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Chapter X Economic assessment of no-till farming systems

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Abstract This chapter considers the nature of the economic benefits of no-till (NT) based farming systems. The focus is on capturing the full costs of resource inputs associated with NT in achieving desired changes in productivity and resource use efficiency. We attempt to place available evidence within a broader framework of economic assessment. We draw on experience in advanced agricultural economies and present insights from India and Sub Saharan Africa, and highlight the nature of externalities that may contribute to the deviation of likely private and social benefits in the technology change associated with NT adoption. Implications for policy and planning for guiding the process of NT adoption and enhancement are mooted.

Keywords: Private and social benefit, technology adoption, adoption drivers

X.1 Introduction

No-till (NT) farming characteristically involves placing seeds directly into undisturbed soil that has retained the crop residue from the previous crop, and has evolved to a farming system that incorporates diversification of crop species, including the inclusion of legumes. Initially introduced to overcome productivity decline in traditional conventional tillage (CT) owing to soil degradation, its wider adoption after the 1990s was supported by the awareness of environmental sustainability prompted by the Brundtland Commission report, *Our Common Future*, in 1987. To date, its major draw card relates to its credentials for conserving soil, water and energy resources and time saving in diversified farming systems involving repeat cropping.

The lowering of tillage intensity and residue retention under NT works to enhance soil organic matter, contributing to better soil structure, water-holding capacity and microbial activity. Hence, compared to CT, which involves several passes of tillage and exposures the soil to moisture depletion, NT systems could offer both yield and cost advantages (Scott & Farquharson, 2004). This is advantageous in particular in environments where soil moisture availability could constrain crop and pasture production. Drawing on this advantage, more recently NT has been presented as a climate-smart agricultural practice for its potential to mitigate net greenhouse gas emissions by increasing soil organic carbon (SOC) and its potential to limit yield variability under exposure to climate variation. More broadly, the reduced time required for land preparation under limited tillage systems have triggered innovations in cropping system design, permitting increased land use intensity through rotational cropping of grain, oilseed and pulse crops. Hence, from the farmers' perspective, NT can be regarded as an alternative to traditional CT farming. However, specific requirements such as seeding equipment, greater precision associated with timing of planting and agronomic care may mean that NT is more suited to high-end farmers who have entrepreneurial skills and abilities to commit a higher level of farm business management.

Overall, the benefits of NT have been widely accepted to be an advantage in production systems prone to seasonal moisture deficits, such as in Australian grain growing areas, the US Mid-West and Canada, and in some parts of Europe. High levels of reported adoption rates of this technology in these locations may lend support to the relative advantages noted above, although those advantages will not always translate to economic benefits. In particular, because this technology represents a package of practices designed to transform conventional industrial farming, various contextual factors that influence the level of adoption will determine the resultant net economic benefit. On the other hand, as this volume claims, NT as a technological innovation has been associated with an increased reliance on herbicides and mechanical inputs for direct seeding. As such, these practices and associated practice change involve spillovers, or externalities, within and beyond farm gate, and create deviations in the level of economic benefits to individuals undertaking practice change, as well as to the wider community.

Although efforts have been made to introduce NT systems into other locations, such as India, Africa, and China, their adoption remains patchy. Like other technological innovations, its impact will vary across locations given the variable nature of farming. Hence the economic assessment of NT systems ought to focus on the objectives of farming, the policy and institutional settings of the operating environment, and the nature of limiting variables in a given context, which collectively influence the optimal combination of inputs to production and the benefits drawn from the outputs generated. Such a comprehensive focus is required to better understand the efficiency of alternative production processes and the conditions under which that efficiency can be sustained.

Such a comprehensive assessment of the economic merits of NT systems is beyond the scope of this chapter. Rather, this paper examines the issues surrounding the need to develop estimates of the full costs of NT, and to identify some of the subsequent issues we expect will arise once reliable measures of full costs are known. We believe it is of wider economic and social benefit that some of these broader and longer-term issues are highlighted at this mature stage of development of NT technologies.

Our objective is to place available evidence within a broader framework of economic assessment and highlight the nature of information asymmetry that may contribute to the deviation of likely private and social benefits. Implications for policy and planning for guiding the process of NT adoption and enhancement are mooted. Because of its extreme reliance on herbicides for weed control, and in particular the use of non-selective herbicides such as Glyphosate, comments are made about the risks faced by NT systems due to potential health and environmental hazards relating to extensive use of agricultural chemicals and the potential for social pressure to limit their use in agriculture. Finally, we draw attention to the care that must be taken in attempts to extend these systems into developing countries where adequate safeguards cannot be guaranteed and the likely costs may outweigh benefits, and risk making societies poorer. Implications for research and development in seeking context-relevant technologies and the need to strengthen policy and institutional settings to safeguard compliance and promote risk mitigation are noted.

