.[4] The substantial ecological diversity on this continent fits less well with the standardised practices required of Green Revolution technologies (Conway and Sechler, 2000). Moreover, the Green Revolution focused especially on high yielding crop varieties of rice and maize and ignored dominant staple crops, like cassava and sweet potatoes, which are grown in Africa.

From our perspective on the relationship between development and innovation we may conclude that innovations associated with the Green Revolution took place in a context in which research was predominantly done in the public domain, funded by governments and non-governmental organisations such as the Rockefeller Foundation and the Ford Foundation. Green Revolution technologies were thus underpinned by a notion of development similar to modernisation theory. In accordance with the linear model of technology driven innovation, the technologies were considered to be readily available and were assumed to trickle down to the farmers (Hounhonnou *et al*., 2012). As we will see next, the relation between development and innovation takes a rather different form with the emergence of modern agricultural biotechnology.

7.3.2. Modern agricultural biotechnology

Modern biotechnology is commonly defined as 'any technological application that uses biological systems, living organisms or derivatives thereof, to make or modify products or processes for specific use' (*United Nations Convention on Biological Diversity*, 1992, Article 2:3). One of the most discussed biotechnological applications is the development of genetically modified organisms (GMOs)–the technology that we focus on in this chapter as well. A GMO is,

> 'an organism, with the exception of human beings, in which the genetic material has been altered in a way that does not occur naturally by mating and/or natural recombination' (European Commission (EC), 2001:5).

GM crops were commercially introduced in the mid-1990s. Since then, the acreage of GM crops has constantly increased worldwide, although very recently growth seems to have levelled off somewhat (International Services for the Acquisition of Agri-Biotech Applications (ISAAA) (2016). Currently, there are approximately 180 million hectares of GM-crops grown in 28 different countries, covering approximately 12 percent of cropland in the world (ISAAA, 2016).

The introduction of GM crops has led to significant scientific and societal controversies. Opponents argue that agricultural biotechnology has only managed to

[4] Interestingly, Evenson and Gollin (2003) point out that since the 1980s and 1990s more high yielding varieties specifically suited to African conditions have become available with associated increases in yields and productivity. Provided that there are favorable institutional and political circumstances, they note that the Green Revolution may still become a success in Africa. For example, Figure 7.4. demonstrates that since the early 1990s cereal productivity increases in Africa.

deliver marginal yield increases and that it may even have adverse societal effects by benefiting larger farmers, making farmers dependent on multinational seed companies, and causing the loss of local varieties (Gurian-Sherman, 2009; Newell, 2008; Scoones, 2008). Proponents, in turn, point out that GM crops may bring benefits with regard to food security through improved disease resistance, drought tolerance and nutrient composition (Juma, 2011). Like the Green Revolution, modern agricultural biotechnology is marked by a strong emphasis on research and development, and the subsequent diffusion of the resulting technologies to farmers (technology supply push) (Friedman, 2009). Proponents often present agricultural biotechnology as a straightforward solution to problems in developing countries, thereby separating the technology from the social and institutional contexts in which they are applied (Glover, 2010; Jansen and Gupta, 2009).

Similarly to the Green Revolution, agricultural biotechnologies are the product of a complex interplay between factors including new scientific insights about genetics, new commercial opportunities for firms, and the food security challenges in many poor countries, which concern many governmental and non-governmental agencies (Parayil, 2003). However, while the Green Revolution is marked by research in the public domain, biotechnology is mainly developed within the private domain, which indicates a shift to quite different notions of development as compared to the Green Revolution.

An important driver of this shift was the 1982 decision in the United States (US) to include products of biotechnology in patent law. Prior to the 1980s, plant breeders' rights were the most common form of legal ownership over crop innovations. They provided a monopoly to plant breeders *selling* the crop, but allowed competitors to use these crops to develop new varieties themselves. The new American patent policies allowed companies to patent living organisms, removing the possibility for competitors to use these crops for further innovations (Barton and Berger, 2001; Parthasarathy, forthcoming). These changes were later adopted in international agreements such as the *Agreement on Trade-Related Aspects of Intellectual Property Rights* (TRIPS) (World Trade Organization, n.d.), which meant that these changes were adopted by a large number of other countries, and were strengthened by other changes in intellectual property rights such as the US *Bayh-Dole Act*, which allowed publically funded research institutes to obtain patents (Barton and Berger, 2001). Thus, these new forms of ownership of plant varieties are now possible on a global scale and are substantiated by international legislation.

This new ownership regime has been widely contested and certainly does not prevent biotechnology from being developed in the public domain. But the ownership regime, in combination with the new technological possibilities opened up by genetic engineering, did spur private investments in agricultural technology, particularly in countries like the US, which were in turn accompanied by a decrease in public funding for agricultural research (Alston *et al*., 1998). This development fits particularly well with neoliberal notions of development that emphasise market-driven globalisation and regard global market forces as the best mechanism for disseminating technologies.

