Food security effects of multinational brands crop protection products: Evidence from cotton-wheat zone Punjab, Pakistan

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Summary

Throughout the past years, agricultural technological inputs have been actively evolving with a moderate rate of technology adoption. The adoption of agricultural technological inputs has been encouraged by, among others, escalating demand in the food sector in both developed and developing countries. While the adoption of agricultural technological inputs has been becoming important in developing countries, rigorous assessment of the quality and origin of available technologies and their outcomes in developing countries is lacking.

Firstly, there are is an abundance and prevalence of generic, nationally produced agricultural products in contrast to multinational brands agricultural products in the agricultural mainland of Pakistan. The widespread adoption of generic agricultural products has serious consequences on sustainable agricultural development. Among the available agricultural technological products, particularly, crop protection products (for example insecticides, fungicides, herbicides, and chemicals for seed treatment) have an obvious impact on the biophysical environment. Secondly, the multinational brands crop protection products outclass generic crop protection products due to their rigorous process of product development and product quality assurance. However, the multinational brands crop protection products are often much more expensive. Thus, the adoption of multinational brands crop protection products *versus* generic crop protection products among smallholder farming households may have important consequences on sustainable agricultural development for developing countries. While some implications of such adoption decisions have been intensively research, some other highly relevant research aspects were not covered.

First, with regard to factors affecting adoption of crop protection products, empirical evidence shows that smallholder farming households in Pakistan, in general, adopt crop protection products. It is known that socioeconomic variables determine adoption of recommended crop protection products practices and the quantity of crop protection products applied. While farm and farmer capital influence initial adoption of crop protection products, the determinants of the adoption of more expensive crop protection products promising a higher quality remains unaddressed. Second, there is a growing body of literature on the outcomes of adoption decisions regarding agricultural technologies. The empirical evidence shows that technology adoption may contribute positively to productivity, poverty alleviation, and food security in developing countries. However, the following points have not been addressed:

(i) food security effects of multinational brands crop protection products in the agricultural mainland of developing countries;

(ii) farm harvest effects of multiple crop protection product categories instead of only one category (pesticides, fungicides, herbicides, insecticides, and chemical seed treatment);

(iii) self-selection biased and potential heterogeneity of multinational brands crop protection products and adopters countenance.

Hence, this dissertation aims to fill respective gaps in the existing literature in two core areas. Firstly, we aim to analyse the association of farm and farmer capital variables with the adoption of improved crop protection products. Compared to generic, nationally produced products, we expect multinational brands crop protection products to promise (and deliver) an improved overall product quality. Secondly, we want to test if the adoption of multinational brands crop protection products improves food security. Both areas use data from a cross-sectional survey conducted in 2017. The survey includes data from 275 smallholder farming households from the cotton-wheat zone in the Punjab province, Pakistan. The Punjab is the agricultural heartland of Pakistan.

First, we employ ordered probit models to estimate the role of farm and farmer capital towards the adoption of multinational brands crop protection products in the Punjab, Pakistan. The results show that agricultural extension services, among others, farm and farmer capital variables are fundamental to technology adoption. The adoption of multinational brands crop protection products is strongly positively correlated to household food security. The cross-sectional survey exclusively contains non-experimental observations. Therefore, this evidence of correlation between the adoption of multinational brands crop protection products and farmers food security may be tainted due to possible self-selection bias and potentially existing, unobserved sources of heterogeneity. This situation represents a substantial methodological challenge.

Second, we address this methodological challenge of relying in non-experimental observations by using an endogenous switching probit model to account for potential heterogeneity in estimating adoption effects on food security. Full information maximum likelihood estimates indicate that adoption of multinational brands crop protection products is guided by comparative advantage: farmers adopt multinational brands crop protection products if they benefit from adoption compared to non-adoption. Furthermore, we find statistically significant evidence of heterogeneity effects. These effects are significantly higher for those farmers who adopted relative to those who did not adopt. On top of that, the result of selection modelling, yet again, decisively supports the hypothesis that the accessibility of agricultural extension information *via* radio is the easiest way to disseminate proven agricultural technologies and to foster the adoption of multinational brands crop protection products.

A few salient take away and policy implications can be drawn from this dissertation. From a fundamental science point of view, these results provide, for the first time, evidence that adoption of multinational brands crop protection products is principally guided by the same farm and farmer capital variables as initial adoption. This result confirms that the intensification of agricultural extension service visits and the promotion of agricultural extension information *via* radio broadcasts stand out as most promising policy options. Additionally, we determine the fundamental role of multinational brands crop protection products for enhancing food security of smallholder farming households. Particularly, we observed that the adoption of multinational brands crop protection products may *reduce* food security of non-adopters if they adopt. So, promoting the adoption of multinational brands crop protection products without carefully considering likely net benefits for individual farming households would be misguided.

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What a constructive journey it was, which has turned my vision into a new horizon of research. A vision which goes beyond materialistic pursuits and we do the effort for the betterment of humanity. To me, nothing could have been better than Göttingen to achieve this milestone.

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List of Abbreviations

ACQ	Agro-chemicals input Quality
ANOVA	Analysis of Variance
BH	Base Heterogeneity
Bt	Bacillus thuringiensis
FANTA	Food and Nutrition Technical Assistance
FAO	Food and Agriculture Organization
FFC	Farm and Farmers Capital
FIML	Full Information Maximum Likelihood
GC	Generic Crop protection products
GDP	Gross Domestic Product
GFSI	Global Food Security Index
GHI	Global Hunger Index
GM	Genetically Modified
HFIAS	Household Food Insecurity Access Scale
HFSSM	Household Food Security Survey Module
MBC	Multinational Brands Crop protection products
NID	Normally and Independently Distributed
OECD	Organization for Economic Cooperation and Development
TH	Transitional Heterogeneity
TT	Treatment effect on the Treated
TU	Treatment effect on the Untreated
UNDP	United Nations Development Programme
USD	United States Dollar
USDA	United States Department of Agriculture

Baba Gee (A.S) ke Dua

1 Salient features of the agriculture sector in Pakistan

1.1 Background

Still being the vital single sector, as agriculture contributes almost 19% in the GDP, unfortunately, the share of the said sector in the country's GDP has been declining over the decades. Currently, it contributes almost 19% in the country's GDP in contrast to 25% for the year 2000. Likewise, the share of the said sector in employment to the country's labour force is following the same pattern. In the year 2000, this single sector absorbed 44% of the national labour force while currently absorption has declined to 39% (The Government of Pakistan, 2000-2019a). Mainly, the stagnant productivity of cash crops and staple food crops (for example cotton, maize, rice, sugarcane, and wheat) contributes to the decline of agricultural GDP (Rehman et al., 2015; Azam and Shafique, 2017; Rehman et al., 2019). Furthermore, the transition towards farm mechanisation especially in large agricultural farms, is additionally reduces the agricultural labour (Rehman, 2012).

There are three categories of agricultural farms in Pakistan according to size. The farms with area less than 5 acres [~2.02 ha] constitute the small farms; the farms with an area more than 5 acres [~2.02 ha] but less than 25 acres [~10.11 ha] constitute the medium farms, and the large farms are categorized as 25 acres [~10.11 ha] or more. According to the Punjab Bureau of Statistics, 65% of agricultural farms are small farms and farmers operating these farms are considered as smallholder farming households, 31% of agricultural farms comprised in the category of medium farms and operated by medium farmers. The medium and small farms in Pakistan account for 96% of all farms, the remaining 4% are large farms (see Fig. 1.1) (The Government of Punjab, 2016).

Smallholder farming households in Pakistan are in the majority. However, this majority comes along with pertinent snags and underpinnings. The use of substandard/low quality crop protection products (for example insecticides, fungicides, herbicides, and chemicals for seed treatment), lack of education, lack of extension contacts, water scarcity and inadequate distribution of water, low off-farm income and less off-farm income opportunities, and lack of farm inputs are the pertinent snags of smallholder farming households (Alene and Manyong, 2007; Jaghdani et al., 2012; Bashir and Schilizzia, 2013; Ali et al., 2014; Hashmi, 2016; Hänke and Barkmann, 2017).

While they are constrained to lack of farm inputs at the same time, they are exposed to inferior and substandard inputs. Farm inputs, especially the application of crop protection products during pest control has overall relevance for agricultural sustainability (Tilman et al., 2002; Sharifzadeh et al., 2018) and with the productive potential of the farms (Oerke, 2006; Alam et al., 2016). On top of that, the lack of availability and accessibility of crop protection products may offset their agronomic benefits (Jalal-ud-din, 2011).

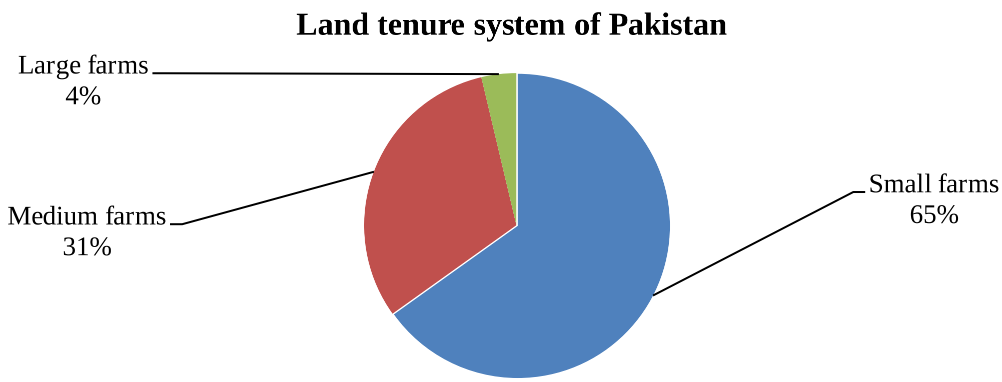

Figure 1. 1. Percentage share of total farms with respect to size of landholding in Pakistan (The Government of Punjab, 2016)

The overall agriculture sector statistics are thought-provoking, and knowing the fact the government of Pakistan initiated "Prime Minister's Agriculture Emergency Programme". The main aim is to enhance the productivity of important crops and the reorganization of extension service at all level (The Government of Pakistan, 2019a). The quality of agricultural products, particularly, the quality of crop protection products is not explicitly vivid as an integral part of this emergency programme. The brief scenario of crop protection products in Pakistan is described below in section 1.2.

1.2 Overview of crop protection products and cotton crop in Pakistan

Pakistan is the signatory of relevant conventions for crop protection products – for example Rotterdam convention on prior informed consent procedure for certain hazardous chemicals and pesticides since 1999 and Stockholm convention on persistent organic pollutant since 2001 – based on the manifesto to discourage the adoption of crop protection products which shows the positive association with severe health issues and environmental degradation (Rotterdam convention, 2019; Stockholm convention, 2019).

According to neoclassical theory, farmers will adopt crop protection products if it gives the positive discounted net present value of stream of returns from its adoption (Wilson and Tisdell, 2001). However, this may favour the adoption of unsustainable pest control strategies, particularly, in developing countries (Aga, 2019). The use of substandard/low quality crop protection products retards agricultural development, and thus induces low productivity (Hashmi, 2016). It also comes along with severe detrimental factors, particularly, on farmers' health (Antle and Pingali 1994; Khooharo et al., 2008) and farm habitat (Khan et al., 2002). Yet the empirical research evidence shows the adoption of and/or prevalence of substandard/low quality crop protection products in the agricultural heartland of Pakistan (Khan et al., 2011; Khan et al., 2013). Therefore, the role of the government institutions is very important in the quality assurance of agricultural inputs (Ali and Sharif, 2012; Saqib and Tachibana, 2014; Baloch and Thapa, 2016). Moreover, according to diffusion of innovation theory (Rogers, 1983), the adoption of improved technology and its efficient utilization goes along with the role of institutions projection mainly the agricultural extension services (see for example Abbas et al., 2003; Aldosari et al., 2017).

In Pakistan, the Department of Plant Protection has established protocols for the registration of crop protection products. There are three different types of registration protocols to be fulfilled based on the origin, field trials, and on the sample analysis of given crop protection products. First, the type A crop protection products registration protocols are based on the country of its origin. The department grants import permission to agricultural crop protection products if they have their origin from a country listed in OECD and China. Second, type B registration protocols based on the efficacy trials of particular agricultural crop protection products and their demonstration in the field trials before their final inception and allocating the trade name. Third, Type C registration protocols involve only the sample analysis and there are no field trials before their marketing permission (The Government of Pakistan, 2018a).

The crop protection products sector of Pakistan is import-dependent and over the time it witnesses an increased in the import volume (see Table 1.1). Pakistan imports multinational brands crop protection products (MBC) from OECD (Organization for Economic Cooperation and Development) countries and from China to meet the domestic demand. However, the demand is also met by generic crop protection products (GC). The GC includes low-quality formulations, unpredictably variable concentration of active agents, insufficient declarations, safety, and usage information in contrast to MBC (Khan et al., 2013; Hashmi, 2016). At the same time, the higher price of MBC tempted smallholder farming households to adopt generically formulated crop protection products (Khooharo et al., 2008). However, the adoption of branded products shows an attraction for consumer due to products information, products specification, and packaging attributes (Lewis et al., 2016). Table 1.1 presents the import volume of the crop protection products and export of raw cotton, cotton yarn, and wheat for the last five years. It is evident from Table 1.1 that import volume of insecticides increases on an average while the export share of wheat and cotton in the country's agricultural GDP faces decline.

Table 1.1. Import volume of insecticides and export volume of wheat, raw cotton, and cotton yarn in million US$

Year	Import of insecticides	Export of wheat	Export of raw cotton	Export of cotton yarn
2017-18	119	60	56	988
2016-17	97	-*	-*	844
2015-16	116	-*	-*	989
2014-15	100	-*	-*	1464
2013-14	96	7	196	1716

Notes: -* means during those particular fiscal years no exports earning for the said items.
Data source: (Pakistan Economic Survey, 2013-14; 2014-15; 2015-16; 2016-17; 2017-18)

Cotton is the life line of Pakistan's economy and contributes 0.8% in the country's GDP. Mainly, due to pests' attack (for example whitefly, pink bollworm) the production of cotton has declined by 18 percent (The Government of Pakistan, 2019b). Most importantly, the initial adoption of crop protection products has been increasing swiftly since the adoption of *Bt* (*Bacillus thuringiensis*) cotton in the year 2002 (Nazli et al., 2010; Spielman and Kouser, 2018). Because, *Bt* cotton fails to resist against detrimental sucking pests (for example whitefly, mealybug, aphids, and jassids) and consequently, farmers increase the use of the crop protection products (Abdullah, 2010; Report, 2015; Spielman et al., 2017).

1.3 Extent of food security in Pakistan

Pakistan has a population of approximately 208 million and only half of its population food secures (The Government of Pakistan, 2019a). According to the 1996 World Food Summit defines food security as; an individual has at all times, access and availability of sufficient, safe, and healthy food to maintain a healthy active life (FAO, 2017). A very recent comprehensive report by Ministry of National Food Security and Research, Pakistan, highlights statistics of food insecurity domains.

It proclaims that 18% of the country's population is undernourished and 45% suffered with high level of severe stunting, 15% wasting, and almost 30% are underweight. On top of that, 46% of rural population is suffering from the malnourishment problems (The Government of Pakistan, 2018b).

This research focuses on the determinants of adoption of MBC by smallholder farming households; the food security effects of the adoption of MBC in the cotton-wheat zone of the Punjab province, Pakistan. We assess the food security outcomes by the Household Food Insecurity Access Scale (HFIAS). HFIAS consists of nine-questions, which captures the households' level of access to food (Coates et al., 2007). HFIAS is widely used in several countries including developing countries of Africa and Asia (Chinnakali et al., 2014; Gebreyesus et al., 2015). We considered HFIAS, due to its applicability across cultures, economical, require less data, and technically appropriate (Kabunga et al., 2014). We have selected cotton-wheat zone of the Punjab province, Pakistan. This selection is also supported by the Pakistani official documentation and empirical research evidences of the prevalence and the accessibility of MBC *versus* GC in the survey area (see section 1.2). Section 1.4 describes the survey area and section 1.5 describes the research objectives with the specific title of the research papers.

1.4 Survey area description

Pakistan is located in the subtropics region and has diverse topography. It hosts several world's highest mountains and glaciers to the few world's hottest spots (Mohenjo-daro and district Sibi ~ 53.5°C) and deserts (Thar and Cholistan). Pakistan is confederation of four provinces. Punjab contributes a major share of cash and staple food crops to meet the domestic demand because of the bounty of cultivated area and its canal irrigation system. Of the total irrigated area of ~14.88 million ha, 79% is irrigated by the canal irrigation system and the rest by tube wells and other sources (Pakistan Bureau of Statistics, 2019).

There are nine divisions (division is the highest administrative unit) in the Punjab province. Among these, Bahawalpur, Multan, and Sahiwal divisions constitute the cotton-wheat zone of Pakistan. Each division based on administration is further delineated into districts, tehsils (below district administrative unit), and union councils (lowest administrative unit with a formal government and comprises several villages). Using a multi-stage random sample, households from 18 villages in the cotton-wheat zone of Punjab province were surveyed from September to December 2017. The final sample size yields N=275 smallholders who were selected for face to face interview. Before final survey, we did a pilot survey[1] in January 2017 and interviewed a small size (*N=45)* of smallholders from Punjab, Pakistan. That helped in the subsequent improvements of the survey instrument and in the knowing of the basics of survey area (for example cropping pattern, agro-ecological zones, substantive farming community, and on top of that, extent of availability and accessibility of different types of crop protection products in the survey area). Table 1.2 presents the percentage shares of important farming indicators of the survey area from the total of province.