X.2 Conceptual Framework

X.2.1 Optimizing Resource use in Production – Private and Social Costs (Opportunity Costs)

At a very general level, economic *production* is the physical conversion of inputs into outputs, which are used either for final consumption or as an input to further production. More specifically, production includes any transformation adding to the *social total* of some desired goods at the expense of a reduction in the amounts of others. The economic value of a particular parcel of land or unit of labor may be defined in terms of its *resource cost, opportunity cost, or social cost*. These can be described as what it might cost to buy, the value of what it might produce, or the value that it might contribute to society. An economically efficient allocation will ensure that the resource cost, opportunity cost, and the social cost of inputs to production are equal at the margin, and, in turn, are (at least) equal to the price of inputs. Economic rationale in optimizing resource use in production is to equate prices to social (marginal) costs, the full cost of producing an additional unit, to obtain the most efficient allocation of resources.

Farmers make production decisions based on the costs they incur and the price they expect to receive for their produce. The farmers' costs are considered private, as they include the costs a farmer pays to purchase capital equipment, hire labor, and buy materials or extension advice. In some situations, fertilizer may be subsidized by the government, or water may be provided below its supply cost. Such incidences create direct subsidies, encouraging farmers to produce more output;

depending on the context that may or may not be socially desirable. While analysts often focus on such direct subsidies, indirect subsidies such as unaccounted externality costs of production are ignored in discussions and hence escape economic analysis.

No-till systems seek to balance objectives of using land and other inputs to generate a marketable output, say wheat, against objectives of conserving farm capital for alternative uses, which may include retirement, or transfer to natural uses. In such choices, it creates a basis for economic benefits in terms of income to input providers, value added opportunities for purchasers of wheat, and benefits to final consumers of food derived from wheat produced.

The prices paid in competitive markets, like in Australia, usually reflect its true benefits. However, inadvertently, NT also creates environmental costs in terms of land and water degradation and health hazards that may arise from chemical use. Such costs are not reflected in farmers' income or the costs to consumers, and are hence borne by the public who suffer from consequences such as losses in biodiversity or by paying for restoration of habitat and polluted waterways. As these costs are external to the producers and consumers, they are considered external costs.

In a competitive market, considering only the private costs in economic assessments will understate the true costs, especially if the production process also creates external costs. The full social costs are equal to:

Private Costs + External Costs = Social Costs (X.1)

In considering the economic benefits of alternative technologies, the difference between these two elements of cost constitutes the net social benefit, or the true measure of economic value.

Social Benefit (Price) – Social Costs = Net Social Benefits (X.2)

X.2.1.1 Environmental Benefits of CT

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A factor behind the development of NT was the minimization of environmental costs, such as soil erosion and high runoff volumes. Reduced tillage also means less fuel use and hence less greenhouse gas emissions. Also, enhanced organic matter retention may, under some circumstances, lead to reduced carbon emissions. Collectively, these improvements could lead to positive external impacts. Economic analysis thus needs to account for such expected benefits and the formula above can be refined to:

Price + Environmental & Health Benefits – Social Costs = Net Social Benefits (X.3)

Given the associated uncertainty, the above estimates would need to be developed taking the probability of success under different contexts into account. Formal methods of economic assessment thus need to be used to derive meaningful estimates.

X.2.2 Why it Matters

Including the full costs of production and consumption in economic assessments has broader implications. The graphical representation of (marginal) costs and demand for a product, say wheat, in Fig. X.1 can help understand these implications. The intersection of the demand curve (the downward sloping line) and marginal cost curve (OSC) represents the socially efficient rate of output (OS) in a competitive market. The social price of such a commodity ought to be P_S. Whereas, when the market price (P_P) does not include external costs, the output produced will rise to O_P. Farmers receive a lower price and consumers pay less at the market. But as citizens they bear the additional cost, represented by the vertical distance between the OSC and the marginal private cost curve (OPC). Moreover, if the commodity so produced is exported, the low price of imports will dampen the incentives for local producers of substitute goods, and encourage the exporting country to produce more of the commodity, while exposing the society to greater costs.