These changes in the agricultural innovation system also introduced incentives that steer innovation in a particular direction: for example, corporations may be more likely to develop applications or innovations that can be patented and sold to farmers with the resources to make such investments. The current system is also more likely to promote the development of those applications that can be combined with other external inputs that are also provided by the private sector. As an example, Monsanto and Bayer provide both the patented seeds for herbicide tolerant crops and the herbicides that can be used on these crops. As a conclusion, the biotechnology innovation system privileges those technologies that can be privately appropriated.

The side effect is that possible technological developments that may have particular benefits for development and the environment but that cannot be privately owned will be ignored. As a consequence, only a few cash crops and limited number of applications still dominate the biotechnology practice at the expense of applications that are perhaps more promising for development and food security like locally grown millets, cowpea, indigenous vegetables, roots and tubers (Naylor *et al*., 2004).

Currently over 99 percent of all GM crops consist of just four crops: soybean, cotton, maize and canola, which have predominantly been modified only for a few traits (ISAAA, 2016):

- herbicide tolerance (so-called HR-crops): these crops enable farmers to spray herbicides (weed killing pesticides) without damaging the genetically modified crops themselves
- insect resistance (so-called Bt-crops): these crops are made resistant against harmful insects, decreasing the need to use insecticides, and
- the combination (or ‘stacking’) of these two traits in one single crop variety.

GM crops were first developed, marketed, and grown in developed countries and the underlying assumption is that these crops, perhaps with a few minor modifications, could help to solve problems in developing countries. To that end, private corporations have helped to set up numerous institutes in developing countries to train scientists, engage publics, and develop policies and regulations. The notion of development that underpins these efforts to make biotechnology work for development is that the technology itself is scale-neutral and can directly benefit farmers in developing countries (Fischer, 2016).

However, this view on technology and development has been highly contested from socio-technological system perspectives, according to which society and technology proceed through mutual and co-evolutionary relationships (Fischer, 2016). Private corporations are more likely to develop crops that are more suitable for large commercial farm systems as compared to small-scaled, remote subsistence farm systems (Fischer, 2016). Scale-neutrality has further been questioned not only because of lower expected turnovers but also because of high transaction costs (Vanloqueren and Baret, 2009). The fact alone that companies ask for a premium for these seeds and hence require higher investments by farmers as compared to conventional seeds potentially creates new vulnerabilities for smallholder farmers who experience difficulties in securing loans.

Like Green Revolution technologies, agricultural biotechnologies do not fit well with notions of development articulated by dependency theorists. The Green Revolution (mostly falling under the regime of breeders’ rights) made farmers dependent on seed companies because they had to buy new seed every season. Thus, the dependency was built into the technology itself (Ruivenkamp, 1993; Kloppenburg, 2005). However, modern biotechnology has realised this dependency through juridical means (by intellectual property rights regulation). Moreover, while the Green

Revolution technologies were developed in the public sector and by non-governmental organisations, biotechnology has mostly been developed by multinational corporations, based in developed countries. This situation has been a prime topic of concern amongst biotechnology opponents because it threatens food sovereignty, i.e. the rights of local communities to be able to produce their own food (see, for example, Biowatch 2002; Patel 2012).

Furthermore, an important element of the existing socio-technical systems for biotechnology is the presence of rather restrictive regulatory regimes in many countries. The purpose of these systems is to reduce environmental and health risks of agricultural biotechnological applications, which is a worldwide concern. There are stringent international regulations under the *Convention on Biotechnological Diversity* and many countries require intensive risk studies before an application can be approved. These regulatory requirements greatly increase the costs of developing, testing, and introducing new applications, which can only be afforded by big international companies (Falck Zepeda, 2006; Parayil, 2003). The *Convention on Biotechnological Diversity* also impacts on the older socio-technological system that grew with the Green Revolution because it offers countries control over the exchange of genetic resources, whereas prior to this situation international research institutes had free access to plant genetic resources (Charles, 2001; Halewood, 2013). Taken together, these developments raise substantial barriers for local and small-scale forms of biotechnology, since smaller corporations and non-governmental organisations find it challenging to raise sufficient funds to finance the expensive regulatory process required to enter the market.

This is not to say that one cannot imagine other notions of development that could theoretically underpin biotechnology developments. For example, US Agency for International Development, the Bill and Melinda Gates Foundation and international civil society organisations like the ISAAA, are involved in negotiations aiming to make patented GM crops freely available in developing countries. These efforts can be read as a reaction to the critique that the current patent system makes farmers in developing countries only more dependent on Western private companies.

In addition, other developments can be identified that make it possible to imagine how biotechnology can be underpinned by different notions of development. For instance, several biotechnology research and training institutes have been set up in developing countries, often with support from the international civil society organisations mentioned above. While this can be understood as an attempt to develop technological capabilities that are needed to make technologies effective in a globalised world, these institutes also may help them to develop biotechnology crops themselves.