Table 1.2. Salient indicators of the survey area

Indicators	Bahawalpur Division	Multan Division	Sahiwal Division	Punjab	% share of survey area
Total reported area (thousands ha)	2,155	1,523	1,030	17,680	27
Area sowed under cotton (thousands ha)	738	744	152	2,322	70
Area sowed under wheat (thousands ha)	991	872	511	6,980	34
Total tube well (numbers)	103,919	60,392	71,876	1,028,424	23
Total tractors (numbers)	51,554	43,027	32,729	331,905	38
Total threshers (numbers)	21,458	17,684	15,670	140,133	39
Harvesters/Reapers (numbers)	9,298	3,386	1,743	31,609	46
Population (numbers)	11,464,031	12,265,161	7,380,386	110,012,442	28
Literacy of rural areas (ratio)	0.26	0.30	0.39	0.38	
Literacy of urban areas (ratio)	0.57	0.61	0.66	0.65	

Data source: (Punjab Development Statistics, 2016; Pakistan Bureau of Statistics, 2017-18)

It is evident from Table 1.2 that a substantial share of area under cotton crop (70%) constitutes the survey area of this research. Also, it presents a considerable percentage of the total population of the province. However, the literacy ratio of the rural urban face of the survey area is substantially low and similarly for Punjab.

Figure 1.2 shows percentage shares of total farms with respect to size of landholding in Punjab. On the top of the agricultural farms' segmentation, it comprises 64% small farms; the agricultural farms comprised in the category of medium farms are 34%. The medium and small farms in Punjab account for 98% of all farms and remaining 2% are large farms (The Government of Punjab, 2016).

[1] A discussion paper based on pilot survey data is online available at: https://ideas.repec.org/p/zbw/daredp/1708.html

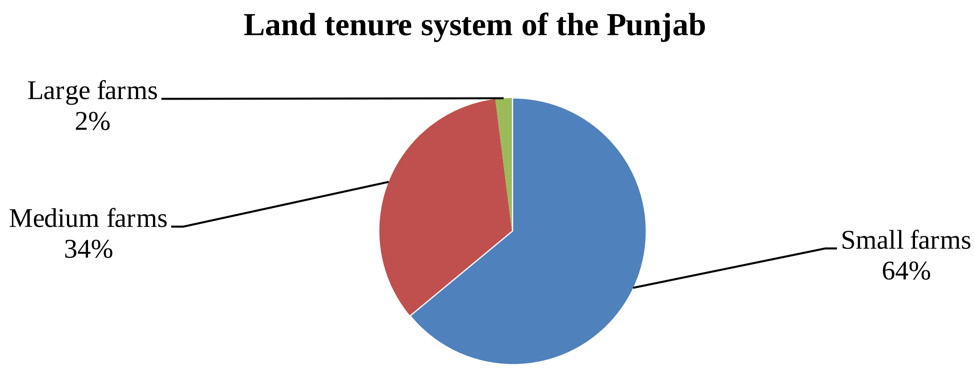

Figure 1. 2. Percentage share of total farms with respect to size of landholding in Punjab (The Government of Punjab, 2016)

1.5 Research objectives

The continuing part of this dissertation is arranged in the following manner. In chapter 2 we explore that how farm and farmer capital foster adoption of improved quality agrochemical inputs[2] (multinational brands crop protection products) in the cotton-wheat zone of the Punjab, Pakistan. Chapter 3 covers the food security effects of MBC with evidence from cotton-wheat zone Pakistan. Chapter 4 is about the general conclusion (take away) in which we summarize the key findings of this dissertation. It is focusing on future guidelines for agricultural administration in Pakistan, in nutshell the policy options perspective. It ends with scope and hope for future research prospects and endeavours.

1.5.1 Farm and farmer capital foster adoption of improved quality agrochemical inputs in the cotton-wheat zone of the Punjab, Pakistan

This paper investigates the role of farm and farmer capital towards the adoption of improved quality agrochemical inputs (multinational brands crop protection products). The paper covers the existing knowledge and research gap about the initial adoption of agrochemical inputs in developing countries of Asia and Africa. We find convincing evidence about research gap regarding the adoption of improved quality agrochemical inputs. We use ordered probit models to estimate the role of farm and farmer capital towards the adoption of improved quality agrochemical inputs in

[2] The chapter has been accepted for publication in *Journal of Agriculture and Rural Development in Tropics and Subtropics*: https://doi.org/10.17170/kobra-20191217881. The chapter is co-authored by Jan Barkmann. The accepted chapter uses the same title "Farm and farmer capital foster adoption of improved quality agro-chemical inputs in the cotton-wheat zone of the Punjab, Pakistan". Therefore, for better understanding we let "improved quality agrochemical inputs" unchanged in this chapter, basically it translates as "multinational brands crop protection products".

the Punjab, Pakistan. The results show the agricultural extension services are fundamental in the disseminations of current technology to the farming community. Due to the fact that this is a variable under rather direct and government controls that can be improved at moderate cost, we suggest that Pakistani and Punjabi agricultural administrations focus on improvements here.

1.5.2 Multinational brands versus generic crop protection products: Does the choice matter for the food security of cotton-wheat farmers in Pakistan?

This paper investigates the food security effects of MBC adoption. The paper covers the adoption of existing technology towards farm harvest, food security, and poverty in developing countries. We find convincing evidence about the research gap regarding the adoption of MBC and its consequences on food security status of the farming community in developing countries. We use HFIAS to elicit food security status. The paper addresses the methodological challenges of non-experimental studies; the potential self-selection bias and potential heterogeneity due to non-random distributions of respondents into treatment (adopters = exclusive MBC) versus control (non-adopters = GC/otherwise) groups. Therefore, we use an endogenous switching probit model to estimate the effect of treatment on food security status. The full information maximum likelihood estimates illustrate that adoption of MBC is guided by comparative advantage. We find statistically significant evidence of transitional heterogeneity; the heterogeneity effects are significantly higher for those smallholder farming households that adopted relative to those that did not adopt. We assess the role of multinational brands crop protection products for enhancing the food security status of smallholder farming households. For policy options, we see listening of agricultural extension information *via* radio by the smallholder farming households in the limelight, among others, key determinants of exclusive MBC adoption (for example farm distance from the farm of village head, farm distance from the main road, off-farm income sources, ownership of farm machinery, and seasonal labour). The intensification of agricultural extension information *via* radio stands out as a most promising policy option for the adoption multinational proven agricultural technologies. For the future research prospects, we suggest investigating further reasons why non-adopter's smallholder farming households are unable to improve their food security status if they will exclusively adopt MBC.

1.5.3 General conclusion and policy options

Few take-away and policy options for the agricultural administration of Pakistan and the developing countries, in general, can be drawn from chapter 2 and chapter 3 of this dissertation.

From a fundamental science point of view, our results provide, for the first time, evidence that adoption of MBC is influenced principally by the same farm and farmer capital variables as initial adoption of crop protection products. We conclude the fundamental role of MBC for enhancing the food security status of smallholder farming households. We also witness that the MBC adoption may cut the food security status of non-adopters if they adopt. Furthermore, our results confirm that the intensification of agricultural extension service visits, among others, key variables stand out as a most promising policy option. These take-away, further suggestions for policy options, and the limitations of this study are briefly discussed in chapter 4 of this dissertation.

2 Farm and farmer capital foster adoption of improved quality agro-chemical inputs in the cotton-wheat zone of the Punjab, Pakistan

Abstract

Adoption of yield-enhancing agricultural inputs fosters agricultural intensification in low-income countries. In Pakistan, initial adoption of agrochemicals is already widespread; the low quality of much of the inputs contributes to severe health, environmental and enduring pest problems, however. While the positive influence of farm capital and farmer capital on initial adoption is well documented, the adoption of improved quality inputs is little researched. We reduce the knowledge gap investigating smallholder adoption of improved quality agrochemical inputs in the Punjab, Pakistan. Using multi-stage random sampling, a pre-tested and piloted farming household survey was administered to smallholder farming households from 18 villages across three districts of the cotton-wheat zone ($N=275$). Ordered probit models show that several farming and farm capital variables (cotton crop area, farm machinery, no-tillage farming, adoption in the neighbourhood) as well as several farmer capital variables (age, education, off-farm income, agricultural extension services, source of agricultural credit) influence adoption of improved quality agrochemical inputs. Of these variables, an intensification of agricultural extension service visits appears as the most promising policy option. From a fundamental science point of view, our results provide, for the first time, evidence that adoption of improved quality agrochemical inputs is influenced principally by the same variables as initial adoption.

Keywords: adoption of agricultural innovations, agrochemical inputs, smallholder farming households, sustainable intensification

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The chapter has been accepted for publication in *Journal of Agriculture and Rural Development in Tropics and Subtropics*: https://doi.org/10.17170/kobra-20191217881. This chapter is co-authored by Jan Barkmann (JB). The contribution of each is as follows: Muhammad Bilal (MB) and JB conceptualized the design of the research. MB carried out survey and collected data with the assistance of two local data collectors. MB analysed data and interpreted. JB assisted by adding constructive comments and important feedbacks at various stages of the research and drafting.

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2.1 Introduction

Adoption of yield-enhancing agricultural inputs is a central component of agricultural development through closing frequently existing yield gaps (e.g., Mueller et al., 2012). There is a persisting yield gap among low-income countries of Asia such as Pakistan and India (wheat yield: 2.97 and 3.22 Mg ha^{-1}) compared to, e.g., Germany and the United Kingdom (7.64 and 8.28 Mg ha^{-1}; FAO, 2019). With high rates of population growth in Pakistan (2.4% a^{-1}, The Government of Pakistan, 2019a) leading to escalating demands for staple food, the adoption of yield-enhancing agricultural inputs appears to be without alternative (Hossain et al., 2006; Khan and Shah, 2011; Salazar et al., 2015; Manlosa et al., 2019). Among these inputs are agrochemicals whose use is positively associated with yield (Pretty and Bharucha, 2014; Koondhar et al., 2018). Adoption of improved quality inputs can be a decisive factor for further sustainable intensification if initial adoption of – low-quality – inputs is already wide-spread but low productivity persists (Khooharo et al., 2008; Hashmi, 2016).

The adoption of low-quality agrochemical inputs comes along with substantial health and environmental risks. Pesticide exposure may reduce the health of, in particular, the rural poor including the female population resulting in income losses and fatalities (Khan et al., 2002; London et al., 2002; Mrema et al., 2017). Aggressive and inappropriate use of agrochemicals is also responsible for water pollution (Azizullah, 2011) and can endanger ecosystem services from soil microorganisms, fish, birds, and other non-targeted organisms (Aktar et al., 2016). In contrast, using improved quality agrochemical inputs may reduce negative health effects (Abedullah et al., 2015) and environmental risks (Kouser and Qaim, 2014).

The initial adoption of yield-enhancing inputs has consistently been shown to be positively associated with farm and farmer capital (FFC) variables such as age, education, land, labour, farm mechanisation, as well as use of improved varieties, and fertilisers (Harper et al., 1990; Doss and Morris, 2001; Iqbal et al., 2002; Ali and Sharif, 2012; Tijani and Nurudeen, 2012b; Hailu et al., 2014; Lambert et al., 2015; Koondhar et al., 2018). Likewise, physical availability of inputs and attributes such as market access and distance to extension service are often positively associated with adoption (Lee, 2005; Mwangi and Kariuki, 2015; Simtowe et al., 2016).

In contrast, the adoption of improved quality agrochemical inputs is little researched. Exceptions include a few studies on the association of socio-economic variables with the adoption of recommended agrochemical practices and extent of pesticide use (Tijani and Nurudeen, 2012a; Issa et al., 2016). In sum, these studies indicate that farmers experience, farmers education, and pesticides price are significantly associated with the extent of given pesticides usage and also with the recommended agrochemical practices. These studies are limited, inter alia, by (i) addressing only one broad category of agrochemicals (pesticides vs. fungicides, herbicides, insecticides, and chemical seed treatment), and (ii) by their focus on recommended practices. Still, they support the hypotheses that the adoption of improved quality agrochemical inputs is positively associated with the same FFC variables as initial adoption.

Initial adoption of low-quality inputs is prevalent in Pakistan where low-quality agrochemicals retard agricultural development (Khan et al., 2013; Hashmi, 2016) as pest problems remain a top of issue impending agricultural development (Oerke, 2006; Khan et al., 2012; Dhaliwal et al., 2015). Likewise, grave environmental (Nafees et al., 2008) and health concerns (Tijani and Nurudeen, 2012b) plague Pakistani agriculture. Thus, investigating the adoption of improved quality agrochemical inputs (fungicides, herbicides, insecticides, and chemical seed treatment) in the agricultural heartland of Pakistan serves two purposes:

(i) improving the regional and national knowledgebase for closing the yield gap in Pakistan,
(ii) contributing to the international debate on factors facilitating sustainable intensification (cf. The Royal Society, 2009; Garnett et al., 2012; USDA, 2016).

Therefore, we use the cross-sectional data collected in 2017 from 275 smallholder farming households of cotton-wheat zone from the Punjab province, Pakistan. We are mainly interested in addressing the following research questions: Do FFC variables of smallholder farming households affect the adoption of improved quality agrochemical inputs?

This paper is part of a more comprehensive study that also investigates the impact of the adoption of improved quality inputs on food security. Respective analyses, in fact, indicate that adoption is not only positively correlated to food security; they also indicate that substantial positive effects of adoption can be documented even if endogeneity effects are considered (Bilal et al., in prep.; Bilal and Barkmann, 2018).

The paper is structured as follows. In section 2, we characterise the study area, the agrochemicals market in Pakistan, and the sampled smallholder farming households. Furthermore, the section describes sampling strategy and data analysis. Section 3 provides the results, which are discussed in section 4, focusing on some institutional implications, in particular for the agricultural administration in Pakistan. Section 5 concludes with some policy implications.

2.2 Material and Methods

2.2.1 Study area and Pakistan smallholder agriculture

In Pakistan, 58 % of farms are categorised as “small farms” (national definition: area ≤ 5 acres [~2.02 ha]; The Government of Punjab, 2010). The smallholders operating these farms use less advanced technological inputs due to socio-economic constraints (Thapa and Gaiha, 2011). Smallholder production systems, among others, tend to lack access to water, authorised and/or improved quality seeds, easy access to input and output markets and to agricultural credit; in contrast, use of adulterated and inferior quality of agrochemical inputs are widespread (Khan et al., 2013; Bilal et al., 2015). This is a serious issue as the potential yield loss due to weeds in cotton may vary from 33-50% and from 24-40% in wheat (Oad et al., 2007; Ali et al., 2013). The potential yield loss due to pests in cotton may vary from 29-40% and from 35-40% in wheat (Khan et al., 2012; Rehman et al., 2015).

2.2.2 Pakistani agrochemical inputs market

In Pakistani agrochemical inputs market recently available agrochemicals on the basis of specific formulation consists of 108 insecticides, 39 herbicides, and 30 fungicides with glyphosate being the most common active ingredient in herbicides in Pakistan (Khan et al., 2010; Hameed et al., 2017). Farm productivity-enhancing inputs including agrochemical inputs and fertilisers worth ~ 735 million USD (United States Dollar) were imported to fulfil the domestic needs during the fiscal year 2017-2018. The agrochemical inputs market import share in Pakistan is estimated to be worth ~ 120 million USD during the fiscal year 2017-2018 (The Government of Pakistan, 2019b). The proportions of agrochemicals input types in the Pakistani agrochemicals market in recent past are as follows: insecticides 42%, herbicides 23%, fungicides 10%, granules 16%, and crop supplement 9%. Among the major crops of Pakistan, most agrochemical inputs by the value are mainly used for cotton and wheat (47%/160 million USD; 18%/60 million USD (Pakistan Crop Protection Associate, 2016).

We differentiated between three tiers (‘types’) of agrochemical input quality following the Department of Plant Protection of the Pakistani national Ministry of National Food Security and Research. We designated these types A to C (The Government of Pakistan, 2018a):

- type A (improved quality) inputs are legally imported based upon their successful registration in an OECD (Organization for Economic Cooperation and Development) listed country or in China.
- type B (intermediate quality) inputs receive a marketing permission based on efficacy trials and field experiments prior to registration. The field trials are conducted over two crop seasons before allocating the trade name.
- type C (base quality) receive a marketing permission without any field trials only based on a sample analysis.

2.2.3 Survey area and administration of the survey

Pakistan is the confederation of four provinces. Punjab province is the largest with respect to population size (53%) and the total net area under arable agriculture (69%) (Pakistan Bureau of Statistics, 2019). There are nine divisions in Punjab province (division is the highest administrative unit). Of these, three divisions (Bahawalpur, Multan, and Sahiwal division) constitute the cotton-wheat zone of Pakistan. Using a multi-stage random sample, households from 18 villages in the cotton-wheat zone of Punjab province (Fig. 2.1) were surveyed from September to December 2017.

At the first stage, one district[3] (Pakpattan, Rahim Yar Khan, Vehari) was selected from each division with type A to C inputs being widely available using a population proportional random selection, and one tehsil[4] (Burewala, Pakpattan[5], Sadiqabad) was randomly selected from each district. In a second stage, five to six union councils[6] were randomly selected from each tehsil (total of 17 union councils). In the third stage, a selection of one to two villages from each union council resulted in a total of 18 villages. In the last stage, we randomly selected 11-20 smallholder farms

[3] District is the subsequent administrative unit with a formal government after division in context to Pakistan.
[4] Tehsil is below district administrative unit.
5 Pakpattan is a district and consists of two tehsils; one of its tehsil bears the same name “Pakpattan”.
6 Union council is the lowest administrative unit with a formal government.

from each village. Thus, the final sample size yields *N=275* smallholders who were interviewed in person by the first author and two advanced student assistants.