Approximate position of Fig. X.1

However, if the technology package incorporated within NT does incorporate substantial reduction in net externality costs, it may represent the situation depicted in OPC' in Fig. X.1. The output will fall, the price would rise and the social cost would be lower. The higher prices may discourage consumption, creating opportunities for producers of substitute goods. It then represents a net improvement in social welfare benefiting all participants. Reaping the full benefit, however, requires that the producers of substitute goods also follow improved practices that create lower social costs. Essentially, improved practices need to be adopted across agriculture to enhance net benefits.

X.3 The Economics of No-Till Farming

X.3.1 Smallholder Production Systems in Sub-Saharan Africa

This section provides a thorough review of the empirical studies conducted on the economics of NT[1] in Sub-Saharan Africa (SSA) using farm household survey

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[1] NT here refers to either zero or single pass/plough while leaving crop residues on the plot.

data. More specifically, the review sheds light on the impacts of NT on gross margin, production risk, and input demand along with the drivers of its adoption.

X.3.1.1The Impact of NT on Gross Margin and Production Risk

Although NT systems have the potential to improve productivity, this alone is not sufficient to encourage adoption by smallholder farmers as improved crop productivity could be accompanied by increased input use and hence higher costs of production. Thus, when investigating the impact of NT systems, gross margin analysis, which captures the revenue advantage over cost of production, has been used as a predictor for assessing its diffusion potential. Teklewold et al. (2013) investigated the impact of NT on gross margin using data on maize plots in Ethiopia and found that NT could lead to a higher gross margin than CT. Adopting both NT and crop diversification (CD)[2] could further increase gross margins.

Another important outcome variable that smallholder farmers would consider when they make adoption decisions is the impact of NT on production risk. Generally, smallholder farmers are risk averse and would be reluctant to adopt productive, but high-risk, agronomic practices. However, they would be happy to trade-off higher yields for more secure outcomes. Hence, a new agronomic practice that could reduce production risk, particularly downside risk, would be preferred even if it does not lead to higher gross margins.

Kassie et al. (2015a) examined the impact of NT adoption on production risk using data on maize plots from Malawi and observed that adopting NT instead of CT decreases production risk. The risk premium—a monetary value that a farm household is willing to pay in order to avoid the uncertainty and secure the same average return—was positive and increased when NT was adopted in combination with CD. The risk premium derived from adopting CT + CD was ~9% of the mean yield.

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X.3.1.2 The Impact of NT on Input Use

As NT adoption includes a range of possible agronomic practices, the impact of NT on input demand hinges on farmers' resource endowment, institutional settings that impact services and costs, and agroecological settings. Hence, the direction of its impact is often an empirical question relating to the operating context.

In SSA, where market imperfections and high transaction costs are pervasive, the impact of NT on input demand has important effects on the likelihood of its adoption by smallholder farmers. For instance, given the thin rural labor markets, a farm household with low labor endowment could fail to take up NT if it demands higher peak labor use compared to CT. Similarly, a credit-constrained farmer is less likely to adopt NT if it requires higher chemical fertilizer and herbicide use, even though this might increase gross margin or reduce production risk.

[2] Crop diversification here refers to spatial or temporal diversification of maize with legumes.

This is particularly so for the many smallholders who are largely subsistence farmers. Any cash outlay would become a large constraint when the surplus available for sale is low and produce markets are poor and unorganized.

Tessema et al. (2018) studied the impact of NT on input demand (chemical fertilizer, herbicide, and female and male labor demand), using data on maize plots from Ethiopia. The econometric analysis shows that while NT increases chemical fertilizer and herbicide use, it reduces female and male labor demand.

X.3.1.3 Drivers of NT System Adoption

The rate of NT and associated CD adoption can vary widely between countries, as illustrated in Fig. X.2. Many factors can contribute to low and uneven rates of NT adoption in the region. As discussed above, gross margin and production risk are important drivers. This implies that socioeconomic and biophysical conditions of smallholder farmers that influence gross margin and production risk are the key underlying factors behind NT adoption (see example, Teklewold et al., 2013; Tessema et al., 2016).

Approximate position of Fig. X.2

The adoption of NT could also be impacted by whether it has been promoted in conjunction with CD as this could affect its impact on gross margin and production risk. Kassie et al. (2015a) studied the interdependence in adoption between NT and CD using maize plots from Ethiopia, Kenya, Malawi and Tanzania. The results show that NT and CD show a positive association in Tanzania, a negative association in Kenya, and no association in Malawi and Ethiopia. Positive associations indicate that the adoption of CD induces the uptake of NT and vice versa, while a negative association indicates that the two practices can substitute for each other. In general, their results suggest that the odds of NT uptake could be further mediated by whether NT is being promoted along with CD, or CD is already part of the farming system.

