1 Introduction

Biotechnology has the making of radical scientific discoveries and technical breakthroughs that can profoundly affect economic growth and social welfare (Persley, 1999; Chrispeels, 2000; Borlaug, 2000a; Conway, 2003; Graff et al., 2005). When radical discoveries – such as gene transfer and cell fusion that marked the dawn of modern biotechnology in the early 1970s – link together and reinforce each other, they create a rostrum for continuing innovation with the potential to affect multiple sectors of the economy, causing far-reaching structural, social and economic changes. Through further discoveries, biotechnology quickly emerged as a collection of diverse and reinforcing technologies with a wide range of applications in agriculture, forestry, food processing, waste management, pollution control and pharmaceuticals (Altman, 1998; Nuffield Council of Bioethics, 2004). It is believed that the greatest ultimate global impact of biotechnology will be on agriculture and in regions where the Green Revolution did not make an impact (FAO, 2004a; Conway, 2003).

The Green Revolution – a term widely used for rapid increases in wheat and rice yields in developing countries – was brought about by improved varieties combined with the expanded use of water, fertilizer and other chemical inputs. This technological development had an important impact on income and food supply in many developing countries (Evenson and Gollin, 2003). It taught us that technological innovation – higher-yielding seeds and the inputs required to make them grow – can bring enormous benefits to poor people through enhanced efficiency, higher income and lower food prices. This virtuous cycle of rising productivity, improving living standards and sustainable economic growth has lifted millions of people out of poverty (Serageldin, 1999; Borlaug, 2000b; Evenson and Gollin, 2003; Evenson, 2005). This technological change, better understood not as a one-time jump in production occurring in the later 1960s, but rather as a long-term increase in productivity, largely benefited parts of Asia and Latin America. The largest impact was in irrigated and rain-fed lowland areas with good water supply. But outside of these favorable environments, varietal improvement was slower and more limited.

This technological development largely bypassed the semi-arid tropics (SAT) that include most of south Asia, parts of southeast Asia, a swathe across sub-Saharan Africa (Chrispeels, 2000; Borlaug, 2000b; Evenson and Gollin, 2003), much of southern and eastern Africa (Chrispeels, 2000; Conway, 2003), and parts of Latin America. Many of these countries are among the poorest in the world. Approximately one-sixth of the world's population lives in the SAT, which is exemplified by unpredictable weather, limited and erratic rainfall and nutrient-poor soils. The arid and semi-arid tracts of India account for over 60 percent of the country's geographical area, over 40 percent of the cropped area and about 60 percent of the unirrigated cropped area. The major crops grown in these tracts are sorghum, millets, pulses, oilseeds, vegetables and cotton. These crops, unlike irrigated rice and wheat, the star performers of the Green Revolution, have shown no significant improvements in yields over the years (Subramanian, 1988). With comparatively limited potential for agricultural growth but rapid population growth, the agriculture-based strategies of rural development pose great difficulty.

The recent advances in agricultural biotechnology have raised hopes in these regions of the world that did not benefit from the Green Revolution (Buttel et al., 1985; Pingali and Traxler, 2002; Ramaswami and Pray, 2005). This so called "Gene Revolution" uses genetic modification to produce crops that are protected from environmental stresses and attacks from pathogens and insects. Though the potentials are still debated, the demand for this technology has continued to grow rapidly. In 1996, approximately 2.8 million hectares were planted to transgenic crops worldwide, and by 2006, the global area had risen to 102 million hectares (James, 2006). This dramatic overall rate of diffusion in some ways suggests that this technology indeed is going to revolutionize agriculture in the years to come, not only in developing countries but also in the developed world.