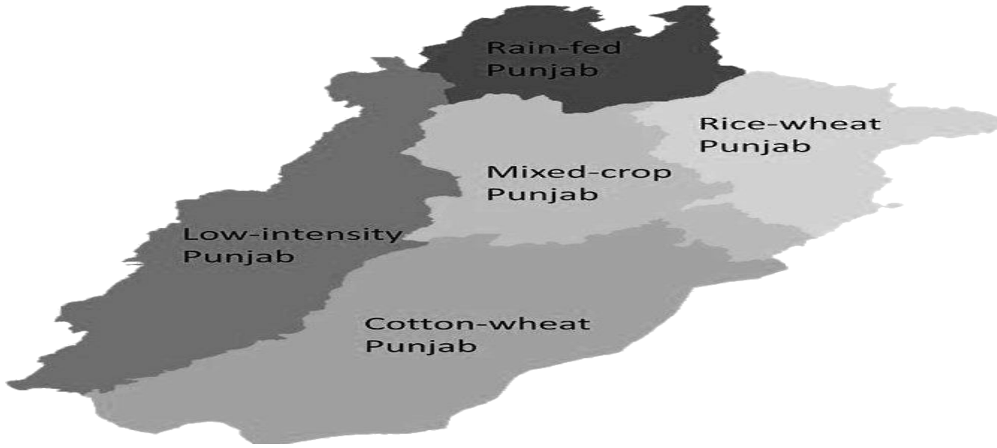

Figure 2. 1. Agro-ecological zone of the Punjab, Pakistan (source: Ahmad et al., 2016)

2.3 Questionnaire

In January 2017, a preliminary version of the questionnaire was piloted in the research area (N=45), and subsequently improved. The final questionnaire included sections on FFC variables, beliefs of respondents on the quality of agrochemical inputs available in local markets, perceptions on the importance of dosage, time of spraying, and recommended instructions for spraying. The questionnaire was originally designed in English, and translated to Urdu by the first author. A copy of the questionnaire is available from the first author upon request.

2.4 Data analysis

To determine influences on input adoption, we used discrete response models with more than two responses. As the input types have a natural quality order, we employed ordered probit models (Verbeke and Ward, 2006). To further rationalize the ordering of the agrochemical's quality, we showed and asked all smallholder farming households about their opinion/knowledge about typical examples of products belonging to the three quality tiers (see introduction). The subjective quality assessment of the farmers about qualitative aspects of agrochemicals being practised at their farms and their knowledge/opinion about other available agrochemicals which in principle not being practised at their farms, closely matched the quality ordering used in this study (see Table 2.1). In particular, the most (83%) of exclusive users of agrochemicals input type A assessed it as improved quality, to the contrary, only a minuscule percentage (14%) of exclusive users of agrochemicals input type C assessed it as improved quality.

Table 2.1. Farmer's opinion about the quality of adopted agrochemical inputs types

Response	Full sample (*N=275*)	Type A users (*N=171*)	Type B users (*N=37*)	Type C users (*N=103*)
Improved quality	51%	83%	42%	14%
Low quality	23%	17%	50%	62%
Poor quality	26%	0%	8%	24%
Total	100%	100%	100%	100%

Since ordered probit coefficients lack an immediately meaningful interpretation, we report marginal effects for each explanatory variable. Using type A, type intermediate (due to highly infrequent proportion of mix use options of adoption of agrochemical inputs in the total sample, we integrated all mix users and termed them as *intermediate users* (see Table 2.3), and type C as responses, each response had a minimum of 50 data points (cf. Sudman, 1976; see Table 2.2). Several farm capital and farmer capital variables for which literature suggested an influence (see introduction), were used as independent variables (see Table 2.4). In detail, our ordered response model assumed the following form (Wooldridge, 2010).

$$y_i^* = x_i'\beta + \varepsilon_i, \quad \varepsilon_i \sim NID\ (0,1)$$

y_i^*= unobserved or latent variable
y_i= observed variable not in the equation
y_i= 0 if $y_i^* \leq \gamma_1$,
y_i= 1 if $\gamma_1 < y_i^* \leq \gamma_2$,
y_i= 2 if $\gamma_2 < y_i^*$,

Where x_i' is set of explanatory variables and β are the estimated parameters for the corresponding explanatory variables, the stochastic disturbance term ε_i is assumed to be normally and independently distributed (0, 1). Here γ is an unknown cut point (or threshold parameter, if y takes three adoption responses, then there will be two cut points, γ_1 and γ_2). Therefore, γ is jointly estimated with β. Consequently, the ordered probit model for three agrochemical inputs types is given as under:

$$ACQ_{ij} = \alpha + \beta X_i + \delta Z_i + \varepsilon_i \qquad \varepsilon_i \sim NID\ (0, 1)$$

where ACQ is the adopted agrochemical inputs quality, subscript i represents a smallholder farming household, and j represents the agrochemical inputs category respondents adopted (j=0,1,2). In particular, j=0 indicates that a household adopted agrochemical input C category, j=1 whether or not a respondent adopts agrochemical input type intermediate category, and j=2 whether or not a respondent adopts agrochemical input type A category (see section 3.1, Table 2.3); X and Z are the FFC variables thought to determine ACQ. α, β, δ, and ε estimated using maximum likelihood procedures. We made a robust standard error calculation for an ordered probit model to address the heteroscedasticity (Greene, 2002). We employed Pregibon's link test for model specification (Pregibon, 1980), which basically implies that when we regress explanatory variables on the predictions squared; the null hypothesis is that predictions squared have no explanatory power. The data were analysed using STATA version 11.

2.5 Results

2.5.1 Smallholder farming households' proportions with respect to input types

Compared to exclusive users of input types A and C, exclusive users of type B as well as users of more than one type are relatively infrequent (Table 2.2). For subsequent analyses, we designated all respondents who did not exclusively use type A (52%) or type C inputs (29%) as users of an intermediate type (Table 2.3).

Table 2.2. Use of agrochemical input types A (improved quality), B (national level quality), and C (base quality) by surveyed smallholder farming households

District	Input Type A	Input Type A+B	Input Type A+C	Input Type B	Input Type B+C	Input Type C	Total
District Pakpattan	32	9	11	5	6	26	89
District Rahim Yar Khan	59	1	3	11	1	31	106
District Vehari	52	2	2	1	1	22	80
Total	143	12	16	17	8	79	275

Table 2.3. Smallholder farming households' distribution with respect to inputs types

Agrochemical inputs type	Ordered	Frequency	Percent
Agrochemical inputs type A only	2	143	52
Agrochemical inputs type Intermediate	1	53	19
Agrochemical inputs type C only	0	79	29
Total		275	100

2.5.2 Farmer and Farm capital

The descriptive summary of FFC variables of smallholder farming households is presented in Table 2.4. Most notably, less than a quarter of all farms own farm machinery (23%), few have access to quality source of agricultural information (16%) and even less have their own tube well for irrigation (15%) or are members of a local farmer association (10%).

Table 2.4. Descriptive summary of farm capital and farmer capital (FFC) variables (*N=275*)

Definition of variables	Mean	SD	Min	Max
Farm capital variables				
Area in ha	1.30	0.55	0.4	2.02
Area in ha (cotton)	0.77	0.58	0	2.02
Farm machinery (yes=1; no=0)	0.23	0.42	0	1
Farm distance to village head (km)	1.32	1.32	0	7
Tube well (own=1; otherwise=0)	0.15	0.36	0	1
No-tillage (yes=1; no=0)	0.45	0.49	0	1
Neighbourhood adopters (numbers)*	2.46	2.32	0	12
Farmers Capital variables				
Age (years)	43.53	12.92	17	73
Education in years	5.70	4.41	0	16
Off-farm income (yes=1; no=0)	0.45	0.49	0	1
Membership of local farmers union (yes=1; no=0)	0.10	0.31	0	1
Number of visits by government agriculture extension service/month	0.80	0.94	0	4
Source of agricultural-credit (government bank: yes= 1; no = 0)	0.16	0.36	0	1
Source of agriculture information (agriculture-extension, village committee, newspaper/TV/Radio=1; otherwise=0)	0.16	0.37	0	1

Notes: * number of adopters of improved quality inputs (type A) in the respondent neighbourhood.

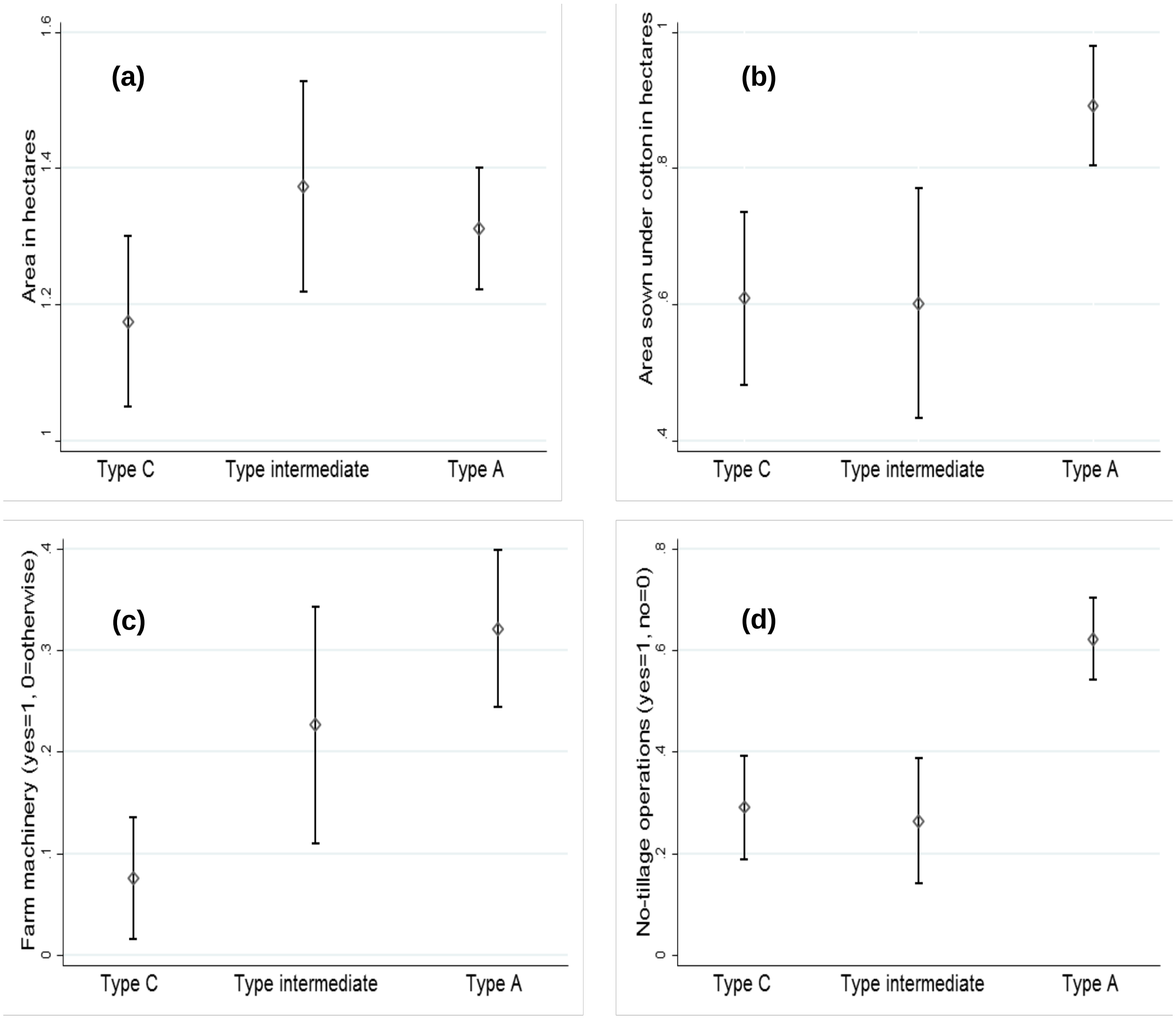

Figure 2. 2. (a)/(b)/(c)/(d): 95% confidence interval plots of farm capital variables with respect to agrochemical inputs types

While the total farm size of farms exclusively using improved agrochemical inputs (type A) is not necessarily bigger than intermediate and type C farms, they have a higher mean area under cotton (Fig. 2.2 (a)/(b)). Ownership of farm machinery and no-tillage cropping also tends to be higher for type A farms (Fig. 2(c)/(d)). The same trend can be seen for education of the household head, number of adopters in the neighbourhood, and visits by agricultural extension service agents/month (Fig. 2.3a/b/c). In contrast, the distance to the home of the village head decreases (Fig. 3(d)). For all variables, ANOVA with post hoc Scheffé test indicates that type C farms differ from type A farms.

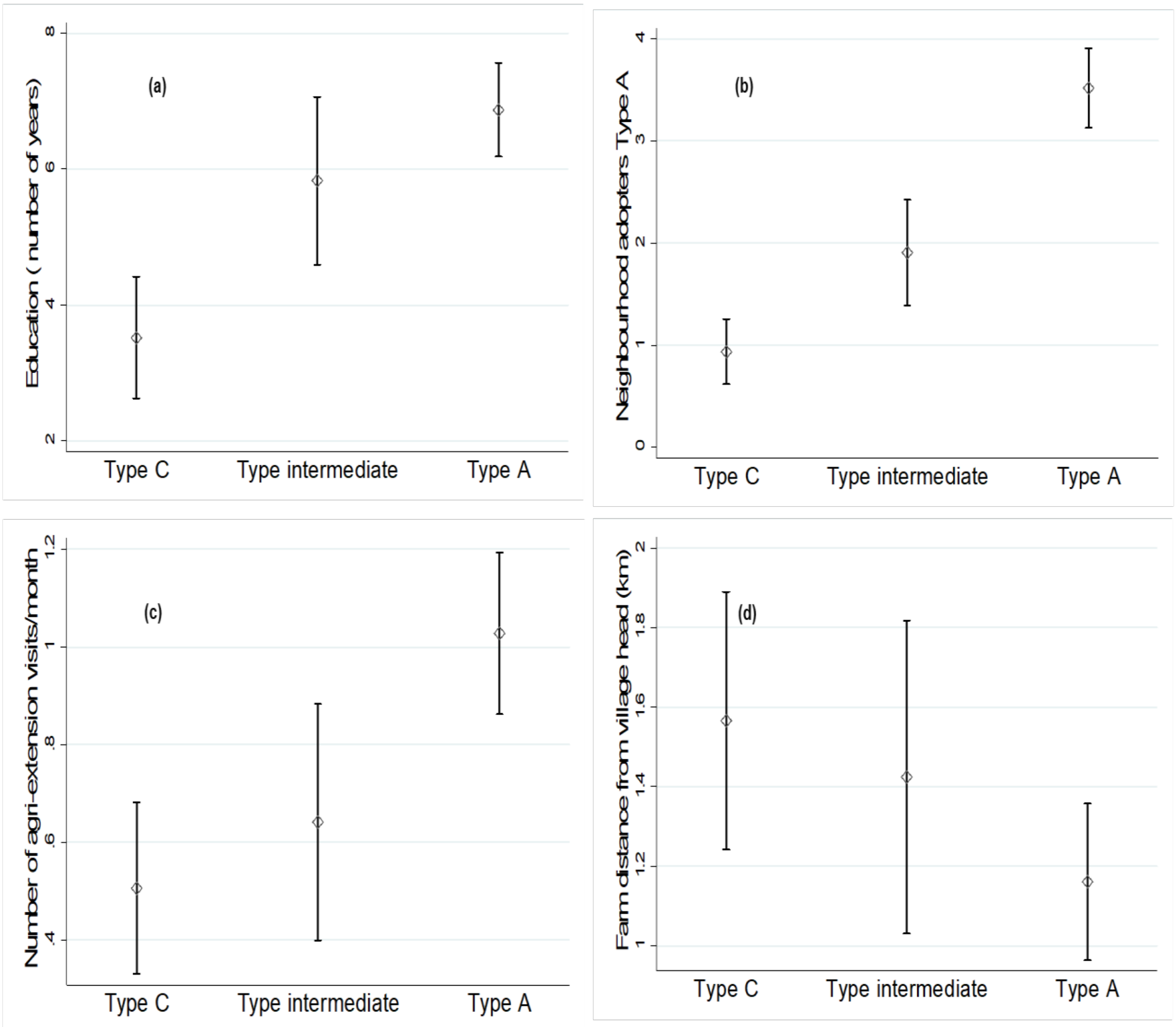

Figure 2. 3. (a)/(b)/(c)/(d): 95% confidence interval plots of farmers' capital variables with respect to agrochemical inputs types

2.5.3 Determinants adoption: ordered probit model

Table 2.5 reports regression estimates of the adoption of agrochemical inputs types from an ordered probit model. The area sown under cotton positively influences the probability of adoption of improved inputs by 13% per hectare; the probability of using intermediate quality (-4%) and base quality (-9%) decreases. Owning farm machinery tends to promote type A adoption strongly (+15%), while farms are less likely to use exclusively type C base quality inputs (-9%). Smallholder farming households practicing no-tillage are (20%) more likely to exclusively adopt type A inputs – with correspondingly decreasing probabilities for intermediate quality (-6%) and base quality (-

13%) inputs. Structurally similar effects are found for the numbers of neighbourhood adopters, age, education, availability of off-farm income, and the number of agricultural extension visits. Of these, the last two have the strongest positive impact on the probability of exclusive type A adoption. Most importantly, one additional visit of an extension agent increases the probability of exclusive type A adoption by 10% while decreasing the adoption probabilities for both other input quality types. Having agricultural credit from a government bank tends to reduce the probability of exclusive type A adoption (-14%). As far as the model's accuracy is concerned, we failed to reject the null hypothesis that predictions squared have no explanatory power because of the probability value greater than 10%, we conclude that our model accurately fit the data as presented in Table 2.5.