As stated earlier, the impact of NT on input demand might also have ramifications for its adoption in SSA where market imperfections and high transaction costs are pervasive. Focusing on resource endowment, Teklewolde et al. (2013) investigated factors underlying adoption using maize plots from Ethiopia. Low farm household asset endowment was found to be a key factor that hinders farmers from adopting NT. Essentially, NT demands higher level of input management skills and requires additional outlays, which poor smallholders may not possess.

It is also important to note that the studies above examined the economics of NT at the plot rather than farm household level, and thus fail to evaluate the tradeoffs and all key drivers involved in adopting NT and its niche zones for scaling up. For example, crop residues, which are integral to NT, can also be used as livestock feed. A farm household is less likely to adopt NT if crop residues generate higher returns for livestock production, even if it may mean lower return from their cropping enterprise. Jaleta et al. (2013) examined the interdependence of NT adoption and livestock production in Kenya. They found that farmers with a lower livestock endowment stand a better chance of adopting NT and vice versa, possibly because using crop residues for livestock might generate higher return.

While potential benefits, such as higher gross margin or lower production risk, may encourage adoption decisions, lack of information and behavioral anomalies could also be important to the diffusion of improved agronomic practices such as NT. Farmers often follow their neighbors, not necessarily taking all information into account (Tessema et al. 2016).

X.3.2 Insights from South Asia

As illustrated in the Africa case study, agroecology and social circumstances significantly influence NT adoption. No-till is regarded as a solution to stubble burning in the Indo-Gangetic Plain (IGP), which extends across eastern Pakistan and northern India to Bangladesh and Nepal. In this region stubble burning can be widespread in rice-wheat production systems and lead to reductions in soil health, and significant environmental and public health issues due to the emission of smoke and particulate matter.

The success of the Green Revolution has seen access to fertilizer, pesticide, and water inputs rapidly increase in the region, resulting in improved regional food security and farmer livelihoods. However, increasing costs of production, shrinking growing windows and market access, and a lack of awareness about alternatives to stubble burning have increased pressure on farmers to burn stubble rather than explore alternatives such as NT.

Despite the existence of NT options for 10–15 years—most notably the Happy Seeder (HS), which can sow wheat into rice stubble with reduced or NT (Fig. X.3)—farmer adoption rates remain very low. Accurate estimates of adoption are not widely available, although some indicate that uptake could be as low as 0.001%.

Approximate position of Fig. X.3

In 2017, a study was conducted with 500 farms to explore the reasons for the poor adoption rate across five regions of Haryana, Punjab, West Bengal, Bihar and northern Bangladesh to assess NT adoption drivers in the IGP.

1.1.1 Results

A detailed account of the study findings are available in Loch et al. (2018). Major practical barriers to adoption across the IGP include low-to-no practical enforcement of stubble burning bans, weed and pest control concerns, poor seed germination under NT, a general lack of awareness of technology availability, and limited access to the machinery, spare parts, service, and technical advice. Farmers also held firm perceptions that a clean (i.e. ploughed and stubble-free) landscape was needed ahead of sowing, and did not appreciate that effective planting could be achieved into standing stubble. Further, although extension officers knew about the technology and its potential benefits, they were unable to demonstrate these to farmers in the field to overcome farmer awareness and/or trust issues.

While a lack of farm labor in the region might drive adoption, this was offset by the requirement for trained operators and expertise when using NT technology. Even where custom-hire center businesses were involved, these often lacked practical expertise and access to incentives, which were more commonly targeted at farmers.

The financial barriers to adoption were particularly important. Although farmers' clubs or cooperative business models were viewed quite favorably by financiers and banks, the underlying cost of the machinery—particularly the HS—remained relatively high, creating adoption challenges for farmers. This was despite the presence of subsidy support packages from national and (some) state governments. There was evidence from the study suggesting that in response to the 50% subsidy manufacturers had doubled the purchase price, meaning that the relative cost to farmers remained unchanged. As such, many farmers viewed the subsidy system as corrupt and thus did not engage with it. Fig. X.4 shows the mean adoption rates for Happy Seeder and NT technologies across the IGP region. As expected, HS adoption was highest in the Haryana and Punjab states where manufacturers and dealers are mainly located.