There are attempts to genetically modify locally important crops like papaya, cassava, and sweet potato (Wambugu, 2003; Shepherd *et al.*, 2009) and to modify maize to be more drought-tolerant or resistant to maize streak virus (Shepherd *et al.*, 2007; Thomson, 2004). In addition, there are attempts to develop biotechnology crops that are appropriate to particular local contexts by moving technology development away from international corporations into the hands of local stakeholders. These so-called ‘tailor-made biotechnologies’ are underpinned by a notion of development that is more similar to ideas of ‘appropriate technology’ that were put forward by dependency theorists (Ruivenkamp, 1993)

However, such initiatives are rather peripheral phenomena. Despite sustained efforts, no GM sorghum, millets, or cassava has entered the market to date, and the tailor-made biotechnology approach has been restricted to a small number of projects. As praiseworthy as these initiatives may be, most biotechnological research is still largely done in Western Europe and Northern America, and developing countries are seen as potential markets for the sales of agricultural technologies, enabled by the progressive removal of trade barriers following the Washington Consensus (Parayil, 2003). Agricultural biotechnology should not be seen as a simple continuation of the Green Revolution with a different technology, but rather as neoliberal change of the socio-technological innovative system in which research is increasingly done in the private domain, predominantly by multinational corporations or in academic domains that are externally by funded private companies.

7.4. Discussion and conclusions

In this chapter we have outlined some notions of development that underpin attempts to make agricultural biotechnology beneficial for development. The impact of agricultural biotechnology on development has been a highly contentious issue. The diverging claims and practices that characterise this issue, we claim, can not only be understood as an expression of different view of how innovation works, but should also be understood by looking into underlying notions of development.

After identifying several approaches to development and innovation, we concluded that modern agricultural biotechnology is underpinned by notions of development that are based on market-driven, private initiatives that deliver beneficial technologies through global markets. The great majority of successful biotechnology innovations are developed by private parties in developed countries, focusing on agricultural crops that are particularly well-suited to rather large-scale industrial farms, which have the capacity to overcome high regulatory hurdles to make it to the market. These notions of development assume that biotechnologies can easily be disseminated through international markets to farmers in order to solve problems in developing countries.

However, none of these perspectives on development are set in stone. There are various initiatives that are underpinned by alternative notions. For example, public research institutes in developing countries aim to develop biotechnologies that answer specific and local needs, international organisations endeavour to make genetically modified crops freely available in developing countries, and biotechnologists aim to develop locally appropriate biotechnologies in dialogue with local communities. These practices demonstrate that alternative trajectories of innovation are possible.

There are several recent changes in socio-technical systems that may signal change for the notions of development that underpin agricultural biotechnology. A recent development is the increasing role of private charity foundations. Funding for the development of biotechnological applications, for improved nutrition quality of crops, for example, granted by the largest fifty US foundations rose from $US680 million in 1994 to $US6.2 billion in 2008 (Herdt, 2012). In 2005, only 2.2 percent of all funding for international agriculture came from foundations: by 2008 this had risen to 12.8 percent, with the Bill and Melinda Gates Foundation providing nearly half of the entire sum (Herdt, 2012). These foundations may affect the way in which agricultural biotechnology develops as such non-commercial funding may lead to different types of applications that can distributed freely among farmers.

Furthermore, in spite of large portions of private research funding that have become available, public-private partnerships may still work to exert influence on the alignment of technological innovation with development strategies (Vanloqueren and Baret, 2009). It is increasingly recognised that innovation intermediaries or brokers may play an important role and it is suggested that a stronger involvement of farmers is necessary as the current socio-technological innovation system does not adequately reflect farmers' innovation needs (Klerkx and Leeuwis, 2008; Rivera-Huerte *et al.*, 2011; Kingiri and Hall, 2012; Klerkx *et al.*, 2009).

Technology itself is also changing. In recent years, we have seen the breakthrough of gene-editing technologies as, for example, CRISPR/Cas9 by which DNA can be adjusted (on the level of one or a few base-pairs) (Barrangou and Doudna, 2016). As with genetic modification, high expectations have been raised about the impact of these technologies on both developing and developed countries. While traditional biotechnology requires large investments and long-term research projects, gene editing may be relatively cheaper and easier to apply, potentially making it affordable for smaller public and private organisations in poorer countries (Gross, 2016). On the other hand, this new technology may also be harder to regulate, which may affect the current socio-technological systems by giving multinational seed companies much more freedom (Sprink *et al.*, 2016; Hartley *et al.*, 2016).

One of the signs that gene editing may open up opportunities to modify plant varieties for development purposes is that there are wide-spread pleas for considering gene-editing technologies not as genetic modification but just a form of artificial mutation as several countries, e.g. the US have already decided to consider applications generated through this technology not as GMOs (Ledford, 2016). The consequence may be that such applications will not be subject to GMO specific regulation, and hence can be more easily accessed and used by different actors, including public actors, and actors in poorer countries.

We hope that as these changes proceed, explicit attention will be paid to the underpinning notions of development. This opens up space to critically engage with claims about the impact of agricultural biotechnology on development; to learn from past experiences with technologies based on similar notions of development; and to systematically compare diverging claims about the technology's impacts. We have provided a starting point for such analysis by fleshing out notions of development underpinning current agricultural biotechnological systems.

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