Table 2.5. Regression estimates of agrochemical inputs categories from an ordered probit model

			Marginal Effects		
Explanatory variables	Coefficients	Robust SE	y_i=0	y_i=1	y_i=2
Area in ha (total crop area)	-0.08	0.17	0.02	0.01	-0.03
Area in ha (cotton)	0.34**	0.15	-0.09**	-0.04**	0.13**
Farm machinery	0.39*	0.22	-0.09**	-0.05	0.15*
Tube well	-0.24	0.25	0.07	0.02	-0.09
No-tillage	0.50***	0.18	-0.13***	-0.06***	0.19***
Neighbourhood adopters	0.31***	0.05	-0.08***	-0.04***	0.12***
Age	0.01*	0.00	-0.00*	-0.00*	0.00*
Education in years	0.04**	0.02	-0.01**	-0.00*	0.01**
Off-farm income	0.33**	0.17	-0.08**	-0.04*	0.13**
Membership	0.11	0.28	-0.02	-0.01	0.04
Agriculture information quality	-0.18	0.23	0.05	0.02	-0.07
Agricultural extension visits	0.25***	0.10	-0.06***	-0.03**	0.10***
Source of agricultural credit	-0.36*	0.21	0.10	0.03**	-0.14*
Farm distance from village head	-0.07	0.06	0.01	0.00	-0.02
Threshold parameters γ_1	1.25***	0.42			
Threshold parameters γ_2	2.01***	0.43			
Model summary					
No. of observations	275				
Pseudo R^2	0.25				
Wald χ^2 (14 d.f.)	119.47***				
Linktest hatsq *p-value*	0.263				
Log-likelihood	-209.76				

Notes: *** p<0.01; ** p<0.05; * p<0.1

2.6 Discussion

Most of the variables incorporated in this study are consonant to previous studies regarding technology adoption in developing countries of South Asia and Africa (Qaim and Kouser, 2013; Abdulai and Huffman, 2014). As the study confined to smallholder farming households, they lack tendency to ownership of farming capital stock (Mottaleb et al., 2017) and we have found a similar trend of that particular variable (e.g., less ownership of farm machinery and tube well). Small farmers are rarely members to farming community groups (Shikuku et al., 2017) also this may be a potential reason of not having a good representation for the membership of local farmers unions (see Table 2.4).

Differentiating three quality types in the adoption of agrochemical inputs by smallholders' famers in Punjab Province, Pakistan, we estimated the econometric influence of several farm capital and farmer capital variables on the adoption of improved quality inputs using an ordered probit model. As expected, farm capital variables such as cotton farm size, ownership of farm machinery, but also off-farm income increased the probability for exclusive adoption of improved quality inputs. Positive technology adoption effects were shown, for instance, for farm size (Bonabana-Wabbi, 2002), area under cotton (Lambert et al., 2015), farm machinery (Morris et al., 1999; Ayandiji and Olofinsao, 2015), and off-farm income (Hailu et al., 2014). These results follow the general pattern that potentially beneficial rural innovations are not first adopted by those most in need but by those able to afford the innovation. Furthermore, our results showed that age is positively associated with input type A adoption. Smallholder age may act as proxy for farming experience, and as such foster's adoption. Asfaw et al. (2012a) find the same positive influence of age on adoption of agricultural technologies. Years of education is a farmer capital variable with five additional years resulting in a high probability of exclusive type A adoption. Years of education have frequently been shown to be positively correlated with adoption of improved quality inputs (cf. Willy and Holm-Müller, 2013).

All of the above variables are characterised by a small or absent short-term ability of the government of a low-income country such as Pakistan to improve variable values. Thus, it is one of the most striking results of our study that the number of contacts of smallholders with agricultural extension service agents has a very strong positive influence on the adoption of improved quality agrochemical inputs: One additional visit per month is associated with a 10%

increase in the probability of exclusively adopting quality type A inputs. This result is in line with findings, e.g., by Handschuch and Wollni (2016) showing that extension contacts promote the adoption of improved farm practices. Agricultural extension services help farmers to diversify their knowledge and experience new technologies resulting in a generally positive association with the adoption of new agricultural technologies (Mwangi and Kariuki, 2015; Simtowe et al., 2016). In particular, underprivileged and uneducated farmers can benefit from extension field staff and farmer field schools in association with adult education (Ashraf et al., 2015). Although implementing a well-run and effective nationwide agricultural extension service has its own challenges (Abbas et al., 2003; Aldosari et al., 2017), this is clearly an area deserving prime government attention for short-term and medium-term improvements. With positive neighbourhood effects clearly shown in our data (cf. Wilson, 1987; Holloway et al., 2007), improved agricultural extension may have self-enhancing effects on adoption.

Access to agricultural credit is another area of government activity believed to foster technology adoption (Hailu et al., 2014). One of these institutions in Pakistan is Zarai Taraqiati Bank Limited (ZTBL). Surprisingly, having credit from a government bank reduces the exclusive adoption of type A inputs in our study. One set of reasons may relate to bureaucratic hurdles to government credit (Bilal et al., 2015). In effect, the more successfully adopting farmers eschew government lending institutions. Because of the lack of a positive influence of government credit on adoption, we cannot recommend easier access to government banks as a means to higher adoption. Still, the unusual result may hint at specific problems with the lenders in the project area.

Farmers who perceive that technology meets their needs are likely to adopt the technology (Doss, 2003; Mignouna et al., 2011). Particularly, no-tillage systems are efficient for soil conservation and reduce labour and energy input as ploughing/tillage is avoided (Barbera et al., 2012). No-tillage systems are frequently based on the use of glyphosate formulations – often imported from China or OECD countries and, thus, categorised as improved quality type A agrochemical inputs in our application of official Pakistani classifications. We suggest that the strong influence of no-tillage cropping on adoption is based on the associated use of imported herbicides based on glyphosate or similar ingredients. A discussion of the pros and cons of the joint adoption of no-tillage systems with glyphosate formulations is beyond the scope of this study (see, e.g., Fernandez-Cornejo et al., 2012; Brookes et al., 2017; Danne et al., 2019).

From scientific point of view, this study conforms – to the best of our knowledge – for the first time that the adoption of improved quality agrochemical inputs follows the same patterns as the initial adoption of agrochemical inputs. This result also holds with respect to influences on the adoption of agricultural innovations at large.

2.7 Conclusions

The results demonstrate that several FFC variables significantly impact decisions of smallholders in the cotton-wheat zone of the Punjab to adopt improved quality agrochemical inputs. The results are broadly in line with previous research investigating initial adoption of agrochemical inputs and/or adoption of improved agricultural technologies at large. Of the variables tested, the number of visits by agents of the agricultural extension service had a very strong impact on adoption. Because this is a variable under rather direct and government control that can be improved at moderate cost, we suggest that Pakistani and Punjabi agricultural administrations focus on improvements here.

3 Multinational brands versus generic crop protection products: Does the choice matter for the food security of cotton-wheat farmers in Pakistan?

Abstract

A rigorous assessment of the quality of available technologies and outcomes in developing countries is lacking. We investigate the role of multinational brands crop protection products *versus* generic crop protection products in ensuring smallholder food security. We survey 275 smallholder farming households from the cotton-wheat zone of Punjab province, Pakistan. Food security outcomes are assessed by the Household Food Insecurity Access Scale (HFIAS). We employ an endogenous switching probit model for binary adoption decisions with the inclusion of a selection instrument to account for observed and unobserved heterogeneity. Full information maximum likelihood estimates illustrate that adoption of multinational brands crop protection products is guided by comparative advantage.

We find statistically significant evidence of heterogeneity; heterogeneity effects are significantly higher for smallholder farming households that actually adopted relative to those that did not adopt. In particular, agricultural extension information *via* radio has a significant and positive relationship on adoption. For policy implications based on these results, we suggest agricultural extension can effectively expedite the process of agricultural information dissemination *via* radio, which may aid to dispel the institutional constraint of lack of extension staff. In sum, this paper suggests that adoption of multinational brands crop protection products enhances food security and can play a key role in the current debate of sustainable intensification, particularly for smallholder farming households.

Keywords: food security, multinational brands crop protection products, smallholders, socio-demographic

JEL classifications: C31, C36, O12, O33, Q12, Q18

This chapter is co-authored by Bernhard Brümmer (BB) and Jan Barkmann (JB). The contribution of each is as follows: Muhammad Bilal (MB) and JB conceptualized the design of the research. MB carried out survey and collected data with the help of two local data collectors. MB analysed data and interpreted. BB and JB assisted in interpretations, constructive comments, and important feedbacks at various stages of the research and drafting of this paper.

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3.1 Introduction

Rural communities of Pakistan are characterized by a rural poverty syndrome including large household size with low per person land holdings, low agricultural yield per unit area, lack of farm capital, lack of communication between farmers and extension service agents, use of sub-standard/non-recommended crop protection products, and food insecurity (Khan et al., 2012; Ali et al., 2013; Khan et al., 2013; Rehman et al., 2015; Bilal and Barkmann, 2019). Particularly, food insecurity is high for a substantial fraction of the Pakistani rural population with 61% of rural households being food insecure (The Government of Pakistan, 2019a). Food security is at alarmingly low levels in Pakistan for a lower-middle-income country: Pakistan only ranks 77th of the 113th countries covered by the Global Food Security Index (GFSI, 2019). Another recent report on the Global Hunger Index (GHI) ranks Pakistan 106th out of 119th developing countries (GHI, 2019).

Technology adoption can be an essential aspect of achieving agricultural sustainability and food security (Vergragt, 2006). Empirical studies show that the use of technologically improved products can enhance farm productivity, and can play a crucial role to enhance food security of smallholder farming households (Nyyssola et al., 2014; Kassie et al., 2015). The most previous studies related to the outcomes of technology adoption highlight the impact of improved verities, genetically modified (GM) crops, improved storage technologies, and extension services in extending food security of smallholder farming households of South Asia and Africa (Mendola et al., 2007; Elias et al., 2013; Negash and Swinnen, 2013; Qaim and Kouser, 2013; Kabunga et al., 2014; Shiferaw et al., 2014; Ricker-Gilbert and Jones, 2015; Simtowe et al., 2016; Tesfaye and Tirivayi, 2018). Many issues on the adoption of improved technological products, particularly, the quality of crop protection products (for example insecticides, fungicides, and herbicides) as well as adoption outcomes in terms of improving food security, still need to be explored (Muzari et al., 2012; Carvalho, 2017; Niles and Salerno, 2018; Bilal and Barkmann, 2019).

In many low-income and middle-income countries, crop protection products are contaminated by hazardous substances or have insufficient declarations and/or safety and usage information which led to the establishment of international conventions to eliminate the usage of highly hazardous substances (for example Montreal Protocol, Rotterdam Convention, Stockholm Convention) (FAO and WHO, 2016). Pakistan is a signatory of the Rotterdam Convention on prior informed consent procedure for certain hazardous chemicals and crop protection products since 1999 and signatory of Stockholm Convention on persistent organic pollutant since 2001 (Rotterdam Convention, 2019; Stockholm Convention, 2019). However, the literature about the quality of crop protection products in Pakistan shows the presence of outdated ingredients or low-quality formulations, low and/or unpredictably variable concentration of active agents (Khan et al., 2013; Bilal and Barkmann, 2019). Therefore, crop protection product adulteration is an issue in Pakistan (Nafees et al., 2008), and mishandling is responsible for major water pollution (Azizullah, 2011). Excessive and inappropriate usage induced pests and weeds infestation that has further increased reliance on crop protection products (UNDP, 2001; Tariq et al., 2007; Aga, 2019). These disadvantages may result in lower yields and worse farmer health. Unfortunately, the higher price of higher quality crop protection products and their lack of accessibility may offset the agronomic advantages of higher quality products (Antle and Pingali 1994; Lee, 2005; Aktar et al., 2009; Government of Punjab, 2015; Aga, 2019).

The adoption of improved agricultural technology and its efficient utilization is often facilitated by organisations such as agricultural extension services (Rogers, 1983). In disseminating the information of improved agricultural technology and modern ways of farming, the government of Pakistan much relies on agricultural extension services (Saqib and Tachibana, 2014; Baloch and Thapa, 2016). Likewise, institutions are very important in the quality assurance of agricultural inputs. In Pakistan, mainly the Department of Plant Protection of the Ministry of National Food Security and Research, Pakistan deals with this subject (The Government of Pakistan, 2018a).

According to the Department of Plant Protection Ministry of National Food Security and Research, Pakistan, there are three different types of crop protection product registrations based on product quality and a procedural check.

- Type 1 category broadly termed as *generic* crop protection products, there are no field trials before their marketing permission and this involves only sample analysis.
- Type 2 is based on field trials prior to registration. The field trials are conducted in two crop seasons before Type 2 final inception and allocating a trade name.
- Type 3 can be broadly termed as multinational crop protection products. The type is based on a registration in the country of origin. An import permission is granted to type 3 crop protection products if they have their origin in an OECD country (Organization

for Economic Cooperation and Development) or China, and are properly registered their (The Government of Pakistan, 2018a).

In addition to the above-mentioned institutional role in technology adoption, it is important to acknowledge institutions for implementing agricultural research and development (R&D) activities (Naseem et al., 2006; Anandajayasekeram, 2011). About one-third of investment in agricultural R&D globally directed towards crop protection products (Pray and Fuglie, 2001). The multinational brands crop protection products (hereafter MBC) may translate as *improved* crop protection products because products formulation generally follows high standards in terms of research and development (R&D; Thirtle et al., 2005; Alston, 2010). Furthermore, the adoption of branded products shows an attraction for consumer due to products information, products specification, and packaging attributes (Lewis et al., 2016). To the contrary, *generic* crop protection products (hereafter GC) may be called *substandard* crop protection products because generic firms generally lacks R&D departments (Piesse and Thirtle, 2010; Khan and Khattak, 2013). Additionally, GC may include outdated ingredients or low-quality formulations, low and/or unpredictably variable concentration of active agents, lacking and/or insufficient declarations, safety, and usage information (Khan et al., 2013; Hashmi, 2016).

Against this diversity of crop protection products of varying quality, it is surprising to find that we could not identify any scientific paper that – to our knowledge – specifically investigates the potential advantages of using MBC over other types for smallholder food security.

There are a few studies on the impact of the adoption of crop protection products in general on productivity. For example, Hameed et al. (2017) showed that the adoption of herbicides (for example glyphosate and paraquat formulations) for weed management is positively associated with cotton yield in Pakistan. However, explicit origin and qualitative aspects of the investigated herbicides are not discussed. A highly relevant study by Kouser and Qaim (2014) highlights the importance of optimal levels of pesticide use, and of the adoption of *Bt* cotton on productivity in Pakistan. The study is limited to the synergy of the quantity of pesticide usage and *Bt* cotton. We extend to this literature by focusing more explicitly on the quality of crop protection products. Specifically, we investigate smallholder farming households from the cotton-wheat zone, Punjab, Pakistan, to elucidate quality impacts on food security.

To the best of our knowledge, this paper is the first empirical *ex-post* impact assessment on the effect of MBC adoption on household-level food security in Pakistan. Food security outcomes are assessed *via* the self-reported Household Food Insecurity Access Scale (HFIAS). HFIAS was firstly used by Food and Nutrition Technical Assistance (FANTA), a USAID-funded project in the year 2006. HFIAS is adapted from a United States Household Food Security Survey Module (HFSSM). HFIAS consists of nine-questions, which capture household access to food (Coates et al., 2007). HFIAS is widely used in several countries including developing countries of Africa and Asia (Chinnakali et al., 2014; Gebreyesus et al., 2015).

We acknowledge the methodological challenges in *ex-post* impact assessments. From the econometric point of view, outcomes of technology adoption may be tainted by observed and unobserved heterogeneity (Heckman and Vytlacil, 2007). As adoption may be endogenous, a correlation between adoption and food security cannot plainly be interpreted as a causal effect of adoption on food security; unobserved sources of heterogeneity may be present. Thus, possible self-selection due to farm level attributes and farming household attributes may create a problem in the assessment of food security effects by MBC adoption. We take this into account when comparing *adopters* (exclusive MBC use) to *non-adopters* (use of generic products/otherwise). We employ endogenous switching regression (endogenous switching probit model) by full information maximum likelihood (FIML) to account for the endogeneity.

In experimental studies, the farmers are randomly assigned to adopters and non-adopters. But here we deal with non-experimental studies. Therefore, we include selection instruments which helps to identify the effect of an adoption decision but which is exogenous to food security outcomes (Heckman and Vytlacil, 2007). Without such an identification strategy, the estimation of the effect of MBC adoption on outcomes may be biased.

In nutshell, this paper reduces the knowledge gap about food security triggered by the adoption of MBC. We, therefore, attempt to answer the specific research question: Does the adoption of MBC affect the food security of smallholder farming households? The paper is structured as follows: In section 2, we introduce study site, sampling methodology, dependent and independent variables, and details of HFIAS and in section 3 the overall conceptual and methodological framework. Section 4 covers the results and discussion focusing more on an institutional role in technology adoption as well as on policy implications for the agricultural administration of Pakistan. Section 5 concludes with policy recommendations and prospects for future research.

3.2 Methodology

3.2.1 Study site and sampling methodology

Punjab province contains 58% of the total cultivated area of Pakistan. The population of Punjab is 101 million; literacy rate of rural Punjab is standing at 55 % (males: 66 %; females: 44 %). The shares of Punjab in the total production of major crops in Pakistan are as follows; cotton 72%, rice 52%, sugarcane 65 %, and wheat 76% (The Government of Punjab, 2015; The Government of Pakistan, 2019a). The cotton-wheat zone of Punjab province is an important retail market for crop protection products. According to the Punjab Bureau of Statistics, farms with area ≤ 5 acres (~2.02 hectares) are considered *small farms*. Smallholder farming households characterize much of the Punjabi farm population (The Government of Punjab, 2010).

The cotton-wheat zone comprises three important agricultural divisions (division is the highest administrative unit) of Punjab province: the Bahawalpur division, the Multan division, and the Sahiwal division. We employed multistage random sampling with the probability of selection of a farming household being proportional to population accounting for the availability and accessibility of crop protection product types.

Firstly, from each division we randomly selected one district Pakpattan, Rahimyar Khan, and Vehari. Secondly, from each district we randomly selected one tehsil (below district administrative unit/ subdistrict) Burewala, Pakpattan, and Sadiqabad. Lastly, six villages from each subdistrict make 18 villages in total (see Fig. 4.1). A total of $N=275$ small farming households were interviewed in 18 randomly selected villages.