Approximate position of Fig. X.4

However, farm economics remains the crucial barrier to adoption. A single farmer purchasing and operating a NT machine would not be economically feasible. The technology is used 2–3 times per year and over a very short window of opportunity between crops, which means that for the rest of the season it is not utilised. While custom-hire center business models that allow the use of a machine across multiple farms are more economically attractive, the short operating window means that farmers must compete for the service and, if not provided on time, would resort back to stubble burning before the planting window closes.

A comparison of adoption drivers derived from cost of production data across conventionally sown wheat crops and NT/Happy Seeder (HS) sowing practices indicated that NT sowing practices were generally associated with lower individual input costs and total system costs; except for fertiliser, herbicide and fungicides in the NE of India and Bangladesh. Happy seeder users reported lower costs across all categories. Some of these cost differences can be explained by the differences in farm input subsidies across Indian states (e.g. there may be lower fertiliser subsidies in West Bengal, Bihar, which are relatively poorer states), and differences in agroclimatic conditions. The relatively wet, humid, and tropical conditions of north-east India and Bangladesh would require additional costs for fungicide, herbicide. and insecticide applications, and irrigation can be relatively more expensive resulting in farmers avoiding such costs. However, overall the gross margin differences between adopters and non-adopters for both technologies was relatively low; NT adopters reported a 0.5% lower gross margin than non-adopters, although HS users reported a 4.5% higher gross margin. In general, the economic benefits did not appear to offset the considerable costs involved in purchasing, operating, and maintaining the technology for users.

The social benefits from adopting NT technology would include reduced stubble burning, along with lower input costs and sustainable intensification. However, the study found that biophysical concerns surrounding practices like NT were not adequate to motivate increased adoption for a majority of farmers. Claims of increased yields are often anecdotally associated with NT, and a recent meta-analysis has concluded that in terms of temporal stability (i.e. yield benefits over time), a transition to NT practices does prove advantageous (Knapp & van der Heijden, 2018). However, farmers, in general, are far-removed from the scientific literature and prefer to gather evidence themselves that clearly demonstrate input savings and yield improvements on their own farms. This is generally near impossible to achieve in the short-term and may be challenging to show even in the longer-term (e.g. soil carbon improvements directly linked to NT adoption).

This case study highlights that while the existing system of cultivation contributes to high social externality costs associated with stubble burning across the IGP region of South Asia, this in itself it has not been a strong driver of adoption of NT practices. Despite potential benefits, the risk-return equation in this case is neutral leading to insufficient transformation by farmers across the IGP. Unless fundamental change is experienced in risk-return trade-offs, social externality costs associated with stubble burning will continue to be borne by the broader society.

X.3.3 Largescale Production Systems

In large scale agricultural production systems in Australia, US, Canada, and parts of Europe, the NT farming system is in a mature phase of development. However, the shift from CT to NT has taken decades to realize and the process of adaption and adaptation to changing circumstances is ongoing (Llewellyn et al. 2012). In Australia, progressive creation of an enabling environment, driven through an aspiration for higher performance and risk management, has been the key feature of success. Demand-induced innovation by farmers and agricultural engineers, enabling agronomic technologies such as herbicides and crop disease resistance, extension processes, and economic influences within a competitive market setting have contributed to this transformative change. The continued search for refinement has also included the incorporation of controlled-traffic farming, remote sensing and climate science technologies, and a strategic approach to risk management based around spatial and temporal diversification, including into off-farm ventures. These activities have been supported through collaborative and on-farm R&D to develop ways to adapt the NT system to suit diverse local farming conditions.

X.3.3.1 Assessing Performance

Wide adoption of NT as an alternative farming approach has led to the consensus that where it is widely adopted, the system is at least as profitable as conventional methods and offers significant nonmonetary advantages, such as preservation of rapidly deteriorating soil or water resources. While a growing body of analyses involving a range of partial to composite measures supports the economic viability of these farming practices, systemwide analyses using timeseries analyses or comprehensive comparative assessments that can account for the dynamic forces at play are lacking. This observation has also been made by Pannell et al. (2014), and National Research Council (1989) in relation to assessment of alternative agriculture systems. While the interest in aspects of environmental sustainability and cleaner production has intensified in recent times, this interest has not translated into systematic studies to assess such credentials.

It is generally believed that farms using the complete NT system (NT + stubble retention + CD) are inclined to have higher yields. Comparison of gross margins also tend to support the general view that they are associated with greater profitability than farms that practice some level of tillage. As suggested in Ibendahl (2016), there are at least two possible explanations for this. First NT could be a superior technology that is both higher yielding and also more profitable. Second, NT producers could be representing a cohort of superior farm managers, which would lead to greater yields and profits. Moreover, it is possible that their entrepreneurial abilities help them choose strategic options that mitigate emerging risks, such as climate variation, and resultant vulnerability to income fluctuations. Therefore, in comparing alternative farming systems, this self-selection bias needs to be accounted for.