The most widely used genetically modified (GM) technologies involve herbicide tolerance (HT) applied to soybean and canola, and insect resistance, based on genes isolated from *Bacillus thuringiensis* (Bt), applied to maize and cotton. Though the potential of biotechnology is wider, the global spread of GM crops is limited to only a few selected countries and crops, and to a small number of attributes primarily due to the dominance of the private sector. Since cotton in India is primarily grown in SAT regions, with an area of about 87 percent of the total cotton area, the main benefits there are currently expected to come from Bt cotton. This is the only transgenic crop that has been approved and grown by farmers in India over the last four years. The adoption of Bt cotton increased from 0.029 million hectares in 2002 to 3.8 million hectares in 2006; this represent 42 percent of the total cotton area in India, and the share is still increasing.

Despite the steady growth of the scientific literature on agricultural biotechnology, little systematic attempt has been made at a comprehensive examination of issues related to the impact of this technology on the level and composition of income and employment. Admittedly, lack of adequate data on the application of biotechnology in developing countries has drawn the limits. When evaluating the impact of technological progress on income distribution, it is useful to separate the outcome into direct and indirect effects. The direct effects reflect the nature of the technology and are often referred to as first-round effects; they are captured by partial equilibrium approaches. A number of studies exist that evaluates the farm-level economic impact of transgenic crops on cultivating households in a partial equilibrium framework. The most extensively studied transgenic crop in developing countries is insect-resistant Bt cotton cultivated in Argentina (Qaim and de Janvry, 2003; Qaim and de Janvry, 2005), China (Pray et al., 2002b), India (Qaim et al., 2006), Mexico (Traxler et al., 2003) and South Africa (Thirtle et al., 2003). Though HT soybean and transgenic maize are also grown in many developing countries, impact studies on soybean are available only for Argentina (Qaim and Traxler, 2005), and for maize, studies are confined to the Philippines (James, 2005) and South Africa (Gouse et al., 2005).

The indirect effects brought about by biotechnology in labor markets, such as changes in employment and wage that are very important for the poor, have hardly been studied. Such indirect effects can be sizeable, as has been shown, for instance, by Hazell and Ramasamy (1991) in the context of the Green Revolution. One contribution of this present study is to examine the economy-wide effects of the most widely used and adopted transgenic crop technology in developing countries, namely insect-resistant Bt cotton. The empirical analysis focuses on India. Special attention is given to the analysis of employment and labor market impacts and related income effects for farm and non-farm households. Bt cotton is often associated with higher effective yields, so that more labor is used for harvesting. On the other hand, the inbuilt pest resistance leads to lower labor requirements for spraying and pest scouting. Net effects on labor input in cotton production are not clear cut. In addition, however, the timing and source of labor inputs matter. While in India, cotton harvesting is predominantly carried out by hired female laborers, pest scouting and spraying is often performed by male members of the farm family. When labor time is saved, the household income effect will depend on how the saved time can be used alternatively, that is, the opportunity income. This can certainly vary by household characteristics. While savings in farmers' management time through GM crop adoption have been recognized in general (e.g., Kirsten et al., 2002; Naseem and Pray, 2004; Fernandez-Cornejo and Caswell, 2006), opportunity income effects have not yet been integrated into empirical analyses, probably because quantifying them is difficult in a partial equilibrium framework.

Though economy-wide models such as Social Accounting Matrix (SAM) based multiplier models (Khan and Thorbecke, 1989; James and Khan, 1997; Hazell and Ramasamy, 1991), national Computable General Equilibrium (CGE) (Elbehri and MacDonald, 2003), Global Trade Analysis Project (GTAP) (Huang et al., 2004; Anderson et al., 2006) or regional archetypes (de Janvry and Sadoulet, 2002) can be designed to capture and evaluate the direct and indirect effects of technological change, these models abstract from local economies, and do not provide the details needed to reliably uncover the full impact on small economies, particularly when the use of the technology and its impact on poverty are both rural in nature. The more recent advances over these SAM-based models focus on developing village based SAM multiplier models to examine the impact of different policy and technological changes on rural economies (Adelman et al., 1988; Subramanian and Sadoulet, 1990; Taylor and Adelman, 1996; Parikh and Thorbecke, 1996; Kuiper, 2005). No previous studies, however, exist that have analyzed the economy-wide effects of GM crops at the micro level. This would be important to better understand the broader development implications. The present study is a first step in this direction.