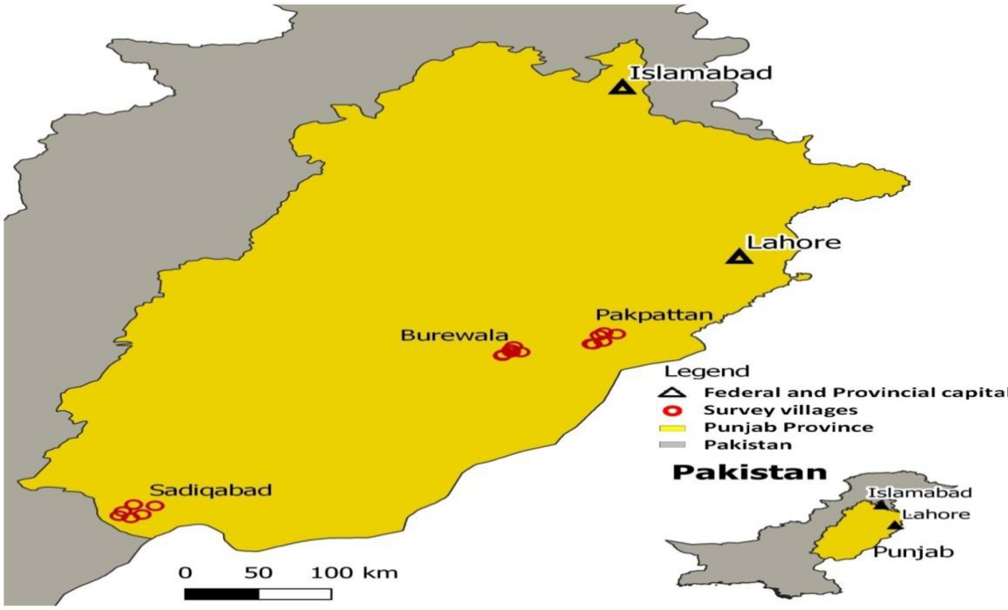

Figure 3. 1. Spatial locations of surveyed villages in three randomly selected subdistricts (tehsils) of Punjab

Source: Made by the first author using QGIS software.

We sampled socio-demographic, farm-specific and food security data (HFIAS) as well as the adoption status of MBC, GC or other crop protection products.

3.2.2 Description of dependent variables

The dependent variable for the selection equation is *adoption status*: adopters (exclusive MBC use, coded 1) and non-adopters (use of GC/otherwise, coded 0). Within the econometric framework, adopters are also referred to as the "treated" group and non-adopters as the "untreated" group. The dependent variable for the outcome's equation is food security status: exclusive food secure households (HFIAS total score = 0 "zero", translates for exclusive food secure=1) and food insecure households (HFIAS total score ≥ 1, translates food insecure=0). Table 3.1 presents the frequency of total sample distribution into adoption status and food security status.

Table 3.1. Adoption and food security status of sampled households

Adoption status	Food security status (HFIAS total score = 0 “zero” = exclusive food secure)		
	Exclusive food secure households=1	Food insecure households=0	Total
Adopters (MBC=1)	86	57	143
Non-adopters (GC/otherwise=0)	26	106	132
Total	112	163	275

3.2.3 The Household Food Insecurity Access Scale (HFIAS)

To compute the dependent variable for outcomes equation, we use the HFIAS scale successfully applied in developing countries of South Asia and Africa (Chinnakali et al., 2014; Kabunga et al., 2014). HFIAS is a subjective assessment of food insecurity consists of questions concerning the assessment of food access from households (Coates et al., 2007). The HFIAS consists of nine questions about access to food. An affirmative answer to any question adds one to a sum total. Thus, the HFIAS scores range from 0 to 9. Advantages of HFIAS include its proven applicability across cultures and its low data requirement (Kabunga et al., 2014; Gebreyesus et al., 2015).

However, subjective assessment may induce response bias (Headey and Ecker, 2013). To reduce response biases, we asked smallholders to outline their main agricultural activities during the agricultural calendar year before asking HFIAS questions. Typical activities include land preparation, harvesting, threshing, buying and selling of milk animals, buying of crop protection products. Moreover, we asked smallholders to identify the months during which they expect grain or food shortage.

For the robustness check about the response from HFIAS, we employ principal component analysis because of the high correlation among the responses. The analysis results to retain two components because of the minimum advisable eigenvalue of above unity (Kaiser, 1960). Component one loaded mainly on first five questions that may reflect “food insecure” while component two loaded mainly on last three questions that may reflect “severely food insecure” (see Table A3.1 in the Appendix A3). The scale reliability coefficient was tested by the Cronbach alpha statistic and value for the scale was $\alpha = 0.95$, we also observed the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy = 0.89, suggesting the data adequacy for component analysis.

The information extracted from these components could have been used as a continuous[7] dependent variable for outcomes equation. However, failing to find sufficient selection instruments, we prefer a binary[8] dependent variable for outcomes modelling. Therefore, we classify smallholder exclusively into two categories with respect to their food security status namely, exclusively food secure households and food insecure households.

The construction of a binary dependent variable based on subjective assessment is greatly supported by the recent past studies. For example, Tesfaye and Tirivayi (2018) constructed binary dependent variable for outcomes equation using HFIAS information. Moreover, closely following the existing literature on self-assessment and subjective assessment of food security by Shiferaw et al. (2014) and Khonje et al. (2015) have had used binary dependent variable for food security outcomes.

3.2.4 Description of independent variables

The detailed descriptive statistics are presented in Table 3.2. The results of two-sample mean-comparison tests indicate statistically significant differences between adopters and non-adopters (off-farm income sources, farm machinery, seasonal labour, and agricultural extension information *via* radio). No substantial difference is observed, e.g., for the total number of males and females in a household, the number of milk animals, agricultural area).

Table 3.2 includes socio-demographic and farming capital variables. The selection of variables is guided by empirical studies and economic theory (cf. Tesfaye and Tirivayi, 2018; Shiferaw et al., 2014; Abdulai and Huffman, 2014; Kassie et al., 2011). The source of agricultural information is very important to keep farmers up-to-date about the development in agriculture sector (Bilal and Barkmann, 2019). At first glance, our sample indicates that adopters listen to the radio more frequently to acquire agriculture extension service information and they have more years of schooling than non-adopters (cf. Asfaw et al., 2012b; Khonje et al., 2015). Similarly, the sample mean of average ownership of farm machinery is significantly higher for adopters than for non-adopters (cf. Di Falco et al., 2011; Kabunga et al., 2014).

[7] The estimations with continuous dependent outcomes variable require movestay command (Lokshin and Sajaia, 2004) and also requires fulfilling the assumption of exclusion restriction to validate selection instruments (Aakvik et al., 2005), regretfully we failed to find the sufficient selection instruments for continuous dependent variable for outcomes equation.

[8] We used switch_probit command (Lokshin and Sajaia, 2011) that is flexible for binary dependent outcomes variable. The estimations were carried out using STATA version 15.

Table 3.2. Descriptive statistics of variables

Variables names	Full sample (*N*=275) Mean	SD	Adopters=1 (*N*=143) Mean	SD	Non-adopters=0 (*N*=132) Mean	SD	Diff
Socio-demographic variables							
Age in years	43.53	12.92	44.17	12.94	42.84	12.90	-1.33
Marital status (yes=1; no=0)	0.84	0.36	0.81	0.39	0.88	0.31	0.07*
Education (years of schooling)	5.70	4.41	6.87	4.17	4.44	4.33	-2.42***
Household size (Hh size)	7.62	3.39	7.58	3.21	7.66	3.59	0.08
Total number of males in Hh	3.39	1.97	3.45	1.93	3.33	2.02	-0.12
Total number of females in Hh	4.22	2.23	4.12	2.08	4.33	2.38	0.20
Total adult family labour (agri-farming)	1.52	0.82	1.53	0.83	1.50	0.80	-0.03
Hired labour (permanent, yes=1; no=0)	0.10	0.30	0.13	0.34	0.07	0.26	-0.05
Total seasonal labour male (agri-farming)	2.85	2.76	3.41	3.09	2.23	2.22	-1.18***
Total seasonal labour female (agri-farming)	3.80	3.21	4.62	3.37	2.91	2.76	-1.70***
Access to credit (yes=1; no=0)	0.41	0.49	0.39	0.48	0.43	0.49	0.04
Credit received (yes=1; no=0)	0.29	0.45	0.23	0.42	0.35	0.48	0.11**
Credit from government bank (yes=1; no=0)	0.16	0.36	0.13	0.34	0.18	0.39	0.05
Agri–extension–info *via* radio (yes=1; no=0)	0.26	0.44	0.32	0.46	0.19	0.39	-0.12**
Cell phone own (yes=1; no=0)	0.10	0.31	0.11	0.31	0.10	0.30	-0.005
Farm distance from the village head (km)	1.32	1.32	1.16	1.18	1.50	1.43	0.34**
Farm distance from the main road (km)	1.10	1.07	0.98	1.13	1.23	1.00	0.25*
Number of males involved in off-farm income	0.60	0.77	0.65	0.74	0.55	0.80	-0.10
Off-farm income sources (yes=1; no=0)	0.45	0.49	0.51	0.50	0.39	0.49	-0.12**
Region1 (if Vehari =1; otherwise=0) [a]	0.29	0.45	0.36	0.48	0.21	0.41	-0.15***
Region2 (if Rahimyar Khan =1; otherwise=0) [b]	0.38	0.48	0.41	0.49	0.35	0.48	-0.05
Region3 (if Pakpattan =1; otherwise=0) [c]	0.32	0.46	0.22	0.41	0.43	0.49	0.20***
Farming capital variables							
Area in acres (1 acre ~ 0.404 hectares)	3.20	1.38	3.27	1.35	3.13	1.41	-0.14
Area wheat in acres	2.29	1.28	2.38	1.31	2.19	1.24	-0.18
High quality wheat seed (yes=1; no=0)	0.60	0.48	0.74	0.43	0.45	0.49	-0.29***
Area sown cotton in acres	1.88	1.43	2.09	1.37	1.51	1.46	-0.71***
Cotton seed if *Bt* (yes=1; no=0)	0.65	0.47	0.80	0.39	0.49	0.50	-0.31***
Area sown other crops in acres	1.27	1.77	1.05	1.62	1.50	1.90	0.44**
Area cotton-wheat in acres	4.17	2.32	4.60	2.33	3.71	2.22	-0.89***
Own capital stock (yes=1; otherwise=0)	0.73	0.44	0.78	0.41	0.68	0.46	-0.10*
Farm machinery (yes=1; otherwise=0)	0.23	0.42	0.32	0.46	0.13	0.34	-0.18***
Number of milk animals	1.26	1.60	1.20	1.37	1.31	1.82	0.10

Notes: The level of significance is *** $p<0.01$, ** $p<0.05$, * $p<0.1$. [a]Region1 and [c]Region3 plots in central Punjab, [b]Region2 plots in southern Punjab. The average distance between the randomly selected regions of central and southern Punjab is about 400 km via National Highway.

From the aspect of factor endowments – especially land and labour, the tendency to hire permanent labour, seasonal labour, and the area sown under cotton crop is higher for adopters than for non-adopters. As we exclusively dealt in with small farming households, only 11% of the total sample hired permanent labour and ~45% of the total sample have off-farm income sources.

From a demographic point of view, the distance of smallholder farming household farms to the main road and to house of the village head is significantly smaller for adopters than for non-adopters (cf. Tesfaye and Tirivayi, 2018).

3.2.5 Conceptual and methodological framework

Ex post impact assessment studies, where farmers are not randomly assigned into treatment and control group, may result in self-selection bias and leads to the problem of endogeneity (Heckman and Vytlacil, 2007). Sometimes unobserved endogenous variables (for example farm management, personal capabilities and abilities, farming decision) impact both the treatment variables and the outcomes variables, and may lead to endogeneity. One possible solution to account for endogeneity is by invoking a selection instrument to improve identification. The selection instrument is supposed to explain the adoption decision but is exogenous to outcomes variables (Bellemare, 2010). To find a good selection instrument is a difficult task as it has to fulfil the conditions of relevance and exogeneity simultaneously (Kassie et al., 2015).

We use the distance (i) of a smallholder farm to the farm of the village head and (ii) from a smallholder farm to the main road as selection instruments. There is substantial empirical evidence of the positive association of demographic attributes on technology adoption (for example Khonje et al., 2015; Tesfaye and Tirivayi, 2018). Recent impact assessment studies by Dedehouanou et al. (2018) have used the household distance in kilometre (km) to the administrative subdivision as a selection instrument; Krishna et al. (2017) have used the altitude of the place of residence to the sea level in meters as a selection instrument. Our selection instruments are similar to those used in these successful implementations of the method.

We employed proper econometrical procedures to validate the inclusion of selection instruments. Firstly, we constructed a correlation matrix between potential selection instruments and adoption status as well as food security status. Secondly, we considered the relevance and exogeneity conditions for selection instruments and employed relevant diagnostic tests (for example Sargan's test and Anderson canonical correlations statistics). Finally, for the admissibility of exclusion restriction we employ the falsification approach by following Di Falco et al. (2011) on considered selection instruments. The selection instruments must be significantly correlated with adoption decision but not correlated with the outcomes of interest among non-adopter's farm households. A

Wald test on selection instruments also confirms that these are potential instruments as the test statistics are significant with P<1% (see Table A3.2, A3.3, and A3.4 in the Appendix A3).

In this paper, we use a binary adoption choice, and binary food security outcomes (Tesfaye and Tirivayi, 2018). Farmers who exclusively incorporate MBC are termed as adopters and those who do not are termed as non-adopters. However, adoption is potentially endogenous and this give no causal interpretation of outcomes of interest because of smallholder own choices for adoption. This condition may be affected by unobserved heterogeneity and possible self-selection due to farm level attributes and farming household attributes that may create problems in the assessment of food security gains by the adoption of technology (Kabunga et al., 2014). We tackle this situation and employ an endogenous switching probit model with FIML (Full Information Maximum Likelihood) which is considered an efficient method to estimate the binary selection equation and the binary outcomes equation simultaneously to yield consistent standard errors of the estimates. The model works under the assumption of joint normality of the error terms in the selection and outcomes equations (Lokshin and Glinskaya, 2009; Lokshin and Sajaia, 2011).

We assume that smallholder farming households have the potential to adopt MBC but the response to adoption may vary. We distinguish the response by introducing a criterion function A_i that determines which regime a smallholder farming household belongs. As discussed above, here the adoption (MBC) and the outcomes (exclusive food secure) have one of two potential values (Aakvik et al., 2005).

$$A_i = 1 \text{ if } \alpha J_i + \mu_i > 0 \quad (1)$$

$$A_i = 0 \text{ if } \alpha J_i + \mu_i \leq 0$$

$$Y^*_{FSi} = \beta_{FS} X_{FSi} + \varepsilon_{FSi} \quad \text{and} \quad Y_{FSi} = I(Y^*_{FSi} > 0) \quad (2)$$

$$Y^*_{NFSi} = \beta_{NFS} X_{NFSi} + \varepsilon_{NFSi} \quad \text{and} \quad Y_{NFSi} = I(Y^*_{NFSi} > 0) \quad (3)$$

The observed Y_i is defined as

$$Y_i = Y_{FSi} \quad if\ A_i = 1$$

$$Y_i = Y_{NFSi} \quad if\ A_i = 0$$

In the present case,

- Y^*_{FSi} and Y^*_{NFSi} are the latent variables (whether the smallholder farming households are exclusive food secure or not) that determine the observed binary outcomes Y_{FSi} and Y_{NFSi} (smallholder farming households' response to adopt exclusive MBC).
- X_{FSi} and X_{NFSi} are vectors of weakly exogenous variables, for the model to specify correctly the exogenous variables in Eqs. (2) and (3) should be same.
- J is a vector of variables that determine a switch between the regimes.
- β_{FS}, β_{NFS}, and α are vectors of parameters.
- and μ_i, ε_{FSi}, and ε_{NFSi} are the error terms under the assumption that μ_i, ε_{FSi}, and ε_{NFSi} are jointly normally distributed in the context of binary outcomes, with a mean-zero vector and correlation matrix (see Heckman and Vytlacil, 2007; Lokshin and Sajaia, 2011).
- Where ρ_{NFS} and ρ_{FS} are the correlations between ε_{NFSi}, μ_i and ε_{FSi}, μ_i and ρ_{FSNFS} is the correlation between ε_{NFSi} and ε_{FSi}. We assume that ρ_{FSNFS} = 1 (α is estimable only up to a scalar factor).

$$\Omega = \begin{pmatrix} 1 & \rho_{NFS} & \rho_{FS} \\ & 1 & \rho_{FSNFS} \\ & & 1 \end{pmatrix}$$

We calculate the probabilities of adoption and adoption outcomes in the actual and counterfactual regime. First, the probability of being treated and having positive outcomes is calculated (Eq. 4). Second, the probability of not being treated and having zero outcomes is calculated (Eq. 5). Third, the probability of being treated and having zero outcomes (Eq. 6), and fourth, the probability of not being treated and having positive outcomes (Eq. 7) is computed.

$$\Pr(A_i = 1, Y_{FSi} | X = x) = \Phi_2(\alpha J_i, X_{FSi}\beta_{FS}, \rho_{FS}) \text{ (actual)} \quad (4)$$

$$\Pr(A_i = 0, Y_{NFSi} | X = x) = \Phi_2(-J_i\alpha, -X_{NFSi}\beta_{NFS} - \rho_{NFS}) \text{ (actual)} \quad (5)$$

$$\Pr(A_i = 1, Y_{NFSi} | X = x) = \Phi_2(\alpha J_i, -X_{FSi}\beta_{FS} - \rho_{FS}) \text{ (counterfactual)} \quad (6)$$

$$\Pr(A_i = 0, Y_{FSi} | X = x) = \Phi_2(-J_i\alpha, X_{NFSi}\beta_{NFS}, -\rho_{NFS}) \text{ (counterfactual)} \quad (7)$$

Following Aakvik et al. (2005) and Lokshin and Sajaia (2011), we calculate the effect of the treatment on the treated (TT) summarized in Eq. (8) as the difference of Eqs. (4) – (6). Actually, Eq. (8) represents the effect of exclusive adoption of MBC on the food security outcomes of the farming households that adopted.

$$\mathrm{TT(x)} = \Pr(Y_{FSi} = 1|A_i = 1, \mathrm{X} = \mathrm{x}) - \Pr(Y_{NFSi} = 1|A_i = 1, \mathrm{X} = \mathrm{x}) \quad (8)$$

Following the same procedure, we calculate, the effect of treatment on the untreated (TU) summarized in Eq. (9) as the difference of Eqs. (7) – (5). In fact, Eq. (9) represents the effect of exclusive adoption of MBC on food security outcomes of the smallholder farming households who did not adopt.

$$\mathrm{TU(x)} = \Pr(Y_{FSi} = 1|A_i = 0, \mathrm{X} = \mathrm{x}) - \Pr(Y_{NFSi} = 1|A_i = 0, \mathrm{X} = \mathrm{x}) \quad (9)$$

3.3 Results

This section describes the estimates of the endogenous switching probit model estimated by FIML with robust standard errors. The FIML estimates of the endogenous switching probit model are presented in Table 3.3 and Table 3.4.