However, a key feature of economic assessment that is embodied in farm management advice has been the reliance on partial measures that focus on marginal changes. They are only relevant for decision making under certainty —when individual, social, institutional and natural conditions that govern production and consumption remain unchanged, or are uniform across contexts. When that is not true, as is often the case, the decisions that are based on marginal changes run the risk of deviation from expected outcomes and declining performance over time. It must also be noted that the competing technology ‘CT’ has itself undergone similar transformation over the past four decades, subjected to similar performance pressures and induced by the same drivers of technological change. Equally, knowledge spillovers between the two sectors are common, and in some cases, the same farmer may undertake both systems as the extent of adoption is largely partial.

Industrywide performance

Productivity analysis undertaken by the Australian Bureau of Agricultural and Resources Economics and Sciences (ABARES) shows that average productivity growth across all broadacre agriculture (that is, non-irrigated cropping and extensive livestock industries) has been ~1% yr^{-1} for more than three decades. This has been largely due to reduced input use (–0.9% yr^{-1}), rather than output growth (0.1% yr^{-1}) (Gray et al. 2014). This may imply that, given a large proportion of farmers in these industries are reported to be engaged in NT-based technologies, their adoption has led more to economizing input use, rather than gaining a yield advantage. That may also imply that the externality load created by these farms may have declined, because externalities are a joint product of input use. These estimates are not corrected for variations in seasonal conditions and the likely impacts of climate change. Such impacts could be substantial (Hochman et al. 2017), as could the impact of other soil limitations (Orton et al., 2018). Incorporating the confounding impacts of these factors in economic assessments is complex and controversial.

Performance parameters themselves are socially determined—as collective and individual consumer preferences progressively change government policy settings and market demand for goods and services. Obviously, technological change has helped farmers meet ongoing performance challenges. The ABARES analysis also points out that productivity growth of cropping specialists averaged 1.5% yr^{-1} between 1977–78 and 2010–11, higher than the rate observed on farms in the beef (0.9%) and sheep (0.0%) industries. Productivity growth also varies considerably across farms, industries, and regions; and productivity growth by itself does not lead to profit growth and farm viability. The Australian dairy industry is a case in point.

Farm scale analyses

As outlined in Thomas et al. (2007) a range of factors work together in determining farm scale performance under NT. Farmer attitudes and aspirations, machinery conversion or replacement costs, build-up of soil and stubble-borne plant diseases, use of residual herbicides that may limit crop options, dual use of land for grazing and cropping, herbicide resistance, build-up of hard-to-kill weeds, the need for soil disturbance in some situations, and concerns by farmers about the effects of herbicides on the environment and human health are noted as important. Moreover, advancing climate change and associated increase in climate variability and performance risks calls for greater flexibility in farming systems to adapt to an uncertain operating environment.

Pannell et al.'s (2014) analysis of farm level economics stands out as they incorporate all the above aspects in their study. The economics are defined broadly to include not just short-term financial benefits and costs, but also the whole-farm management context, constraints on key resources such as labor and capital, risk and uncertainty, interactions between enterprises, and time-related factors such as interest rates and the urgency of providing for the farm family. They confirm the oft-noted fact that, as with other technologies, NT systems can increase or decrease farm profits, depending on the context. They note that favorable contexts include larger farms, more resources, less uncertainty, and longer time horizons. These aspects have been noted in the progress made in NT in developed economies, as are benefits of partial adoption of a subset of components, which can sometimes be superior to full adoption (Stevenson et al. 2014).

X.4 The Drivers of No-Till Farming Future

X.4.1 Largescale Production Systems

In looking forward, as a technology in its mature phase of development in western economies, the priority is for maintaining the efficacy of NT, and especially to find ways to minimize the social costs of individual elements, such as herbicide use. This is particularly so because the observed success factors are highly related to overcoming environmental constraints, mainly moisture, for private benefit (Bellotti & Rochecouste, 2014). For example, limited available studies that take account of the full range of costs and benefits suggest that the potentially higher social and private profit of NT over CT could be context specific, and depend on the choice of crop, the local costs of inputs, and the social valuation in environmental benefits. Essentially, the key factors determining the private and social profitability of NT and CT are yields and production costs, rather than environmental performance (Lankoski et al. 2006).