The usual starting point for village-wide economic analysis is a SAM, designed to capture the complex interlinkages among village production activities, village institutions, and the outside world. Though a handful of micro SAMs exist, to my knowledge almost all of them are based on sample surveys.[1] It is not clear how sample surveys can capture most economic transactions between households within a village in any given year. Sample surveys in a village can capture only part of the transactions to the extent that these households are included in the sample, leading to a sample bias that causes unbalanced markets. Since SAMs by construction require both receipts and payments, unbalanced markets and transactions can lead to serious problems in their construction. One way to reduce these discrepancies as much as possible is to base the SAM on census surveys, which can capture most economic transactions, and which also make it easy to track transactions within the village during the survey.

In this study, I construct a unique and detailed village-wide SAM, incorporating the dual cotton technologies – transgenic and conventional – within a single accounting structure that is capable of estimating and evaluating the distributional impact of alternative technological choices in a general equilibrium framework. Given this framework, I formulate a micro-SAM multiplier model to examine and simulate the impact of alternative technological choices on income distribution using a unique data set collected through a census in a single village, Kanzara, located in the SAT of India, namely in the cotton growing Indian state of Maharashtra.

Its agronomic potential notwithstanding, biotechnology cannot be a panacea for overcoming the gaps in infrastructure, efficient markets, credit, breeding capacity, input delivery systems and extension services that hinder agricultural growth in developing countries (Borlaug, 2000b; Pinstrup-Andersen and Cohen, 2000; Conway, 2003; FAO,

[1] For instance, Adelman et al. (1988); Subramanian and Sadoulet (1990); Taylor and Adelman (1996) and Parikh and Thorbecke (1996).

2004a). The gains from adoption of transgenic cotton also depend on the nature of markets, the level of rural infrastructure and ultimately on the price at which the output is sold. This is especially important in the case of cash crops, like cotton, where most of the harvested output is sold. In general, however, relative to farm production, agricultural product marketing in developing economies has received much less intense scrutiny (Hayami and Kikuchi, 2000). Although substantial economic studies have been accumulated in this area, including the classic work on export cash crops in West Africa by Bauer (1964) followed by major studies for food crops in India by Lele (1971) and in Africa by Jones (1972), their quantitative analyses were mainly based on the broad observations of price spreads across various markets over a wide region. In the absence of solid empirical evidence, a popular perception persists of greedy middlemen exploiting poor peasants.[2] As Mears (1981, p. 133) wrote about Indonesia, "it is not unusual to hear judgment … that farmers or consumers are exploited by the market control exercised by ethnic Chinese middlemen. At times one even hears that all private traders are exploitative and discouraging to producers."

The complex village markets can subtly and profoundly affect the distribution of gains from plant biotechnology. Hence, a study of both distribution of benefits in production and distribution of gains from trade are essential for the development of agriculture and improvement of rural welfare. Therefore, beyond the SAM approach, village markets are examined more closely in this study. Since in the census survey almost all transactions of village households are captured, linkages between sellers and buyers and between interlocked markets can be analyzed explicitly. In this context, the village cotton market exhibited two behavioral anomalies: first, the repeal of the law of one price and second, a trader-idiosyncratic effect, namely that large volumes of cotton are sold to a trader who does not offer the best price, but on whom sellers depend through transactions in other interlocked village markets. Apart from market exchange, reciprocal exchange and kinship exchange still remain widespread means of obtaining goods and services. Such traditional institutions are generally believed to play an important role in low-income

[2] Similar observations are not just confined to developing countries but are also reported for developed countries (Adelman and Robinson, 1986).

countries by facilitating economic activity when markets fail (Townsend, 1994; Fafchamps and Lund, 2001).