3.3.1 Determinants of MBC adoption

The first column of Table 3.3 presents the estimated coefficients of the selection equation. Those farmers who acquired the agricultural extension service information *via* radio, have off-farm income generation means, employed seasonal labour for agricultural farming, and own farm machinery were more likely to adopt. From a demographic point of view, the smallholder farming households whose farms were located closer to the main road and closer to the farm of the village head were more likely to adopt MBC. Interestingly, those farming households with a higher number of females in the household, have received credit, and located in Pakpattan (region3) were less likely to adopt MBC. Table A3.5 (see Appendix A3) presents the estimates of variables included in the main model by separate probit models of the selection equation without switching. The dependent variable equals 1 if the smallholder farming households exclusively decided to adopt MBC and 0 for GC/otherwise.

Table 3.3. Estimates of the endogenous switching probit model

		Food security status	
	Adoption status (1/0)	Adopter households	Non-adopter households
Total number of males in household	0.05(0.04)	0.01(0.05)	-0.02(0.07)
Total number of females in household	-0.08*(0.04)	-0.05(0.05)	0.05(0.05)
Marital status of respondent (yes=1, no=0)	-0.43(0.26)	-0.41(0.27)	-0.44(0.39)
Agri–extension-info *via* radio (yes=1, no=0)	0.43*(0.26)	0.24(0.24)	0.54(0.50)
Cell phone own (yes=1, no=0)	-0.36(0.36)	-0.33(0.38)	0.60(0.61)
Number of milk animals	-0.04(0.05)	0.10(0.07)	0.01(0.07)
Off-farm income sources (yes=1, no=0)	0.34*(0.19)	0.52**(0.21)	0.57*(0.30)
Credit received (yes=1, no=0)	-0.38**(0.19)	-0.55**(0.23)	-0.19(0.32)
Area in acres (1 hectare = 2.47 acres)	0.04(0.04)	0.06(0.04)	0.03(0.08)
Total seasonal labour male (agri-farming)	0.08**(0.03)	0.12***(0.03)	0.05(0.07)
Total seasonal labour female (agri-farming)	0.07**(0.02)	0.05(0.03)	0.01(0.06)
Farm machinery (yes=1; otherwise=0)	0.61**(0.24)	0.64**(0.25)	0.14(0.37)
Region1 (if Vehari =1; otherwise=0)	0.26(0.22)	0.67***(0.25)	-0.93**(0.36)
Region3 (if Pakpattan =1; otherwise=0)	-0.44*(0.23)	-0.43(0.27)	-0.54(0.37)
Farm distance from the village head (km)	-0.18***(0.06)		
Farm distance from the main road (km)	-0.17**(0.07)		
Log pseudo likelihood	-277.75		
pseudo-R^2 (*N=143*)		0.20	
pseudo-R^2 (*N=132*)			0.22
Wald χ^2 (16)	52.92***		
Errors correlation coefficients		ρ_{FS} *0.99****	ρ_{NFS} -0.39
Wald test of independent equations $\chi^2(2)$	7.24**		

Notes: Robust standard errors are in parentheses, the level of significance is *** p<0.01, ** p<0.05, * p<0.1. ρ_{FS} indicates the errors correlation coefficient for adopters and food secure smallholder farming households and ρ_{NFS} indicates the correlation coefficient for adopters and food insecure smallholder farming households.

3.3.2 Estimates of the endogenous switching probit model: treatment effects

In the last row of Table 3.3, we report Wald tests statistics of the joint significance *(*$\rho_{FS} = \rho_{NFS} = 0$*)* of the error correlation coefficients in the selection and outcomes equations. The test rejects the null hypothesis that $\rho_{FS} = \rho_{NFS}$ because of the prob $>\chi^2 = 0.02$. Therefore, we are justified employing an endogenous switching probit model to account for endogeneity (Dedehouanou et al., 2018).

The second last row of Table 3.3 presents the correlation coefficients among error terms. The estimated correlation coefficient (ρ_{FS}) for adopters and food secure smallholder farming households is significantly different from zero. This may imply that the adoption of MBC had a significant effect on food security, and the adopters would have gained greater benefits from MBC adoption than non-adopters had non-adopters decided to adopt MBC. However, the estimated correlation coefficient (ρ_{NFS}) for non-adopters is not significantly different from zero. This may imply that adopters and non-adopters have the same value of outcomes provided their observed characteristics.

Additionally, the signs of the correlation coefficients are important to derive economic interpretations. The positive sign of the correlation coefficient between the error terms of adopters and food secure smallholder farming households and the negative sign of the correlation coefficient between the error terms of non-adopters and food insecure smallholder farming households illustrate that adoption of MBC is guided by comparative advantage (Fuglie and Bosch, 1995). This suggests that adopters have higher average values of food security outcomes than non-adopters, and non-adopters also have higher average values of food security outcomes from non-adoption.

The above interpretations of correlation coefficients sign are in line with the estimates of outcomes equation presented in the last two columns of Table 3.3. This indicates the presence of significant differences in both, observed and unobserved characteristics among adopters and non-adopters. The positive effects of the off-farm income sources[9], seasonal labour, farm machinery ownership, and the region1 (if farmer located in Vehari =1, otherwise=0) on food security status were more prominent among the farmers who exclusively adopted MBC. Surprisingly, the negative effect of credit received[10] on food security status was also more prominent among the smallholder farming households who exclusively adopt MBC. The positive effect of the off-farm income sources on food security status among adopter and non-adopters were the same but with varying magnitude.

[9] We acknowledged the potential endogeneity in the variables i.e., off-farm income sources and the ownership of farm machinery in outcomes equation, failure to find a sufficient instrument, we drop all potentially endogenous variables in outcomes equation from the main model, but interestingly, the magnitude and sign of TT and TU remains almost same (see Table A3.9 and A3.10 in the Appendix A3). Therefore, on the basis of highly significant likelihood ratio test LR $\chi^2(12)$ = 35.99 at less than 1%, we include these variables in the model presented above.

[10] We also investigated potential endogeneity in the variable access to credit for the second model (see Table A3.6 in the Appendix A3), therefore, we use the variable credit received in the model presented above, which translates the number of respondents who actually received credit. The negative sign associated with credit received can be interpreted as respondents who actually received credit are those with low food security status (higher HFIAS score) than those do not actually received credit (Di Falco et al., 2011).

However, the negative effect of region1 on food security status was more apparent among the smallholder farming households who did not exclusively adopt MBC.

Most importantly, Table 3.4 presents the predicted probabilities food security outcomes of smallholder farming households under actual Eqs. (4) and (5) and counterfactual Eqs. (6) and (7) regimes. We report the treatment effects of adoption status on food security status of smallholder farming households in the last column of Table 3.4.

Table 3.4. Treatment effects of MBC adoption on food security status

	Decision stage		
Sub-samples	To Adopt	Not to Adopt	Treatment Effects
Adopter smallholder farming households	0.31	0.09	TT = 0.22***
	(0.01)	(0.00)	(0.01)
Non-adopter smallholder farming households	0.20	0.39	TU = -0.19***
	(0.00)	(0.01)	(0.01)
Heterogeneity effects	BH1 = 0.11	BH2 = -0.30	TH = 0.41***
	(0.01)	(0.01)	(0.01)

Notes: TT stands for the effect of the treatment on the treated, TU for the effect of the treatment on the untreated, BH1 and BH2 for base heterogeneity for the smallholder farming households those adopted (MBC) and those did not adopt, and TH for transitional heterogeneity. Standard errors are in parentheses, the level of significance is *** $p<0.01$, ** $p<0.05$, * $p<0.1$

In the counterfactual regime Eq. (6), the smallholder farming households who actually adopted may have 22 percentage points less to food security if they had not adopted. This positive and significant value of TT suggests that adoption to MBC would positively contribute to food security of adopters, and their decision to opt MBC presumably robust and rational. These findings corroborate the finding of recent studies on food security impact of adoption, (for example Tesfaye and Tirivayi, 2018; Shiferaw et al., 2014: Negash and Swinnen, 2013) which states that the adoption of improved storage innovations, adoption of improved wheat varieties, and adoption of castor production as a biofuel crop increases the positive probability of food security of the adopter households.

If the actual non-adopters had adopted, adoption may have reduced food security by 19 percentage points. This result of treatment effect for non-adopters on food security is consistent with Krishna et al. (2017) who find that adoption to oil palm expansion may reduce household welfare by 7% for actual non-adopters if they had adopted. Similarly, Negash and Swinnen (2013) find that non-adopter households of castor production as a biofuel crop decreases the probability of food security if they had adopted. The finding of Noltze et al. (2013) also suggests that non-adopters would suffer from household income loss if they adapted to natural resource management technologies. This negative and significant value of TU suggests that adoption to MBC would not positively contribute to the food security of non-adopters[11], and their decision not to opt MBC presumably robust and rational. This may indicate the presence of heterogeneity because the transitional heterogeneity effect is positive and significant in the present case. This may depict that base heterogeneity effects are significantly higher for those smallholder farming households that actually did adopt relative to those that did not adopt (cf. Krishna et al., 2017).

In addition to above-mentioned results and discussion we controlled for different explanatory variables (for example total number of adult family labour, age of respondents, hired labour, number of males involve in off-farm, access to credit, area sown cotton, area sown wheat, and area sown other crops). On the basis of highly significant statistical evidence, we preferred the estimates which we have discussed in the main body of this paper. But it is worth to mention that the estimates of TT and TU of other analysis did not differ in sign (see Appendix A3 Table A3.6, A3.7, and A3.8).

3.3.3 Policy Implications

Among the variables tested, we see government extension service broadcast *via* radio is the most promising policy option to encourage the adoption of improved agricultural technologies. This finding is in line with previous research findings (see for example Al-Hassan et al., 2011; Schreinemachers et al., 2016; Carvalho, 2017) and confirms that agricultural extension contacts promote the adoption of improved agricultural technologies. To aid diffusion of innovations among farmers, salient and practical information regarding agricultural improved technologies connotes the significance of institutional support for rural areas (Rogers, 1983). Consonant to that, this paper and recent literature shows the role of agricultural extension services on adoption, productivity enhancement, poverty alleviation, and particularly for food security in developing countries (Lee, 2005; Davis et al., 2012; Simtowe et al., 2016; Bilal and Barkmann, 2019). A focus on the

[11] For robustness, we separately executed a model for exclusive MBC adopters *versus* exclusive GC adopters ($N=222$). We have found the similar evidence of the negative and significant value of TU and the positive and significant value of TT on food security status but slight difference in magnitude. That further validates and proved our hypothesis of positive food security effects of exclusive MBC adoption (see Table A3.11).

improvement of government extension service broadcast *via* radio may also alleviate resource constraints of extension the services such as lack of extension staff (cf. Abbas et al., 2003; Aldosari et al., 2017).

Constructive policy implications can be drawn from the result that adoption is guided by comparative advantage. Exclusive adoption of MBC promotes food security among those smallholder farming households that actually adopted. What about non-adopters whose food security would have decreased if they had adopted. Should they be discouraged to switch to an exclusive use of MBC? Not necessarily. For example, off-farm income sources, if available, are more lucrative and help to alleviate capital constraints to adoption (Asfaw et al., 2012b; Ali et al., 2014; Simtowe et al., 2016). Likewise, farm mechanization also encourages adoption (Di Falco et al., 2011). From this perspective, an exclusive adoption of MBC appears as complementary to other smallholder farming inputs. Therefore, a policy that helps non-adopters to become mechanized and/or that increases off-farm income may facilitate adoption – with positive synergies on food security outcomes.

3.4 Conclusion

In this paper, we are mainly interested in the food security effects of the adoption of multinational brands crop protection products. The food security outcomes were assessed by the Household Food Insecurity Access Scale (HFIAS). This paper is confined to smallholder farming households of the cotton-wheat zone of the Punjab, Pakistan. We estimated an endogenous switching probit model with FIML to account observed and unobserved heterogeneity.

The treatment effects estimate suggests substantial positive effects of multinational brands crop protection products on food security. Smallholder farming households who actually adopted may have 22 percentage points less to food security if they did not adopt. In contrast, adoption may reduce food security by 19 percentage points to if non-adopters had adopted. This varying effect of adoption on food security indicates that the decision to adopt or not is guided by a realistic and rational assessment of the comparative advantage of adoption given the higher price of MBC (cf. Negash and Swinnen, 2013; Noltze et al., 2013; Krishna et al., 2017).

Based on FIML estimates, we conclude adoption is guided by the comparative advantage, we therefore, cannot suggest easy policy implications for enhancing food security of non-adopters.

The negative effect of multinational brands crop protection products on food security status of non-adopters is an interesting finding of this research. Thus, similar negative effects of technology adoption on household welfare/income and food security for non-adopters in the recent past studies (cf. Negash and Swinnen, 2013; Noltze et al., 2013; Krishna et al., 2017) opens the door for future research to look into the matter deeply.

In particular, a policy that helps non-adopters to become mechanized and/or that increases off-farm income may foster adoption and have substantial positive synergies with food security outcomes. For example, among the variables tested, farmers listening to agricultural extension information *via* radio, off-farm income sources, seasonal labour, ownership of farm machinery, farm distance from the farm of village head, and farm distance from the main road were significantly pronounced for the adopters of multinational brands crop protection products. However, the study provides evidence regarding rural livelihood constraints (for example lack of farm machinery, less off-farm income sources, and low trend for listening of extension information *via* radio) *vis-à-vis* non-adopters that may have hint for negative adoption effects on their food security. For instance, multinational brands crop protection products are complementary to other input markets (for example farm machinery) and off-farm income helps cost to capital market access constraints.

In addition, the study provides positive evidence regarding institutional support such as extension information *via* radio on technology adoption. Positive effects of extension information and farmers training were shown for technology adoption (for example Larsen and Lilleør, 2014; Baloch and Thapa, 2016; Carvalho, 2017). However, lack of extension staff in developing countries context hinders the overall response to adoption (Abbas et al., 2003; Aldosari et al., 2017), hence, acquiring extension information *via* radio may reduce resource constraints.

This paper was solely confined to smallholder farming households, the inclusion of medium and large farming households will be an interesting case to investigate the causal effect of the adoption of multinational brands crop protection products on prevailing food insecurity at the country level.

Appendix A3

Table A3.1. Rotated component loading from PCA

HFIAS Questions	Comp1	Comp 2	Unexplained
Q1.In the month of shortage, did you have anxiety that you and any of your household would not have enough food?	0.47		0.11
Q2.In the month of shortage, were you and any of your households remains unable to eat the specific types of foods you like due to resource constraints?	0.50		0.06
Q3.In the month of shortage did you and any of your households have to eat limited types of foods because of resource constraints?	0.48		0.07
Q4.In the month of shortage did you and any of your household have to eat some types of foods that you and they really not preferred to eat due to resource constraints to have other varieties of food?	0.35		0.13
Q5.In the month of shortage did you and any of your household have to eat a less quantity of meal than you felt you needed due to not enough food?	0.31		0.13
Q6.In the month of shortage did you and any of your household has to eat fewer meals in a day due to not enough food?			0.18
Q7.In the month of shortage, were you and your household remains foodless of any kind due to lack of resources to obtain food?		0.51	0.06
Q8.In the month of shortage did you and any of your household goes to sleep at night hungry due to not enough food?		0.54	0.03
Q9.In the month of shortage did you and any of your household remains hungry for full day and night due to not enough food?		0.54	0.05

Table A3.2. Correlation of selection instruments with adoption and food security status

Correlation of adoption status with demographic attributes		
	Farm distance from the main road	Farm distance from the farm of the village head
Correlation	-0.11	-0.13
p-value	0.05	0.02
Correlation of food security status with demographic attributes		
	Farm distance from the main road	Farm distance from the farm of the village head
Correlation	-0.04	-0.02
p-value	0.44	0.63

Table A3.3. The relevance and exogeneity conditions for selection instruments

Test	Null hypothesis	*p*-value
Wu-Hausman test	Exclusion instruments are exogenous	F=0.43,p=0.51
Wooldridge's score test	Exclusion instruments are exogenous	χ^2=0.46,p=0.49
Anderson canonical correlation statistic	Underidentification	χ^2=7.33,p=0.02
Sargan statistic	Instruments uncorrelated with error terms (Overidentification)	χ^2=0.03,p=0.85
Anderson-Rubin's test	Weak instrument robust test	χ^2=0.06,p=0.96

Table A3.4. Falsification approach to validate selection instrument

	Dependent variable	
	adoption status	food security status (for non-adopters)
Farm distance from the main road	-0.13* (0.07)	-0.23 (0.17)
Farm distance from the farm of the village head	-0.15** (0.07)	-0.07 (0.12)
LR chi2	75.09***	30.87***
Wald test on selection instrument	χ^2=11.88***	
Number of observations	275	132

Notes: Standard errors given in parentheses. The level of significance is *** p<0.01, ** p<0.05, * p<0.1

Table A3.5. Regression estimates of adoption of MBC from a probit model (main model)