Of particular importance are the growing social concerns over extensive use of herbicides, in particular Glyphosate, due to its potential negative impacts for human health, ecosystems, and agricultural system stability. The public and scientific debate about the use of Glyphosate continues (Danne et al. 2019), as does some successful legal proceedings for compensation. Reductions in herbicide availability have the potential to erode any benefits of NT if its dependence on extensive herbicide use cannot be addressed. Advances in precision agriculture technologies and improved understanding of alternative management options (Rogers et al. 2016) could offer some ways to overcome such challenges. However, there is also a clear role for public policy in setting standards, and for industry in adhering to improved protocols to minimize exposure to future economic and social costs.

X.4.2 Smallholder production systems

The challenge in extending the technology set to resource poor settings with limited markets and poor institutional arrangements looms large, and insights drawn from the studies above identify key problems that need to be overcome. The problem of quality, availability, and safe and effective use of herbicides in resource-poor conditions stands out as critical, and hence greater development of appropriate integrated weed management strategies that can be combined with small-scale planters are required. There is also a need to optimize the performance of small-scale planters to suit farmers' needs in different agro-ecological environments. To make the better use of developed country experience and the positives associated with NT concepts for small holders, more adaptive research and on-farm evaluation is needed across a diverse range of soils, cropping systems and agro-ecological regions (Johansen et al. 2012).

These include addressing i) participation constraints, such as land fragmentation; ii) capital constraints that makes machine purchases unviable and enhancing private sector participation in providing machinery services; and iii) socially responsible provision of input services generally. Critical assessments such as Pender (2008) and Giller et al. (2009) offer useful insights, as do studies that show the potential for success (Keil et al. 2015; Keil et al. 2019). Additionally, it is also critical that the impact of NT on the landscape and the ecosystem services that underpin agricultural production and livelihoods are taken into account in relevant assessments (Snyder et al. 2016). Accommodating these concerns in socially diverse and spatially heterogeneous farms and farming systems remains challenging (Tittonell et al., 2010).

For instance, technological change and its transfer to developing countries is often portrayed as a critical part of the solution to a resource problem such as climate change, based on the assumption that the transfer of resource-conserving technologies will result in reduced use of natural capital. However, the well-known potential for a rebound effect, where a technological change that is directed to reduce resource use in fact leads to higher use prompted by lower costs, could undermine ultimate outcomes. For this reason, the transfer of resource-conserving technologies without incentives to alter behaviors may not result in desired resource-conservation benefits (Sarr & Swanson, 2017). Enablers such as climate information services, in particular, should become part of the solution (Singh et al. 2016).

In considering these challenges, the nature of the production function embedded in NT, which determines the aggregate supply function and the marginal cost of supply and hence the offer price of farm output, becomes the critical lever for change. If the price of inputs is not determined in a competitive market and the market price does not take the full account of externalities, or unpaid costs of resource use, then production functions that incorporate different proportions of inputs will lead to suboptimal resource use. This means the value of output produced will exceed its true social value as the costs of externalities are often borne by society.

Matters become complicated, because agriculture is often considered a special case because the demand for food is price inelastic, meaning the basic demand for sustenance is price non-responsive. Socially, the basic food demand needs to be met and the inability of society to meet this also creates social externalities. Economists themselves disagree on the way to separate these two issues of production and consumption. Although they are inextricably linked, at the minimum, production can be a source of a living wage that guarantees basic consumption income and thereby social stability and opportunities for progression. Hence, the authors believe that the social externalities of food supply and consumption can both be treated within the problem of production by taking account of the array of opportunity costs and the value of forgone alternatives in the use of available resources.

This involves understanding the linkages across sectors within the economy, and in particular between the rural non-farm economy and the farm economy (Van Den Berg & Kumbi, 2006).

X.5 Conclusion

Economic assessment of NT can yield useful information that helps maximize its benefits and establish its technical feasibility. To make such technologies attractive to producers, both in resource rich and resource poor contexts, the private benefits from additional output produced and the extra effort expended needs to be presented along with the likelihood of success under existing operating conditions. Because the benefits of technological change ultimately spill over to wider society as enhanced consumption opportunities, how the technology set affects such opportunities at the present and in future needs to be appropriately assessed, together with the risks to wider resource use and health and environment. Establishing the social desirability of technological change can only be made through such efforts. A successful technology bundle, such as NT, will only become so if it is technically feasible, economically viable, and socially sustainable. Therefore, the scope of assessments can range from a simple comparison of annual gross margins, through to whole farm assessment of technological change, to sectoral assessments examining change in agricultural sector productivity, to international comparisons.