Recent evidence suggests that whether or not reciprocal exchange is enforceable depends on market size and agents' preferences; if a market is thick enough, it can be an attractive alternative, and reciprocity cannot be enforced (Kranton, 1996). Evidence also suggests that kinship based informal mutual assistance can exist even if not being an equilibrium strategy in an infinitely repeated game, due to distinctive mutual assistance ethics and social sanctions to enforce (Hoff and Sen, 2005). Under this system, reciprocity may exist, encompassing a large number of near and distant relatives sharing rights and obligations (Wolf, 1955). Less well understood is how such traditional exchange institutions affect one another influencing economic outcomes in naturally occurring competitive markets.[3] Whether inefficient forms of exchange can persist or displace efficient forms still remains an open question. While Kranton (1996) presents conditions under which either market or reciprocal exchange survives, in this study, I examine the further possibility that both forms of exchange institutions can persist alongside.

In particular, I examine the role of traditional exchange institutions – kinship and reciprocity – in shaping outcomes in an otherwise competitive market. Kinship is exemplified by the caste system, while reciprocity occurs because of interlocked markets within the village. Empirical analysis of interlinkages between markets, and how they evolve through social preferences and incentives, is difficult, because detailed data and information are often available only for one single market.[4] This is different here, because in the census also village transactions in other markets were captured. Nevertheless, the cotton market is particularly interesting, because – with many farmers

[3] A recent body of literature has shown that historical institutions have long-run consequences for growth in low-income countries (Acemoglu et al., 2001; Banerjee and Iyer, 2002) and how they persist during economic transformation (Munshi and Rosenzweig, 2004). These empirical studies, however, are far from providing conclusive insights into how traditional institutions respond when faced with competitive markets.

[4] Instead, laboratory experiments have emerged to examine the nature of social preferences and their role in the gift exchange hypothesis (Fehr and Falk, 1999; Fehr and Gächter, 2000; Fehr et al., 1993; Fehr et al., 1997; Cox, 2004). Recently, this large and influential body of evidence has been re-examined using field experiments to check on the robustness of laboratory experiments (Gneezy and List, 2006).

as sellers and different traders as buyers – it can be characterized as near perfect. Although prices within the village vary between traders, the maximum bid is determined outside the village market. The commodity traded is homogeneous, and both buyers and sellers know with certainty its monetary value; i.e., there is no information asymmetry.

This dissertation examines two aspects of the gains from technological change in the SAT of India. Firstly, it uses a SAM model to examine the distributional effects of alternative technological choices. Secondly, this dissertation turns to examining the nature of village markets, trade flows and the role of prices, aspects that also determine the distribution of gains and future adoption of biotechnology. This study comprises five more chapters, apart from this introduction. The next chapter first documents the current applications of agricultural biotechnology worldwide, and then evaluates and synthesizes the economic impact of GM crops in developing countries by reviewing previous empirical studies. Subsequently, I compare this technological development – the so called Gene Revolution – with the previous Green Revolution. Finally, I examine the existing evidence on risks associated with transgenic crops, focusing especially on health and the environment. In chapter 3, a description of the village and data that was collected is presented, with details regarding construction of the village SAM and explanations pertaining to every account. I then present the characteristic structure of the village based on the SAM and briefly comment on how to surmount the major problem in SAM construction – namely, SAM balancing.

The fourth chapter begins with an illustration of the potential role played by the opportunity income in Bt technology adoption. Subsequently, I present the direct benefits from Bt cotton adoption followed with an analysis of the economy-wide effects by decomposing the SAM multipliers and running different adoption experiments. In chapter 5, I first present a brief discussion of the village commodity market and document two deviations from economic theory, showing that sometimes even competition is unable to render irrationality irrelevant. These behavioral anomalies result in two types of equilibria: competitive and cooperative equilibrium. Following this, I then illustrate and explore various competing theories to explain the persistence of a Pareto inefficient equilibrium within a competitive trading institution. Each of these theories is then tested by assessing the role of alternative modes of exchange in a competitive paradigm. Chapter 5 ends with a discussion of the potential implications of trader-idiosyncratic effects. The last chapter summarizes the main findings and draws policy conclusions.