Adoption status (1/0)	Coefficient	Standard error
Total number of males in household	0.05	0.05
Total number of females in household	-0.07*	0.04
Marital status (yes=1; no=0)	-0.36	0.26
Agri–extension-info *via* radio (yes=1; no=0)	0.48**	0.24
Cell phone own (yes=1; no=0)	-0.34	0.34
Number of milk animals	-0.03	0.05
Off-farm income sources (yes=1; no=0)	0.38**	0.18
Credit received (yes=1; no=0)	-0.38**	0.19
Area in acres (1 hectare = 2.47 acres)	0.04	0.03
Total seasonal labour male (agri-farming)	0.06*	0.03
Total seasonal labour female (agri-farming)	0.07**	0.03
Farm machinery (yes=1; otherwise=0)	0.54**	0.22
Region1 (if Vehari =1; otherwise=0)	0.22	0.22
Region3 (if Pakpattan =1; otherwise=0)	-0.45**	0.22
Farm distance from the village head (km)	-0.15**	0.07
Farm distance from the main road (km)	-0.13*	0.07
Log pseudo likelihood	-152.85	
LR χ^2	75.09***	
Number of observations	275	

Notes: The level of significance is *** p<0.01, ** p<0.05, * p<0.1

Table A3.6. Estimates of the endogenous switching probit model (second model)

		Food security status	
	Adoption status (1/0)	Adopter Households	Non-adopter households
Age in years	0.00	0.01	-0.00
	(0.00)	(0.00)	(0.01)
Total number of adult family labour	0.16	-0.00	-0.21
	(0.12)	(0.13)	(0.19)
Hired labour	0.46	0.19	1.22**
	(0.31)	(0.34)	(0.56)
Total number of females in Hh	-0.07*	-0.08*	0.05
	(0.04)	(0.05)	(0.06)
Number of males involve in off-farm income	0.11	-0.00*	-0.21***
	(0.11)	(0.13)	(0.18)
Agri–info *via* radio	0.43**	0.13	1.06***
	(0.19)	(0.20)	(0.39)
Access to credit	-0.03	-0.51**	-0.08
	(0.17)	(0.21)	(0.31)
Capital own	0.58***	1.04***	0.59*
	(0.21)	(0.27)	(0.33)
Regional dummy 1	0.78***	1.30***	0.32
	(0.23)	(0.29)	(0.47)
Regional dummy 2	0.31	0.10	1.07**
	(0.26)	(0.30)	(0.48)
Area sown wheat (acres)	-0.01	-0.01	0.09
	(0.07)	(0.09)	(0.15)
Area sown cotton (acres)	0.19**	0.27***	-0.08
	(0.08)	(0.09)	(0.13)
Area sown other crops (acres)	-0.07	0.04	0.06
	(0.06)	(0.07)	(0.12)
Farm distance from the village head (km)	-0.14**		
	(0.06)		
Farm distance from the main road (km)	-0.14**		
	(0.07)		
ρ_{FS}/ρ_{NFS}		0.99***	-0.25
		(0.00)	(0.41)
Wald test of indep. eqns. chi2(2)			8.98**
Log pseudo likelihood			-285.82

Notes: Robust standard errors are in parentheses, the level of significance is *** p<0.01, ** p<0.05, * p<0.1. ρ_{FS} indicates the errors correlation coefficient for adopters and food secure smallholder farming households and ρ_{NFS} indicates the correlation coefficient for adopters and food insecure smallholder farming households.

Table A3.7. Treatment effects of MBC adoption on food security status (second model)

	Decision stage		
Sub-samples	To Adopt	Not to Adopt	Treatment Effects
Adopter smallholder farming households	0.32	0.10	TT = 0.22***
	(0.01)	(0.00)	(0.01)
Non-adopter smallholder farming households	0.20	0.40	TU = -0.20***
	(0.00)	(0.01)	(0.01)
Heterogeneity effects	BH1 = 0.12	BH2 = -0.30	TH = 0.42***
	(0.01)	(0.01)	(0.02)

Notes: TT stands for the effect of the treatment on the treated, TU for the effect of the treatment on the untreated, BH1 and BH2 for base heterogeneity for the smallholder farming households those adopted (MBC) and those did not adopt, and TH for transitional heterogeneity. Standard errors are in parentheses, the level of significance is *** p<0.01, ** p<0.05, * p<0.1

Table A3.8. Regression estimates of adoption of MBC from a probit model (second model)

Adoption status (1/0)	Coefficient	Robust standard error
Age in years	0.00	0.00
Total number of adult family labour	0.15	0.12
Hired labour	0.41	0.30
Total number of females in Hh	-0.07**	0.03
Number of males involved in off-farm income	0.11	0.11
Agri–info *via* radio	0.46**	0.19
Access to credit	-0.05	0.17
Capital own	0.62***	0.20
Regional dummy 1	0.80***	0.23
Regional dummy 2	0.27	0.26
Area sown wheat (acres)	-0.04	0.08
Area sown cotton (acres)	0.19**	0.08
Area sown other crops (acres)	-0.07	0.06
Farm distance from the village head (km)	-0.11*	0.06
Farm distance from the main road (km)	-0.12*	0.07
Constant	-1.03**	0.47
Log pseudo likelihood	-161.73	
Wald χ^2	52.78***	
Number of observations	275	

Notes: The level of significance is *** p<0.01, ** p<0.05, * p<0.1

Table A3.9. Treatment effects of MBC adoption on food security status (reduced model excluding all potentially endogenous variables)

	Decision stage		
Sub-samples	To Adopt	Not to Adopt	Treatment Effects
Adopter smallholder farming households	0.31	0.09	TT = 0.22***
	(0.01)	(0.00)	(0.01)
Non-adopter smallholder farming households	0.21	0.39	TU = -0.18***
	(0.00)	(0.01)	(0.01)
Heterogeneity effects	BH1 = 0.10	BH2 = -0.30	TH = 0.40***
	(0.01)	(0.01)	(0.01)

Notes: TT stands for the effect of the treatment on the treated, TU for the effect of the treatment on the untreated, BH1 and BH2 for base heterogeneity for the smallholder farming households those adopted (MBC) and those did not adopt, and TH for transitional heterogeneity. Standard errors are in parentheses, the level of significance is *** p<0.01, ** p<0.05, * p<0.1

Table A3.10. Estimates of the endogenous switching probit model (reduced model excluding all potentially endogenous variables)

		Food security status	
	Adoption status (1/0)	Adopter households	Non-adopter households
Total number of males in household	0.09**(0.04)	0.07(0.05)	0.01(0.07)
Total number of females in household	-0.06(0.04)	-0.01(0.05)	0.04(0.05)
Marital status (yes=1; no=0)	-0.33(0.24)	-0.33(0.26)	-0.37(0.39)
Agri–extension-info *via* radio (yes=1; no=0)	0.46*(0.25)	0.11(0.28)	0.57(0.48)
Cell phone own (yes=1; no=0)	-0.41(0.35)	-0.27(0.35)	0.51(0.60)
Area in acres (1 hectare = 2.47 acres)	0.03(0.03)	0.06(0.04)	0.01(0.07)
Total seasonal labour male (agri-farming)	0.09**(0.03)	0.12***(0.04)	0.04(0.07)
Total seasonal labour female (agri-farming)	0.07**(0.02)	0.05*(0.03)	0.00(0.06)
Region1 (if Vehari =1; otherwise=0)	0.25(0.22)	0.65***(0.25)	-0.79**(0.36)
Region3 (if Pakpattan =1; otherwise=0)	-0.51**(0.21)	-0.42*(0.24)	-0.54*(0.33)
Farm distance from the village head (km)	-0.18***(0.06)		
Farm distance from the main road (km)	-0.18***(0.06)		
Log pseudo likelihood	-295.75		
Wald χ^2 (12)	61.54***		
Errors correlation coefficients		ρ_{FS} *0.90****	ρ_{NFS} -0.46
Wald test of independent equations $\chi^2(2)$	4.72*		

Notes: Robust standard errors are in parentheses, the level of significance is *** p<0.01, ** p<0.05, * p<0.1. ρ_{FS} indicates the correlation coefficient for adopters and food secure smallholder farming households and ρ_{NFS} indicates the errors correlation coefficient for adopters and food insecure smallholder farming households.

Table A3. 11. Treatment effects of exclusive MBC adoption *versus* exclusive GC adoption on food security status (*N=222*)

Sub-samples	Decision stage		Treatment Effects
	To Adopt	Not to Adopt	
Adopter smallholder farming households	0.39	0.06	TT = 0.33***
	(0.01)	(0.00)	(0.02)
Non-adopter smallholder farming households	0.25	0.29	TU = -0.04***
	(0.01)	(0.01)	(0.02)
Heterogeneity effects	BH1 = 0.14	BH2 = -0.23	TH = 0.37***
	(0.02)	(0.01)	(0.02)

Notes: TT stands for the effect of the treatment on the treated, TU for the effect of the treatment on the untreated, BH1 for base heterogeneity for the smallholder farming households those adopted (MBC) and BH2 for those adopted (GC), and TH for transitional heterogeneity. Standard errors are in parentheses, the level of significance is *** p<0.01, ** p<0.05, * p<0.1

4 General conclusion and policy options

4.1 Background and conceptual framework

With this dissertation, we were aiming at filling the persisting knowledge gap on the adoption of multinational brands crop protection products (MBC) *versus* generic crop protection products (GC) (for example fungicides, insecticides, and herbicides). Additionally, we focused the food security effects of the adoption of MBC for the smallholder farming household of the cotton-wheat zone Punjab, Pakistan. Primarily, we contribute to the present body of knowledge by twofold: in second chapter, we determine what influences the smallholder farming households to adopt improved quality agrochemical inputs and in third chapter, we determine the food security effects of the exclusive adoption of MBC versus non-adoption.

The second chapter encompasses the pros and cons of using agrochemical inputs, the adoption of existing agricultural technologies in developing countries and the justification to focus on the improved quality agrochemical inputs. It also comprises the Pakistani official registration procedure for the categorization of available agrochemical inputs in terms of quality in the agricultural mainland of the country. For better understanding of the registration procedure, we assign the title type A to given agrochemical inputs if it is imported from an OECD (Organization for Economic Cooperation and Development) listed country and China (improved quality agrochemical inputs). The Type B agrochemical inputs follows field trails before marketing permission (intermediate quality), and type C agrochemical inputs only involve sample laboratory examination before marketing permission (base quality). We particularly in this chapter interested to see the influence of farm and farmer capital variables of the smallholder farming households on exclusive adoption of improved quality agrochemical inputs.

Before performing the empirical analysis, we had initially observed that there is little proportion of smallholder farming households who use a mix of all available quality of agrochemical inputs. Based on our sample, we observed six different options of adoption of agrochemical inputs by the smallholder farming households (see Table 2.2 chapter 2). Due to highly infrequent proportion of mix use options of adoption of agrochemical inputs in the total sample, we integrated all mix users and termed them as *intermediate users*. Finally, we left with three popular options of adoptions by the smallholder farming households, which we subsequently used in empirical analysis (see Table 2.3 chapter 2). The first option consists of *type A* exclusively improved quality agrochemical inputs adopters, second option consists of *intermediate users* of all type A type C, and type B (intermediate adopters), and the third option consists *type C* (exclusively base quality adopters). Due to the ordinal nature of the dependent variable, we employ ordered probit models.

In the third chapter, we exclusively segregated the smallholder farming households into two groups: adopters (exclusive MBC) and non-adopters (GC/otherwise). We use an internationally accepted module to measure food security status of farming households in context to developing countries of Asia and Africa. For the very first time, the Household Food Insecurity Access Scale (HFIAS) is used to measure food security status in context agricultural farming community of Pakistan (Coates et al., 2007). Subsequently, we assigned the smallholder farming households into two groups: exclusive food secures households and food insecure households and assigned discrete values depend upon the nature of group they belong respectively. Due to discrete nature of two sets of the dependent variable (see Table 3.1 chapter 3), we employed an endogenous switching probit model. The main intuition behind to employed this model is to address the methodological challenges of non-experimental studies. For example, the main purpose of using the model is that it controls for potential self-selection bias and account the potential heterogeneity. Additionally, we also considered selection instruments for better identification of the model, and the consideration of selection instruments is guided by economic theory and empirical research evidence. We considered demographic variables; farmers farm distance from the main road and farmers' farm distance from the farm of the village head. The relevance and exogeneity of selection instruments are checked by exclusion restriction approach by Di Falco et al. (2010) and with further statistical tests (e.g., Sargan test for overidentification and Anderson canonical correlation statistic for underidentification) employed for the robustness of inclusion of selection instruments.

4.2 Main findings

With the second chapter, we have analysed the potential role of farm and farmer capital in the exclusive adoption of improved quality agrochemical inputs. In doing so, on one hand, the subjective opinions of the farmers about quality of agrochemical inputs reported with 51% for improved quality, 23% reported low quality, and 26% reported poor quality respectively. It is the relevant finding which supports past research and indicates the occurrence and prevalence of low to poor quality agrochemical inputs in the agricultural mainland of Pakistan (Khan et al., 2002; Khooharo et al., 2008; Nafees et al., 2008; Khan et al., 2012; Hashmi, 2016). On the other hand, we find statistically significant evidence of several farming and farm capital variables (cotton crop area, farm machinery, no-tillage farming, and adoption in the neighbourhood) stimulate adoption of improved quality agrochemical inputs. Likewise, several farmer capital variables (age, education, off-farm income, agricultural extension services, and source of agricultural credit) stimulate adoption of improved quality agrochemical inputs.

Furthermore, agricultural extension service visits enhance the probability with 10% increase in the adoption of improved quality agrochemical inputs. This is important finding and explicitly the result of the need which supports theory of diffusion of innovation, which signifies the role of agricultural extension services to help farmers to diversify farmers' knowledge and experience about innovative technologies. In nutshell, we find robust and rationale results, which in principle show that the farm and farmer capital variables which determine the initial adoption of agrochemical inputs exhibit the similar relationship for the adoption of improved quality agrochemical inputs.

The third chapter of this dissertation focuses on the food security effect of the exclusive adoption of MBC. We assume that adopters and non-adopters would adopt depending upon their nuance about MBC and their socio-economics characteristics. At first glance, the socio-economic characteristics, in particular, the frequent reliance on the electronic media by the farmers, especially listening of the agricultural extension information *via* radio indicate positive and significant association with the adoption of MBC. Second, the full information maximum likelihood (FIML) estimates indicate that adoption is guided by comparative advantage (see Table 3.3 chapter 3). This suggests that adopters have higher average values of food security outcomes than non-adopters, and non-adopters also have higher average values of food security outcomes from non-adoption.

On top of that, our main hypothesis about the food security gains by the adoption of MBC to visible extent is supported by our results. Our results confirm that the treatment effect (food security) on treated (adopters) is positive and significant. This suggests that adoption to MBC would positively contribute to the food security of adopters (+22 percentage points) and their decision to opt for MBC presumably robust and rational. Surprisingly, the negative significant value of treatment effects on untreated (-19 percentage points) suggest that adoption to MBC would not positively contribute to the food security of non-adopters. The negative effect of MBC on food security status of non-adopters is the most striking part of this research which may suggest their decision not to opt for exclusive adoption of MBC presumably robust and rational as well. This finding supports the recent past research findings regarding technology adoption, wherein, they proclaimed negative effect of technology adoption on household welfare/income and food security for non-adopters (cf. Negash and Swinnen, 2013; Noltze et al., 2013; Krishna et al., 2017). Lastly, we find the positive significant results of the potential heterogeneity (+0.41; *p-value* <1%) in the sample. This may depict that heterogeneity effects are significantly higher for those smallholder farming households that actually did adopt relative to those that did not adopt.

4.3 Implications for farming households and potential policy options

Knowing the circumstances that the substantive farming community of Pakistan belongs to small farmers' community and the illiterate farmers can benefit from extension field staff visits and farmers field school for the latest agricultural technologies and methods (Saqib and Tachibana, 2014; Larsen and Lilleør, 2014; Baloch and Thapa, 2016). For that reason, we see agricultural extension services in the limelight for the most promising policy options. Our results showed that agricultural extension service visits contribute positively to the adoption of MBC. Thus, it is important to make sure the effective and active part of government agricultural extension service in rural villages. Similar policy options can be extracted from the farmers' frequent reliance on the electronic media, especially listening of the agricultural extension information *via* radio (cf. Manda and Wozniak, 2015). It entangles the fundamental role of government extension service as an easiest way to disseminate information on latest technologies, which may aid to dispel their constraint of lack of extension staff (Abbas et al., 2003; Aldosari et al., 2017). Therefore, we suggest that the country's federal and provincial agricultural administrations focus on effective outreach of extension service in rural villages.

Based on FIML estimates, we conclude adoption is guided by the comparative advantage. It illustrates that adoption of MBC would contribute positively and significantly in the food security status of adopters. However, negative effects of technology adoption on household welfare/income and food security in this paper and in the recent past studies (cf. Negash and Swinnen, 2013; Noltze et al., 2013; Krishna et al., 2017) for non-adopters clearly deserve the prime attention of agricultural policy makers to take up the issue for amendments. Hence, the comparative advantage of using multinational brands crop protection products between adopters and non-adopters do not preclude that some of the characteristics of non-adopter's smallholder farming households could not be changed.

For agriculture and development policy scenario and with the view of sustainable intensification based on these results, we see provision of off-farm income sources pronounced to mitigate liquidity constraints, support regarding mechanised farming, and increased access to extension service illustrate the pathway leads to incorporation of multinational technologies among non-adopters. Therefore, effective policy which facilitates smallholders to incorporate proven multinational technologies in their production system to overcome existing food insecurity is a dire need of time.

4.4 Limitations and future research prospects and endeavours

We hereby acknowledge the limitations of the research presented in this dissertation. This research was confined solely to smallholder farming households, who are characterized on the basis of their landholdings if equal or less than 5 acres [~2.02 ha]. The inclusion of medium farming households (landholdings if equal or less than 25 acres [~10.11 ha] acres but more than 5 acers [~2.02 ha]) and large farmers (landholdings if more than 25 acers [~10.11 ha]) will be an interesting case to investigate the causal effect of the adoption of MBC on prevailing food insecurity at the country level.