Accessible literature and farm management advice on NT and related technologies have largely relied upon assessments of gross margins that have essentially led to the development of the technology as a popular choice. While they are useful, the ability of gross estimates to cover variable costs is an ongoing concern, and they are of little use in comparing economic benefits of practice change.

Methods of commercial agriculture have evolved over time with mixes of public and private investment, involving varying levels of taxation and subsidies. This has caused distortions within agriculture, as well as distortions between agriculture and rest of the economy. This makes economic assessments much harder to undertake. The first step is to develop accurate and comparable measures of the full costs of the various modes of production that are not distorted by differences in taxes or subsidies, both implied and real. This is particularly important in assessing an externally induced innovation regime such as NT, where the technology set involves imported knowledge and input bundles, as well as local adaptations to accommodate the input bundle to suit local constraints. This gives rise to many specific issues such as measuring and valuing capital inputs, comparing expenditures at different points in time of the innovation cycle.

We hope the private and social cost framework and the discussion provided will help inform opportunities for improving economic assessments in considering further developments in NT and in the ongoing efforts to make the technology set more desirable for all concerned.

X.6 References

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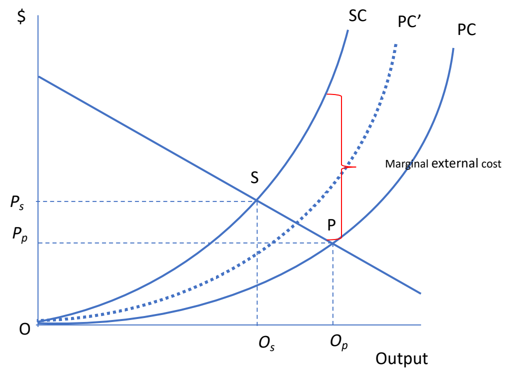
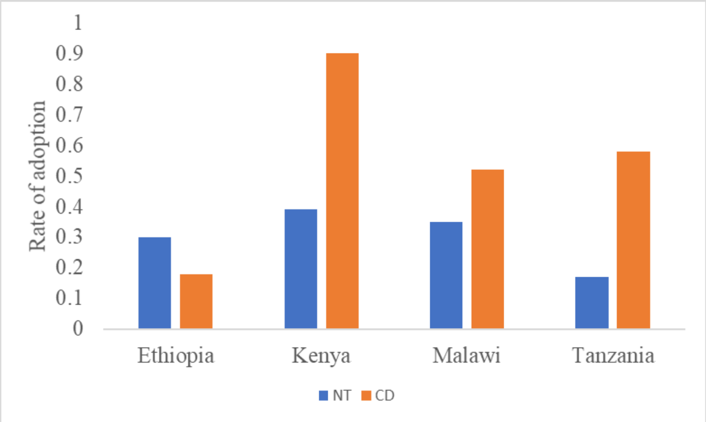


Fig. X.1 Cost implications of technology choice (Adapted from Field & Field (2016, p. 69))



Source: Kassie et al. (2015a)

Fig. X.2 The rate of NT and crop diversification adoption in Sub-Saharan Africa

Fig. X.3 A Turbo Happy Seeder zero-till seeding machine (source: Sidhu et al., 2015)

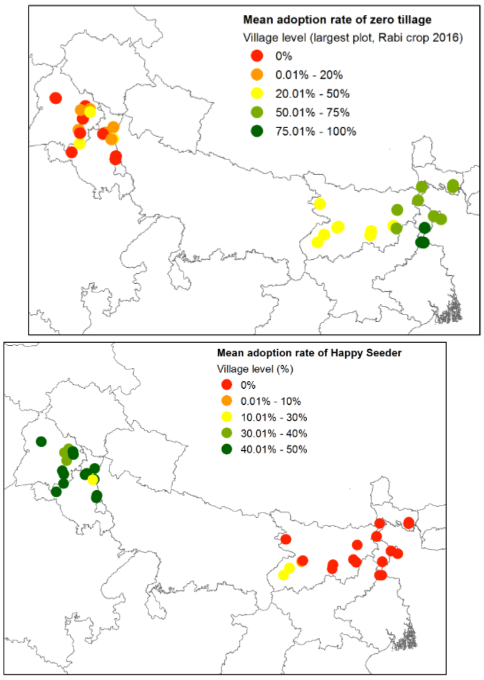


Fig. X.4 Spatial distributions of Happy Seeder and (generic) NT technology, IGP (Loch et al., 2018)