Secondly, this dissertation focused only one agro-ecological zone of Punjab province i.e., cotton-wheat Punjab, but the other agro-ecological zones, i.e., mixed cropping Punjab, rice-wheat Punjab, rain-fed Punjab, and low-intensity Punjab were not covered. Additionally, though, the number of respondents used in this dissertation is fairly match with previous research regarding cotton-wheat zone of Punjab, Pakistan (Abedullah et al., 2015; Battese et al., 2017) but relatively less in contrast to similar farming households globally (Qaim and Kouser, 2013; Karimov, 2014; Makombe et al., 2017).

On top of that, the societal hindrance to access interviewing the females' household head was not controlled, but can be address if future research will hire female assistants to interview the household head in case of female govern households in rural Pakistan. Lastly, considering the aforementioned potential heterogeneity between adopters and non-adopters, it would be interesting to understand the potential heterogeneity in research and development sectors of generic crop protection products firms of Pakistan *versus* multinational brands crop protection products to seek for alleviating food insecurity issue.

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Appendix

Agricultural Inputs Uses, Social, and Food Security Characteristics of Smallholder in Pakistan

(Questionnaire)

Introduction to respondent: I am… from … collecting data on behalf of Mr. Muhammad Bilal, (a Ph.D. student from Germany) on Agricultural Inputs Uses, Social, and Food Security Characteristics of Smallholder in Pakistan. Your responses are very helpful to improve future policies and programmes regarding the smallholder. Your responses will be exclusively used for research purposes and will be treated as confidential.

We will respect all your answers and appreciate your cooperation, are you willing to participate in this survey?

If 'Yes' continue for the interview, if 'No' then please stop here.

Questionnaire Code: ___________ GPS Location: ______________________

Name of Interviewer: _________________________

1. Area details:

1.1 Country: __________________ 1.2 Province: __________________

1.3 District: ___________________ 1.4 Tehsil: ___________________

1.5 Union Council: _____________ 1.6 Village: __________________

2. Basic Household Characteristics of Farmer:

2.1 Gender: ___________

2.2 Name of Respondents:

First Name: __________________ Middle Name: _____________________Last Name: _______________

2.3 Age: _____

2.4 Respondent the head of the household Yes=1; Otherwise=0; ______ (if 0 then ask 2.6)

2.5 Marital status Married=1; unmarried=0; _____

2.6 Household Head Male=1; Female=0; _____

2.7 Ethnicity: ________

2.8 Number of years of residence in this village: ___________

2.9 Total house members: ____ 2.10 Total number of males in house: ____________

2.11 Number of males over 18 years of age: _____ 2.12 Total education of respondent in years: ________

3. Access to basic social facilities:

Facilities	Distance in Km
3.1 School	
3.2 Basic health Centre	
3.3 Veterinary Hospital	
3.4 Agriculture Bank/Commercial Bank	
3.5 Post office	
3.6 Police station/Police chowki	
3.7 Do you have mobile phone access: Yes=1; No=0	
3.8 Do you have internet access: Yes=1; No=0	
3.9 Mode of transportation you used please specify	

What is the main source of drinking water in your house? Please tick only one			
3.10.1 Drum water		3.10.2 Tap water	
3.10.3 Hand pump		3.10.4 Motor pump	
3.10.5 Well		3.10.6 River	
3.10.7 Lake		3.10.8 Other, please specify	

What is the main source of energy (light) in your home/farm? Please tick only one	
3.11.1 Electricity	
3.11.2 Generator	
3.11.3 Kerosene lamp	
3.11.4 Other, please specify	

What is the main source of fuel in your home? Please tick only one			
3.12.1 Electric Stove		3.12.2 Wood	
3.12.3 Sui Gas Connection		3.12.4 Dung	
3.12.5 Gas cylinder		3.12.6 Crop residue	
3.12.7 Coal		3.12.8 Other, please specify	

4. Access to agriculture facilities / Information:

4.1 Distance of Agriculture Extension office from your farm in Km: __________

4.3 Number of field visits to farmers by Agri-Ext representative per month: _____

4.4 Number of field visits by private agricultural firms' representative per month: _____

4.5 Number of visits by Veterinary or para-veterinary per month: ________

4.6 Information about Agricultural Credit:

4.6.1 Do You have access to Credit? Yes =1; No=0	
4.6.2 Did you applied for credit? Yes =1; No=0	
If Yes from which of the following sources	(Tick the relevant)
4.6.3 Government banks (ZTBL, National bank)	
4.6.4 Private Commercial Bank	
4.6.5 NGO	
4.6.6 Input supplier/Distributors	
4.6.7 Private Money lender	
4.6.8 Friends/Relatives	
4.6.9 Other	

5. Information regarding social indicators of farmers (a):

5.1 How you will compare yourself to the all other people in this village.	Little worst off	Much worst off	Like most of others	Little bit better off	Much better off

Where: 1= little worst off, 2= Much worst off, 3= Like most of others, 4= little bit better off, and 5= Much better off. (Please tick the relevant box)

5.2 Information about main activities over the calendar year (***Please tick the relevant Months***)								
Important: Food shortage means not enough food and grain to meet daily household consumptions.								
Months	Land Preparation	Cultivation	Harvesting	Threshing	Buying and selling of milk animals	Buying of crop protection products	In which months you expect shortage of food?	Other please Specify
January								
February								
March								
April								
May								
June								
July								
August								
September								
October								
November								
December								

5.3 Information about Household Food Access (a)			
#	**QUESTION**	**RESPONSE OPTIONS**	**RESPONSE**
5.3.1	In the month of food shortage, did you have anxiety that you and any of your household would not have enough food?	0 = Never 1= Rarely 2=Sometimes 3=Often	
5.3.2	In the month of food shortage, were you and any of your household remains unable to eat the specific types of foods you like due to resource constraints?	0 = Never 1= Rarely 2=Sometimes 3=Often	
5.3.3	In the month of food shortage, did you and any of your household have to eat limited types of foods because of resource constraints?	0 = Never 1= Rarely 2=Sometimes 3=Often	
5.3.4	In the month of food shortage, did you and any of your household have to eat some types of foods that you and they really not preferred to eat due to resource constraints to have other varieties of food?	0 = Never 1= Rarely 2=Sometimes 3=Often	
5.3.5	In the month of food shortage, did you and any of your household have to eat a less quantity of meal than you felt you needed due to not enough food?	0 = Never 1= Rarely 2=Sometimes 3=Often	
5.3.6	In the month of food shortage, did you and any of your household have to eat fewer meals in a day due to not enough food?	0 = Never 1= Rarely 2=Sometimes 3=Often	
5.3.7	In the month of food shortage, were you and your household remain foodless of any kind due to lack of resources to obtain food?	0 = Never 1= Rarely 2=Sometimes 3=Often	
5.3.8	In the month of food shortage, did you and any of your household go to sleep at night hungry due to not enough food?	0 = Never 1= Rarely 2=Sometimes 3=Often	
5.3.9	In the month of food shortage, did you and any of your household remains hungry for full day and night due to not enough food?	0 = Never 1= Rarely 2=Sometimes 3=Often	

5.4 Information regarding social indicators of farmers (b)

Are you or any member of your Hh a member of any of the following associations /organisation/groups?	Yes=1	No=0	If Yes how often do you attend association meetings (number/month)
Farmers Association			
Farmers Field School			
Community/Neighbourhood committee			
NGO´s			
Member of Mosque committee			
Village Aman/Zakat committee			
Other, Please Specify			

5.5 Housing structure of the Household			
5.5.1 Boundary wall Yes=1; No=0		5.5.2 Toilet flush system Yes=1; No=0	
5.5.3 Cemented Yes=1; No=0		5.5.4 Number of rooms	
5.5.5 Concrete floor Yes=1; No=0		5.5.6 Number of toilets	

6. Farms and Geographic Specific Attributes:

6.1 Total Area under cultivation: _______

6.2 Own: ____________

6.3 Rented in: _______ 6.4 what is the rent of land/acre: ________________ (Rs)

6.5 Please give estimated value (price) of an acre if it would to be sold: __________________(Rs)

6.6 Farms Specific Attributes	Yes=1; No=0; Both=2
6.6.1 Distance of farm from Tehsil in Km: _______	
6.6.2 Distance of farm from Input Market in Km: _____	
6.6.3 Travelled time to Input Marker in minutes: _______	
6.6.4 Distance of farm from output Market in Km: _____	
6.6.5 Travelled time to Output Marker in minutes: _______	
6.6.6 Distance of farm from the head of village farm in Km: ______	
6.6.7 Distance of farm to Metalled Road in Km: _____	
6.6.8 Irrigated=1; Unirrigated=0	
6.6.9 Canal irrigation=1; Tube well=0; Both=2	
6.6.10 Tube well Own Yes =1; Otherwise/No=0	
6.6.11 Tube well cost	

7. Information about Soil quality of farming unit:

7.1 How would you describe the soil quality of your farm? **Encircle the relevant box below**					7.2 Are you practicing any of the following measures on your farm? Please show images				
Very fertile	Fertile	Medium fertile	Less fertile	No idea	7.2.1 Inter-cropping Yes =1; No=0	7.2.2 Crop rotation Yes =1; No=0	7.2.3 Laser levelling Yes =1; No=0	7.2.4 No-tillage Yes=1; No=0	7.2.5* Other please specify
1	2	3	4	5					

*____

8.1 Information about input quality & quantity:

We are showing you three different types of pesticides, each different type includes pesticides, weedicides, fungicides and seed treatments.

8.1.1 Have you been using the Product type A currently or in past 5 years: ______________________

8.1.2 What is your knowledge and your view about product type A: ___________________________

8.1.3 If product A is identified and used, which one & since when you are using Product A?

Types of Product A	Tick the relevant box	Duration
8.1.3.1 Insecticides		
8.1.3.2 Fungicides		
8.1.3.3 Weedicides		
8.1.3.4 Seed treatment		
Other		

8.1.4 Have you been using the Product type B currently or in past 5 years: ______________________

8.1.5 What is your knowledge and your view about product type B: ___________________________

8.1.6 If product B is identified and used, which one & since when you are using Product B?

Types of Product B	**Tick the relevant box**	**Duration**
8.1.6.1 Insecticides		
8.1.6.2 Fungicides		
8.1.6.3 Weedicides		
8.1.6.4 Seed treatment		
Other		

8.1.7 Have you been using the Product type C currently or in past 5 years: ________________________

8.1.8 What is your knowledge and your view about product type C: ______________________________

8.1.9 If product C is identified and used, which one & since when you are using Product C?

Types of Product C	**Tick the relevant box**	**Duration**
8.1.9.1 Insecticides		
8.1.9.2 Fungicides		
8.1.9.3 Weedicides		
8.1.9.4 Seed treatment		
Other		

8.1.10 Products specification for different crops: **Product A= 1, Product B=2**, and **Product C = 3**, and if respondents do not apply any one of the listed products = N/A.					
Name of crop	Pesticide	Fungicide	Weedicide	Seed treatment	Total cost/ Acre

Code: 8.1.10.1Wheat=1, 8.1.10.2Rice=2, 8.1.10.3Sugarcane=3, 8.1.10.4 Cotton=4, 8.1.10.5 Maize=5, 8.1.10.6 Other=6

Adoption status? (Please fill according to above answer)

After demonstration of three different samples, tick the relevant answer	
Product type A	
Product type B	
Product type C	

8.2 From which of the following source you have heard about these different types? (Please tick the relevant box)

8.2.1 Friends/Neighbourhood farmers	
8.2.2 Farmer's union meetings	
8.2.3 Newspaper/TV/Radio	
8.2.4 NGO	
8.2.5 Private firm's representatives	
8.2.6 Distributors	
8.2.7 Extension service	
8.2.8 Other please specify	

Name of Crop	8.2.9 Urea Bags/Acre	8.2.10 DAP Bags/Acre	8.2.11Others Bags/Acre	8.2.12 Total Cost/Acre

Code: Wheat=1, Rice=2, Sugarcane=3, Cotton=4, Maize=5, Other=6

Name of Crop	8.2.13 Number of Manures Trolley's/Acre	8.2.14 Cost/ Trolley	8.2.15 Total Cost/Acre

Code: Wheat=1, Rice=2, Sugarcane=3, Cotton=4, Maize=5, Other=6

Name of Crop	8.2.16 Bt-Cotton= 1; Improved/Hybrid Saeed variety =2; Domestic/local variety; otherwise=0	8.2.17 Cost/Acre

Code: Wheat=1, Rice=2, Sugarcane=3, Cotton=4, Maize=5, Other=6

Access to Farm Machinery:

8.3 Farm Machinery own=1; otherwise=0; ______ 8.4 If yes, Specification of farm machinery:

Name of Machine	Yes=1; Otherwise=0	Model	Since when you are using this?	Price of Machine (Used)	Price of Machine (New) Market info
8.4.1 Tractor					
8.4.2 Trolley					
8.4.3 Thresher					
8.4.4 Rotavator					
8.4.5 Plough					
8.4.6 Spray machine					
8.4.7 Other					

8.5 Livestock own=1_____; otherwise=0; _______ 8.6 If yes, Number of Milk Animals; ________

8.6.1 Number of Oxen; _____; 8.6.2 Number of Donkey; _____; 8.6.3 Number of Sheep & Goat; _______

9. Output per Acre 2017:

Name of Crop	9.1Total area sown in acre	9.2 Yield Mounds/Acre in 2017	9.3 Marketed/ Sold in Mounds	9.4 Left in stock after sale	9.5 Price/ Mounds in Rs	9.6 Total value in Rs	9.7 Total yield in 2017

Code: Wheat=1, Rice=2, Sugarcane=3, Cotton=4, Maize=5, Other=6

10. Distribution of labour force:

Family Labour who works for crop production only						Permanent Hired Labour who works for crop production only					
10.1 No of Males	10.2 No of Females	10.3 Months/ year	10.4 Weeks/ month	10.5 Days/ week	10.6 Hours/ day	10.7 No of Males	10.8 No of Females	10.9 Months/ year	10.10 Week/ month	10.11 Days/ week	10.12 Hours/day

Year	10.13 Salary of permanent hired labour at village Rs/month		10.14 Salary of seasonal labour at village Rs/day		10.15 Number of seasonal labours employed at your farm in 2017	
2017	10.13.1 Male	10.13.2 Female	10.14.1 Male	10.14.2 Female	10.15.1 Male	10.15.2 Female

11. Household Off-farm income:

Number of Household engaged in Off-Farm Income?									
11.1 How much time Hh members devote for off-farm activity		11.2 Number of Hh members engaged in off-farm activities		11.3 Education level of Hh members involve in off- farm activity		11.4 Age of Hh members engaged in off-farm activity		11.5 Total income from off-farm activities in (Rs)	
11.1.1 Days/ week	11.1.2 Hours/ Day	11.2.1 Male	11.2.2 Female	11.3.1 Male	11.3.2 Female	11.4.1 Male	11.4.2 Female	11.5.1 Male	11.5.2 Female

12. Input specific aspects of sample farmers.

12.1 When you need agricultural information who do you turn for from the following?

Neighbourhood farmers =**1**; Village committee=**2**; Newspaper/TV/Radio=**3**; Private firms rep=**4**; Distributors =**5**; NGO=**6**; Extension dept. = **7**; __________

12.2 Do you listen to agricultural radio or TV programmes? Yes=1; No=0; ______

12.3 Do you listen to agricultural information via cell phone (input prices, agricultural practices)

Yes=1; No=0; ____

12.4 Do you hire expert for spraying? Yes=1; No=0; _____

12.5 What is your opinion about quality of agricultural information's about advanced technologies from?	Not at all useful	Rarely useful	Neutral	Useful	Very useful
12.5.1 Extension Services					
12.5.2 Private Firms Rep					
12.5.3 Distributors					
12.5.4 NGO					
12.5.5 Newspaper/TV/Radio					
12.5.6 Community Meetings					
12.5.7 Neighbourhood Farmers					
12.5.8 Others please specify					

Where: 1= Not at all useful, 2= Rarely useful, 3= Neutral, 4= Useful, and 5= Very useful (Please tick the relevant box)

12.6 What do you think about the following below mentioned factors for crop protection w.r.t final harvest?	Not at all important	Low importance	Somewhat important	Very important	Extremely important
12.6.1 Timing of Spraying					
12.6.2 Instructions for spraying					
12.6.3 Dosage for spraying					

Where: 1= Not at all important, 2= Low importance, 3= somewhat important, 4= Very important, and 5= extremely important. (Please tick the relevant box)

12.7 How concerned are you about International Organization for Standardization (ISO) certification in crop protection products?	Not at all concerned	Not really concerned	Neither concerned or Unconcerned	Concerned	Very concerned

Where: 1= Not at all concerned, 2= Not really concerned, 3= neither concerned nor Unconcerned, 4= Concerned, and 5= Very concerned. (Please tick the relevant box)

12.8 Would you be willing to adopt High quality crop protection product that would necessitate an initial investment of 10,000**(1)**–15,000**(2)**–20,000**(3)**–25,000**(4)**–30,000**(5)**–35,000**(6)** Rupees (i.e., US$ 100–150 200–250–300–350) but which would increase your annual harvest by 10 Percent? Before asking the question please first through a dice and the points according to dice upper position will show **(e.g., 1-6)** afterwards ask the questions? (Please tick the relevant box)

Yes	
No	

12.9 If NO: why not:

(a) Do not have enough cash and no easy access to credit: ____________

(b) Do not trust promise to increase harvest by 10%: ________________

(c) I trust promise of 10% if from reliable source but other risks are too high (selling price change, drought, other unforeseen problem: _________________

(d) Input provider would have to give cash advance/informal credit: ________

12.10 How many of yours neighbours are using product A: __________

Important: please take picture of farmer at their farm or place where interview conducted & say thanks to farmer for their time and patience to complete this survey.

DECLARATIONS

1. I, hereby, declare that this Ph.D. dissertation has not been presented to any other examining body either in its present or a similar form.

Furthermore, I also affirm that I have not applied for a Ph.D. at any other higher school of education.

Göttingen, ...

....

(Signature)

....

(Name in block capitals)

2. I, hereby, solemnly declare that this dissertation was undertaken independently and without any unauthorised aid.

Göttingen, ...

....

(Signature)

....

(Name in block capitals)